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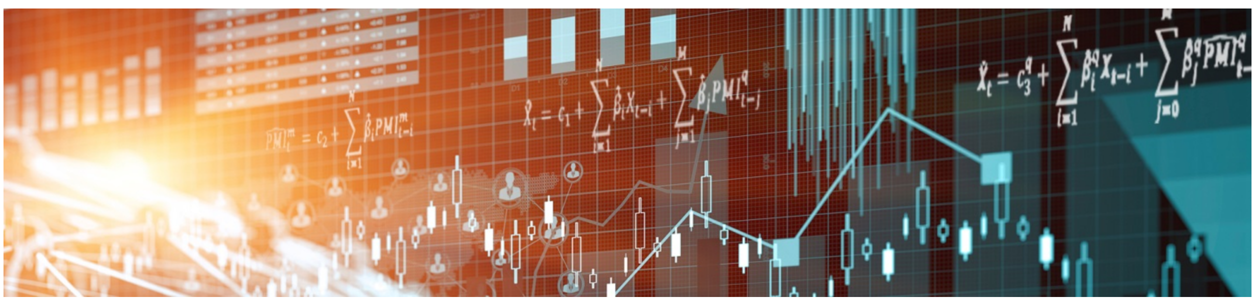
Calibrating the Magnitude of the Countercyclical Capital Buffer Using Market-Based Stress Tests



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Abstract

This paper proposes a novel methodology to calibrate the magnitude of the cap on the countercyclical capital buffer (CCyB) using market-based stress tests. The macroprudential authority in our paper aims to contain the possibility of a breach of a minimum capital ratio in the event of a severe system-wide shock within a certain permissible failure probability. To meet its objective during periods of challenging macro-financial conditions, the macro-prudential authority requires banks to build up the CCyB during credit booms. We show how market-based stress tests can be used to estimate the necessary magnitude of the CCyB. We apply the methodology to major banks in six advanced economies. Our estimates suggest a magnitude of the cap on the CCyB in a range from 1.4 to 1.7 per cent of total assets, depending on the ability of the macro-prudential authority to forecast macro-financial conditions.

Bank topics: Financial institutions; Financial stability; Financial system regulation and policies
JEL codes: G10, G21, G28

Résumé

Nous proposons une méthode originale pour le calibrage du volant de fonds propres contracyclique. Nous utilisons pour cela des tests de résistance reposant sur les données de marché. Nous considérons un scénario dans lequel une autorité macroprudentielle cherche à limiter la possibilité de non-respect d'un ratio minimum de fonds propres réglementaires en cas de choc de grande ampleur qui toucherait l'ensemble du système financier, compte tenu d'une probabilité d'échec acceptable. Pour que son objectif soit atteint si les conditions macrofinancières se détérioraient, l'autorité exige des banques qu'elles constituent leurs volants de fonds propres contracycliques durant les phases d'expansion du crédit. Nous montrons comment les tests de résistance reposant sur les données de marché peuvent servir à déterminer le volant de fonds propres qui devrait être constitué. Nous appliquons la méthode à des grandes banques de six économies avancées. D'après nos estimations, le volant de fonds propres devait être de l'ordre de 1,4 à 1,7 % de l'actif total, selon la capacité de l'autorité macroprudentielle à prévoir les conditions macrofinancières.

Sujets : Institutions financières; Stabilité financière; Réglementation et politiques relatives au système financier
Codes JEL : G10, G21, G28

NON-TECHNICAL SUMMARY

The macro-prudential objective of banking regulation is to maintain the stability of the banking system as a whole. The countercyclical capital buffer (CCyB) is one of the instruments to achieve this objective. Its underlying idea is that authorities need to ensure that the banking sector has sufficient capital at hand to support the flow of credit in the economy during a period of financial stress that could occur after a strong credit expansion. This is achieved by requiring the build-up of a cyclical capital add-on during strong credit expansions. Once the economy enters a period of challenging macro-financial conditions, this buffer is released to offset the increase in risk and the reduction in banks' capital ratios. This cyclical add-on is called the CCyB.

The implementation of the CCyB requires the relevant macro-prudential authority to form an opinion of the necessary magnitude of the CCyB. International members of the Basel Committee on Banking Supervision have agreed to a level of the CCyB of up to 250 basis points (bps) of risk-weighted assets. This somewhat arbitrary cap of 250 bps of risk-weighted assets has been a point of debate, with some jurisdictions indicating that they may choose to set a cyclical capital add-on in excess of this cap if necessary.

The present paper proposes a novel methodology to calibrate the magnitude of the cap on the CCyB in a more formal manner using market-based stress tests. We apply the methodology to major banks in six advanced economies. Our estimates suggest a magnitude of the cap on the CCyB in a range from 1.4 to 1.7 per cent of total assets, depending on the ability of the macro-prudential authority to forecast macro-financial conditions. This implies that, if the average risk weight of banks are, say 50 per cent, then a CCyB of 280 to 340 basis points of risk-weighted assets may be necessary to offset the reduction in banks' capital buffers as macro-financial conditions move from peak to bottom. These estimates are based on the macro-prudential authority aiming at banks not breaching the minimum capital ratio with a 95 per cent confidence level after a six-month system-wide stress scenario that occurs on average every 10 years.

1 Introduction

This paper proposes a methodology to calibrate the level of the 'cap' of the countercyclical capital buffer (CCyB) using market-based stress tests. The main objective of the CCyB is to strengthen the resilience of the banking system by increasing banks' capital buffers during periods of rising systemic risk, thereby supporting the flow of credit during periods of financial stress.[1] For this purpose, macro-prudential authorities need banks to meet a sufficiently prudent level of capital during challenging macro-financial conditions. This is achieved by requiring the build-up of a cyclical capital add-on during strong credit expansions that can be released to offset the expected reduction in capital buffers once the economy enters a period of challenging macro-financial conditions.

The internationally agreed magnitude of the CCyB ranges from 0 to 2.5 per cent of risk-weighted assets (BCBS, 2010). The somewhat arbitrary cap of 2.5 per cent of risk-weighted assets has been a point of debate with some jurisdictions indicating that they may choose to set a cyclical capital add-on in excess of this cap if necessary (BCBS, 2017). Nevertheless, international reciprocity arrangements to ensure a level playing field between domestic and foreign bank lending cap the mandatory reciprocity at 2.5 per cent of risk-weighted assets.

This study proposes a novel methodology to calibrate the CCyB in a more formal manner using market-based stress tests. This methodology can be used both to calibrate the magnitude of the cap of the CCyB as well as to select indicators of macro-financial conditions. In particular, we show how to calibrate the magnitude of the cyclical capital add-on for a given level of risk tolerance of the macro-prudential authority using market-based stress tests.

Our method starts with estimating a *point-in-time prudential capital ratio* using market-based stress tests. This level is set such that the possibility of banks' capital ratios breaching some minimum in the event of a severe system-wide shock is contained within a certain

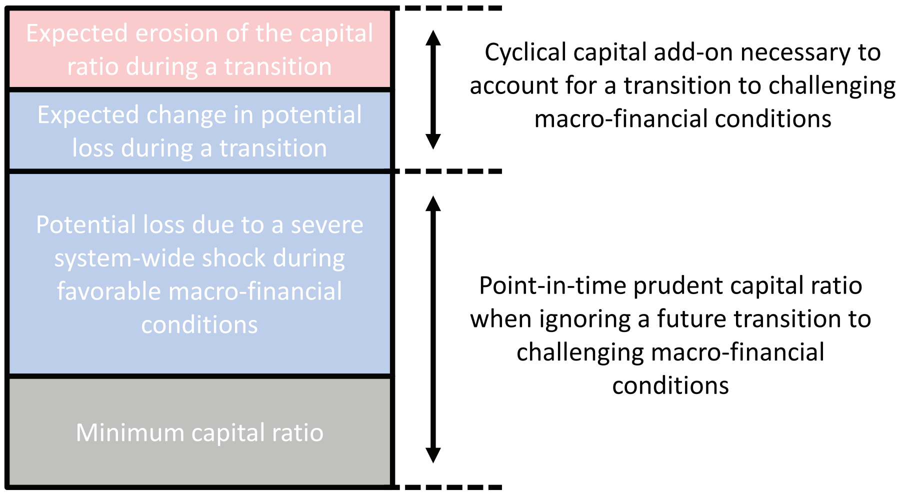
[1] The BCBS (2010) states the main objective as "*the aim is to ensure that the banking sector in aggregate has the capital on hand to help maintain the flow of credit in the economy without its solvency being questioned, when the broader financial system experiences stress after a period of excess credit growth*" while "*[a] side benefit of operating the buffer (...) is that it may lean against the build-up of excess credit in the first place.*"

permissible failure probability. This point-in-time prudential capital ratio depends on the risk tolerance of the macro-prudential authority along two dimensions. The first dimension is the severity of the system-wide shock that the authority considers, with more severe scenarios corresponding to a smaller likelihood that the system-wide shock materializes. The second dimension is the permissible failure probability if the system-wide shock were to materialize, with a smaller permissible failure probability corresponding to a higher confidence in the stability of banks when the shock occurs.

The estimation methodology of the point-in-time prudential capital ratio is constructed from three important contributions in the systemic risk literature. First, it relies on Brownlees and Engle (2017), who model the dynamic relationship between the returns on individual bank stocks and stock market indices in the context of market-based stress tests. Second, the methodology relies on the exposure CoVaR concept of Adrian and Brunnermeier (2016), which measures the maximum loss of an institution conditional upon a system-wide shock with a certain level of confidence. Third, the methodology relies on an adjusted version of the methodology of Acharya et al. (2014) to translate systemic risk measures into prudential capital ratios. We show how these three contributions, when fit together, can be used to estimate a point-in-time prudential capital ratio that safeguards the resilience of banks for system-wide shocks with a certain confidence level.

This point-in-time prudential capital ratio may be time-varying because of a variety of reasons. One reason is that the impact of a system-wide shock on any given bank could be smaller when the initial fundamentals are strong. For example, an unemployment shock may have less impact on banks' mortgage portfolios in periods with stable house price growth and low average loan-to-value ratios (Elul et al., 2010). Another reason is that financial institutions may build up more risks in their balance sheets when volatility is low (Brunnermeier and Sannikov, 2014). A further reason is that larger shocks may be more likely in an environment of weak initial fundamentals and high levels of overall uncertainty. To summarize, potential losses vary over time and so does the point-in-time prudent level of

Figure 1: Point-in-Time Prudential Capital Ratio and the Cyclical Capital Add-On



capital.

To ensure the resilience of the banking system, the macro-prudential authority needs banks to meet their point-in-time prudential capital ratios in the period after a strong credit expansion. This requires banks' capital buffers to be sufficiently high when approaching the end of a credit expansion. To achieve this, the macro-prudential authority sets a cyclical capital add-on that must account for two factors (Figure 1). The first factor is the aforementioned time-variation in potential losses, which could increase the point-in-time prudential capital ratio during a transition to challenging macro-financial conditions. The second factor is that the transition from a strong credit expansion to a challenging macro-financial environment may be associated with a reduction in the net worth of banks and a corresponding erosion in bank capital. The cyclical capital add-on indicated in Figure 1 combines both factors to ensure that banks meet the point-in-time prudential capital ratio after a transition in macro-financial conditions.

To estimate the necessary magnitude of the cyclical capital add-on at the end of a credit expansion, we construct a time series of the difference between banks' actual capital ratios and the point-in-time prudential capital ratio. The difference between the two reveals the evolution of capital that banks maintain above the prudent level of capital. We use regression analysis to estimate the expected decline in this buffer during a transition from a credit expansion to a challenging macro-financial environment. These estimates reveal the magnitude of the cyclical capital add-on that is necessary at the end of a credit expansion to maintain capital ratios above the point-in-time prudential capital ratio after the transition to a challenging macro-financial environment.

Empirically, we apply our methodology on data for large banks and macro-economic aggregates in six advanced economies. In our sample, the indicators based on the credit-to-GDP ratio and house prices perform relatively well as indicators of macro-financial conditions when compared to the bank-credit-to-GDP ratio. Given a statutory pre-announcement period of 12 months for any increases in the CCyB, our estimates suggest that the cyclical capital add-on may have to offset a decline in the capital buffer of around 1.4 per cent of total assets when the macro-prudential authority uses a naive forecast of future macro-financial conditions. The estimates further suggest that the magnitude of this buffer may potentially increase to up to 1.6 to 1.7 per cent of total assets if the authority could perfectly forecast macro-financial conditions. Sensitivity analysis shows that these estimates are not very sensitive to a variety of changes in our baseline methodology.

All of the aforementioned estimates are conditional upon an explicit calibration of the risk tolerance of the macro-prudential authority. This calibration aims at banks not breaching the minimum capital ratio with a 95 per cent confidence level after a six-month system-wide stress scenario that occurs on average every 10 years. One could easily imagine that, in practice, the risk tolerance of a macro-prudential authority could deviate in terms of the confidence level that banks' capital ratios remain above the minimum, the severity of the system-wide shocks or the length of those shocks. The methodology proposed in the present paper is flexible in the sense that it is straightforward to make adjustments to allow for reasonable alternative levels of risk tolerance.

The academic literature generally provides two rationales for implementing the CCyB.

The first rationale is that static risk-based capital requirements can have a mechanistical procyclical effect on credit supply because such requirements are more constraining in economic downturns due to fluctuations in risk (Kashyap and Stein, 2004; Catarineu-Rabell et al., 2005; Saurina and Trucharte, 2007; Repullo and Suarez, 2012) or negative shocks to bank capital (Repullo, 2013; Moyen and Schroth, 2017). The second rationale is that the CCyB may counterbalance pecuniary externalities that exacerbate fluctuations in the credit supply à la Lorenzoni (2008), Bianchi (2011) and Dávila and Korinek (2017). For example, the model of Gersbach and Rochet (2017) suggests that banks may lend too much in favorable macro-financial conditions, because individual banks do not internalize the positive impact of their own lending on asset prices. Banks in the model of Malherbe (2015) lend too much during periods of strong credit expansion, because they do not internalize the positive impact of their lending on the credit risk exposure of other banks increasing the overall credit supply. In these models, the implementation of a countercyclical capital buffer increases aggregate output and social welfare.

The macro-prudential authority follows a clear policy rule in our framework, i.e., maintaining the probability of breaching some minimum capital ratio in the event of a severe system-wide shock within a certain permissible failure probability. The benefit of such a rule is that it closely follows the regulatory objective, which is maintaining the credit flow while the financial system experiences stress after a period of excess credit growth. Moreover, it requires the macro-prudential authority to explicitly specify the level of risk tolerance for breaches of the minimum as well as the severity of the potential financial stress in terms of the probability that the shock may materialize. A disadvantage is that the policy rule has a relatively ad-hoc nature and follows only in a rather indirect manner from the aforementioned economic theory on macro-prudential capital requirements.

Three immediately relevant issues for the implementation of the CCyB are the selection of indicators to measure macro-financial conditions, the calibration of the (maximum) magnitude or 'cap' on the cyclical capital add-on, and the best timing for phasing-in the capital add-on. Our methodology focuses on the selection of macro-financial indicators for the CCyB as well as the calibration of the magnitude of the cap on the CCyB, but provides less information on the best timing for phasing-in and release of the cyclical capital add-on.

Policy makers and scholars generally recommend using multiple approaches to address issues related to the the calibration of the CCyB; see, e.g., Bennani et al. (2017), Federal Reserve Board (2016) and Bank of England (2016). Broadly speaking, these approaches can be classified into three largely complementary categories, with each category having its own merits.

The first approach is based on early warning models of banking crises or the build-up of macro-economic vulnerabilities; see, e.g., Behn et al. (2013), Anundsen et al. (2016), Brave and Lopez (2017) and Tölö et al. (2018). The rationale is that indicators that perform well as an early warning signal are better suited to signal the need for additional capital buffers before a banking crisis occurs.

The second approach relies on general equilibrium models with an explicit role for bank capital. After calibration or estimation, such a model may be used to assess the impact for different rules for the CCyB; see, e.g., Angelini et al. (2014), Clerc et al. (2015) and Carrasco-Gallego and Rubio (2018). Therefore, it may provide guidance on how to operate the CCyB while targeting an explicit objective, such as maximizing social welfare or reducing the volatility of credit supply.

The third approach relies on regulatory stress tests of the banking system; see, e.g., Bennani et al. (2017) and Anderson et al. (2018). This approach relies on a stress test model for the banking sector, which could potentially incorporate feedback effects to the macro-economy. Such a model is then used to assess how a counterfactual level of bank capital would alter the impact of adverse stress scenarios on the banking sector and the economy. The methodology proposed in the present paper fits best in this stress test category. However, our methodology relies on market-based stress tests instead of regulatory stress tests.

There are both advantages and disadvantages of relying on market-based stress tests in the context of calibrating the CCyB when compared to regulatory stress tests. The primary advantages are the low cost and data requirements. For this reason, it is relatively straightforward to construct a historical time series by implementing market-based stress tests in a retroactive manner. Moreover, market-based stress tests rely on market-based capital ratios, which may better reflect the forward-looking nature of the theoretical concept of banks' net worth used in most of the academic literature underpinning the CCyB, while regulatory definitions of capital often rely on historical cost accounting (Flannery, 2014; Sarin and Summers, 2016). Finally, by reflecting the views of market participants, market-based stress tests can provide an indication of market participants' decisions, such as their willingness to roll-over bank funding in times of stress. Moyen and Schroth (2017) explicitly model some of the difficulties that arise when the regulator relies on a more backward-looking concept of regulatory capital ratios, while the willingness of market participants to provide funding to a bank depends on its net worth, which also depends on its future performance.

There are also disadvantages of relying on market-based stress tests vis-à-vis regulatory stress tests. Some factors that influence market prices, such as changes in global risk premia, may only be partially relevant for assessing the stability of financial institutions (Cochrane, 2011). In our empirical framework, we try to partially address this issue by adding control variables in our regressions. Moreover, regulatory stress tests may also provide a more granular view since they can be based on confidential information. They may also be better at identifying the impact of different channels of shock propagation, such as common exposures, fire sales or network effects (Gauthier et al., 2014). These channels can be hard to disentangle when solely relying on market information. Nevertheless, this concern bears less relevance in the present context, because it is more the evolution of system-wide risk rather than the underlying sources that is important for the calibration of a relatively broad instrument such as the cyclical capital add-on.

The remainder of the paper is organized as follows. Section 2 explains the regression model that will be used to derive the cap on the CCyB once the point-in-time prudential capital ratio is estimated. How this point-in-time prudential capital ratio is estimated using market-based stress tests is explained in Section 3. Section 4 discusses the data used in our regression models. Section 5 presents the main results with the aforementioned estimates of the cap on the CCyB based on several indicators of macro-financial conditions. Section 6 reports results based on several variations in our methodology, such as different calibrations of the minimum capital ratio, estimates based on the pre-crisis period, and alternative specification of macro-financial indicators.

2 Empirical Approach

The main objective of the CCyB is to strengthen the resilience of the banking system by increasing banks' capital buffers during periods of rising systemic risk, thereby supporting the flow of credit during periods of financial stress. The starting point of our methodology is that, to pursue this objective, the macro-prudential authority has to ensure that banks' capital ratios are sufficiently high to withstand system-wide shocks when macro-financial conditions are weak. This is achieved by requiring a cyclical capital add-on in favorable macro-financial conditions, which offsets the expected increase in risk and the reduction in banks' capital ratios once the economy enters a period of challenging macro-financial conditions.

Let the estimate of the point-in-time prudential capital ratio for bank i, from a macro-prudential authority's point of view, be denoted as $k^*_{i,t}$. The level of $k^*_{i,t}$ is defined as the capital ratio that contains the probability of the bank breaching some minimum ratio in the event of a severe system-wide shock occurring at time t within a certain permissible failure probability. The method to estimate the level of $k^*_{i,t}$ will be discussed in the next section. Moreover, let the actual capital ratio of bank i be denoted as $k_{i,t}$. Then the capital buffer of the bank, which is defined as any capital in excess of the point-in-time prudential capital ratio, can be calculated as

$$B_{i,t} = k_{i,t} - k^*_{i,t}. \tag{1}$$

The capital buffer $B_{i,t}$ may decline during a transition from favorable to challenging macro-financial conditions because of two factors (Figure 1). The first factor is that the point-in-time prudential capital ratio, $k^*_{i,t}$, can be different in a period of challenging macro-financial conditions. Such a change could be the consequence of the build-up of vulnerabilities resulting in higher credit risk and an increasing impact of system-wide shocks on banks. The second factor is a decrease in the level of the actual capital ratio, $k_{i,t}$. This can, for example, be a result of weaker macro-financial conditions being associated with lower bank earnings because of new business and credit losses. Even if profit remains positive, this can result in an erosion in the capital ratio when the balance sheet tends to grow.

To assess the relationship between potential indicators of macro-financial conditions for the CCyB and the capital buffer $B_{i,t}$, we estimate the following model

$$B_{i,t} = \alpha_i + \alpha_t + \beta I_{c,t} + \delta X_{i,t} + \gamma Z_{c,t} + \varepsilon_{i,t}, \tag{2}$$

where $I_{c,t}$ represents the potential indicator of macro-financial conditions in region c. The coefficient β measures the average sensitivity of the capital buffer to the macro-financial indicator, while holding constant the other right hand side variables in the regression. The bank-specific variables $X_{i,t}$ are included to control for changes related to bank business models over time. The $Z_{c,t}$ stands for region-specific macro-economic state variables that may affect the capital buffers of banks, but whose impact on banks' capital buffers should not be accounted for in the cyclical capital add-on. The fixed effects denoted by α_i and α_t control for permanent differences in $B_{i,t}$ across banks as well as time-variation in $B_{i,t}$ due to global factors. The $\varepsilon_{i,t}$ captures the usual error term as well as estimation uncertainty in the dependent variable.[2]

[2]Estimation uncertainty in the dependent variable does not bias the estimate of β under a wide range of assumptions, but it does reduce the precision of the estimate, which will be reflected by the standard errors

Coefficient $\hat{\beta}$ allows us to estimate the expected erosion of banks' capital buffers as the indicator of macro-financial conditions drops from its peak to trough level, while holding the control variables constant, as

$$\begin{aligned} C^* &:= \mathbb{E}\left(B_{i,t}|Peak, X_{i,t}, Z_{c,t}, \alpha_t\right) - \mathbb{E}\left(B_{i,t}|Trough, X_{i,t}, Z_{c,t}, \alpha_t\right), \\ &= \hat{\beta}\left[\mathbb{E}\left(I_t|Peak\right) - \mathbb{E}\left(I_t|Trough\right)\right]. \end{aligned} \tag{3}$$

If coefficient $\hat{\beta}$ is statistically indistinguishable from zero, then the null hypothesis that a transition from favorable to challenging macro-financial conditions – as measured by indicator I_t – is irrelevant for banks' capital buffers. If we find a significant coefficient $\hat{\beta}$ instead, then the transition from favorable to challenging macro-financial conditions as measured by indicator I_t is associated with a statistically significant erosion in banks' capital buffers.

The CCyB is meant to safeguard the resiliency of the banking system when macro-financial conditions are weak (i.e., when I_t is low). Given the risk tolerance of the macro-prudential authority, this can be achieved by ensuring that banks' capital ratios equal at least $k^*_{i,t}$ when macro-financial conditions are weak. In order to do so, the macro-prudential authority must take into account that the transition from favorable to challenging macro-financial conditions is expected to be associated with an erosion of banks' capital buffers equal to C^* in Eq. (3). To account for this fact, the capital ratio before a transition to challenging macro-financial conditions (i.e., when I_t is still high) needs to be at least $k^*_{i,t} + C^*$ (Figure 1). In other words, C^* can be interpreted as the level of the CCyB that is necessary to offset the expected reduction in banks' buffers once the economy enters a period of challenging macro-financial conditions.

in our tables; see, e.g., Hausman (2001).

3 Point-in-Time Prudential Capital Ratio

Estimating the model in Eq. (2) requires observing the level of banks' capital buffers, which critically depends on the point-in-time prudential capital ratio $k^*_{i,t}$. The point-in-time prudential capital ratio is defined as the capital ratio that contains the probability of breaching the minimum in the event of a severe system-wide shock within a certain permissible failure probability. In this section, we show how we implement a market-based stress test to estimate the point-in-time prudent level of bank capital $k^*_{i,t}$. This methodology relies on combining features of the approaches proposed in Acharya et al. (2014), Adrian and Brunnermeier (2016) and Brownlees and Engle (2017).

As in Acharya et al. (2012) and Brownlees and Engle (2017), the macro-prudential authority is concerned about a potential capital shortfall relative to some minimum capital ratio k at time $t+h$. The level of k could, for example, correspond to a market-based capital ratio that, when breached, is believed to be associated with substantial default risk or a serious disruption in credit provision due to financial distress. Although alternative choices of k obviously results in level-shifts in the point-in-time prudential capital ratio, it will turn out that it has very little impact on our results regarding the CCyB, which depend more on the time-variation in the point-in-time prudential capital ratio.[3] While assuming a fixed level of bank debt D_{it}, the capital shortfall is defined as

$$\begin{aligned} CS_{i;t+h} &= kA_{i,t+h} - MV_{i,t+h} \\ &= kD_{i,t} - (1-k)(1+R_{i,[t;t+h]})MV_{i,t}, \end{aligned} \tag{4}$$

where $MV_{i,t+h}$ is the market value of bank i's common stock at time $t+h$, $R_{i,[t;t+h]}$ denotes bank i's stock return between t and $t+h$, and $A_{i,t+h}$ denotes the quasi-market value of the bank's assets, which is measured as the sum of the market value of common stocks and the

[3]For this reason, our results regarding the CCyB are also insensitive to choosing different levels of k for a subset of banks to account either for differences in accounting standards in different jurisdictions as in, e.g., Acharya et al. (2012), or for higher regulatory minimums for certain banks within jurisdictions.

book value of all other liabilities.

The intermediate step is to derive the hypothetical capital ratio that avoids a capital shortfall given some simulated path of the future stock return $R_{i,[t,t+h]}$. One can derive the initial level of the capital ratio that results exactly in a zero capital shortfall after dividing both sides of Eq. (4) by $A_{i,t}$ and reordering. This level equals

$$k_{i,t}^{0} = \frac{k}{1 + (1-k)\widehat{R}_{i,[t;t+h]}\left(k_{i,t}^{0}\right)}, \tag{5}$$

where $\widehat{R}_{i,[t;t+h]}\left(k_{i,t}^{0}\right)$ represents the future stock return path if the bank hypothetically had an initial capital ratio of $k_{i,t}^{0}$ instead of $k_{i,t}$. Hence, this equation shows that, in order to calculate the hypothetical capital ratio that results in a zero capital shortfall, one needs to specify the relationship between $R_{i,[t;t+h]}$ and $\widehat{R}_{i,[t;t+h]}\left(k_{i,t}^{0}\right)$.

One potential assumption is that the future stock return path is independent of the bank's initial capital position, i.e., $\widehat{R}_{i,[t;t+h]}\left(k_{i,t}^{0}\right) = R_{i,[t;t+h]}$ for any $k_{i,t}^{0}$. Such an assumption, however, would theoretically imply that a hypothetical bank with a twice as high initial capital ratio $k_{i,t}^{0}$ and further identical in every other respect, would also experience shocks to the value of its assets that are twice as high. Moreover, such an assumption would neglect the well-known stylized fact that an increase in equity financing is associated with a reduction in the volatility of stock returns, and vice versa.[4]

Instead, we account for the leverage effect in stock returns by using a simple theoretical approximation, which imposes the constraint that the market-value of the bank's assets is independent of the bank's initial capital ratio. When assuming a fixed return on bank debt, this implies that the future stock return path of a bank with some hypothetical capital ratio

[4]Several papers document empirical evidence on the negative relationship between bank capital and several measures of risk of equity returns. In particular, see Kashyap et al. (2010) and Miles et al. (2013) for evidence on the negative relationship of stock market betas to bank capital. Moreover, Adrian and Brunnermeier (2016) document a negative relationship of $CoVaR$ to bank capital; Van Oordt and Zhou (2018) document that better capitalized banks are less sensitive to extremely adverse system-wide shocks.

$k^0_{i,t}$ is given by

$$\widehat{R}_{i,[t;t+h]}\left(k^0_{i,t}\right) = R_{f,[t;t+h]} + \frac{k_{i,t}}{k^0_{i,t}}(R_{i,[t;t+h]} - R_{f,[t;t+h]}), \tag{6}$$

where $R_{f,[t;t+h]}$ is the level of the return on bank debt.[5] Substitution of Eq. (6) into Eq. (5) allows us to calculate for any simulated stock return $R_{i,[t;t+h]}$ the initial capital ratio that results exactly in a zero capital shortfall.

The next step is to estimate the level of capital necessary to avoid a capital shortfall given the maximum loss on a bank's stock that will not be exceeded within a certain confidence level in the event of a severe system-wide shock. This maximum loss is conceptually comparable to the 'exposure CoVaR' measure of Adrian and Brunnermeier (2016), which is the maximum loss on the bank's stocks within a certain confidence level in the event of a severe system-wide shock. In particular, to calibrate the level of the prudential capital ratio, we rely on the concept of a 'long-run exposure CoVaR,' $LRCoVaR^q_{i,t}(p)$, which is implicitly defined as

$$\Pr\left(R_{i,[t;t+h]} < -LRCoVaR^q_{i,t}(p) | R_{s,[t;t+h]} < -LRVaR_{s,t}(q)\right) = p, \tag{7}$$

where $LRVaR_{s,t}(q)$ denotes the 'long-run value-at-risk' of the system, i.e., $LRVaR_{s,t}(q) := -\sup\{b : \Pr\left(R_{s,[t;t+h]} \leq b\right) \leq q\}$, and where $R_{s,[t;t+h]}$ denotes the stock return of the system. The definition in (7) adopts the terminology of Adrian and Brunnermeier (2016), except for the phrase 'long-run', which indicates that it measures risk over a longer horizon of h periods. Another subtle difference is that the definition in (7) focuses on the loss in the system exceeding its long-run value-at-risk, as opposed to matching it exactly, as suggested by, e.g., Girardi and Ergün (2013). For example, the long-run exposure CoVaR represents the maximum percentage loss on the bank's stock with a 95 per cent confidence level in the

[5]The assumption that the market value of the bank's assets will be the same holds both at time t and at time $t+h$. This implies that the return on the bank's assets is the same across the two firms. Eq. (6) is obtained from equating the return on total assets for two different levels of leverage as $k^A_{i,t}\widehat{R}_{i,[t;t+h]} + (1 - k^A_{i,t})R_{f,[t;t+h]} = k_{i,t}R_{i,[t;t+h]} + (1-k_{i,t})R_{f,[t;t+h]}$, where $R_{f,[t;t+h]}$ is the given return on bank debt. Modigliani and Miller (1958) derive one set of conditions under which this holds true. Note that the level of SRISK (Acharya et al., 2012; Brownlees and Engle, 2017) is not affected by the relationship in Eq. (6), because it is directly calculated from Eq. (4).

5 per cent worst system-wide scenarios if $p = q = 0.05$.

The final step to estimate the point-in-time prudential capital ratio $k^*_{i,t}$ is to calculate the capital ratio that results in a zero capital shortfall for $R_{i,[t;t+h]} = -LRCoVaR^q_{i,t}(p)$. This gives the point-in-time prudent level of capital $k^*_{i,t}$ that contains the probability of a breach of a minimum ratio k in the event of a severe system-wide shock at time t within a permissible failure probability p as

$$k^*_{i,t} = \frac{k + k_{i,t}(1-k)(LRCoVaR^q_{i,t}(p) + R_{f,[t;t+h]})}{1 + (1-k)R_{f,[t;t+h]}}. \quad (8)$$

This equation shows how the point-in-time prudential capital ratio based on permissible failure probabilities can be obtained using market-based stress tests by combining the methodologies of Acharya et al. (2012, 2014), Brownlees and Engle (2017) and Adrian and Brunnermeier (2016). An important element in Eq. (8) is the long-run exposure CoVaR and the next subsection explains how simulations based on the model of Brownlees and Engle (2017) can be used to estimate this component.

3.1 Estimation of long-run exposure CoVaR

The estimation of the long-run exposure CoVaR requires modelling the bank's stock return and the return of the system. For this purpose, we follow the approach of Brownlees and Engle (2017, Appendix A.1) to statistically model the daily bivariate return process $\left(R_{i,[t-1;t]}, R_{s,[t-1;t]}\right)$ using a GARCH-DCC model. This approach allows for time variation in the correlation structure by relying on the DCC model of Engle (2002), while it allows for the leverage effect and volatility clustering in stock returns by relying on the GJR-GARCH model of Glosten et al. (1993).

Before statistically modelling the return process $\left(R_{i,[t-1;t]}, R_{s,[t-1;t]}\right)$, it is necessary to construct the series with the returns on the banking system $R_{s,[t-1;t]}$. Since the focus of the CCyB is on the domestic level, we will focus on system-wide risks in local banking systems.

Following López-Espinosa et al. (2012), we construct the return of the banking system for each bank as the weighted average stock return of all other banks. Formally, for each bank i, we calculate the return of the banking system at each time t as

$$R_{s(i),[t-1;t]} = \frac{\sum_{j\neq i} MV_{j,t-1} R_{j,[t-1;t]}}{\sum_{j\neq i} MV_{j,t-1}}. \tag{9}$$

For each bank i, the parameters of the GARCH-DCC model are estimated for the return pair $\left(R_{i,[t-1;t]}, R_{s(i),[t-1;t]}\right)$ at the end of each quarter from historical daily stock returns of up to 10 years preceding t. Based on these parameter estimates, we simulate 10,000 daily stock future returns paths of approximately six months (130 trading days). All simulations with an $R_{s(i),[t;t+h]}$ smaller than the order statistic that corresponds to the q-th quantile of the six-month system returns are flagged as corresponding to a severe system-wide shock. The level of $LRQNT_{it}^{q}$ is then estimated as the order statistic that corresponds to the p-th quantile of the simulated six-month bank returns within the flagged simulations. Finally, we obtain the point-in-time prudential capital ratio $k_{i,t}^{*}$ by plugging the estimate of $LRCoVaR_{it}^{q}(p)$, the actual market-based capital ratio $k_{i,t}$ and the interest on interbank borrowing accumulated over a six-month period $R_{f,[t;t+h]}$ into Eq. (8).

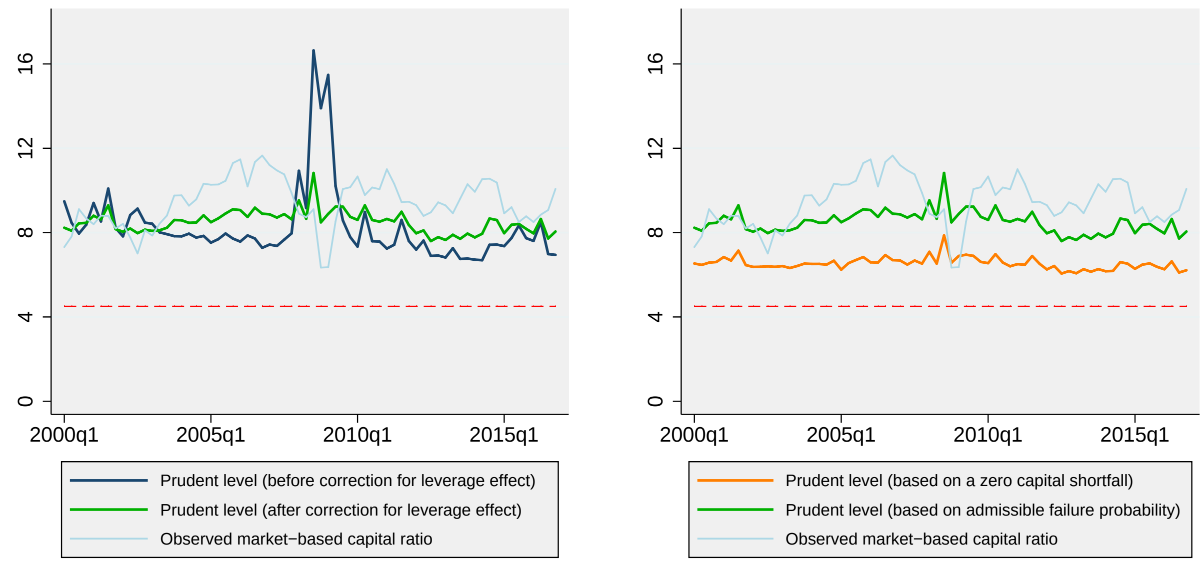
3.2 Comparing approaches

The point-in-time prudential capital ratio in Eq. (8) deviates from that in Acharya et al. (2014) in two respects. The first difference is that the prudential capital ratio in Eq. (8) explicitly accounts for the leverage effect in stock returns. Failing to account for the leverage effect may result in large spikes in the prudential capital ratio whenever volatility increases as a consequence of an increase in leverage. This is illustrated for Canadian banks in Figure 2, panel (a). The figure reports the average point-in-time prudential capital ratio both without and with accounting for the leverage effect. The figure shows that accounting for the leverage effect does substantially reduce the time-variation in the point-in-time prudential

Figure 2: Point-in-Time Prudential Capital Ratios of Canadian Banks, 2000-2016.

(a) Impact of correction for the leverage effect

(b) Impact of using an admissible failure probability



Note: In per cents of total assets. The charts show the impact of the two main differences between the prudential capital ratio in Eq. (8) and that in Acharya et al. (2014). The parameter values are 4.5 per cent for the minimum capital ratio k (red dashed line) and 5 per cent for the admissible failure probability after the 5 per cent worst system-wide shocks ($p = q = 0.05$) over a period of 6 months ($h = 130$). The averages are weighted by the book value of total assets.
The solid green line in both panels is the point-in-time prudential capital ratio obtained from Eq. (8). The solid blue line in panel (a) reports the prudential capital ratio without the correction for the leverage effect. This level is obtained by substituting the long-run exposure CoVaR for $-\widehat{R}_{i,[t;t+h]}$ in Eq. (5). The solid orange line in panel (b) reports the point-in-time prudential capital ratio based on aiming at a zero capital shortfall instead of an admissible failure probability. This level is obtained by replacing the long-run exposure CoVaR in Eq. (8) with the long-run marginal expected shortfall.

capital ratio. Hence, even though this may be less relevant for a cross-sectional analysis as in Acharya et al. (2014), accounting for the leverage effect is important in the time-dimension.

The second difference is that the point-in-time prudential capital ratio in Eq. (8) aims at avoiding a breach of the minimum capital ratio with a given permissible probability, instead of aiming at a zero capital shortfall *on expectation*. Note that a zero capital shortfall on expectation will be the result of averaging over outcomes with capital shortfalls and surpluses, and is therefore not necessarily informative on the likelihood that the minimum capital ratio will be breached in the event of a severe system-wide shock. Nevertheless, if preferred, it is still possible to calibrate the level of the prudential capital ratio aiming at a zero $CS_{i,t+h}$ on expectation. This can be achieved by simply replacing the $LRCoVaR^{q}_{i,t}(p)$ in Eq. (8) by the long-run marginal expected shortfall. Figure 2, panel (b) illustrates the difference by reporting the point-in-time prudential capital ratios of Canadian banks based on both a zero expected shortfall approach and an approach using an admissible failure probability of 5 per cent (both including the correction for leverage). The main difference is that the prudential capital ratios based on the maximum loss given the admissible failure probability is about 2 percentage points higher than that based on the expected loss. Moreover, the prudential capital ratio based on the admissible failure probability shows slightly more changes stemming from time-variation in the estimated (conditional) tail risks of banks.

4 Data

In this study, we collect data for macro-economic aggregates and large banks in the following six advanced economies: Australia, Canada, the euro area, Japan, the United Kingdom and the United States. The baseline analysis concerns the 26-year period from 1990Q1 until 2016Q4. The total sample includes 7,474 bank-quarter observations covering the list of banks provided in Appendix A. The list is intended to cover the major banks in the respective economies for which we have at least 40 bank-quarter observations for the variables in our regressions.[6] Descriptive statistics are reported in Table 1.

At the end of each quarter, we estimate the point-in-time prudential capital ratio, $k^{*}_{i,t}$, from Eq. (8). Data on stock market returns and market capitalization are obtained from Thomson Reuters Datastream. As a starting point of the analysis, the prudential authority is assumed to avoid breaches of a minimum capital ratio of 4.5 per cent of total assets with a confidence level of 95 per cent for each bank after the 5 per cent worst system-wide shocks over the next six months (i.e., $k = 0.045$ and $p = q = 0.05$). Based on this calibration,

[6] To avoid potential distortion in bank-specific variables caused by large mergers and acquisitions, we exclude observations in which banks report a year-on-year asset growth rate that exceeds 50 per cent.

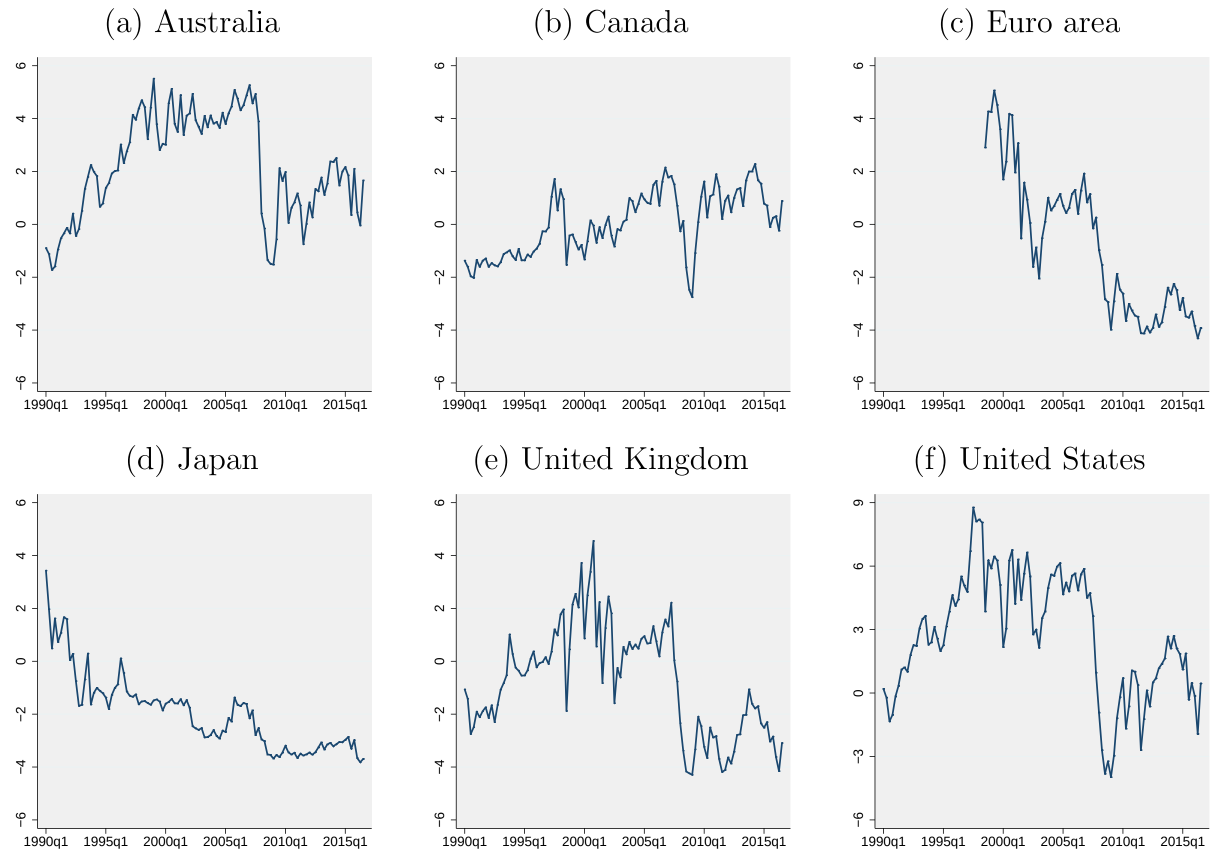
the point-in-time prudential capital ratio equals 9.23 per cent on average, while the average market-based capital ratio, $k_{i,t}$, equals on average 10.02 per cent across all bank-quarter observations. This implies a market-based capital buffer, $B_{i,t}$, of, on average, +0.80 per cent.

Figure 3 shows the evolution of market-based capital buffers for each of the six advanced economies. Several patterns emerge from the charts. First, market-based capital buffers are relatively low in the early 1990s in most advanced economies. Second, the 2001-2002 recession and, to a lesser extent, the Asian Crisis and Russian debt crisis in 1997 and 1998, are associated with significant shocks to banks' capital buffers. Third, all advanced economies show a strong decline in buffers early in the 2007-2009 financial crisis, which, depending on the region, sets in during either 2007Q3 or 2007Q4. Finally, there is considerable variation in the extent to which buffers are restored to pre-crisis levels after the financial crisis when comparing, for example, the euro area and the US.

For the macro-financial conditions, we consider three indicators that are popular in the literature as an illustration: the credit-to-GDP ratio, the bank-credit-to-GDP ratio and residential real estate prices, which we refer to as 'house prices' going forward (Drehmann et al., 2011; Schularick and Taylor, 2012; Anundsen et al., 2016). Quarterly time series are obtained from the Bank of International Settlements. For the sake of consistency, we construct two series for each indicator of macro-financial conditions in our baseline results. The first series contains the values of the year-on-year growth rates. The second series ranges from zero to one based on how the current level of the year-on-year growth rate compares to a 12-year backward-looking window ('rolling-window percentiles'). In the sensitivity analysis, we also consider some other popular series such as the credit-to-GDP gap and real credit growth with relatively little impact on the main results.

As an explorative analysis, we calculate simple correlation coefficients between the market-based capital buffer and each of the indicators of macro-financial conditions after demeaning those variables at the level of the institution. These correlations, which are re-

Figure 3: Evolution of Market-Based Capital Buffers, 1990-2016 (per cents of total assets)



The charts show the median market-based capital buffer of banks, $B_{i,t}$, for each advanced economy in our sample. The values are estimated from Eq. (8) while assuming that the prudential authority aims at avoiding breaches of a minimum capital ratio of 4.5 per cent of total assets with a confidence level of 95 per cent for each bank after the 5 per cent worst system-wide shocks over the next six months (i.e., $k = 0.045$ and $p = q = 0.05$ and $h = 130$). The period for the euro area starts with the introduction of the euro in 1999.

ported in Table 2, suggest that the capital buffers tend to be higher when macro-financial conditions are stronger. The correlations are strong and positive as they peak above 0.40 for each of the three indicators of macro-financial conditions. Moreover, the correlations of the rolling-window percentiles of the indicators with the capital buffer are of a similar order of magnitude, which is important for overcoming practical difficulties when implementing the capital buffer. Nevertheless, the timing differs across the three indicators: The correlation with house price growth peaks when house price growth is used as a leading indicator of the capital buffer, while the correlation with the credit aggregates tends to be stronger as a lagging indicator.

The macro-economic controls aim to capture variation in the market-based capital buffers based on standard business cycle variation in bank performance (Albertazzi and Gambacorta, 2009; Bolt et al., 2012), as well as changes in discount rates and risk premia in financial markets (Cochrane, 2011). The macro-economic controls include the year-on-year real economic growth rate, the unemployment rate, the inflation rate, the stock market return, the short-term interest rate and the slope of the yield curve. All these data are obtained at a quarterly frequency from the OECD.[7]

The bank-specific controls aim to capture variation in market-based capital buffers due to gradual changes in their business models (Van Oordt and Zhou, 2018; Köhler, 2015). These control variables include proxies of the traditionality of the bank's business model, such as the level of the non-interest-income-share, the size of the loan portfolio as a percentage of total assets, as well as a liquid-assets-to-total-assets ratio. Moreover, proxies of banks' funding profiles included in the regressions are the accounting-based equity-to-assets ratio and the deposit funding gap, measured as the difference between the loans and deposits as a percentage of total assets. Finally, as a measure of bank size, we include the bank's asset share in the banking system as well as the Herfindahl index calculated from the amount of total assets to control for time-variation in banking concentration. These bank-specific controls are based on the banks' annual reports as recorded in Thomson Reuters Datastream.

5 Results

We first estimate the model in Eq. (2) without macro-economic variables to control for standard business cycle variation in the market-based capital buffer. This first set of estimates also excludes time dummies to control for global factors. Table 3 reports these estimates for

[7]Moreover, for Canadian banks, the impact of the introduction of those standards was particularly pronounced for the annual growth rate of bank-credit-to-GDP in 2011Q4-2012Q3. This is a consequence of the introduction of International Financial Reporting Standards. Therefore, we add a dummy that equals one for Canadian banks in those quarters, and zero otherwise.

each of the three indicators of macro-financial conditions. The coefficients are statistically significant for both the values of the growth rates as well as the rolling-window percentiles. The positive sign is consistent with an expected erosion in banks' capital buffers during a transition to a challenging macro-financial environment. The coefficients for credit-to-GDP and house prices have the highest level of statistical significance.

The magnitudes of the coefficients for the values of the measures cannot be directly compared since the amplitude of the variation across the macro-financial indicators depends on the indicator. The table also provides the implied magnitude of the cyclical capital add-on for each estimate and the corresponding confidence interval. The magnitude of the cyclical capital add-on is calculated from Eq. (3) using the estimated coefficient (and its confidence interval) for the relevant macro-financial indicator. This coefficient is multiplied with the expected difference in the level of the indicator in favorable and challenging macro-financial conditions. When using the value of the growth rates, this difference is calculated as the difference between the 90th percentile and the 10th percentile of the indicator reported in Table 1. When using the rolling-window percentiles, this difference simply is set at 0.80 (i.e., 0.90 minus 0.10).

The implied magnitude of the cyclical capital add-on without controlling for standard business cycle variation in the market-based capital buffer in Table 3 ranges from 2.7 to 2.9 per cent of total assets when based on the credit-to-GDP ratio. The magnitude is similar, with a range from 2.8 to 3.1 per cent, when based on house prices. Based on the bank-credit-to-GDP ratio, the cyclical capital add-on is around 2.1 per cent of total assets. Note, however, that a significant fraction of the estimated cyclical add-on may be the consequence of standard business cycle risks, while the CCyB is not intended to be used as a cushion for standard business cycle variation (BCBS, 2010, 2017).

When controlling for standard business cycle variation, the coefficients are substantially smaller. Table 4 shows the results while including the macro-economic control variables and time dummies. The implied magnitude of the cyclical capital add-on based on the credit-to-GDP ratio ranges from 1.4 to 1.7 per cent of total assets. Those based on the bank-credit-to-GDP ratio are around 0.6 per cent of total assets. However, coefficients based on the bank-credit-to-GDP ratio turn out to have a lower level of overall significance, suggesting that this is not a great indicator to calibrate the CCyB in our sample. Finally, the indicators based on house prices suggest a coefficient in the range from 1.0 to 1.6 per cent of total assets.

A practical issue with the implementation of the cyclical capital add-on is that the macro-prudential authority has to pre-announce increases in the CCyB to give financial institutions a sufficiently long period to react. In general, the length of the pre-announcement period for increases in the CCyB is set at 12 months. Hence, to effectively implement the CCyB, the macro-prudential authority has to set its policy based on a forecast of macro-financial conditions 12 months ahead. In this context, the estimates in Table 4 can be considered as representing the ideal situation where the macro-prudential authority has the ability to perfectly forecast the values of macro-financial indicators after the pre-announcement period.

Table 5 presents results for a macro-prudential authority that would use a naive approach by using the current values of macro-financial indicators as a forecast of their values 12 months ahead. In this table, the magnitude of the cyclical capital add-on is based on re-estimating by regressing the market-based capital buffer on the macro-financial conditions 12 months earlier. These estimates can be considered as a lower bound, because, in practice, the macro-prudential authority could do better by relying on a more enhanced projection model to forecast the indicators of macro-financial conditions.

For the credit aggregates, the coefficients are somewhat smaller when regressing on macro-financial conditions 12 months earlier. In particular, while the overall credit-to-GDP ratio remains statistically significant at the 1 per cent significance level, the bank-credit-to-GDP ratio loses its overall statistical significance in Table 5. Nevertheless, the credit-to-GDP ratio may still justify a cyclical capital add-on of 1.0 per cent of total assets. Shifting to indicators of macro-financial conditions 12 months earlier does not affect the results too much when the macro-prudential authority relies on house prices, suggesting a cyclical capital add-on of around 1.4 per cent of total assets. Overall, these results are in line with the pattern in the correlations in Table 2, where the indicators based on house prices tend to lead the market-based capital buffer, while those based on credit aggregates tend to lag in our sample.

6 Sensitivity Analysis

Tables 6 and 7 summarize the results for several deviations in our baseline calibration and methodology. For brevity, we report only the estimated coefficient, its standard error and the implied cyclical capital add-on in Table 6. Unless mentioned, the methodology of the results shown is equivalent to the methodology used to obtain the estimates in Table 4.

6.1 Minimum capital ratio

The point-in-time prudential capital ratio $k^*_{i,t}$ depends on the calibration of the minimum level of capital k. Table 6, panels (a) and (b), shows how the results change when setting the minimum level of capital at, respectively, 3.0 per cent and 6.0 per cent of total assets. This relatively wide range of k clearly results in changes in the point-in-time prudential capital ratio $k^*_{i,t}$, and therefore in a change in the dependent variable. Nevertheless, a comparison of the results in panels (a) and (b) with those in Table 4 shows that such a level-shift has very little impact on the estimated magnitude of the cyclical capital add-on, which depends more on the variation over time.

6.2 Sample period

For some banks we have data available in the decade before 1990. However, the composition of the panel strongly changes in this earlier period, with the number of banks in our sample increasing over the period 1980-1990. Adding these additional observations from the 1980s to the sample does not have a large impact on the results, as shown in Table 6, panel (c).

Most of the policy debate around the CCyB occurred in the aftermath of the 2007-09 financial crisis. Moreover, some papers document challenges to generate accurate out-of-sample predictions of the simultaneous recession using credit aggregates (Gadea Rivas and Perez-Quiros, 2015; Kiley, 2018). Hence, it may be interesting to verify whether the methodology suggests any significant cyclical capital add-on based on only observations before the 2007-09 financial crisis. Table 6, panel (d), shows the results based on estimates using observations until 2007Q2 only. Interestingly, the impact of this change depends on whether the cyclical capital add-on is based on credit aggregates as an indicator of macro-financial conditions or not. The significance and magnitude of the cyclical capital add-on is almost unaffected when relying on house prices. In contrast, the magnitude of the implied cyclical capital is smaller when relying on the credit aggregates, although the estimates based on credit-to-GDP remain statistically significant.

6.3 Regional data

The results look very similar when estimating the magnitude of the cyclical capital add-on based on region-level medians instead of data on individual banks. One practical concern when constructing region-level data is that changes in the panel composition could have a significant impact on region-specific averages. To deal with the impact of such changes, we rely on region-specific medians instead. For each advanced economy, we calculate time series with region-specific medians of the buffers and the bank-specific control variables. Table 6, panel (e), shows that implied capital buffer is slightly higher, but very comparable in magnitude, when estimating the model based on those region-specific medians.

6.4 Trends

One concern always remains that we may not properly control for all possible factors that could affect the level of the capital buffer over time. Besides a careful selection of the control variables, we further address this concern by repeating the estimation while also including bank-specific trends besides the bank and time fixed effects. Table 6, panel (f), shows that this has little impact on the results.

6.5 Random coefficient

The magnitude of the CCyB imposed by macro-prudential authorities is the same for exposures of all banks. Similarly, the model in Eq. (2) imposes a common coefficient β on all banks. Alternatively, the model could be estimated while allowing for heterogeneity in the manner that banks' buffers respond to changes in macro-financial conditions. Table 6, panel (g), reports the results when estimating a mixed effects model that is identical to the model in Eq. (2), except that it allows the coefficient β to contain a random element that can differ across banks. The implied coefficients and the implied cyclical capital add-on are very similar to the baseline results.

6.6 Excluding internationally focused banks

Some of the large banks in our sample have a strong international focus. For example, HSBC's claims in foreign jurisdictions exceeded 60 per cent of its total exposures in 2017. Capital buffers of internationally focused banks could be less sensitive to macro-financial conditions in the region where their head office is located, which could potentially lead to a downward bias in our results (this is a common problem in empirical studies using international banking data).

To assess the severity of this bias, we re-estimate Eq. (2) while excluding banks for which G-SIB disclosure data indicates that cross-jurisdictional claims exceed 40 per cent of a bank's total exposures in 2017 (those banks are indicated in Appendix A). These results are presented in Table 6, panel (h). The results are very similar to the baseline results.[8] The most notable difference is that the add-on based on house price growth is at 1.8 per cent,

[8]Estimates based on a cut-off percentage of 35 per cent are even closer to the baseline results.

slightly higher than the original results (1.6 per cent). These estimates provide confidence that the downward bias in our results due to internationally focused banks is limited in magnitude.

6.7 Alternative credit measures

Two popular alternative measures of credit growth in the context of the CCyB are the credit-to-GDP gap (Drehmann et al., 2011), as calculated by the Bank of International Settlements, and real credit growth (Schularick and Taylor, 2012). Table 7 shows the results when using these measures as an indicator of macro-financial conditions while both excluding and including macro-economic control variables. The significance and sign of the coefficients are not very sensitive to using alternative measures of credit growth. The implied capital add-on when excluding macro-economic control variables is at 1.9 to 2.4 per cent of total assets, somewhat lower when relying on these alternative measures of credit growth when compared to the estimates for the growth in credit-to-GDP in Table 3. Nevertheless, the difference in results is smaller, in particular for real credit growth, when macro-economic control variables are included.

7 Concluding Remarks

For the selection of the indicators, our estimates suggest that the indicators based on the credit-to-GDP ratio and house prices perform relatively well as indicators of macro-financial conditions when compared to the bank-credit-to-GDP ratio. Regarding the magnitude of the countercyclical add-on, both indicators result in similar estimates of the cyclical capital add-on. Our estimates suggest that it may have to offset a decline in buffer of around 1.4 per cent of total assets when the macro-prudential authority takes a relatively naive view of future macro-financial conditions (Table 5). The estimates further suggest that the magnitude of this buffer may potentially increase to up to 1.6 to 1.7 per cent of total assets when the authority has the ability to perfectly forecast macro-financial conditions (Table 4).

Sensitivity analysis shows that these estimates are not very sensitive to changes in our baseline methodology. An exception is that the estimated cyclical capital add-on – when using credit aggregates as an indicator of macro-financial conditions – would be smaller when relying on pre-crisis data only. An interesting feature is that – when using house price growth as the indicator – it is irrelevant for the estimate of the cyclical capital add-on whether it is based on pre-crisis data only or also on post-crisis data.

The estimates are economically significant when considering that these numbers are expressed in terms of total assets rather than risk-weighted assets. For example, if the average risk weight of banks amount to 50 per cent, then a cyclical capital add-on of 1.4 to 1.7 per cent of total assets implies that a buffer of 280 to 340 basis points of risk-weighted assets may be necessary to offset the reduction in the capital buffer when macro-financial conditions move from peak to bottom.[9] This is more conservative than, but close to, the internationally agreed maximum reciprocatory level for the CCyB of 250 basis points, which also applies as a cap on the CCyB in several jurisdictions.[10] Moreover, these estimates are conditional upon the macro-prudential authority aiming at banks not breaching the minimum capital ratio with a 95 per cent confidence level after a six-month system-wide stress scenario that occurs on average every 10 years. A lower (higher) level of risk tolerance would positively (negatively) impact the required level of the cap for the CCyB.

There is some reason to believe that the estimated cyclical add-on is smaller than what is needed in terms of the regulatory definition of equity. This comes from the fact that our estimate, which is defined in terms of market values, needs to be translated into book values for the purpose of regulation. The literature suggests several mechanisms that may

[9]The 50 per cent is close to the average risk weight of 52 per cent reported for the sample of banks in advanced economies in the study of Mariathasan and Merrouche (2014).

[10]The 280 to 340 basis points also exceeds the highest levels for the CCyB that are currently observed among jurisdictions that have activated the CCyB, which is around a level of 200 basis points or risk-weighted assets in jurisdictions such as Hong Kong, Norway and Sweden (BCBS, 2018). Note, however, that the 280 to 340 basis points is an estimate of the cap rather than a recommendation for the current level of the CCyB.

cause equity financing to be relatively expensive compared to debt financing for banks.[11] As a consequence of these mechanisms, substituting one dollar of bank debt for one dollar of equity is likely to change the market value of bank equity by less than a dollar. This suggests that, *ceteris paribus*, one may need to build up a capital add-on of more than 1.4 to 1.7 per cent in terms of book values to achieve a capital add-on of 1.4 to 1.7 per cent in terms of market values.

Appendix A. List of Banks

See Table 8.

[11] For example, Stein (2012) suggests that banks could benefit from cheaper debt funding because of the liquidity services they provide to their customers. This benefit is eroded if banks are forced to use less debt financing. A somewhat different question from how these mechanisms affect the level of the cyclical capital add-on is how they reduce the optimal average through-the-cycle level of capital, see, e.g., Kashyap et al. (2010) and Miles et al. (2013).

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Table 1: Descriptive Statistics

Variables	Mean	Sd	p10	p90	Obs
Panel (a): Macro-financial indicators					
Credit-to-GDP (percentage change)	1.03%	2.75%	-2.38%	4.41%	7,377
Bank-Credit-to-GDP (percentage change)	0.84%	3.64%	-3.44%	4.71%	7,471
House Price Growth	3.37%	6.58%	-4.29%	10.92%	5,649
Panel (b): Banks' capital ratios					
Capital Buffer, $B_{i,t}$	0.80%	3.88%	-3.54%	6.09%	7,471
Actual Market-Based Capital Ratio, $k_{i,t}$	10.02%	6.53%	2.84%	18.54%	7,471
Point-in-Time Prudential Capital Ratio, $k^*_{i,t}$	9.23%	3.28%	5.97%	13.30%	7,471
Panel (c): Macro-economic controls					
Real GDP Growth	1.85%	1.99%	-0.42%	4.13%	7,471
Unemployment	6.97%	2.33%	4.23%	10.20%	7,471
Inflation	1.95%	1.43%	0.00%	3.51%	7,471
Interbank Rate	2.72%	2.57%	0.07%	5.80%	7,471
Slope of the Yield Curve	1.44%	1.20%	-0.09%	3.17%	7,471
Stock Return	5.14%	17.86%	-18.73%	24.47%	7,471
Panel (d): Bank-specific controls					
Equity-to-Total-Assets	6.45%	2.83%	3.33%	10.33%	7,471
Non-Interest-Income-Share	29.13%	14.11%	12.67%	47.43%	7,471
Liquid-Assets-to-Total-Assets	3.85%	3.89%	0.76%	7.15%	7,471
Loans-to-Total-Assets	61.94%	15.51%	39.92%	79.29%	7,471
Deposit Funding Gap	1.02%	19.64%	-24.55%	22.36%	7,471
Asset Share	6.69%	8.90%	0.25%	21.90%	7,471
Herfindahl Index	0.150	0.065	0.077	0.245	7,471

Note: The time period is from 1990Q1 until 2016Q4. All percentage changes, growth rates and returns are on a year-over-year basis. The table reports the descriptive statistics of the data used to produce the estimates in Tables 3–5. The data on macro-financial conditions are from the BIS; the point-in-time prudential capital ratios are calculated using stock market returns from Thomson Reuters Datastream, the macro-economic data are from the OECD; the bank-specific data are from Thomson Reuters Worldscope.

Table 2: Correlations of Market-Based Capital Buffers with Macro-Financial Conditions

Timing of Indicator	Growth in Credit-to-GDP (y-o-y)	Growth in Bank-Credit-to-GDP (y-o-y)	House Price Growth (y-o-y)
Panel (a): Value of the macro-financial indicator			
Lead of 12 quarters	-0.095	-0.163	0.165
Lead of 8 quarters	0.010	0.016	0.304
Lead of 4 quarters	0.146	0.165	0.463
Coincident	0.327	0.314	0.472
Lag of 4 quarters	0.449	0.427	0.258
Lag of 8 quarters	0.503	0.433	0.103
Lag of 12 quarters	0.408	0.284	0.052
Panel (b): Rolling-window percentile of the macro-financial indicator			
Lead of 12 quarters	-0.026	-0.105	0.142
Lead of 8 quarters	0.065	0.073	0.274
Lead of 4 quarters	0.177	0.223	0.366
Coincident	0.403	0.350	0.342
Lag of 4 quarters	0.485	0.423	0.222
Lag of 8 quarters	0.373	0.358	0.130
Lag of 12 quarters	0.275	0.184	0.068

Note: Correlations are between the market-based capital buffer and different indicators of macro-financial conditions. All variables are demeaned at the level of the institution. The time period is from 1990Q1 until 2016Q4.

Table 3: Macro-financial Conditions and the Capital Buffers of Banks (without macro-economic controls)

Dependent Variable: Capital buffers of global banks based on market-based stress tests						
	(1)	(2)	(3)	(4)	(5)	(6)
	Value	Percentile	Value	Percentile	Value	Percentile
Growth in Credit-to-GDP$_{i,t}$ (y-o-y)	0.391***	0.036***				
	(0.059)	(0.005)				
Growth in Bank-Credit-to-GDP$_{i,t}$ (y-o-y)			0.261***	0.026***		
			(0.041)	(0.005)		
House Price Growth$_{i,t}$ (y-o-y)					0.206***	0.035***
					(0.023)	(0.006)
Implied cyclical capital add-on	2.7%	2.9%	2.1%	2.1%	3.1%	2.8%
(95% confidence interval)	(1.9% - 3.4%)	(2.1% - 3.7%)	(1.5% - 2.8%)	(1.4% - 2.9%)	(2.4% - 3.8%)	(1.9% - 3.8%)
Observations	7,377	6,431	7,471	6,593	5,649	5,649
Banks	88	88	88	88	61	61
Bank-specific controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro-economic controls	No	No	No	No	No	No
Bank fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	No	No	No	No
Cluster at time level	Yes	Yes	Yes	Yes	Yes	Yes
Cluster at bank level	Yes	Yes	Yes	Yes	Yes	Yes
R-squared (within)	0.149	0.193	0.121	0.121	0.246	0.195

Note: The table presents least squares estimates of the model in Eq. (2). The magnitude of the cyclical capital add-on is calculated from Eq. (3) using the estimated coefficient for the indicator of macro-financial conditions and the data in Table 1. 'Value' means that the dependent variable is calculated as the level of the growth rate; 'percentile' means that it is calculated as a rolling-window percentile that compares the current growth rate to a 12-year backward-looking window. When the model is estimated using the value of the growth rates, the implied cyclical capital add-on is calculated by multiplying the coefficient with the difference between the 90th percentile and the 10th percentile of the indicator. The implied cyclical capital add-on equals the estimated coefficient multiplied by 0.8 (i.e., 0.9 minus 0.1) when the model is estimated using the rolling-window percentiles of the indicator. Observations are from 1990Q1 until 2016Q4. Significance at the 10%, 5% and 1% levels is denoted by *, ** and ***, respectively.

Table 4: Macro-financial Conditions and the Capital Buffers of Banks (with macro-economic controls)

Dependent Variable: Capital buffers of global banks based on market-based stress tests

	(1)	(2)	(3)	(4)	(5)	(6)
	Value	Percentile	Value	Percentile	Value	Percentile
Growth in Credit-to-GDP$_{i,t}$ (y-o-y)	0.202***	0.021***				
	(0.034)	(0.003)				
Growth in Bank-Credit-to-GDP$_{i,t}$ (y-o-y)			0.078*	0.008**		
			(0.041)	(0.003)		
House Price Growth$_{i,t}$ (y-o-y)					0.103***	0.013***
					(0.016)	(0.003)
Implied cyclical capital add-on	1.4%	1.7%	0.6%	0.6%	1.6%	1.0%
(95% confidence interval)	(0.9% - 1.8%)	(1.1% - 2.2%)	(0.0% - 1.3%)	(0.1% - 1.1%)	(1.1% - 2.1%)	(0.6% - 1.5%)
Observations	7,377	6,431	7,471	6,593	5,649	5,649
Banks	88	88	88	88	61	61
Bank-specific controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro-economic controls	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Cluster at time level	Yes	Yes	Yes	Yes	Yes	Yes
Cluster at bank level	Yes	Yes	Yes	Yes	Yes	Yes
R-squared (within)	0.543	0.515	0.536	0.494	0.532	0.523

Note: The table presents least squares estimates of the model in Eq. (2). The magnitude of the cyclical capital add-on is calculated from Eq. (3) using the estimated coefficient for the indicator of macro-financial conditions and the data in Table 1. 'Value' means that the dependent variable is calculated as the level of the growth rate; 'percentile' means that it is calculated as a rolling-window percentile that compares the current growth rate to a 12-year backward-looking window. When the model is estimated using the value of the growth rates, the implied cyclical capital add-on is calculated by multiplying the coefficient with the difference between the 90th percentile and the 10th percentile of the indicator. The implied cyclical capital add-on equals the estimated coefficient multiplied by 0.8 (i.e., 0.9 minus 0.1) when the model is estimated using the rolling-window percentiles of the indicator. Observations are from 1990Q1 until 2016Q4. Significance at the 10%, 5% and 1% levels is denoted by *, ** and ***, respectively.

Table 5: Macro-financial Conditions and the Capital Buffers of Banks (4 quarters leading signal)

Dependent Variable: Capital buffers of global banks based on market-based stress tests

	(1)	(2)	(3)	(4)	(5)	(6)
	Value	Percentile	Value	Percentile	Value	Percentile
Growth in Credit-to-GDP$_{i,t-4}$ (y-o-y)	0.104***	0.012***				
	(0.040)	(0.004)				
Growth in Bank-Credit-to-GDP$_{i,t-4}$ (y-o-y)			0.058*	0.006		
			(0.031)	(0.003)		
House Price Growth$_{i,t-4}$ (y-o-y)					0.087***	0.017***
					(0.020)	(0.003)
Implied cyclical capital add-on	0.7%	1.0%	0.5%	0.5%	1.3%	1.4%
(95% confidence interval)	(0.2% - 1.2%)	(0.3% - 1.5%)	(0.0% - 1.0%)	(0.0% - 1.0%)	(0.7% - 1.9%)	(0.8% - 1.8%)
Observations	7,298	6,251	7,407	6,413	5,649	5,577
Banks	88	88	88	88	61	61
Bank-specific controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro-economic controls	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Cluster at time level	Yes	Yes	Yes	Yes	Yes	Yes
Cluster at bank level	Yes	Yes	Yes	Yes	Yes	Yes
R-squared (within)	0.532	0.501	0.532	0.492	0.524	0.524

Note: The table presents least squares estimates of the model in Eq. (2). The magnitude of the cyclical capital add-on is calculated from Eq. (3) using the estimated coefficient for the indicator of macro-financial conditions and the data in Table 1. 'Value' means that the dependent variable is calculated as the level of the growth rate; 'percentile' means that it is calculated as a rolling-window percentile that compares the current growth rate to a 12-year backward-looking window. When the model is estimated using the value of the growth rates, the implied cyclical capital add-on is calculated by multiplying the coefficient with the difference between the 90th percentile and the 10th percentile of the indicator. The implied cyclical capital add-on equals the estimated coefficient multiplied by 0.8 (i.e., 0.9 minus 0.1) when the model is estimated using the rolling-window percentiles of the indicator. Observations are from 1990Q1 until 2016Q4. Significance at the 10%, 5% and 1% levels is denoted by *, ** and ***, respectively.

Table 6: Sensitivity Analysis

Indicator:	Growth in Credit-to-GDP$_t$ (y-o-y)		Growth in Bank-Credit-to-GDP$_t$ (y-o-y)		House Price Growth$_t$ (y-o-y)	
	(1) Value	(2) Percentile	(3) Value	(4) Percentile	(5) Value	(6) Percentile
Panel (a): Low k ($k = 0.03$)						
Coefficient	0.200***	0.020***	0.078*	0.008**	0.103***	0.013***
(s.e.)	(0.034)	(0.003)	(0.041)	(0.003)	(0.016)	(0.003)
Implied add-on	1.4%	1.6%	0.6%	0.6%	1.6%	1.0%
Panel (b): High k ($k = 0.06$)						
Coefficient	0.203***	0.021***	0.079*	0.008**	0.104***	0.013***
(s.e.)	(0.034)	(0.003)	(0.041)	(0.003)	(0.016)	(0.003)
Implied add-on	1.4%	1.7%	0.6%	0.6%	1.6%	1.0%
Panel (c): Longer sample (sample from 1980Q4 until 2016Q4)						
Coefficient	0.170***	0.021***	0.062**	0.008***	0.090***	0.015***
(s.e.)	(0.029)	(0.003)	(0.027)	(0.003)	(0.015)	(0.003)
Implied add-on	1.2%	1.7%	0.5%	0.6%	1.5%	1.2%
Panel (d): Excluding the 2007-09 crisis (sample from 1990Q1 until 2007Q2)						
Coefficient	0.130**	0.011**	0.078*	0.003	0.076***	0.014***
(s.e.)	(0.055)	(0.005)	(0.046)	(0.004)	(0.017)	(0.003)
Implied add-on	0.9%	0.9%	0.6%	0.2%	1.2%	1.1%
Panel (e): Region-level data (medians)						
Coefficient	0.213***	0.023***	0.148**	0.013***	0.109***	0.016**
(s.e.)	(0.033)	(0.002)	(0.055)	(0.002)	(0.023)	(0.003)
Implied add-on	1.7%	1.8%	1.2%	1.0%	1.7%	1.3%
Panel (f): Bank-specific trends						
Coefficient	0.194***	0.022***	0.105***	0.011***	0.103***	0.015***
(s.e.)	(0.011)	(0.001)	(0.010)	(0.001)	(0.006)	(0.001)
Implied add-on	1.3%	1.8%	0.9%	0.9%	1.6%	1.2%
Panel (g): Random slope model						
Coefficient	0.233***	0.019***	0.083*	0.007**	0.102***	0.017***
(s.e.)	(0.036)	(0.003)	(0.044)	(0.003)	(0.013)	(0.003)
Implied add-on	1.6%	1.5%	0.7%	0.6%	1.6%	1.4%
Panel (h): Excluding internationally focused banks						
Coefficient	0.209***	0.021***	0.094**	0.008**	0.116***	0.015***
(s.e.)	(0.038)	(0.004)	(0.044)	(0.003)	(0.017)	(0.003)
Implied add-on	1.4%	1.7%	0.8%	0.6%	1.8%	1.2%

Note: Panels (a)-(f) and (h) present least squares estimates of the model in Eq. (2). Panel (g) presents maximum likelihood estimates. The models in all panels include bank-specific controls, macro-economic controls, time fixed effects, and bank (panel (e): region) fixed effects. Standard errors ('(s.e.)') in panels (a)-(d) and (h) are clustered on both the time and bank dimension, while standard errors in panels (e)-(g) are clustered on the bank (panel (e): region) dimension only. The magnitude of the cyclical capital add-on ('implied add-on') is calculated from Eq. (3). 'Value' means that the dependent variable is calculated as the level of the growth rate; 'percentile' means that it is calculated as a rolling-window percentile that compares the current growth rate to a 12-year backward-looking window. When the model is estimated using the value of the growth rates, the implied cyclical capital add-on is calculated by multiplying the coefficient with the sample-specific difference between the 90th percentile and the 10th percentile of the indicator. The implied cyclical capital add-on equals the estimated coefficient multiplied by 0.8 (i.e., 0.9 minus 0.1) when the model is estimated using the rolling-window percentiles of the indicator. Observations are from 1990Q1 until 2016Q4, except for panels (c)-(d). Significance at the 10%, 5% and 1% levels is denoted by *, ** and ***, respectively.

Table 7: Alternative Credit Measures

Dependent Variable: Capital buffers of global banks based on market-based stress tests

	(1)	(2)	(3)	(4)
	Value	Value	Value	Value
Credit-to-GDP $\text{gap}_{i,t}$	0.077***	0.048***		
	(0.011)	(0.011)		
Growth in Real $\text{Credit}_{i,t}$ (y-o-y)			0.273***	0.182***
			(0.033)	(0.033)
Implied cyclical capital add-on	1.9%	1.2%	2.4%	1.6%
(95% confidence interval)	(1.3% - 2.4%)	(0.7% - 1.7%)	(1.8% - 2.9%)	(1.0% - 2.1%)
Observations	6,512	6,512	7,377	7,377
Banks	88	88	88	88
Bank-specific controls	Yes	Yes	Yes	Yes
Macro-economic controls	No	Yes	No	Yes
Bank fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	No	Yes	No	Yes
Cluster at time level	Yes	Yes	Yes	Yes
Cluster at bank level	Yes	Yes	Yes	Yes
R-squared (within)	0.450	0.506	0.490	0.542

Note: The table presents least squares estimates of the model in Eq. (2). The magnitude of the cyclical capital add-on is calculated from Eq. (3) using the estimated coefficient for the indicator of macro-financial conditions. The implied cyclical capital add-on is calculated by multiplying the coefficient with the difference between the 90th percentile and the 10th percentile of, respectively, the credit-to-GDP gap and real credit growth. Observations are from 1990Q1 until 2016Q4. Significance at the 10%, 5% and 1% levels is denoted by *, ** and ***, respectively.

Table 8: List of Banks in Our Sample

Economic Region	Banks
Australia	ANZ Banking Group (A:ANZ), Bank of Queensland (A:BOQ), Commonwealth Bank of Australia (A:CBA), Macquarie Group (A:MQG), National Australia Bank (A:NAB), Westpac Banking (A:WBC).
Canada	Bank of Montreal (C:BMO), Bank of Nova Scotia (C:BNS), Canadian Imperial Bank of Commerce (C:CM), Canadian Western Bank (C:CWB), Laurentian Bank (C:LB), National Bank of Canada (C:NA), Royal Bank of Canada (C:RY), Toronto-Dominion Bank[a] (C:TD).
Euro area	Aareal Bank (D:ARL), AIB Group (A5G), Alpha Bank (G:PIST), Banca Carige (I:CRG), Banca Monte dei Paschi (I:BMPS), Banca Popolare di Sondrio (I:BPSO), Banco Comercial Portugues (P:BCP), Banco Santander[a] (E:SAN), Bank Of Piraeus (G:PEIR), Bankinter (E:BKT), BBVA[a] (E:BBVA), BNP Paribas[a] (F:BNP), BPER Banca (I:BPE), Bank of Ireland (BKIR), Commerzbank (D:CBK), Credit Agricole (F:CRDA), Deutsche Bank[a] (D:DBK), Dexia (B:DEXB), Erste Group Bank[a] (O:ERS), Eurobank Ergasias (G:EFG), Intesa Sanpaolo (I:ISP), KBC Group[a] (B:KB), Mediobanca (I:MB), National Bank of Greece (G:ETE), Societe Generale[a] (F:SGE), Unicredit[a] (I:UCG), Unione di Banche Italiane (I:UBI).
Japan	Hachijuni Bank (J:HABT), Hokuhoku Financial (J:HFIN), Juroku Bank (J:JURT), Kansai Urban Banking (J:KANS), Minato Bank (J:HANS), Mitsubishi Ufj Financial Group (J:MITF), Mizuho Financial (J:MIZH), Ogaki Kyoritsu Bank (J:OKBT), Resona Holdings (J:DBHI), Shinsei Bank (J:SHBA), Shizuoka Bank (J:ZB@N), Sumitomo Mitsui Financial Group (J:SMFI), Sumitomo Mitsui Trust (J:SMTH).
United Kingdom	Barclays[a] (BARC), HSBC[a] (HSBA), Lloyds Banking Group (LLOY), Royal Bank of Scotland (RBS), Standard Chartered[a] (STAN).
United States	Associated Banc-Corp (U:ASB), Bank of America (U:BAC), Bank of New York Mellon (U:BK), BB&T Bank (U:BBT), BOK Financial (@BOKF), Citigroup (U:C), Comerica (U:CMA), Credicorp (U:BAP), Cullen/Frost Bankers (U:CFR), East West Bancorp (@EWBC), Fifth Third Bancorp (@FITB), First Citizens BancShares (@FCNCA), First Horizon National (U:FHN), JP Morgan Chase (U:JPM), Keycorp (U:KEY), M T Bank (U:MTB), New York Community Bancorp (U:NYCB), Northern Trust (@NTRS), PNC Financial Services (U:PNC), Banco Popular (@BPOP), Regions Financial (U:RF), State Street (U:STT), Sterling Bancorp (U:STL), Suntrust Banks (U:STI), SVB Financial (@SIVB), Synovus Financial (U:SNV), US Bancorp (U:USB), Wells Fargo Co (U:WFC), Zions Bancorp (@ZION).

Note: Thomson Reuters Datastream identifiers in parenthesis.
([a]) Cross-jurisdicional claims exceed 40 per cent of total exposures based on Basel III disclosure in 2017 (in Canada: 2018Q1).