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Interactions of capital and liquidity requirements: a review of the literature

Quynh-Anh Vo

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Abstract

One prominent feature of the regulatory framework put in place after the global financial crisis of 2008 is its reliance on multiple regulatory metrics, which has prompted new research on the interactions between them. This paper reviews the growing literature on the interactions between capital and liquidity requirements – the two primary requirements of the Basel III framework – with the focus on what the literature conveys on the extent to which capital and liquidity requirements are substitutes or complements. The paper also identifies gaps for further research.

Key words: Capital requirements, liquidity requirements, substitutability and complementarity.

JEL classification: G21, G28.

(1) Bank of England. Email: quynh-anh.vo@bankofengland.co.uk

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Bank of England, Threadneedle Street, London, EC2R 8AH
Email enquiries@bankofengland.co.uk

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1 Introduction

The regulatory framework put in place after the Great Recession is comprised of multiple regulatory requirements. This shift from the previous framework, which relied mostly on a risk-weighted capital requirement, allows for the use of a range of regulatory tools to deliver both the safety and soundness of individual banks as well as the stability of the whole system. While being a more robust approach in principle, in practice such a framework runs the risk that interactions among the multiple requirements lead to unintended consequences. Understanding those interactions is thus one of the key issues for the evaluation of post-crisis reforms underway in the BCBS.

This paper reviews the literature on the interactions between capital and liquidity requirements[1] with the focus on what it tells us about the extent of substitutability and complementarity between these two requirements. This issue is important since it helps to assess the advantage in using multiple prudential regulatory requirements compared to the use of any single requirement and, in the extreme case, the existence or absence of any redundancy among the requirements.

To facilitate the assessment of how the interaction between these two primary tools of the Basel III framework affects its overall net welfare benefit, this review will look to map various contributions of the literature into their implications for different components of the so-called "*cost-benefit framework*" - a standard method used to evaluate the overall net benefit of a policy. Specifically, the net benefit of having both capital (k) and liquidity (l) requirements can be expressed in a stylised form as:

$$NetBenefits(k,l) = Prob_{Crisis}(k,l) \times Costs_{Crisis}(k,l) - Costs_{Opportunities}(k,l)$$

Reflecting this, contributions in the literature will be grouped around four key questions: how the interactions of the two requirements would affect (i) the probability of crisis, (ii) the cost of crisis, (iii) the opportunity costs - the macroeconomic costs of prudential regulations, and (iv) the overall net benefit of those requirements.

[1] There exist papers that analyse the interaction between liquidity requirements and central bank liquidity support. However, in this review, I focus on the interaction of liquidity requirements with capital requirements.

Two key messages emerge from the literature. First, capital and liquidity requirements can act in both substitutable and complementary ways in reducing the probability of crisis. Both requirements are substitutes (i.e. the tightening of one requirement could allow for the loosening, at least to some extent, of the other) in reducing the probability of crisis by mitigating banks' incentives for excessive risk-taking, decreasing banks' exposure to the risk of banks runs, and curbing contagion via direct interconnections between banks. However, this substitutability is imperfect since the efficiency of these two requirements in dealing with some of these sources of financial instability is different. For example, the literature suggests that liquidity requirements are more efficient than capital requirements in dealing with liquidity-driven runs. Additionally, capital and liquidity requirements can act as complements in affecting the probability of crisis through other channels including contagion via fire sales and the risk of insolvency.

Second, from the perspective of the overall net benefit of the interactions between the two requirements, the literature suggests that using both would help to achieve the highest attainable level of welfare. The reason is that using both requirements helps attain a level of stability with the least long-term cost to the real economy, where the latter is measured in terms of foregone economic activities due to reduced financial intermediation.

This literature is intertwined closely with the two literatures that examine the impact of capital and liquidity requirements separately. While I try to be as comprehensive as possible in this survey, I will limit the scope of the review to papers that analyse simultaneously capital and liquidity requirements.

The structure of the paper is as follows. In Section 2, I propose an intuitive way to think about substitutability and complementarity between regulations. Then I will summarise, in Sections 3, 4, 5 and 6, the main findings of the literature related to their implications for, respectively, the probability of crises, the cost of crises, the opportunity costs and the overall net benefit. Finally, in Section 7, I highlight some important gaps for further analysis and conclude in Section 8.

2 Substitutability and complementarity of prudential regulations

I propose in this section a heuristic definition of complementarity and substitutability between two requirements. I will also discuss the implications of complementarity versus substitutability for redundancy within the regulatory framework.

In economics, formal definitions of complementarity and substitutability exist, for example, in consumer theory and game theory. In the consumer theory, whether two goods are complements or substitutes depends on how the consumption of those two goods interact to affect the utility or satisfaction of the consumer. Two goods are substitutes if an increase in the consumption of one good combined with some decrease in the consumption of the other good can leave a consumer with the same utility. The opposite is true for complements: For instance, if two goods are perfect complements, an increase in the consumption of one good does not increase a consumer's utility unless her consumption of the other good increases commensurately. In the game theory, two activities are defined as (strategic) complements if "doing more of one thing increases the returns to doing more of another" and the reverse is true for (strategic) substitutes.[2]

Complementarity and substitutability between prudential regulations can be understood in a similar vein. The 'utility' of prudential requirements is to advance regulatory objectives. Hence, whether two requirements are substitutes or complements depending on how the use of one requirement affects the need for the other requirement to achieve the regulatory objectives. Alternatively, in the spirit of game theory, two regulations are considered to be complements (substitutes) if tightening one requirement increases (decreases) the returns to tightening the other.

An intuitive way to determine the substitutability or complementarity between two requirements is to look at how their transmission channels interact. When considering two requirements that aim to achieve the same overarching objectives, there are three possible cases, which are illustrated in Figures 1-3.

[2]See Milgrom and Roberts (1995). This intuition is formally defined by the mathematical condition on the cross derivative of some payoff function. If this cross derivative is positive, two activities are strategic complements while, if it is negative, those two activities are strategic substitutes.

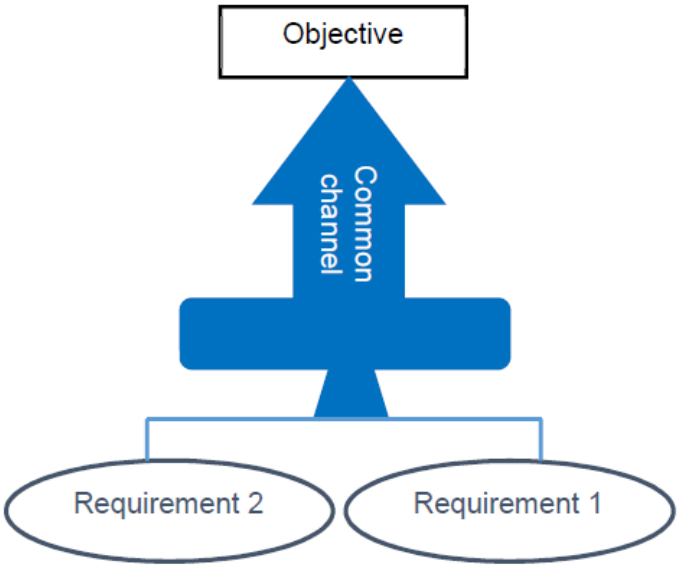

Figure 1: **Two substitutable requirements**
The figure shows the case of two substitutable requirements since they work through the same channels to achieve the common overarching objectives.

Figure 1 represents the case in which both requirements work through the same transmission channels to achieve that overarching objective. As such, the two requirements are substitutes because using one reduces the need to use the other.

Figure 2 shows a case in which two requirements can be complements with respect to each other because they use different channels to fulfil the common objectives. One example of this situation is capital regulations and disclosure regulation. The first regulation works through a shareholder risk-taking channel while the second works through the transparency channel.

Figure 3 depicts the circumstance where Requirement 1 has damaging effect on the transmission channel via which Requirement 2 helps to achieve the objectives. In such a case, the use of Requirement 1 will result in an increasing need to use Requirement 2. In other words, Requirement 2 is a complement to Requirement 1.

Note that both substitutability and complementarity are a matter of degree. Two requirements would be perfect substitutes only if the extent to which one requirement could be relaxed when the other becomes more stringent while leaving the objective function unchanged - i.e. the marginal rate of substitution between two requirements -

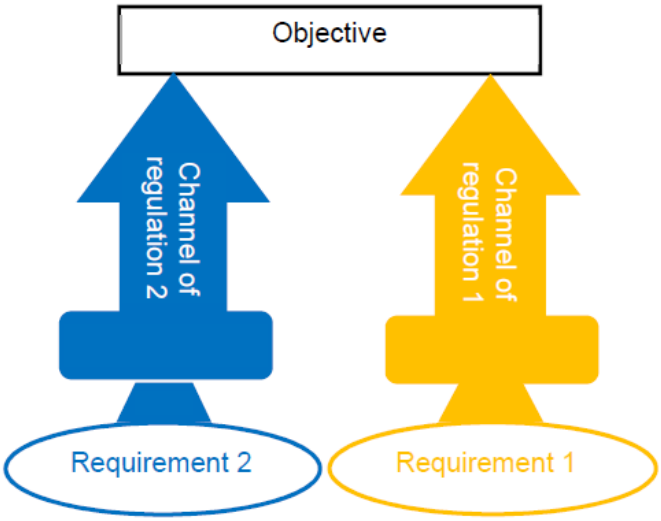

Figure 2: **Two complementary requirements**
The figure shows the case in which two requirements can be complement since they work through different same channels to achieve the common overarching objectives.

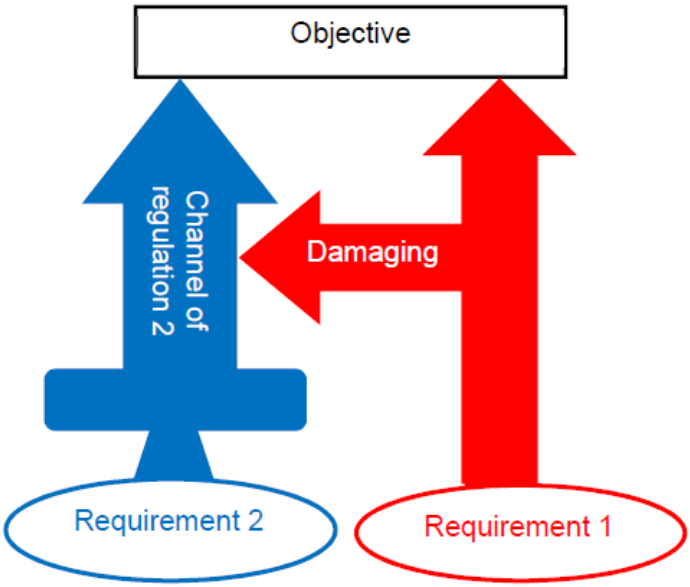

Figure 3: **Case of asymmetric complementary**
The figure shows the case of two requirements where Requirement 2 is complement to Requirement 1 but not the converse.

is constant.[3] To determine the degree of substitutability, it is necessary to investigate

[3]A similar definition is applied to goods. Two goods are perfect substitutes if the number of one good the consumer could give up in order to obtain one additional unit of the other good without affecting her total utility is a constant.

whether the way that these two requirements work through the common channels to affect the objectives is the same in terms of efficiency and cost.

In relation to the complementarity, two requirements are perfect complements if they must be used in tandem. One simple real-world example for the perfect complementarity case is a left shoe and a right shoe. For the case of prudential regulations, two requirements will be perfect complements if the two requirements have exclusive effects on two separate risks that always crystallise at the same time.

Note also that the degree of complementarity may not have to be symmetric. As shown in Figure 3, Requirement 2 is a complement to Requirement 1, but the converse is not the case. A real world example is a specific video game and a video game console. The specific video game has to be used with, and so complement to, the video game console, but it does not work the other way: a video game console can be used with many different games, not just that specific game.

3 Capital-liquidity interaction and the probability of crisis

Bank illiquidity and insolvency are closely intertwined and often difficult to tell apart in a crisis. On the one hand, liquidity problems can lead to solvency problems if they force banks to sell their assets at significant discounts. On the other hand, fears about banks' solvency may induce creditors to withdraw funds and thus, precipitate liquidity problems. Pierret (2015) provides empirical evidence on the banks' solvency-liquidity interaction for a sample of fifty US bank holding companies over 2000 to 2013. The paper finds that a bank's capital shortfall under stress, measured by SRISK[4], determines how much short-term debt it can raise. That shows there is an interaction between bank solvency and the capacity of a bank to fund itself. Moreover, the paper also finds that solvency measures that reflect a bank's idiosyncratic risk, rather than its exposure to aggregate risk captured in SRISK, do not have predictive power with respect to the short-term debt level of banks. This result implies that the interaction between insolvency and funding illiquidity may

[4]SRISK is a measure of the expected capital shortfall at a bank conditional on aggregate stress (see Acharya et al. (2020, 2012))

be specific to instances of aggregate stress rather than cases of isolated bank failure.

The apparent close link between bank solvency and liquidity motivates this discussion about the effects that the interactions between capital and liquidity requirements may have on financial stability. One way to examine these interactions is to look at how each of these two requirements would affect the channels through which the other requirement affects the resilience of the banking system, as reflected in the likelihood of a systemic crisis, as well as on the probability of individual bank failure.

The fragility of the banking system arises from a wide range of sources, including the excessive exposure of individual banks to different types of risk as well as the degree of systemic risk in the whole banking system. Figure 4 shows a transmission map from financial instability sources to the probability of crises. The literature has identified four channels through which capital and liquidity requirements can interact and thus affect the probability of crises. They are precisely excessive liquidity-risk taking, bank runs, insolvency risk, and contagion. Each of them will be considered in turn below.

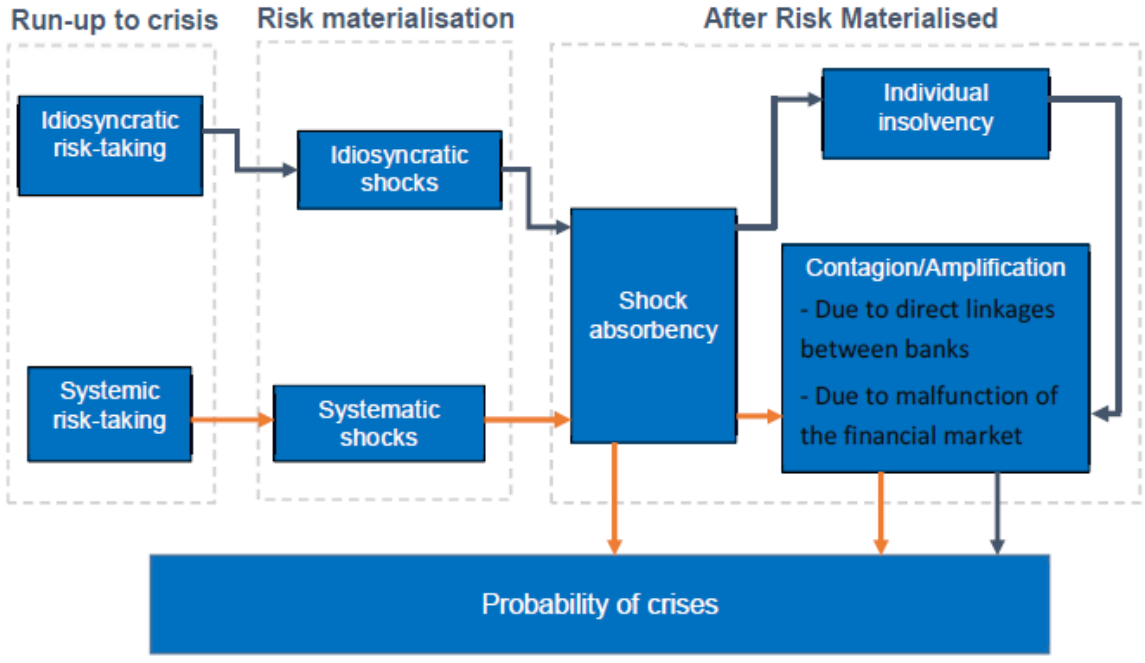

Figure 4: Chain of financial stability sources

3.1 Interaction via banks' liquidity-risk taking incentives

Liquidity requirements contribute to enhancing the resilience of the banking system by curbing banks' incentives to engage excessively in liquidity transformation. Several papers therefore analyse the interaction of capital and liquidity requirements by examining how capital levels affect banks' incentives to manage their liquidity risk profile - the transmission channel of liquidity requirements.

Acosta-Smith et al. (2019) construct a simple and stylised model to analyse the impact of banks' capital ratios on the extent to which banks choose to engage in liquidity transformation. In their model, banks that face uncertainty about the timing of deposit withdrawals choose their liquid asset holdings to insure themselves against the risk of failure due to a liquidity shortage.

They find that banks' capital level positions have two competing effects on their liquidity holdings. First, an increase in a bank's capital ratio means that it has a more stable liability structure, which in turn implies a lower need for liquidity holdings and so causes a bank to reduce its holding of liquid assets. Second, an increase in a bank's capital ratio also means that shareholders face higher losses and so a greater cost in the event that the bank is forced into an early liquidation due to insufficient liquidity holdings; - i.e. a 'skin-in-the-game' effect. Importantly, this second effect induces banks to hold more liquidity. While the second effect clearly lowers the degree of liquidity transformation on banks' balance sheets following an increase in their capital ratio, the first effect may raise it if the decrease in liquidity holdings outweighs the impact of the increase in the capital ratio. Using a numerical analysis, the paper finds that overall, an increase in banks' capital ratios would lead banks to engage in less liquidity transformation and so, make them less vulnerable to liquidity shocks.

Gomez and Vo (2020) reach a similar conclusion at the individual bank level when considering a baseline setting in which banks hold liquidity just for precautionary reasons. The paper finds that banks will hold an adequate level of liquid assets to shield themselves from liquidity shocks if and only if they are well capitalised. The paper then investigates the impact of the distribution of leverage in the banking system on the severity of liquidity crises by extending the baseline setup to incorporate a "strategic" motive for liquidity

holdings, namely holding liquid assets to be able to take advantage of fire sales by other banks. The paper finds that the greater the cross-sectional variation in banks' leverage is, the more severe the liquidity crises are.

The negative relationship between banks' capital ratios and their liquidity risk profile that has been established theoretically is supported by recent empirical work. Acosta-Smith et al. (2019) provide an empirical test for their own theoretical prediction using a sample of banks in United Kingdom from 1989 to 2013. To overcome the reverse causality problem that arises from banks in practice choosing capital and liquidity positions simultaneously, the paper relies on exogenous changes in individual banks' capital requirements imposed by the supervisor. The main finding of the paper is that an increase in banks' capital ratios would lead them to take less liquidity risk.

DeYoung et al. (2018) study the relationship between bank capital and bank liquidity for a sample of US banks before the introduction of Basel III. Their identification strategy relies on a negative shock to bank capital such that the capital ratios of banks that already operate below their own internal capital target go further below that target. Since this reduction would be involuntary for banks, the shock could constitute an exogenous change to bank capital. They find that US banks have historically treated capital and liquidity as substitutes.

The main lesson from this strand of the literature is that capital requirements could be used to incentivise banks to refrain from excessive liquidity transformation. If so, the effects of both capital and liquidity requirements on the probability of crises via excessive liquidity transformation would be lower than the sum of the individual effects of the two requirements on the probability via this channel. The reason for this is that in setting one requirement, one gains in part some of the benefits that result from setting the other. In other words, capital and liquidity requirements are, at least to some extent, substitutes.

Note also that although the above-described papers shed light on the question of whether capital requirements could be substituted for liquidity requirements in restraining banks' engagement in excessive liquidity transformation, they remain silent on the relative efficiency of using capital requirements to address this risk compared to liquidity requirements. This is an important empirical question if one would like to assess the

exact degree of substitutability between the two requirements with respect to preventing excessive liquidity-risk taking.

3.2 Interaction via the incentives of creditors to run on banks

One important source of banks' fragility is the risk of bank runs - i.e. the risk banks' short-term debt holders withdraw funds or refuse to roll their claims over. In principle, liquidity requirements could make banks less vulnerable to runs since they force banks to hold enough liquid assets to meet short-term funding demands, or to finance their illiquid assets with more stable funding sources.

Higher capital may also help to mitigate the risk of runs if it reduces investors' concerns about the financial health of banks. This in turn reduces the risk that creditors refuse to roll over outstanding debt or withdraw funds prematurely. However, empirical observations suggest capital may not be sufficient to mitigate this risk. The run on Bear Stearns in March 2008 provides an example whereby an otherwise solvent institution can fail due to a lack of liquidity.[5]

In the literature, several papers examine, in a so-called global games framework, how banks' capital and liquidity interacts to affect the incentives of their short-term creditors to run on them. In that setting, creditors will decide whether to run based on some private information that they receive about banks' fundamentals. In some cases banks experience runs by their creditors since they are indeed insolvent and so creditors are justified in running on them. However, there are also situations where initially a bank is financially healthy, but, due to a coordination failure, a large number of creditors decide to withdraw funds from it, which forces it to sell its assets at fire-sale prices and so leads to their closure.[6] Banks in this situation are usually referred to as solvent but illiquid banks.

Vives (2014) uses such a framework to investigate how banks' balance sheet charac-

[5]See Letter to the Chairman of the Basel Committee on Banking Supervision, dated March 20th, 2008, posted on the SEC website on: https://www.sec.gov/news/press/2008/2008-48.htm.

[6]This is referred to as a coordination failure since, if creditors do coordinate to roll over their debt, the bank will survive and creditors' payoff would be higher. The run in these situations is due to the presence of strategic complementarity among debt holders, in that each of them does not roll over due to their self-fulfilling belief that others will do the same.

teristics, such as the ratio of liquid assets to unsecured short-term debt and the ratio of equity to unsecured short-term debt, would affect the likelihood of a run. Note that investors' incentives to run depend on the difference between the expected payoffs to running versus those to waiting. This difference in turn depends on the solvency and liquidity conditions of banks' balance sheets as well as the magnitude of fire-sale discounts.

Vives (2014) finds that banks can use both the liquid assets-to-short-term debt ratio and the equity to unsecured short-term debt ratio to control the probability of failure due to a run. The latter ratio is more effective in controlling the probability of runs due to insolvency. The former ratio is more effective at controlling runs due to illiquidity. Hence, in Vives, capital and liquidity requirements are substitutable but the degree of substitutability is imperfect. Moreover, Vives also finds that in an environment in which fire-sale discounts are high, strengthening the liquidity requirement has bigger impact on probability of run than strengthening the capital requirement.

Carletti et al. (2020) also use the global games framework to examine the interdependent effects of bank capital and liquidity on the probability of banking crises due to runs. In contrast to Vives (2014), Carletti et al. (2020) model directly the withdrawal decisions of banks' individual debt holders and allow for a richer structure for debt holders' payoffs.[7] With the richer payoff structure, they find that the individual effects of capital and liquidity as well as the effects of the interaction between the two on the likelihood of runs are more complicated than in Vives and are non-linear. However, consistent with Vives (2014), Carletti et al. (2020) also finds that in the presence of high fire-sales discount, tightening the liquidity requirement is a more efficient method to limit the probability of run.

In summary, although there are some differences in the conclusions on the effect of bank capital and liquidity on the incentives of creditors to run on banks, this strand of the literature broadly finds that capital and liquidity requirements are substitutable in controlling the probability of runs, but this substitutability is again not perfect. Specifi-

[7]Vives (2014) considers the case in which banks are financed by uninsured short-term wholesale deposits held by collective investment funds such as mutual funds. The withdrawal decision is thus made by fund managers rather than individual depositors. The payoffs of fund managers are binary depending on whether their withdrawal decisions turn out to be "right" or "wrong". In contrast, in Carletti et al. (2020) the payoff to withdrawal for banks' individual debt holders is a more continuous function of the proportion of debt holders withdrawing.

cally, in the presence of severe fire-sale discounts, liquidity requirements are more efficient than capital requirements in dealing with bank runs.

3.3 Interaction via insolvency risk

Bank capital is a buffer against losses. Thus, capital requirements are justified as a tool to improve banks' resilience since higher capital requirements help reduce the likelihood of bank insolvency. Some papers therefore examine the interaction between capital and liquidity requirements by analysing the effect of bank liquidity on bank solvency.

Eisenbach et al. (2014) build a simple framework to analyse how bank capital and liquidity ratios affect bank resilience. In their model, a bank funds itself with short-term debt, long-term debt, as well as equity, and invests this funding into two types of asset, liquid and illiquid assets. Short-term debt holders could decide to withdraw their fund before maturity. Depending on the return on illiquid assets, the bank can be either fundamentally insolvent or conditionally solvent but illiquid or fundamentally solvent. Eisenbach et al. (2014) find that if the return on illiquid assets is higher than the return on liquid assets, the probability of a bank being fundamentally insolvent will increase with a bank's liquidity ratio. The intuition is that when illiquid assets pay more than liquid assets, higher liquidity holdings reduce the bank's revenues and therefore weaken its solvency position. In this sense, capital is a complement to liquidity since an increase in liquid asset holdings requires an increase in capital for the bank to maintain the same level of stability.

De-Bandt et al. (2021) also construct a simple model to study the interaction between solvency and liquidity constraints. In their setup, the bank is financed by equity and demandable deposits, which are invested into loans and marketable securities. Differently from Eisenbach et al. (2014), the bank in De-Bandt et al. (2021) is assumed to behave as a mean-variance investor. The latter paper however also finds that an increase in the liquidity requirement can reduce the bank's profit and thus weaken its solvency.

While the two above papers assume an exogenous fraction of banks' short-term debt holders who withdraw their funds, Koenig (2015) endogenises this decision using the global games approach. The setting considered in Koenig is similar to Vives (2014).

However, Koenig fully takes into account the adjustments to the bank's balance sheet needed to accommodate the specific variations in the regulatory capital and liquidity ratios. The main finding in Koenig is that a higher liquidity requirement could undermine bank resilience if its negative impact on bank's solvency outweighs its positive impact on bank's liquidity. Hence, similarly to Eisenbach et al. (2014), Koenig finds that from the solvency risk perspective, bank capital is a complement to bank liquidity.

3.4 Interaction via contagion channels

Contagion occurs when the distress of one financial institution propagates to others in the financial system, potentially leading ultimately to a systemic crisis. There are many different contagion channels, including direct linkages between banks via the interbank market and common asset exposures.

In principle, both capital and liquidity requirements can help to lower the risk of contagion. As highlighted in Cifuentes et al. (2005), capital buffers can help to reduce the risk of contagion because capital absorbs losses banks incur following a negative shock on their balance sheet, which in turn reduces banks' needs to further adjust their balance sheets and the negative externalities that these adjustments could generate for other banks. Turning to liquidity buffers, Cifuentes et al. (2005) find that these help to mitigate contagion risk by allowing banks to adjust their balance sheets without suffering losses from fire sales.

Aldasoro et al. (2017) construct a network model of the interbank market to analyse the efficiency of capital and liquidity requirements in lessening contagion risk. Their model embeds three channels of contagion, namely direct cross-exposures in the interbank market, fire sale externalities, and liquidity hoarding due to banks' precautionary behaviour.[8] The paper finds that both capital and liquidity requirements could be used to reduce contagion risk, but an increase in the liquidity requirement reduces this risk more sharply and more rapidly. Specifically, an increase in the liquidity requirement induces banks to reduce both their illiquid assets and their interbank loans. Therefore, banks be-

[8]The liquidity hoarding channel works as follows: in the face of shocks to one segment of the financial system and increasing uncertainty, banks choose to hoard liquidity and refuse to lend in the interbank market. This would lead the market to freeze and make it difficult for other banks to obtain the funding they need.

come less interconnected in the interbank market and less exposed to swings in the price of non-liquid assets. Put differently, an increase in the liquidity requirement reduces the scope for contagion via both interconnectedness and common exposures. In contrast, the paper finds that following an increase in capital requirements, banks reduce their reliance on interbank borrowing as a source of funding, which lowers the demand for interbank borrowing and thus the interbank rate. Banks then replace interbank loans, which have become less profitable, with investments in illiquid assets. Thus, following an increase in capital requirements, the scope for contagion via interconnectedness in the interbank market is reduced since banks lend less to each other, but the scope of contagion due to shocks to common exposures increases.

Hence, in line with the strand that analyses the interaction via the incentives of creditors to run, the main conclusion from this strand of the literature is that capital and liquidity requirements are partially substitutes since both can be used to contain the risk of contagion via direct linkages. However, to tackle contagion via asset prices, liquidity requirements are more useful.

3.5 Complementary predictive power with respect to banks' failure

While the above-described strands of the literature examine the interactions and thus the complementarity or substitutability between capital and liquidity requirements by looking at a specific source of banks' fragility, some empirical papers address this question by asking whether measures of bank liquidity have added benefits as compared to bank capital measures in predicting banks' failures or financial crises.

Vazquez and Federico (2015) as well as Lallour and Mio (2016) study the importance of structural funding metrics such as the Net Stable Funding Ratio (NSFR)[9] in predicting banks' failures. Vazquez and Federico (2015) use a bank-level data set that covers about

[9]The NSFR is defined as the amount of available stable funding relative to the amount of required stable funding. "Available stable funding" is defined as the portion of capital and liabilities expected to be reliable over one year. The amount of such stable funding required ("Required stable funding") of a specific institution is a function of the liquidity characteristics and residual maturities of the various assets held by that institution as well as those of its off- balance sheet exposure. This ratio is required to be greater than one.

11,000 US and European banks during 2001-2009 and proxy NSFR measure for those banks. Lallour and Mio (2016) analyses a smaller sample of banks (i.e. 121 banks, mostly in Europe and North America), which allows them to build a much more precise proxy of the NSFR. Both papers find that the NSFR contributes to predicting bank failure after controlling for a bank's solvency ratio. Vazquez and Federico (2015) also finds that for a subsample of banks with NSFR ratios lower than one, the capital ratio has much stronger predictive power as compared to the whole sample. All else equal, that implies that bank capital and liquidity are partially substitutes.

De-Ramon et al. (2012) and Brooke et al. (2015) examine how different capital and liquidity metrics predict, instead of individual banks' failure, the probability that a banking crisis occurs. Brooke et al. (2015) estimate the relationship between banking system capital ratios and systemic crises assuming that liquid assets and deposit ratios of banks are broadly at the level of liquidity reforms implemented after the financial crisis 2007-2009. They found that the Tier 1 leverage ratio associated with a 1% crisis probability in normal times is estimated to lie between 3% and 4%. De-Ramon et al. (2012) study factors that help to explain the probability of banking crises in a panel of OECD countries between 1980 and 2008. Their crisis prediction model includes the capital ratio in the banking sector, the broad liquidity ratio, the lagged increase in the real house prices and the second lag of the UK current account balance.[10] They found that capital adequacy and liquidity ratios are the main factors explaining banking crisis.

While the papers above use a regression technique, Aikman et al. (2018) examine how efficient various regulatory metrics - including capital and liquidity ratios - would have been in identifying banks which failed during the 2007/2008 crisis (the "hit rate"), while at the same time avoiding incorrectly signalling distress among banks which survived the crisis (the "false alarm rate"). They find that a combination of multiple regulatory requirements namely, the leverage-ratio requirement, the risk-weighted capital requirement, and the proxy of NSFR, would have performed better than the requirements on an individual basis, in the sense of achieving the same hit rate with a lower false alarm rate. Moreover, the paper also finds that the calibration of each requirement in the portfolio

[10] De-Ramon et al. (2012) includes the current account balance as an independent variable to follow the finding of Barrell et al. (2010) that the ratio of the current account balance to GDP plays a significant role in determining the probability of crisis.

of requirements is less stringent than the calibration of each requirement when these are employed individually.

4 Capital-Liquidity interaction and the cost of crisis

Conditional on crises occurring, their costs may also vary with levels of capital and liquidity in the banking sector. Jorda et al. (2017) provide an analysis of how bank capital affects the economic costs of financial crises. The paper finds that bank capital matters for these costs. The better capitalised is the banking sector at the start of a recession triggered by a financial crisis, the milder the recession and swifter the recovery. They show depending on whether bank capital is above or below its historical average, the difference in output costs is five percentage points of real GDP per capita five years after the start of the recession. The paper does not find that bank liquidity has a significant impact on these output costs. They consider two liquidity ratios: loans to deposit ratio and non-core liabilities ratio.

To the best of my knowledge, there is so far no work on how the capital and liquidity requirements interact to affect the costs of crises. Given the insights from other strands of the literature, one can expect that the existence of both requirements may help to reduce the severity of crises by mitigating the size of losses incurred by banks and the scope of fire sales. This in turn could also support the economy to recover more quickly. Note also that these potential effects would depend on banks' incentives to use their regulatory buffers.

5 Capital-Liquidity interactions and the opportunity costs

While capital and liquidity requirements help to reduce the occurrence and severity of banking crises, they may also entail macroeconomic costs[11] because they interfere with

[11]Prudential requirements could also entail other costs such as compliance costs or cost due to the wedge in the price of different types of funding. These costs are, at least partly, borne by banks, which make them different from macroeconomic costs that are borne by the society.

banks' activities in normal times. These costs can come from the distortions to the following three main economic services that banks provide to society:

First, banks play important role in expanding the amount of credit that borrowers can obtain relative to direct lending by individual savers.[12] A reduction in banks' capacity or incentives to grant loans may thus have significant consequences for total investment and growth of the economy. Capital and liquidity requirements can affect banks' lending if they lead to an increase in banks' funding costs. Capital requirements can have such effect since capital is more expensive funding source than debt while liquidity requirements may cause higher funding costs for banks if they induce banks to replace short-term debt by long-term debt. Note that the effect of these regulations on funding cost can be offset by their impact on banks' resilience - the Modigliani-Miller offset, which expect to result in a decrease in the cost of equity and debt.

A second widely posited role for banks is helping people and businesses share risks because by offering both deposits and equity to savers, banks can create two different types of claims and increase hedging possibilities. These additional hedging opportunities will benefit savers.

The third role played by banks is to provide liquidity by transforming illiquid assets into liquid claims that facilitate transactions.[13] Banks could also provide liquidity to the economy via their role as market makers in financial markets. Any distortion to this role of banks would harm the efficient functioning of financial market, which in turn can undermine the efficient allocation of investment and then reduce the economic growth.

When analysing the opportunity costs of prudential requirements it is useful to distinguish between short-term transitional costs and long-term steady state costs. While transitional costs could be mitigated by lengthening the transition period over which a change in requirements take full effect, the long-term steady state costs need to be taken into account when determining the calibration of the prudential requirements.

The literature to date has focussed primarily on the individual impact of capital or

[12] Banking theory typically argues that as specialised and sophisticated lenders, banks are more efficient in monitoring borrowers, which allow them to expand more credit than individual savers.

[13] The most seminal work that formalises this role of banks is Diamond and Dybvig (1983). They show that a bank can cross-insure consumers' needs for liquidity by exploiting the law of large number among customers.

liquidity requirements on the cost and the volume of lending. The main papers that combine both requirements to examine their joint impact on the supply of credit to the real economy are DeNicolo et al. (2014), Behn et al (2019), and Covas and Driscoll (2014). These papers each develop a dynamic structural model of bank behaviour to study the quantitative impact of prudential requirements on bank lending. In these models, banks are financed with debt and equity and can invest in two types of assets - non-financial loans and a liquid asset. While DeNicolo et al. (2014) and Behn et al (2019) examine the impact in a partial equilibrium setup where all prices, in particular interest rates on loans and return on securities, are assumed to be exogenously given, Covas and Driscoll (2014) allow for a general-equilibrium feedback effect on the prices. All of these papers find that adding liquidity requirements to capital requirements leads to a larger reduction in lending to non-financial corporations. Unsurprisingly, Covas and Driscoll (2014) also highlight that the effects on lending volume are substantially larger when prices are not allowed to adjust. These papers, however, do not assess the effect on lending of using both requirements as compared to the sum of the effects when each requirements is used individually. Answering this question is essential to understand whether capital and liquidity requirements are substitutes or complements from the perspective of the impact on credit supply.

In relation to the role of banks as liquidity providers, most of the literature on the effects of the Basel III reforms on the provision of market liquidity focus on the impact of the leverage ratio requirement on the functioning of financial markets.[14] One exception is Van den Heuvel (2018) which quantifies the welfare costs of capital and liquidity requirements in a model where the main role of banks is to provide liquidity to households. Although Van den Heuvel estimates the costs of these two requirements separately rather than analysing how these costs are affected by the interaction between the two requirements, his exercise provides a useful indication of the relative macroeconomic costs of these two requirements. The main conclusion is that in general capital requirements generate higher costs than liquidity requirements because the former reduce liquidity creation by banks much more than the latter do. Capital requirements effectively reduce the supply of bank deposits by replacing deposits to some degree with equity, an instrument

[14]See, for example, Acosta-Smith et al. (2018) and Kotidis and Van Horen (2018).

that does not provide liquidity services. In contrast, liquidity requirements effectively transform some government bonds held by the public into bank deposits. Since government debt and bank deposits are both liquid instruments, the net reduction in liquidity is much smaller.

6 Net benefits of the co-existence of capital and liquidity requirements

The above strands of the literature look at the partial effects of the interaction of capital and liquidity requirements on the probability and costs of crises and provide some quantitative insights on the opportunity costs of the two requirements in terms of foregone economic activity. A number of more recent papers have sought to analyse the overall net benefits of the co-existence of capital and liquidity requirements. The analysis of the net benefits would ideally incorporate all three main economic services that banks provide to the society. However, existing contributions focus only on the role of banks in extending credit.

Kara and Ozsoy (2020) examine the interaction between capital and liquidity requirements in addressing the inefficiency arising from the fire-sale externalities.[15] The main conclusion is that using both requirements would allow for more credit and lower fire-sale discount as compared to the case in which only capital regulation is employed.

Adrian and Boyarchenko (2018) examine the effects of the co-existence of capital and liquidity requirements on social welfare by focusing on the trade-off between financial stability and the volume of lending. The paper finds that liquidity requirements are less costly than capital requirements in terms of reducing consumption growth. But the highest level of households' welfare is achieved by using both requirements. They also find that the supply of risk-free assets plays an important role in affecting the costs and benefits of liquidity requirements. For the interaction of capital and liquidity requirements, this means that the optimal joint calibration of the two requirements would depend on the supply of risk-free assets.

[15] In Kara and Ozsoy (2019), there is no banks' failure and financial stability is measured by the magnitude of fire-sale discounts.

Boissay et al. (2016) also study how the co-existence of capital and liquidity requirements affects the trade-off between financial stability and bank lending. The paper, however, focuses on the efficient allocation of credit rather than the total volume of credit supplied. The paper finds that in an economy in which banks are subject to prudential regulations, there is less, but more socially efficient financial intermediation. More interestingly, based on a version of the model calibrated to US data, the paper shows that both liquidity and capital requirements are necessary to implement the socially optimal outcome, and reinforce each other.

In Adrian and Boyarchenko (2018) as well as in Boissay et al. (2016), some important aspects of liquidity problems such as runs or fire sales are not featured. Ikeda (2018) proposes a model that embeds the bank run global game approach into a two-period general equilibrium model to analyse the need for using both capital and liquidity requirements. He finds that the optimal regulatory mix includes both capital and liquidity requirements. In terms of the optimal joint calibration of the two requirements, he finds that with a liquidity requirement in place, the socially optimal capital requirement is lower than the socially optimal capital requirement when this is the only prudential requirement.

Hence, these studies suggest that overall using both requirements would help to attain a level of stability while incurring lower long-term costs to the real economy (in terms of foregone economic activities due to reduced financial intermediation) than when only one requirement is used. The most important challenge for this strand of literature is to develop a model that could incorporate all three main economic services that banks provide to the society so that a more broad assessment of the costs and benefits of the two requirements could be done.

7 Main gaps

The literature on the interaction between capital and liquidity requirements is still at the early stage and most of the existing contributions are theoretical. The lack of empirical analyses is mainly because liquidity requirements are quite new and data that allows one to construct proxies for the two Basel III liquidity requirements do not exist for the period before the 2007-2009 crisis. Another remark is that while the liquidity

requirement considered in theoretical contributions mimics the Liquidity Coverage Ratio (LCR)[16], empirical research on the interaction between capital and liquidity requirements seem to focus more on the NSFR.[17] Below are several important questions that are still left unanswered in the literature.

On the effect of the interactions on the probability of crises, while current contributions highlight different ways the two requirements are substitutes, they do not provide a quantitative assessment of the rate of substitution between them. This is an important gap if one would like to consider the joint calibration of two requirements.

More research that empirically tests the inconclusive theoretical predictions on the links between bank capital, bank liquidity and the likelihood of runs is needed. This will help to assess the degree to which capital and liquidity requirements are substitutes as well as the degree to which the rate of substitution between the requirements varies with the levels of the requirements (for instance, to see the rate of substitution at the Basel calibration levels). To do these things, it is necessary to have data on the withdrawal behaviours of banks' creditors when they are in a financial distress situation. Getting these data may be challenging.

More work is also needed to assess empirically the materiality of the impact of LCR/NSFR on banks' profitability, which is highlighted in some theoretical works as a channel through which capital and liquidity regulations could work at cross-purposes.

Another challenge is to examine how the co-existence of both capital and liquidity requirements affect the degree of similarity of banks' balance sheets? Does it lead to a greater risk that banks have common exposures?[18] Answering this question is necessary since correlated investments and herding behaviours are important sources of systemic risk.

In terms of the impact of the interactions on the costs of crises, examples of questions that need investigating are how the co-existence of capital and liquidity requirements affect banks' deleveraging decisions. What determines banks' incentives to use capital

[16]The LCR requires banks to hold enough high-quality liquid assets (HQLA) - such as short-term government debt - that can be sold to fund banks during a 30-day stress scenario designed by regulators.

[17]The literature that analyses the effects of only liquidity requirements focuses more on LCR.

[18]One observation is that the post-crisis regulatory framework increases substantially the use of collateral. If banks tend to use the same types of assets as collateral, those assets could become a source of systemic risk.

and liquidity buffers during the crisis?

With respect to the effects of the interaction on the opportunity costs, important gaps exist across each type of economics services banks provide to the society. Precisely, more theoretical and empirical research is needed on the impact of the co-existence of two requirements on the cost and volume of lending before we can be confident about the robustness of current results. One important development in that research is to expand the spectrum of assets/liabilities that banks could invest in/ use for funding.

Other issues that need more research are how the co-existence of the capital and liquidity requirements affect the liquidity provision in the economy. Some angles that are worth investigating are the impact of the interaction between capital and liquidity requirements on banks' choices between wholesale and retail deposits and on banks' roles as market makers.

Finally, the implications of the interaction for the degree of risk sharing in the economy is also an important open issue.

As mentioned above, the main gap in the strand of literature that analyses the overall net benefit of capital and liquidity requirements is to develop a more comprehensive general equilibrium model that could incorporate all three main economic services that banks provide to the society.

In seeking to fill these gaps, given that some requirements have been in force for only a short time period, data on their effects may not be available yet. Therefore, in addition to doing rigorous econometric analyses, using case studies or gathering anecdotal evidence could also be useful.

8 Conclusion

Assessing the interactions between capital and liquidity requirements is an important task in order to assess whether the post-crisis regulatory framework works as intended. The current literature identifies several channels through which the two requirements act as substitutes or complements in reducing the probability of crisis. It also indicates, overall, that having both requirements is better than relying on one requirement only.

The literature is however still at the early stage and significant gaps exist, especially in relation to how the interaction between the two requirements affects the costs of crisis and the opportunity costs.

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