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Assessing the Impact of Basel III: Evidence from Structural Macroeconomic Models

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Abstract

This paper (i) reviews the different channels of transmission of prudential policy highlighted in the literature and (ii) provides a quantitative assessment of the impact of Basel III reforms using "off-the-shelf" DSGE models. It shows that the effects of regulation are positive on GDP whenever the costs and benefits of regulation are both introduced. However, this result may be associated with a temporary economic slowdown in the transition to Basel III, which can be accommodated by monetary policy. The assessment of liquidity requirements is still an area for research, as most models focus on costs, rather than on benefits, in particular in terms of lower contagion risk.

Keywords: Basel III Reforms, DSGE Models, Solvency Requirements, Liquidity Requirements

JEL classification: E3, E44, G01, G21, G28.

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NON-TECHNICAL SUMMARY

In the aftermath of the 2008 Global Financial Crisis, the Basel Committee on Banking Supervision (BCBS) developed a set of reforms – the Basel III Accords – aimed at improving regulation, supervision, and risk management within the banking sector. By requiring banks to keep a higher level of reserve capital on hand, and to maintain adequate liquidity ratios, Basel III addresses a number of shortcomings in the pre-crisis regulatory framework.

To quantitatively assess the impact of Basel III reforms from a macroeconomic perspective, structural quantitative macroeconomic models have been developed that capture the transmission mechanisms of prudential policies. Central banks and supervisory agencies have been at the forefront in the development and application of such models.

The first part of the paper reviews the different channels of transmission of financial shocks (including regulatory changes) highlighted in the literature in the last 15 years. It distinguishes between, on the one hand, standard quantitative Dynamic Stochastic General Equilibrium (DSGE) models routinely used by central banks and, on the other hand, alternative models that investigate potential additional channels, and new issues. The conclusion of this journey into the world of macroeconomic models is that a very large number of new models have been made available since BCBS (2010), but standard models still concentrate mostly on capital requirements and more rarely on liquidity. Alternative models consider other policies (unconventional monetary policies, etc) as well as new, highly relevant challenges like interactions with the shadow banking system. However, the latter models are not yet sufficiently operational to allow an empirical assessment of the impact of the regulatory changes.

The second part of the paper provides a simulation of regulatory scenarios replicating the implementation of Basel III reforms, using "off-the-shelf" macro-finance models at the European Central Bank, the Board of Governors of the Federal Reserve System, the Banque de France and the Norges Bank. These simulations provide novel estimates of the impacts of Basel III. The variety of models and jurisdictions on which the macroeconomic impact of Basel III is assessed ensures the robustness of the findings. Some models do not measure the benefits, so that the latter may be inferred by difference with the output of the models that assess both costs and benefits. In addition, the models are used to provide a first assessment of the resilience of the post-Basel III banking system to very large shocks replicating the current Covid-19 environment.

In a nutshell, whenever the costs and benefits of regulation are introduced in the model, the effects of Basel III are positive on GDP (this is the case for the 3D model applied to the euro area and the United States, as well as the model by de Bandt and Chahad (2016) with run probability). This holds both for the United States and euro area economies. The positive effect of Basel III on GDP may however be associated in the transition to Basel III by a temporary slowdown accommodated by monetary policy. In additional exercises, we assess the costs related to the transition from Basel II to Basel III. First, the Central Bank of Norway's NEMO model concludes that the net benefits of Basel III depend on the magnitude of the crisis probability and severity. In the case of moderate crisis probability and severity, Basel III has a small negative effect on GDP although it reduces both the crisis probability and the severity. However, when both the probability and the severity nearly double, Basel III has positive effects on GDP as its net benefits become substantial. Second, using the Gerali et al. (2010) framework for the euro area, which only identifies the cost of implementation of the regulation, yields a negative effect on GDP, but this results is an obvious consequence of the absence of modelling of the benefits of regulation.

All in all, one needs to emphasise that the results of the models crucially depend on the assumptions regarding the magnitude and the sensitivity of the bank default probability or the financial crisis probability. This is consistent with BCBS (2010) and Birn et al. (2020). Expectations regarding the

likely impact of the regulation also play a significant role in the positive assessment of the impact of Basel III regulations.
To conclude, while significant advances have been made for the modelling of solvency requirements, the assessment of liquidity requirements is still an area for research, as most models still concentrate on the costs of liquidity.

Table 1. Long-term impact of a move from Basel II to Basel III (solvency)

Unit	GDP % dev	Bank probability of default, % pts dev	Cost of crisis (% of GDP), % pts dev
Euro area with 3D model (Mendicino et al. 2020)	1.2%	-7.50	-2.55% (1)
Euro area with de Bandt and Chahad (2016)	0.2%	-0.29	-0.34% (1)
Euro area with Gerali et al. (2010) framework (cost approach)	-0.4%	NaN	NaN
United States (Clerc et al., 2015, with US calibration)	0.9%	-9.21	-3.36% (1)
Norway - moderate crisis prob. and severity (Kockerols et al., 2021)	-0.2%	-0.16 (2)	-0.85% (3)
Norway - high crisis prob. and severity (Kockerols et al., 2021).	2.1%	-1.63 (2)	-4.39% (3)

Note: The move from Basel II to Basel III is measured by a 5 percentage point increase in capital requirements. (1) Change in bail out costs. (2) Change in the probability of a financial crisis. (3) Change in the cost of a financial crisis.

L'impact de Bâle III : des évaluations à partir de modèles macroéconomiques structurels

RÉSUMÉ

Cet article (i) passe en revue les différents canaux de transmission de la politique prudentielle mis en évidence dans la littérature et (ii) fournit une évaluation quantitative de l'impact des réformes de Bâle III à l'aide de modèles DSGE utilisés par diverses banques centrales. Il montre que les effets des accords de Bâle III sont globalement positifs sur le PIB lorsque les coûts et les avantages de la réglementation sont conjointement introduits dans les modèles. Cependant, ce résultat peut être associé à un ralentissement économique temporaire pendant la transition vers Bâle III, qui peut être compensé par la politique monétaire. L'évaluation des exigences en matière de liquidité reste toutefois un domaine de recherche, car la plupart des modèles se concentrent sur les coûts plutôt que sur les bénéfices de la régulation, notamment en termes de moindre risque de contagion.

Mots-clés : Réformes de Bâle III, modèles DSGE, exigences de solvabilité, exigences en matière de liquidité.

1. Introduction

In the aftermath of the 2008 Global Financial Crisis, the Basel Committee on Banking Supervision (BCBS) developed a set of reforms – the Basel III accord – aimed at improving regulation, supervision, and risk management within the banking sector. By requiring banks to maintain adequate liquidity ratios and keep certain levels of reserve capital on hand, Basel III addresses a number of shortcomings in the pre-crisis regulatory framework. In order to quantitatively assess the impact of Basel III reforms from a macroeconomic perspective, structural quantitative macroeconomic models have been developed. Central banks and supervisory agencies have been at the forefront in the development and application of such models.

In this paper, we (i) review the different transmission channels of prudential policy highlighted in the literature in the last 15 years and (ii) provide a quantitative assessment of the impact of Basel III reforms using "off-the-shelf" Dynamic Stochastic General Equilibrium (DSGE) models, in particular those routinely used by the European Central Bank, the Board of Governors of the Federal Reserve System, Norges Bank and the Banque de France.

Such considerations were present in the initial development of Basel III, as discussed in the Basel Committee's Long-term Economic Impact (LEI) report (Basel Committee on Banking Supervision, BCBS 2010) and the Macroeconomic Assessment Group (MAG 2010) report. However, after a decade it is useful to revisit these issues in order to take stock of the large number of developments in macroeconomic models since then, which include a much more detailed description of the interaction between the financial sector and the rest of the economy, as well as other potential trade-offs.[1]

We first show that a very large number of new models have been made available since BCBS (2010), but standard models still concentrate mostly on capital requirements and more rarely on liquidity. Alternative models consider other policies (unconventional monetary policies, etc.) as well as new, highly relevant challenges like interactions with the shadow banking system. However, the latter

[1] In contrast, the LEI and MAG rely mostly on real sector macroeconomic models without a banking sector and the transmission of regulation was implemented through a calibration of the transmission of higher regulatory requirements on bank lending rates (i.e. prices) assuming a full pass through of a higher cost of capital. Since then, the academic literature has investigated the direct impact of higher requirements on loan supply (in particular loan quantities). See Birn et al. (2019).

models are not yet sufficiently operational to allow an empirical assessment of the impact of the regulatory changes. Second, our harmonized regulatory scenarios, which replicate the implementation of Basel III reforms, provide novel estimates of the impacts of Basel III. The variety of models and jurisdictions on which the macroeconomic impact of Basel III is assessed helps ensure the robustness of the findings. Some models do not measure the benefits, but these may be inferred by difference from the output of the models that assess both costs and benefits. Evidence displayed in Table 1 indicates that the macroeconomic impact of Basel III has the expected positive sign on GDP, although the effect is not large. Whenever the costs and benefits of regulation are both introduced into models, the effects of Basel III are generally positive on GDP. The positive effect of Basel III on GDP may however be associated with a temporary economic slowdown in the transition to full implementation of Basel III, accommodated by monetary policy.

In additional exercises, we assess the costs related to the implementation of Basel III. First, the Central Bank of Norway's NEMO model concludes that the net benefits of Basel III depend on the magnitude of the crisis probability and severity. In the case of moderate crisis probability and severity, Basel III has a small negative effect on GDP although it reduces both the crisis probability and the severity. However, when both the probability and the severity nearly double, Basel III has positive effects on GDP as its net benefits, in terms of reduced frequency of crises and lower GDP loss in case of crisis, become substantial. Second, using the Gerali et al. (2010) framework for the euro area, which only identifies the cost of implementing the regulation, yields a negative effect on GDP, but this result is an obvious consequence of the absence of modelling the benefits of regulation. The long-run gross benefits of the Basel III framework for the euro area could be estimated between 0.6 and 1.6% of GDP (as measured by the difference between the net benefits found by the 3D model, 1.2%, or by the model by de Bandt and Chahad 2016, 0.2%, and the cost found by the Gerali et al. 2010 framework, -0.4%).

Table 1. Long-term impact of a move from Basel II to Basel III (solvency)

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Note: The move from Basel II to Basel III is measured by a 5 percentage point increase in capital requirements. (1) Change in bail out costs. (2) Change in the probability of a financial crisis. (3) Change in the cost of a financial crisis.

All in all, one needs to emphasize that the results of the models crucially depend on the assumptions regarding the magnitude and the sensitivity of the bank default probability or the financial crisis probability. This is consistent with BCBS (2010) and Birn et al. (2020). Expectations regarding the likely impact of the regulation also play a significant role in the positive assessment of the impact of Basel III regulations. While significant advances have been made in the modelling of solvency requirements, more research is needed assessing liquidity requirements. Most models concentrate only on the costs of liquidity, and more work is still needed to provide a full assessment of the costs and benefits, in particular in terms of lower contagion risk.

This paper is organized as follows. Section 2 presents the relevant economic channels and documents what the literature already implies about the impact of reforms. We distinguish between, on the one hand, standard quantitative DSGE models used by central banks on the one hand, and alternative models that investigate additional channels, as well as new issues, on the other. Section 3 discusses the results of model-based simulation exercises where we compare the outputs of some of the models surveyed in the previous section and in current use by regulators. Section 4 concludes.

2. The Transmission channels of prudential policy

The macroeconomic transmission mechanisms of prudential regulation have been widely discussed in the economic literature and implemented in macroeconomic models. The approach taken here is to limit the analysis to those models that allow an assessment of the impact of the reforms on both the financial sector and the real economy. For this reason, we place some emphasis on general equilibrium models that highlight possible trade-offs beyond just those in the financial sector. Two types of models are considered:

(1) Standard quantitative DSGE models, which have experienced much improvement since the Global Financial Crisis (GFC) with the introduction of fully-fledged banking sectors relative to the earlier generation of models (Section 2.1).

(2) Alternative modelling approaches consisting of more stylized/qualitative DSGE models that investigate new channels of transmission of regulatory changes as well as new issues (Section 2.2).

The first type of models are calibrated or estimated using a broad set of real macro and financial data. The channels considered are simple to introduce in a medium-scale model. Empirical macroeconomic models have also been developed but are not discussed here (see BCBS, 2021 for more details on these models).

2.1. **Operational macroeconomic models (standard quantitative DSGE models).** Policy institutions rely on various types of DSGE models that are used to assess the impact of reforms. DSGE models were developed in central banks in the 1990s and 2000s, initially focussed on monetary transmission mechanisms used to define optimal monetary policy. The Smets and Wouters (2003) model is a good illustration of this kind of New-Keynesian General Equilibrium model where macroeconomic cycles are explained by real and nominal frictions. On the financial side, Bernanke et al. (1996) introduced asymmetric information in the financing of firms so that lending rates include a yield spread that fluctuates over the cycle and creates acceleration effects, and financial cycles that may amplify real cycles.

Similarly, the analysis of lending cycles introduced by Kiyotaki and Moore (1997), where non-financial firms are credit constrained and lending is limited by the amount of collateral they can pledge, is a backbone of many subsequent macroeconomic models. According to this collateral channel, also extended to household mortgage loans, the price of collateral plays a major role in tightening financial constraints in general equilibrium, amplifying the effects of exogenous shocks.

Table 2. Standard quantitative DSGE models by channels of transmission

Channels	Papers
Bank capital channel	Gertler and Karadi (2011), Meh and Moran (2010), Gerali et al. (2010), Clerc et al. (2015), Mendicino et al. (2018, 2020), Kravik and Mimir (2019) (Central Bank of Norway's NEMO model), Kockerols et al. (2021) (NEMO with Markov regime switching)
Banks' funding and liquidity	Covas and Driscoll (2014), De Nicolò et al. (2014), de Bandt and Chahad (2016), Begenau (2020), Van den Heuvel (2019), Hoerova et al. (2018), Boissay and Collard (2016)
Risk taking	Martinez-Miera and Suarez (2014)

Since the GFC, these models have been expanded to include a more complete banking sector that takes into account banks' balance sheet constraints and additional transmission channels of financial shocks, taking on board the results of models developed in the banking and finance literature. The majority of papers on financial cycles focus on frictions affecting financial intermediaries. For example, Bernanke (2018) argues that the unfolding of the GFC in the United States can be characterised by an amplification through the financial sector of a shock originating in the household sector.[2]

In this section, we describe the building blocks of these quantitative DSGE models, with a particular focus on models that directly incorporate banking regulation or develop transmission channels that allow the future integration of banking regulation. Table 2 sets out the papers that are summarized in

[2]Bernanke (2018) writes "Although the deterioration of household balance sheets and the associated deleveraging likely contributed to the initial economic downturn and the slowness of the recovery, I find that the unusual severity of the Great Recession was due primarily to the panic in funding and securitisation markets, which disrupted the supply of credit."

this section. The models used in policy institutions are usually built around a core element that features the bank capital channel (Section 2.1.1). There is a well-developed theory on this channel in the context of DSGE modelling, highlighting its relevance and feasibility. This channel is complemented in some cases by the channels of bank funding liquidity and collateral (Section 2.1.2) and banks' risk-taking channel (Section 2.1.3).

2.1.1. *Bank capital channel.* The bank capital channel is at the core of many current operational models. These models are usually built on an agency problem between banks and their creditors, or on regulatory capital requirements. Some models combine both approaches by introducing (socially costly) financial frictions based on an agency problem mitigated with bank capital requirements. In this case, regulatory bank capital requirements have both costs and benefits: they impose credit supply constraints, but mitigate risks and lower inefficiencies associated with banks' agency problem.

When the bank capital channel is active, the impact of an adverse shock to bank capital is accompanied by a drop in bank credit supply. The exact transmission mechanism depends on the type of friction considered between banks and their creditors, and on the final use of bank funding: any fall in bank capital can result directly in higher funding costs for banks or limit banks' ability to attract funds (e.g., deposits). In both cases, a decline in credit supply affects business and/or housing investment. Some models also incorporate consumer loans which directly affect consumption. The bank capital channel thus generates interactions between the financial and nonfinancial sectors: adverse nonfinancial shocks depress activity and weaken banks' balance sheets and credit supply, exacerbating the impact of the shock on overall economic activity.

Before the 2008 crisis, a capital channel was routinely incorporated in operational models, but with a focus on nonfinancial firms. Two different approaches based on different agency problems were generally used. In the first approach, the costly state-verification problem (Townsend 1979) was introduced. Information asymmetry requires lenders to pay a verification cost when borrowers default. Better capitalized borrowers are less likely to default and thus pay a lower external finance premium (Carlstrom and Fuerst 1997; Bernanke et al., 1999). The second approach builds on the human capital assumption of Hart and Moore (1994). When borrowers cannot pre-commit to work and have the option to repudiate their debt, the value of capital pledged as collateral must match the value of the debt. Thus, better capitalized borrowers can attract more funds to finance their expenditures (Kiyotaki and Moore 1997). In both cases, the capital channel has the potential to amplify business cycle fluctuations.

The bank capital channel builds on these earlier works by applying similar frictions directly to financial intermediaries. The state-verification friction was introduced between banks and their creditors in addition to the usual friction between banks and entrepreneurs. Hence, both banks' and entrepreneurs' capital ratios drive lending spreads (Davis 2010; Hirakata et al., 2011). A double moral hazard problem between banks and their creditors, and between banks and entrepreneurs (Holmstrom and Tirole 1997) is another friction that was introduced in DSGE models (Meh and Moran, 2010). Banks exert monitoring efforts, which are costly and unobserved but can incentivize entrepreneurs to behave optimally. Higher bank capital acts as a monitoring incentive for banks and determines the amount of funds banks can attract from their creditors to fund entrepreneurs' investment. A different moral hazard problem between banks and creditors arises where banks hold equity stakes in non-financial corporations and have the option to divert a fraction of their assets to these corporations (Gertler and Karadi, 2011). Depositors will liquidate the bank to avoid losses where banks divert assets. Consequently banks hold sufficient capital to assure depositors that they do not have an incentive to divert assets and attract sufficient deposits. In all these models, changes in banks' capital affect banks' credit supply. In the same vein, Clerc et al. (2015) incorporate in a model optimizing financial intermediaries, which allocate their scarce net worth together with funds raised from saving households across two lending activities, mortgage and corporate lending. For all borrowers (households, firms, and banks), external financing takes the form of debt which is subject to default risk. Their three default (3D) model illustrates how the three interconnected net worth channels may cause financial amplification and the distortions due to deposit insurance.

The introduction of capital requirements directly into models with the bank capital channel is crucial for measuring the costs and benefits of capital regulations. Most models capture the costs of tighter capital requirements as a reduction in credit supply. In some models, regulatory capital-to-asset ratios directly affect credit volumes (Clerc et al., 2015). In other models, stricter capital requirements are transmitted through higher bank funding costs. For example, banks deviating from exogenously given capital requirements can incur a cost given by an ad-hoc penalty function (Gerali et al., 2010).

Some models also measure the benefits of capital requirements. There is an incentive for excessive risk taking by banks where they are protected by limited liability and consumers are protected by deposit guarantees. Higher bank capital requirements reduce bank default rates and the resources lost in the liquidation process. In addition, in Clerc et al. (2015), higher default probability for banks increases the required interest rate on uninsured bank debt and raises the cost of providing loans to the real economy. When the capital ratio is too low, the probability of bank default is high. Conversely, increasing capital from a low level may lower the weighted average cost of bank funding, as the cost of uninsured bank debt decreases, implying higher steady state bank lending and GDP. Transition effects can also be important. The costs of tighter capital requirements can be higher in the short run (as banks must reduce credit supply) while benefits emerge in the long run as banks accumulate more capital (Mendicino et al., 2020).

The bank capital channel thus opens important interaction with macroprudential policies, but also with monetary policy. The introduction of nominal rigidities and monetary policy allows the central bank to adjust interest rates downwards in the transition phase towards tighter capital requirements to mitigate any economic slowdown caused by a drop in credit supply (Mendicino et al., 2018, 2020). Unconventional monetary policy can also be modelled as central bank credit intermediation, which interacts with the bank capital channel (Gertler and Karadi, 2011, see Section 2.2.5).

However, some important limitations remain in these models. First, financial crises are rare but extreme events, which cannot be nested in typical business cycles. Bank capital constraints may be binding during crises but not in normal times. While some models explicitly allow for the presence of occasionally binding constraints on bank capital, the simulations are performed assuming that these constraints are always binding. A compromise is to consider a regime switching model to account for the possibility of financial crisis (Kockerols et al., 2021).

Second, bank capital is modelled in a simple fashion. There is only one type of capital which is accumulated only through retained earnings, and there is no distinction between regulatory and voluntary capital buffers. On this last issue, Benes and Kumhof (2015) assume that banks hold voluntary buffers to mitigate the risk of breaching capital requirements in an operational model. However, they do not account for the possibility of banks defaulting and hence the model does not fully capture the benefits of capital regulations.

2.1.2. *Funding, liquidity and collateral requirements.* Consideration of both capital and liquidity constraints is less frequent in the literature, and also less prevalent in operational models. Liquidity regulation is implemented in some models by imposing constraints on the maturity of funding sources, or on the liquidity of assets to avoid bank runs. Models in this part of the literature include De Nicolò et al. (2014) in partial equilibrium, or Covas and Driscoll (2014) or de Bandt and Chahad (2016), in general equilibrium. In the latter model, liquidity requirements are implemented through multiperiod assets and liabilities. Including households with a preference for liquidity, which banks can supply through their mix of liquid and illiquid assets, can allow for an analysis of the interaction between capital and liquidity policy (Van den Heuvel, 2019; Begenau, 2020). Bank capital requirements directly limit the fraction of assets that can be financed with liquid deposits, while regulation requiring banks to hold more liquid assets increases the required bank return on loan assets and reduces credit as a consequence. These effects have differing implications for the macroeconomic costs of these policies, measured as the welfare cost to households from reduced liquidity, and lost investment and production from higher costs of intermediation.

In the model of Begenau (2020), which includes deposits in households' utility functions, deposits are cheaper compared to equities, because they offer a convenience yield. Higher equity requirements reduce bank deposits. This is welfare-decreasing for households that derive utility from deposits. However, it also decreases the deposit rate (since the marginal convenience yield increases), which lowers banks' financing costs. Higher equity requirements also increase banks' incentive to monitor projects, as shareholders have more "skin in the game". This lowers banks' risk and raises their average returns, leading to more credit provision. Overinvestment in low-quality projects decreases. This reduces the volatility of output and consumption and boosts their average levels. Benefits from higher and smoother consumption outweigh the costs of lower deposits.

Hoerova et al. (2018) focus on the costs and benefits of liquidity regulation. The paper demonstrates the positive role that liquidity policy can have on reducing the need for lender of last resort interventions during financial crises. The authors examine the opportunity costs of liquidity policy, providing evidence for the presence of private costs to banks of requirements that force them to hold more liquid assets than their own preferences, with a negative impact on profitability (see also de Bandt et al., 2021). One major finding is that the opportunity cost of liquidity regulation is small, and smaller than that of capital regulation.

Finally, the introduction of heterogeneous banks with an interbank market can also create a role for liquidity policy (Boissay and Collard, 2016). In the interbank market, borrowing banks divert funds that lending banks cannot easily take back, creating an agency problem. As banks do not fully internalize the effect of their funding decisions, capital and liquidity regulations can address these issues. These policies can be reinforcing where capital requirements reduce risky lending decisions and liquidity requirements encourage the purchase of lower risk liquid assets (government bonds). That said, the latter effect can reduce government bond yields, increasing demand for deposits and bank leverage (and hence risk).

2.1.3. *Risk-taking channel.* In order to highlight the risk-taking channel, Martinez-Miera and Suarez (2014) develop a discrete time DSGE model. The economy is made of patient agents, who essentially act as providers of funding to the rest of the economy, and impatient agents, who include "pure" workers, bankers and entrepreneurs. Savers provide a perfectly inelastic supply of funds to banks in the form of deposits but cannot directly lend to the final borrowers. Banks finance at least a fraction of their one-period loans with equity capital (i.e., with funds coming from bankers' accumulated wealth). Banks complement their funding with fully-insured, one-period deposits taken from patient agents.

Banks finance firms that invest in a good asset or in a bad asset. The bad asset has a lower expected return on average, but a higher return when the economy is in the boom phase of the business cycle: systemic firms are overall less efficient than non-systemic ones. However, it is assumed that, conditional on the systemic shock not occurring, systemic firms yield higher expected returns. As a consequence, systemic risk-taking peaks after long periods of calm. Undercapitalized banks take a risk by holding the bad asset.

Regarding the impact of regulation, higher capital ratios (i) discourage investing in the bad asset, i.e., reduce the proportion of resources going into inefficient systemic investments, and (ii) increase the demand for scarce bank capital in each state of the economy, reinforcing bankers' dynamic incentives to guarantee that their wealth (invested in bank capital) survives if a systemic shock occurs. Such a mechanism is also active in the Begenau (2020) model discussed above. Although operational models display several relevant channels, the economic literature investigated many other channels, or refinements of the existing ones, that we discuss below.

2.2. **Alternative modelling approaches (mostly stylized/qualitative models).** In this section, we present some of the recent contributions to the literature on general equilibrium models with a financial sector. They offer alternative transmission channels to the ones reviewed in Section 2.1., and are summarized in Table 3.

2.2.1. *Further modelling of the bank capital channel.* One of the criticisms of the operational models is that they fail to adequately capture observed economic outcomes during crisis periods. Linearized solutions to DSGE models around a steady state disregard underlying non-linear dynamics. Furthermore, while some of the models presented in Section 2.1 allow for the presence of occasionally binding constraints on bank capital, for the purpose of the simulations it is assumed that these constraints are always binding. As a consequence, these models (deterministically) drift back towards a steady state more quickly than real economic data demonstrate.

Table 3. Alternative modelling approaches by channels of transmission

Channels	Papers
Bank capital channel (nonlinear dynamics included, occasionally binding constraints)	Brunnermeier and Sannikov (2014); Jondeau and Sahuc (2018); He and Krishnamurthy (2019); Holden et al. (2019); Elenev et al. (2021); Schroth (2021)
General collateral channel	Korinek and Simsek (2016); Walther (2016); Ikeda (2018); Jeanne and Korinek (2020)
Savings gluts and boom-bust cycle dynamics	Boissay et al. (2016); Martinez-Miera and Repullo (2017); Swarbrick (2019); Coimbra and Rey (2020)
Bank runs (with coordination failure and strategic complementarity)	Angeloni and Faia (2013); Gertler and Kiyotaki (2015); Miller and Sowerbutts (2018); Gertler et al. (2019); Kashyap et al. (2020)
Interactions with unconventional monetary policies	Brunnermeier and Koby (2018); Adrian and Boyarchenko (2018); Eggertsson et al. (2019); Lopez et al. (2020)
Interactions with shadow banking	Plantin (2015); Ikeda (2018); Durdu and Zhong (2019); Martinez-Miera and Repullo (2019); Begenau and Landvoigt (2021)

One approach to addressing this shortcoming is to introduce uncertainty over the future persistence of any crisis (Brunnermeier and Sannikov, 2014). Greater instability is generated once the economy moves sufficiently away from the steady state (crisis times) as equity capital is increasingly misallocated due to the uncertainty, leading to underinvestment and distorted household consumption decisions. Similarly, where the amount of equity raised by an intermediary depends on uncertain equity returns subject to shocks, a negative shock when intermediaries are relatively unconstrained ("normal" times) triggers a small decline in equity, asset prices and investment. However, when these equity constraints are binding or likely to be binding in the near future ("crisis" times), a negative funding shock triggers a more substantial decline (He and Krishnamurthy, 2019). In addition, Jondeau and Sahuc (2018) show that non-linearities (fire sales and bank default) in a DSGE model with two types of banks play a fundamental role in the development of a crisis.

Occasionally binding constraints on bank debt can generate similar non-linear dynamics and outcomes. Under normal circumstances, banks rely on debt finance whereas under financial stress borrowing constraints can bind and banks must eventually raise additional equity finance at a higher cost. This results in occasional episodes with sharp increases in spreads and deeper downturns, helping explain observed macroeconomic asymmetries such as negatively skewed aggregate investment (Holden et al., 2019). A similar approach has been used to analyze the effectiveness of policy: pre-crisis capital requirements in the United States were found to be close to optimal in terms of the aggregate welfare of savers and borrowers where default and occasionally binding borrowing constraints in both the non-financial and financial sectors are present (Elenev et al., 2021); while capital buffers are found to be more effective in restricting bank equity payouts, rather than bank lending over financial cycles, in examining the implementation of the capital conservation buffer and the countercyclical capital buffer (Schroth, 2021).

2.2.2. *General collateral channel.* Another strand of literature that aims to overcome the inability of operational DSGE models to produce a prolonged and severe crisis relies on a more general collateral channel. The idea was first developed in a model economy by Kiyotaki and Moore (1997). Where agents' price-taking behaviour fails to internalize the feedback mechanism from collateral price changes, fire sales are accelerated and there is overborrowing relative to a constrained-optimal allocation (Kiyotaki and Moore, 1997). Relative to a social optimum, crises happen more frequently in an unregulated economy with overborrowing since collateral constraints are more likely to be binding as the amount of debt to be rolled over increases. The magnitude of an (endogenous) crisis tends to be large as agents fire-sell more assets for consumption smoothing, leading to larger declines in collateral prices and further tightening of collateral constraints. Ex ante macroprudential regulation can subsequently help reduce a build-up of debt and reduce the probability and severity of crises.

Aggregate demand externalities can also play a role where a liquidity trap may occur at the interest rate zero lower bound (ZLB) (Korinek and Simsek, 2016). Where constrained households deleverage after a financial shock, decreases in interest rates are needed to induce unconstrained households to support aggregate demand. If the interest rate reduction is limited by the ZLB, aggregate demand is insufficient and the economy enters a liquidity trap. In this environment, households' ex ante leverage and insurance decisions are associated with aggregate demand externalities.

Some three-period models with a banking sector rely on a collateral channel that can trigger fire sales. They can provide insights into the effect of liquidity policies alongside capital regulation. Where banks' creditors have a preference for liquidity by assumption (Walther, 2016) or where the amount of liquidity is not enough in the case of a bank run (Ikeda, 2018), the economy is inefficient without regulation. In these models, both capital and liquidity requirements play a role to counter these inefficiencies. In a similar framework, Jeanne and Korinek (2020) investigated how macroprudential policy should be designed when policymakers also have access to liquidity provision tools to manage crises.

2.2.3. *Savings gluts and boom-bust cycle dynamics.* Empirical studies find that credit is not only depressed during and following a financial crisis but is also often elevated prior to financial crises (Schularick and Taylor, 2012), pointing to a causal link between high credit ex ante and the occurrence of a financial crisis ex post. A series of recent papers have used this kind of domestic "savings glut" argument (as proposed by Bernanke, 2005) to model financial crisis. A savings glut lowers interest rates and induces more risky lending such that a financial crisis becomes more likely. There is additional feedback because the financial instability created by a savings glut further increases the incentive to save and to bid up asset prices.

Several financial frictions can play a role as a feedback mechanism within this boom-bust cycle. The introduction of the interbank market is one mechanism. The late-cycle savings glut reduces interbank interest rates, inducing banks with poor risk capability to lend funds directly to firms rather than to more able banks through the interbank market. As the average risk capability of the banking sector falls, credit supply drops even more as a consequence (Boissay et al., 2016). Another mechanism is banks' investment in costly monitoring of loan quality. Banks optimally choose to monitor less as any boom progresses, since monitoring is costly and their profit are lower due to lower lending spreads, just as borrowers become riskier and crises (endogenously) more likely (Martinez-Miera and Repullo, 2017).

A third mechanism is asymmetric information on credit risk between firms (which know the risk) and banks (which do not), leading to adverse selection and credit rationing. During a savings glut the risk of default increases to the point where banks decide not to lend all available funds and restrict credit to safe firms (Swarbrick, 2019). Lastly, intermediaries can differ with respect to their probability of default. Riskier banks (closer to default) increase leverage during a savings glut, which raises aggregate risk taking as riskier banks increase their holdings of risky assets ("selection" effect) and more assets in total are held by riskier banks ("composition" effect) (Coimbra and Rey, 2020).

2.2.4. *Further modelling of bank runs.* A theoretical approach suitable for studying crisis phenomena (including bank runs) are global coordination games of regime change (see Morris and Shin, 2001). Agents take an action (e.g., withdraw deposits from a bank, or refuse to roll over short-term debt) and their incentive to act rises with the proportion of agents taking similar actions (strategic complementarity). This innovation in the global game solution methods has spurred the development of extensions to the classical bank run model by Diamond and Dybvig (1983) (see, for example, Goldstein and Pauzner, 2005).

An extension to this approach includes the introduction of safe alternative opportunities for investors to provide deposits that fund bank lending in a three-period model. Investors receive a private signal about a bank's solvency and can decide to withdraw their funding. In this way, runs are predicated on expectations about a bank's solvency. Banks have to offer a risk premium to attract funding, and more liquid banks have lower premiums. Liquidity regulation reduces the probability of a run and can be demonstrated to reduce the profits of banks to a lesser extent than for other approaches (Miller and Sowerbutts, 2018). Similar approaches have been used to examine the complementarity between capital and liquidity regulation (Hoerova et al., 2018; de Bandt et al., 2021). Another extension of the Diamond and Dybvig framework is to include endogenous funding, with banks and borrowers subject to limited liability. Banks monitor borrowers (when profitable) to ensure that they repay their loans, while depositors may choose to run based on beliefs about both banks' monitoring and resources available for those withdrawing early (Kashyap et al., 2020).

In a different strand of the literature, authors have started investigating infinite horizon DSGE models combining financial accelerator effects and bank runs. In this approach, the probability of a run increases with bank leverage. Expansionary shocks increase bank leverage, bank risk, and the probability of runs. A recession that constrains bank lending due to conventional financial accelerator effects raises the possibility of runs due to the associated weakening of balance sheets. Where banks optimize over a finite (two-period) horizon, regulatory constraints on leverage (in particular, countercyclical capital requirements) reduce the probability of runs, stabilize the banking system, and reduce fluctuations of the economy (Angeloni and Faia, 2013).

Additional effects arise where banks optimize over an infinite horizon (Gertler and Kiyotaki, 2015). In this case, individual banks do not take account of the effect of their leverage on asset fire sales in distressed times, leading to excessive leverage in (no regulation) equilibrium. Capital requirements correct this bias and reduce the probability of runs, although there is a trade-off as tighter capital requirements also reduce the level of financial intermediation. Extending this model further to a more conventional macroeconomic setting including a production sector allows for more quantitative conclusions (Gertler et al., 2019). Compared to the more conventional models discussed in Section 2.1, the models discussed above have the advantage of capturing the highly non-linear nature of bank runs in case of a financial system collapse: when bank balance sheets are strong, negative shocks do not push the financial system to the verge of collapse; when they are weak, a similar negative shock leads the economy into a crisis in which bank runs exist in equilibrium.

2.2.5. *Interactions with unconventional monetary policy.* DSGE models with a bank capital channel (see Section 2.1.1) have also been used to analyze interactions between banking regulation and monetary policy (Mendicino et al., 2020). In examining the interactions, the response of monetary policy is crucial in determining the size of the short-term output costs of increasing capital requirements. Aggressive interest rate cuts support output and significantly reduce the transitional costs of higher capital requirements. However, at the ZLB, monetary policy is constrained so increasing capital requirements is more costly. This has implications for optimal capital requirements. At the ZLB, a lower optimal capital requirement will be chosen compared to a situation in which monetary policy is free to react aggressively over the transition. Capital requirements should be increased gradually at the ZLB in order to smooth the impact on credit supply and output when monetary policy cannot react.

Unconventional monetary policy (UMP) may be able to overcome the constraint imposed by the ZLB for nominal interest rates, but may also exhibit different interactions with banking regulation. One should mention the paper by Adrian and Boyarchenko (2018), which presents a framework with endogenous pricing of risk to examine both capital and liquidity regulations in relation to the supply of risk-free assets (which can be interpreted as unconventional monetary policy). Liquidity requirements are preferable to capital requirements, as tightening liquidity requirements lowers the likelihood of systemic distress without impairing consumption growth. Intermediate ranges of risk-free asset supply achieve higher welfare because very low levels of the risk-free asset make liquidity requirements costly, while a very high supply of risk-free assets limits the effects of prudential liquidity regulation. Brunnermeier and Koby (2018) and Eggertsson et al. (2019) show that UMP may be contractionary, with adverse effects on aggregate lending, due to the existence of a "reversal rate". The reason is a possible decrease in bank profits if lending rates are reduced and this effect dominates capital gains. Furthermore, the deposit rate faces a lower bound, adversely affecting banks' profits. While existing evidence suggests that, so far, negative interest rate policy has not reduced bank profitability (Lopez et al., 2020), the analysis of interactions between UMP, prudential regulation and financial stability remains an area for future research.

2.2.6. *Interactions with shadow banking.* The ability to include a "shadow banking" sector is an important modelling feature that increases the relevance of macroeconomic models used in policy analysis for economies that rely comparatively less on banking finance. A number of recent papers try to explicitly include shadow banking, which is comprised of financial intermediaries that are more lightly regulated than commercial banks, and highlight the relative impacts on both sectors.

The introduction of shadow banks in models with a collateral channel (see Section 2.2.2) shows that tighter leverage restrictions on regulated banks leads to increased leverage (and, as a result, higher default probability) by shadow (unrestricted) banks (Ikeda, 2018). In a quantitative general equilibrium (real business cycle type) setting, increasing capital requirements forces regulated commercial banks to find more expensive equity funding leading to an expansion of the shadow banking sector as it becomes relatively more profitable (Begenau and Landvoigt, 2021). A further insight from this class of model is that the broader effect of higher capital requirements in the (regulated) banking sector on non-financial sector borrowing may be ambiguous, as reduced leverage (and capacity for lending) in the banking sector is absorbed by higher leverage (and lending) in the shadow banking sector (Durdu and Zhong, 2019).

More detailed characterization of the banking and shadow-banking sectors in a stylized setting has also provided insights into the relative merits of different types of capital regulation (Martinez-Miera and Repullo, 2019). In this framework, financial intermediaries (lenders to entrepreneurs) face costs to certify their (unobservable) capacity to screen lenders: banks choose to do this by being regulated and subject to capital requirements; while shadow banks choose private certification, which is more expensive, but avoids the capital regulation. This characterization of the banking and shadow-banking sector yields some interesting insights. First, safer borrowers tend to favor shadow banks in the presence of capital requirements. Second, increases in flat (leverage-like) capital requirements are costly for those relatively safe bank customers and can raise default risk compared to increases in risk-based requirements. Similarly to the aforementioned literature (as well as Plantin, 2015), they find that a tightening of capital requirements in the banking sector may lead to substitution effects (see empirical evidence in Jiménez et al., 2017, Irani et al., 2021). As a consequence, the optimal capital ratio may be lower compared to a situation without a shadow banking sector (or financial market). But at the same time, the overall financial system is riskier, due to the existence of an unregulated shadow banking sector. The overall macroeconomic effect of a larger shadow banking sector is still an area for additional research.

3. Model-based quantitative illustrations

This section provides building blocks for future regulation assessments by illustrating the functioning of off-the-shelf DSGE models and shedding light on their capabilities (e.g., the type of response they provide, distinguishing between benefits and costs) to study the macroeconomic impact of Basel III reforms. We highlight similarities/differences across countries by gathering contributions from a representative set of jurisdictions and models: (i) the euro area (3D model by Clerc et al., 2015, complemented by a monetary policy channel, as described by Mendicino et al., 2020;[3] model by de Bandt and Chahad, 2016; and a modified version of Gerali et al., 2010, as described by Bennani et al., 2017), (ii) the United States (3D model by Clerc et al., 2015, with a country-specific calibration used by the Board of Governors)[4] and (iii) Norway (Norges Bank, Norwegian Economic Model, NEMO, see Kockerols et al., 2021).

Parameter calibration of these models is based on the most recent data, in order to capture the current state of the economy, and to be able to perform simulations applied to the current context, such as a Covid-19 shock. In the calibration process, we thus assume that most of the Basel III regulatory agenda has been implemented, which is true to a large extent, and set out deep structural parameters to match the means and variances of our data in the recent period. With this calibration of deep structural parameters at hand, we can perform various types of experiments by adjusting the values of our "Basel III parameters".

To study the macroeconomic impact of Basel III reforms, we implement several scenarios, which consider solvency and liquidity regulation. First, we increase capital requirements to capture the increase in the quantity and quality of capital requirements that the Basel III reform imposed. In a second scenario, we also consider the fact that Basel III imposed an increase in liquidity requirements. In each case, we analyze the impact of Basel III on long-run equilibrium values of important macroeconomic variables, and study the transition to the new regime, from Basel II to Basel III. In addition, we assess

[3] In the rest of the paper, simulations referring to the 3D model in the euro area are based on Mendicino et al. (2020).

[4] The version of the 3D model used by the Board of Governors also features nominal rigidities and monetary policy. These differences along with the country-specific calibration contribute to the slight differences in quantitative results reported by the ECB and the Board of Governors for the euro area and the United states, respectively.

the dynamic response of equilibrium values to shocks and to what extent they differ across the two regimes. This includes a very preliminary scenario where we assess the impact of large shocks, mimicking the impact of Covid-19 (including a supply shock on total factor productivity – TFP –, as well as additional business defaults and/or a negative shock to investment).

3.1. **Overview.** In order to compare the results of the different models used, in connection with the previous literature, the analysis distinguishes between the costs and benefits of various regulations, as shown in Tables 4 and 5. A key benefit of increasing capital and liquidity requirements is the expected reduction in the probability of bank failure and bank runs. Fewer bank failures imply lower bank failure costs – both public and private. The public costs of deposit insurance and the bailing out (or resolution) of failing banks are ultimately borne (for simplicity) by all households because they are taxpayers. Other deadweight costs also affect households' consumption. The private costs are captured by the spread banks are forced to pay over the risk-free rate in order to attract debt funding. Some bank debt is uninsured and its interest rate decreases when banks are safer because debt holders no longer need to be compensated for the potential losses. When banks are competitive, as in the 3D model, this cost reduction will be passed on to borrowers (ceteris paribus), stimulating economic activity. When they are facing monopolistic competition, like in NEMO, the pass-through is smaller in the short run, but ultimately passed on to borrowers. Nevertheless, tighter solvency regulation in NEMO reduces the probability of occurrence of crisis periods characterised by a large increase in lending spreads, hence partially reducing the ergodic mean of lending spreads over the business cycle.[5]

An effect that pushes in the opposite direction, and that is a key cost of increasing capital requirements, arises when the required rate of return on equity is higher than the cost of debt (which is usually the case) and assumed in the 3D model, in NEMO and in many other macro-financial models. The higher return on equity means that higher capital requirements adversely affect banks' profits,

[5]When there is an occasional financial crisis, lending spreads in NEMO become higher during crisis episodes due to asymmetrically large credit supply shocks. In this case, a benefit of reducing the crisis probability (by raising capital requirements) is to have lending spreads with a lower ergodic mean over the business cycle, but which remain higher than before the increase in solvency requirements.

which increase the spread of lending rates over deposit rates in order to achieve higher profitability and attract equity investors. Indeed, as shown in the fifth column of Table 4, the spread of lending interest rates over the bank's debt funding rate increases.

The implementation of these scenarios on the different jurisdictions provides interesting results. The implementation of the same 3D model on simulations for the euro area, as well as for the US, permits an assessment of the contribution of country/area idiosyncrasies. In contrast, the Norges Bank's model offers a different modelling perspective. All in all, Basel III appears to have the effects anticipated, in terms of positive effects on GDP and financial stability (and the exercise offers a useful quantification of these effects), although its contribution to real macroeconomic outcomes appears to be small. In particular, we find that:

- The calibration/measurement of the bank default probability (or financial crisis probability) and its evolution plays a crucial role in the assessment.
- The expectation channel plays an important role, conditioning the final impact of the reforms: if economic agents anticipate that the reforms will effectively reduce the probability of bank failure or the probability of a run, this triggers, beyond the initial supply shock, a positive demand effect on GDP.
- While long-run impacts are satisfactory, the modelling of short-run dynamics is still incomplete.

3.2. **Solvency scenario.** In the case of solvency regulation, the models include risk weights, but there is only one capital variable. This prevents the impact of Basel III regulation being studied in its full richness, that includes requirements in terms of quality and quantity of capital. This is the reason why we implement solvency regulation in terms of two quanta of additional capital requirements: 2.5 and 5 percentage point increases which take place over 20 quarters. The 5 percentage point scenario is broadly in line with the actual implementation of Basel III when the quality of capital is included. Possible non-linearities may lead to responses that are not proportional.

Table 4 exhibits the results for each jurisdiction. There are some differences across models, but this is explained by differences in the scope of the assessment, hence in terms of transmission channels of regulation. In a nutshell, in most models, whenever the costs and benefits of regulation are introduced in the model, the long-run/steady-state effects of Basel III are positive on GDP. This is the case for the 3D model applied to the euro area and the United States, as well as the model by de Bandt and Chahad (2016) with run probability applied to the euro area. The models employed by the ECB and the Board of Governors exhibit a positive effect of Basel III on GDP in the long-run, even if the transition to Basel III triggered a temporary slowdown accommodated by monetary policy. The implementation of higher capital requirements leads to a significant reduction in the probability of bank failure (-7.5 percentage points in the euro area and -9.21 percentage points in the United States). Lending spreads increase in all countries. However, all in all, GDP is 1% higher (1.19% in the euro area, 0.87% in the United States). The results for the euro area from the model of de Bandt and Chahad (2016) also show a positive effect on GDP, although the magnitude is smaller. The Norges Bank's NEMO model concludes that the net benefits of Basel III depend on the magnitude of the crisis probability and severity. In the case of moderate crisis probability and severity, Basel III has a small negative effect on GDP although it reduces both the crisis probability and the severity. However, when both the probability and the severity nearly double, Basel III has positive effects on GDP as its net benefits become substantial. In particular, the negative impact on GDP may turn into a positive effect if higher requirements help reduce the probability and the severity of a deeper financial crisis (about 10% reduction in output during the crisis). In the latter case, the ergodic mean of GDP increases by 2.1% in the long run under the higher capital requirements of the Basel III regime.

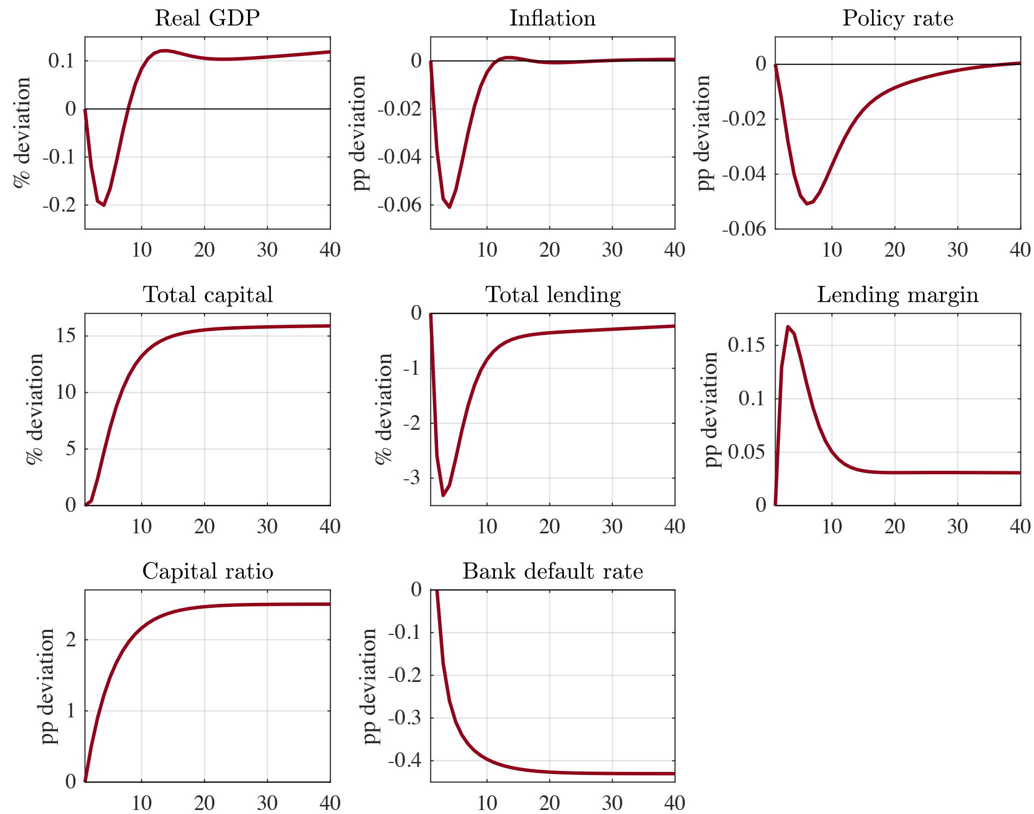
Table 4. Long-run impact of a 5% increase in capital requirements

	Expected benefits of regulation				Costs of regulation	Real macro variables			Financial macro variables
	Bank probability of default	Cost of crisis	Bailout cost as % of GDP	Bank debt funding cost spread over risk-free rate	Lending spread over bank debt fund. cost	GDP	Aggregate investment	Aggregate cons.	Total lending
Unit	% pts dev	% pts dev	% pts dev	% pts dev	% pts dev	% dev	% dev	% dev	% dev
Euro area with 3D	-7.50	NaN	-2. 55	-0.59	0.34	1.19	0.29	1.45	2.55
Euro area with de Bandt and Chahad	-0.29	NaN	-0.34	0.08	0.02	0.2	0.56	0.18	1.26
Euro area (cost approach)	NaN	NaN	NaN	0.17	0.11	-0.4	-1.31	-0.45	-5.85
United States with 3D	-9.21	NA	-3.36	-1.43	2.48	0.87	7.53	4.07	8.03
Norway (NEMO) (1)	-0.16 (*)	-0.85(**)	NaN	NaN	0.59	-0.18	-2.96	0.57	-3.18
Norway (NEMO) (2)	-1.63 (*)	-4.39 (**)	NaN	NaN	0.59	2.1	12.4	0.28	12.9

Note: (*) Change in the probability of a financial crisis. (**) Change in the cost of a financial crisis. (1) Under moderate crisis probability and severity. (2) Under higher crisis probability and severity. 3D-EA: Mendicino et al. (2020); Cost approach-EA: Gerali et al. (2010); 3D-US: Clerc et al. (2015) with US calibration; NEMO: Kockerols et al. (2021).

In additional exercises, we also assess the opportunity costs related to the implementation of Basel III without separate consideration of benefits. The Gerali et al. (2010) framework for the euro area ("cost approach"), which only identifies the cost of implementation of the regulation, yields a negative effect on GDP, but this result is an obvious consequence of not modelling the benefits of regulation. Comparing these results with those of the other models for the euro area (3D model and de Bandt and Chahad, 2016), the long run benefits of the Basel III framework could be estimated by the difference between, on the one hand, the steady state increase in GDP in the euro-area 3D model (1.2%) or according to the model by de Bandt and Chahad (0.2%), and, on the other hand, the decrease in GDP for the euro area according to the simulation based on the Gerali et al. (2010) framework (GDP growth down by 0.4%). This yields a long run benefit between 0.6 and 1.6% of GDP in the euro area.

Figure 1. Transition from 14% capital ratio to 16.5% in the euro area with 3D model



Note: Variables are expressed in deviation from initial steady state. "3D model" refers to the model used by Mendicino et al. (2020).

Finally we investigate the transition dynamics between Basel II and III. The models employed by the ECB and the Board of Governors exhibit a positive effect of Basel III on GDP, even where the transition to Basel III triggeres a temporary slowdown accommodated by monetary policy. Note that most models highlight the role of the monetary policy reaction in accompanying the reforms by reducing the policy rate at the start of the implementation period. We illustrate the monetary policy response in Figure 1 using the case of an increase in the capital ratio by 2.5 percentage points for the euro-area 3D model.

All in all, one needs to emphasize that the results of the models crucially depend on the assumptions regarding the magnitude and the sensitivity of the bank default probability (euro area and United

States) or financial crisis probability (Norway). This is consistent with the LEI study (BCBS 2010) and Birn et al. (2020).

3.3. **Liquidity scenario.** There are two liquidity instruments in Basel III – the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR). The LCR involves the obligation to hold a sufficient quantity of high-quality liquid assets (HQLA) so as to withstand one month of elevated deposit withdrawals. The NSFR involves the obligation to fund long-term assets at least in part with longer-term liabilities (e.g., bank bonds). In practice both the LCR and NSFR are complex regulations, which aim to increase banks' resilience to funding stress. To make the analysis operational, we concentrate on the LCR and provide the results of two sets of models in Table 5: (i) analysis of the costs of liquidity following the approach in Hoerova et al. (2018); and (ii) a more detailed analysis based on the multi-asset model of de Bandt and Chahad (2016) with bank runs.

Regarding the first approach, most models do not include an analysis of the benefits of the LCR. In this case, the simulations follow Hoerova et al. (2018) and only consider the impact of an LCR scenario through its effect on bank profits, measuring the opportunity cost of raising additional deposits and investing in lower yielding HQLA. We assume that HQLA are government bonds.[6] We also assume that the government bonds have a zero risk weight in the capital regulation. Regulation only affects the profit and loss statement, as the return on HQLA is lower than interest and non-interest costs on deposits needed to fund the HQLA holdings. Hoerova et al. (2018) identify the cost of holding a unit of HQLA to be 0.68%, meaning that a bank makes a loss of EUR 0.68 on an HQLA holding worth EUR 100, which is fully financed with deposits.[7] They argue that the move from pre-crisis LCR levels to full compliance with the new Basel III standard (100% LCR) involves banks increasing their HQLA holdings by an amount worth 10% of total deposits.[8] In equilibrium, loan rates must increase following a negative shock to loan supply in order to restore banks' profitability at least partially. This is how the LCR exerts a negative impact on lending and economic activity.

[6]For the Norwegian banks, HQLA includes both government bonds and covered bonds.

[7]For the Norwegian banks, the cost of holding a unit of HQLA is calculated to be 0.46%.

[8]For the Norwegian banks, implementing an LCR of 100% is approximated by asking the bank to hold government bonds and covered bonds equal to 11.2% of deposits.

Table 5. Long-run impact of the implementation of a 100% LCR requirement (in percent)

	Expected benefits of regulation			Costs of regulation	Real macro variables			Financial macro variables
	Bank PD	Bailout cost as % of GDP	Bank debt funding cost spread over risk-free rate	Lending spread over bank debt fund. cost	GDP	Aggregate investment	Aggr. cons.	Total lending
Euro area 3D (cost approach)	0.00	0.00	0.00	0.06	-0.14	-0.31	-0.10	-0.73
Euro area de Bandt and Chahad	-0.68	-0.01	-0.61	0.20	0.27	0.28	0.87	1.94
Norway with NEMO (cost approach)	0.00	0.00	0.00	0.05	-0.04	-0.38	0.05	-0.40
United States with 3D (cost approach)	-0.30	0.00	-0.02	0.08	-0.04	-0.30	0.02	-0.50

Note: 3D-EA: Mendicino et al. (2020); 3D-US: Clerc et al. (2015) with US calibration; NEMO: Kockerols et al. (2021).

A key limitation of this exercise is that, in most of the cases, it only measures the costs of the LCR and not the benefits. One would need a richer framework with bank runs in order to quantify the benefits of liquidity regulations. Such a framework has been developed in the model by de Bandt and Chahad (2016), where the LCR requirement is explicitly modelled in a multi-asset framework, mimicking the actual regulation, which allows an assessment of the impact of liquidity regulation on the probability of runs.

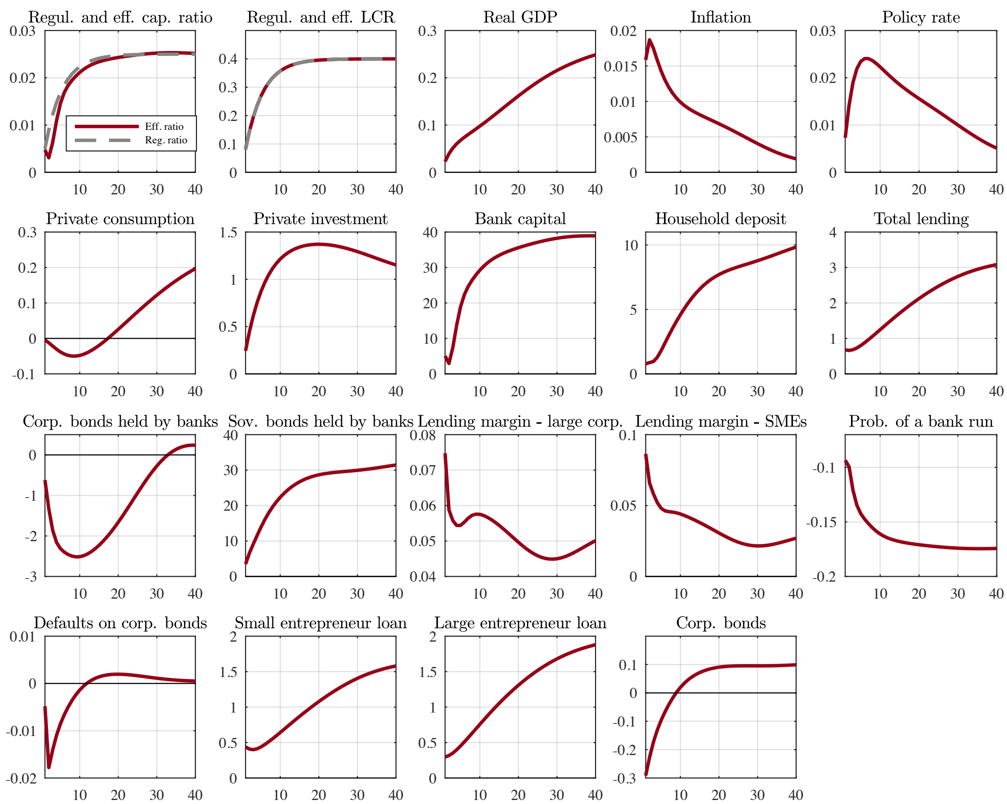
Table 5 shows the steady state impact of the LCR regulations. For the euro-area 3D model, the implementation of the LCR does not affect banks' probability of default (PD) and consequently bailout costs and private lending spreads are also unaffected.[9] As already discussed, the LCR regulation affects bank profitability negatively and, in a partial equilibrium setting, raises the default probabilities of banks. In general equilibrium, however, following a negative shock on loan supply, banks increase their lending rates. Thus, bank solvency does not suffer but as the fourth column of Table 5 shows,

[9]There is a very small increase in banks' PDs but this is less than 1 basis point and is rounded to zero in the table. In the transitional figures, a negative effect on bank solvency can be seen; however, it is extremely small.

lending spreads over bank funding costs increase by 6 basis points in the case of the LCR for the euro area with the 3D model, and 20 basis points with the model by de Bandt and Chahad (2016).

The higher cost of funding for borrowing firms and households reduces real economic activity by a moderate amount. The LCR reduces consumption by 0.1%, investment by 0.31% and GDP by 0.14% in the new steady state. Total lending falls by 0.73%. These relatively small costs should be set against the benefits of the regulatory measures. The model by de Bandt and Chahad (2016) is the only one that finds a small positive effect, due to a strong expectation channel associated with lower bank runs.

Figure 2. Impact of LCR implementation with the model by de Bandt and Chahad (2016) for the euro area (with regulated and effective capital ratios)



Note: This figure represents the dynamics of several macroeconomic and financial variables to an increase in LCR and capital ratio. The top left 2 charts exhibit the actual (or effective) ratios contrasted to the regulatory requirements. All variables are expressed as deviations from the initial steady state.

We end our analysis of the impact of the LCR by including the transitional dynamics from a world with no liquidity regulation to a world with full compliance with the LCR. The real costs of liquidity regulation are not very large mainly because the cost to banks of holding liquid assets or of funding with long-term (rather than short-term) debt is not very high. The cost of the LCR would rise significantly, for example, if the yield of HQLA fell further relative to that of deposits, increasing the cost to banks of holding HQLA.

When taking into account the expectation channel (where runs are anticipated to be less likely as a consequence of the regulation), the impact of the LCR becomes positive, with an increase in consumption, investment and lending (Figure 2). Banks hold more sovereign bonds and temporarily less corporate debt, but lending increases to both small and large banks.

3.4. **Covid-19-like scenario.** In order to contribute to the discussion on the resilience of the banking system to shocks like the Covid-19 lockdowns, we study an additional scenario with a real macroeconomic shock. There are different ways to consider such an environment characterised by both negative supply and demand shocks. The choice was made to implement a negative Total Factor Productivity (TFP) shock, associated with an increase in corporate defaults or a decrease in investment.[10]

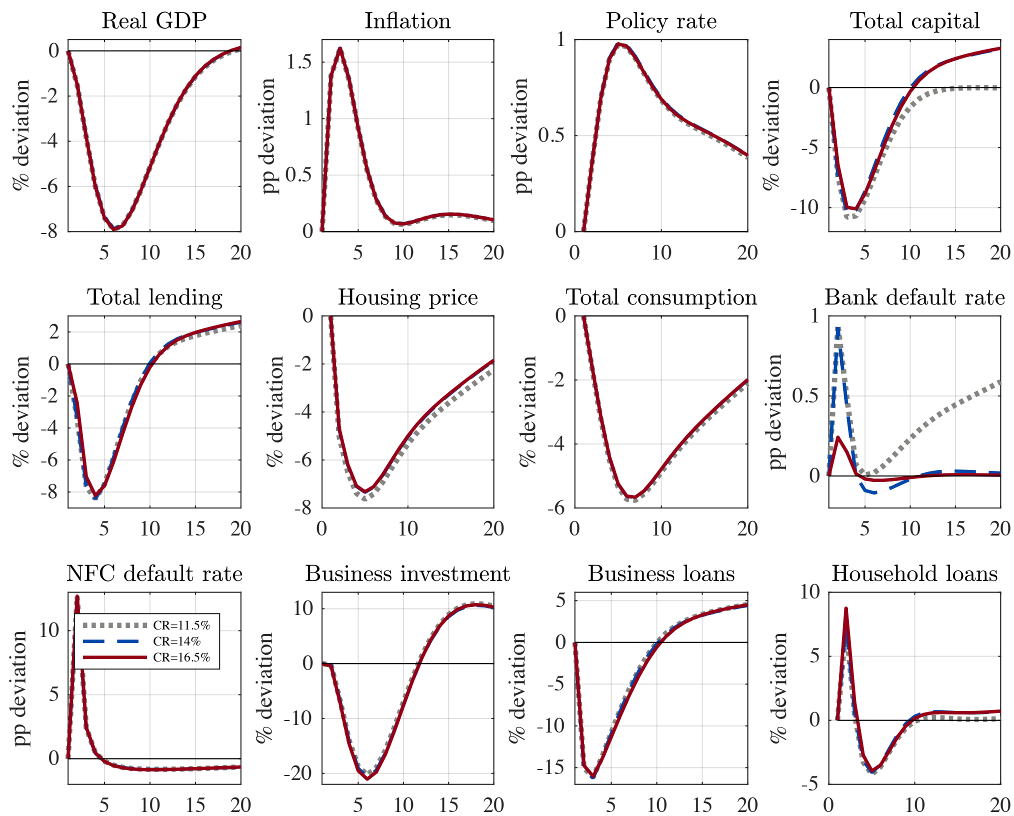
A Covid-19-like TFP shock reduces the level of bank capital, providing evidence that the extra capital accumulated through the Basel III process provides extra protection, while the other variables do not exhibit significant differences elsewhere. Indeed, the modelling of short-run dynamics is rather crude in the various models. We provide two examples: first, the impact simulated by the euro-area 3D model; and, second, the impact simulated by the Gerali et al. (2010) model. In these two examples, we compare the impact of the shocks under Basel II and III.

With the euro-area 3D model, the TFP shock, associated with a non-financial corporation (NFC) default rate increase, is a supply shock which leads to lower GDP and an increase in inflation which triggers a monetary policy reaction with a view to preventing second round effects on inflation. The

[10]Other types of shock, in particular regarding consumption, could also be considered. This would require expanding the demand side of these models, which usually have a more developed supply side.

persistence of the initial shock leads to a protracted negative effect on GDP. All scenarios lead to a decrease in total capital of 10% (only slightly more in the Basel II regime) but also to a steeper recovery for the Basel III regime than for Basel II (Figure 3). Since initial capital is higher in the Basel III scenario, it implies that the new regulations provide an additional capital buffer that proves useful following the Covid-19 crisis.

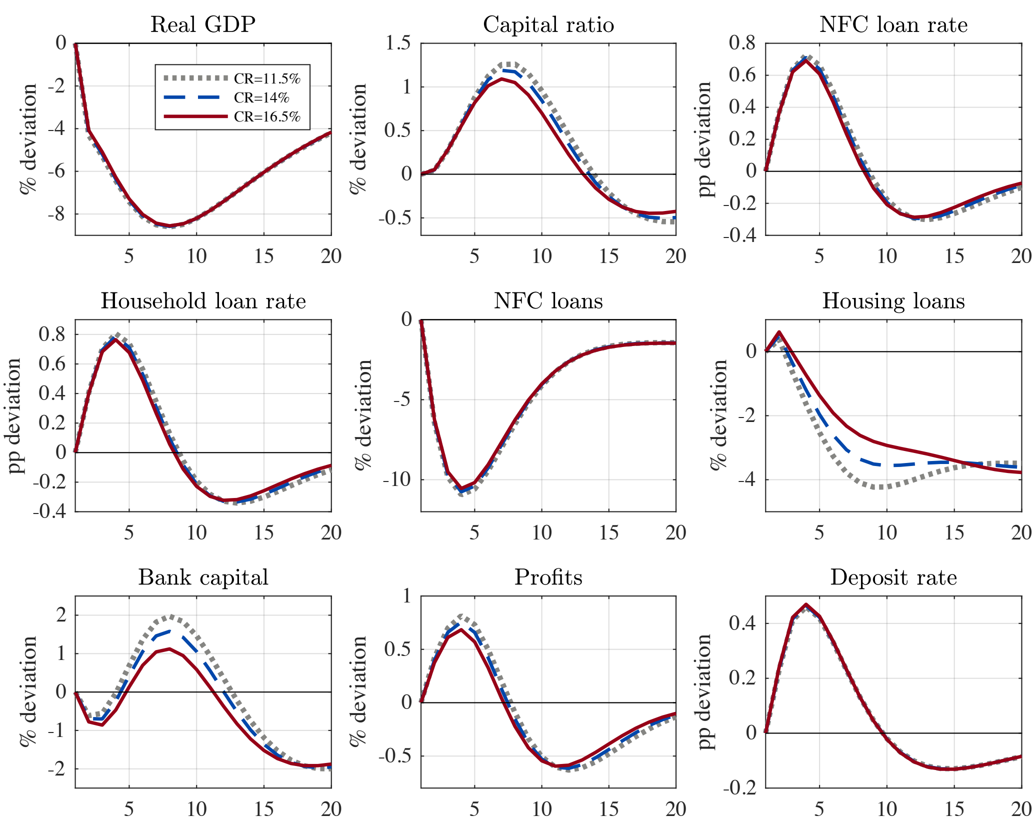
Figure 3. Impulse response function of an adverse TFP shock with an increase in non-financial corporation (NFC) default rate (euro-area 3D model)



Note: This figure shows the transitions following a -25% TFP shock and non-financial corporation default rate up to 15%. The different lines exhibit the euro-area response with different capital ratio (CR) levels. "3D model" refers to the model version used by Mendicino et al. (2020). All variables are expressed as deviations from the initial steady state.

A version of the Gerali et al. (2010) model calibrated to the euro area delivers similar results with a TFP shock (-14.4%) complemented by an additional shock to private investment (-27.6%). Such a calibration of shocks is designed to replicate a GDP drop of 8% one year after the shock arrives. TFP and investment shocks have opposite effects on inflation: the investment shock reduces the positive pressure on inflation caused by the TFP shock. Overall, this will trigger a smaller increase in the policy rate than under the TFP shock presented above with the 3D model. The collateral channel prevails, and lending falls. However, the benefits of Basel III are more visible for housing loans than for NFC loans. Indeed, the reduction in housing loans is more significant in Basel II than in the two Basel III scenarios, showing that the collateral channel is somewhat less strong when banks are better capitalized. In addition, banks exhibit a cyclical reaction: in the short run, the increase in lending rates positively affects profits and capital.

Figure 4. Impulse response function of adverse shocks to TFP and investment (euro area with Gerali et al. (2010) framework)



Note: This figure displays the impulse responses to TFP and investment shocks under different levels of CET1 ratios. The different lines exhibit the euro area response with different capital ratio (CR) levels. NFC: non-financial corporations. All variables are expressed as deviations from the initial steady state.

4. Conclusion

The analysis of channels of transmission of prudential regulation has highlighted the very large number and the variety of models that have been produced since the Global Financial Crisis. The conclusion of the harmonized simulations we run is that many models show that Basel III leads to an increase in GDP, although some models show some negative effects. The increase in GDP comes through an initial supply shock, which may translate into a demand shock as economic agents expect a decrease in banking instability.

However, the models only offer a partial assessment of the macroeconomic impact of the new regulatory environment. In particular, when assessing the effects of banking regulations, it is crucial to distinguish models that assess both costs and benefits (e.g., the 3D model and NEMO) from models that are used for assessing only costs (Gerali et al., 2010). A few limitations have been identified: the models are still quite stylized with only one capital variable, total capital; funding liquidity has only been incorporated in a basic way; and liquidity regulation is not fully integrated in most models.

One conclusion may be that there is no perfect model. Quantitative DSGE models basically focus on capital requirements, while empirical models lack micro-foundations, which is problematic for policy analysis. More complicated issues, such as interactions between multiple regulations, still depend on qualitative models. In addition, these models have only recently started to investigate additional policy issues and there is scope for further research regarding the role of shadow banking and the interaction between unconventional monetary policy and financial stability policy.

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