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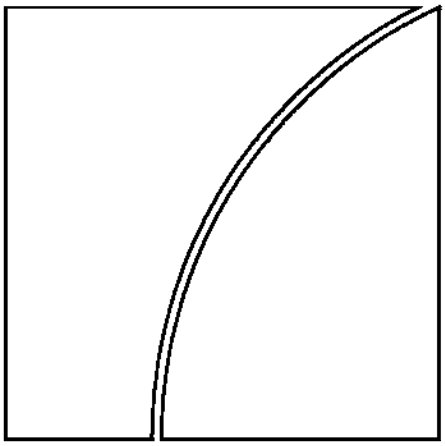

Models and tools for macroprudential analysis

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Mr Pierre-Francois Weber	Bank of France, Paris
Mr Andrew Willis	Secretariat of the Basel Committee on Banking Supervision, Bank for International Settlements, Basel

* Former member of the working group who prepared valuable inputs into the review before leaving the working group.

Prologue

The Research Task Force Transmission Channels Project

The Research Task Force Transmission Channel (RTF-TC) project was conceived before the onset of the recent global financial crisis. From the beginning, RTF-TC was intended to be a long-term project that would involve many RTF member institutions. The primary goal was to generate new research on various aspects of the credit channel linkages in the monetary transmission mechanism. Under the credit channel view, financial intermediaries play a critical role in the allocation of credit in the economy. They are the primary source of credit for consumers and businesses that do not have direct access to capital markets. Among more traditional macroeconomic modelling approaches, the credit view is unique in its emphasis on the health of the financial sector as a critically important determinant of the efficacy of monetary policy.

Subsequent to the start of the RTF-TC, the onset of the global financial crisis focused policymakers' attention on the health of the financial sector. While the RTF-TC did not anticipate the financial crisis, its work did progress as the financial crisis unfolded. Many of the research papers produced in this project made use of new data and insights gained from the work that many RTF member institutions undertook during the course of the financial crisis. Six workshops hosted by the Bank of Italy, by the Bank of France and the French Prudential Supervisory Authority, by the UK Financial Services Authority, by the Bank of Canada and the Canadian Office of the Superintendent of Financial Institutions, by the US Office of the Comptroller of the Currency, and by the Central Bank of Norway provided venues to present innovative research studies, but also, importantly, to receive feedback from RTF member institution colleagues.

The research papers and findings produced by the RTF-TC are in most cases preliminary and still undergoing revision and refinement. Still, RTF-TC research has produced many new insights and analysis that help us to better understand the linkages between the financial sector and real economy. The work of the RTF-TC included detailed econometric analysis of credit data from many RTF member countries, theoretical modelling contributions, dynamic stochastic general equilibrium calibration exercises and experiments, and the investigation of new analytical approaches for financial stability monitoring and systemic risk analysis. The results of these projects should help to inform macroprudential policy development.

The final products of the RTF-TC project are two working papers that summarise the findings of the many individual research projects that were undertaken and discussed in the course of the project. The first working paper, Basel Committee Working Paper No 20, "The policy implications of transmission channels between the financial system and the real economy", analyses the link between the real economy and the financial sector, and channels through which the financial system may transmit instability to the real economy. The second working paper, Basel Committee Working Paper No 21, "Models and tools for macroprudential analysis", focuses on the methodological progress and modelling advancements aimed at improving financial stability monitoring and the identification of systemic risk potential. Because both working papers are summaries, they touch only briefly on the results and methods of the individual research papers that were developed during the course of the project. Each working paper includes comprehensive references with information that will allow the interested reader to contact any of the individual authors and acquire the most up-to-date version of the research that was summarised in each of these working papers.

Paul Kupiec, FDIC and Chairman of the Basel Committee Research Task Force

Models and tools for macroprudential analysis

Introduction

The findings of the Research Task Force Transmission Channel (RTF-TC) project are reported in two summary papers. The role that the financial system played in transmitting instability to the real sector of the economy is examined in the first report of the RTF-TC (Basel Committee Working Paper No 20). This report focuses on the methodological progress and modelling advancements useful for improving the existing financial stability analytical framework – that is the framework to identify, assess and monitor systemic risk. Systemic risk is defined as the risk of disruptions in the provision of key financial services that can have serious consequences for the real economy.[1]

The RTF-TC contributing member institutions conducted new research that was presented at international workshops organised by the group. This research allowed the group to study the interactions between the financial system and the real economy and, more generally, those interactions that have the potential for producing systemic risk. The workshops facilitated communication among member institution researchers. In summarising the findings of the group, this report acknowledges the joint contribution of the members of the group and of all the other participants at the workshops (both authors and discussants). The Appendix lists the papers presented and the workshop participants. We caution that this document is not a comprehensive literature review, but reflects the specific contributions and insights of the RTF-TC members.

This summary of the RTF-TC's findings is organised into four sections. Section 1 discusses analytical methods used to measure the impact of macro-financial shocks on the real economy. This section includes studies that use dynamic stochastic general equilibrium models (Section 1.1) as well as studies that use more traditional macro stress testing methods (Section 1.2). Section 2 discusses developments in modelling financial sector liquidity risk including the potential for contagion. Section 3 discusses methods for measuring the potential for systemic risk. Section 4 summarises RTF-TC studies that quantify bank behavioural responses to changing central bank and macroprudential policies and macroeconomic conditions. Each section includes a summary of the remaining gaps in the literature.

1. What are the impacts of a macro-financial shock on the financial sector and the real economy? How should the transmission of a macro-financial shock on the banking sector, the macroeconomy, and the possible feedback between the two sectors be measured?

The recent global financial crisis highlighted some key features that need to be incorporated into operational macroprudential models. One feature models must take into account is the

[1] The methodologies and tools useful for financial stability analysis as they existed at the start of the work of the RTF-TC group are discussed in a literature review prepared by the group. See the Appendix of Basel Committee on Banking Supervision (2011a) for details. For a discussion of the key aspects of a general framework in the area of macroprudential analysis and policy tools see also Financial Stability Board et al (2011).

importance of the credit and maturity transformation mechanism that lies at the heart of banking. In normal times, banks fund themselves with short-term liquid contracts and invest in illiquid credit instruments with longer maturity duration. Financial sector shocks have the potential to disrupt the normal credit intermediation process and may result in a widespread curtailment of credit to bank dependent customers.

A second important modelling feature identified by the crisis is the ability to account for interdependencies (both linear and non-linear) among key financial and macroeconomic variables and for feedback effects between the financial and real sectors. Models should also account for the fact that, for a set of interconnected, highly leveraged financial institutions, systematic risk is likely to play a more important role than idiosyncratic risk.

These two modelling features, in addition to the lessons learned from the recent crisis, emphasised the need to build a model that can incorporate out-of-equilibrium dynamics, learning, herding behaviour, and contagion.[2] The RTF-TC research included studies using two different methods for macroprudential modelling that encompasses those aspects: dynamic stochastic general equilibrium (DSGE) models and traditional econometric macro stress testing models. DSGE models are computable general equilibrium models built from microeconomic-consistent foundations. These models are calibrated to mimic historical data patterns but are not estimated in the traditional econometric sense. While DSGE models can be designed to include interesting behavioural features in their representative agents, they do not generate time-series forecasts. DSGE models are instead designed to answer comparative static or "what if" exercises. In contrast, traditional macroprudential stress testing methods rely on reduced form econometric model specifications that are estimated using historical data. These models need not be linked to an underlying model of a rational optimising representative agent.

The ideal macro-financial model would incorporate features of both of these approaches, but the development of operational hybrid models is unlikely in the near term. Additionally, an important challenge is that this ideal model cannot be overly complex. Model results must be intuitive and their logic accessible for financial stability authorities to better understand the most important features of the transmission channels between the financial sector and the real economy during periods of extreme widespread stress. At present, there is no single "best" approach for macroprudential modelling; the approach must be tailored to the data available and to the question at hand.

1.1 Are dynamic stochastic general equilibrium (DSGE) models useful for understanding the channels of transmission of financial sector shocks? Can they be used to quantify the impact of a financial sector shock on the real economy? Can DSGE models help identify whether macro prudential regulations will attenuate or amplify a shock? How do monetary and macroprudential policies interact? Can DSGE models be used to optimise macro prudential regulation?

DSGE models are complex, non-linear systems of equations. Initially, DSGE models were developed in the Real Business Cycle literature. Enhanced DSGE models that included market imperfections and nominal rigidities were developed in the so-called New

[2] Methods for complex systems developed in other fields, such as physics, engineering, and biology, provide a new way to model the macroeconomic and financial sectors where non-linear feedback effects and collective behaviour play an important role. As such, these methods may hold great promise in allowing financial supervisory authorities and central banks to identify efficient approaches in pursuing their macroeconomic and financial stability goals.

Neoclassical Synthesis which created models in which monetary policy is no longer neutral in the short run.[3]

DSGE models have three distinguishing features. First, they are constructed from microeconomic foundations assuming rational forward-looking optimising behaviour of individual economic agents. Secondly, DSGE models are constructed to be internally-consistent with their assumptions and can capture the behavioural interactions between households, firms, and policymakers. As such, DSGE models assume the existence of a stable equilibrium and the risks in these models are purely exogenous shocks that drive the economy temporarily away from the steady state to which it dynamically converges according to the optimising behaviour of the different agents. Thirdly, typical DSGE methods cannot easily incorporate irrationality, inefficient markets, and the formation of asset price bubbles.

DSGE models can be used to analyse and understand the mechanisms through which exogenous shocks are transmitted to the real economy as the real economy adjusts towards a new equilibrium. In this capacity, DSGE models have been used to explain: (i) how macro variables react to aggregate shocks, either real (eg productivity, exogenous demand, etc) or monetary shocks, (ii) the transmission channels of different economic policies, and (iii) the role of different real and nominal rigidities that may be sources of the observed dynamics of the macroeconomy. In this context, systemic risk is represented by macroeconomic instability, which is originated either by a real or a financial exogenous shock, and is propagated through excessive lending and excessive GDP growth in booms, and vice versa in downturns.[4]

In the aftermath of the recent global financial crisis, DSGE models have been criticised for relying too heavily on the assumption of a perfectly competitive capital market. Indeed, under this assumption, the Modigliani-Miller (M-M) theorem holds, and models are incapable of capturing credit channel effects.[5] Because these models lacked a realistic financial sector, they were of little use during the crisis. In this section, we discuss RTF-TC research efforts to attempt to include an accurate financial sector into a DSGE framework and how this research has made DSGE models more useful in answering questions regarding financial sector shocks and regulation.

The original models of banking activities are too simplistic to use for policy analysis on the effects of capital regulation on credit intermediation.[6] RTF-TC studies have attempted to improve existing models by developing a stylised model of the banking sector that recognises financial frictions on the borrowing and lending side and thereby including a role for bank capital. Micro-founded financial frictions are modelled by assuming imperfect information between lenders (interbank market or depositors) and borrowers (financial intermediaries). Credit contracts in the funding market for banks are not perfect, due to the

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[3] See the Appendix of Basel Committee on Banking Supervision (2011a) for details.

[4] See also Angelini et al (2011), who observe that, given the currently agreed definition of systemic risk as the risk of disruptions in the provision of key financial services that can have serious consequences for the real economy, it is appropriate to assume that the authority is interested in minimising fluctuations in output.

[5] Basel Committee Working Paper No 20 discusses at length various credit channel effects that influence the monetary transmission mechanism.

[6] See Basel Committee on Banking Supervision (2011a). More recently, a new line of research reconciles finance, risk, and macroeconomic fluctuations within a structural framework. It shows that an exogenous increase in uncertainty that agents face when making their investment decisions, combined with financial frictions, can produce economic fluctuations that are observationally equivalent to those generated by traditional total factor productivity shocks (see Gilchrist et al, 2010).

possibility for banks to be impacted by shocks and the impossibility for their creditors to fully observe these shocks.[7] In some cases, the modelling approach allows for banks to default in equilibrium, as well.[8]

Once the model includes financial frictions, there is a natural economic role for bank capital. Several papers analyse how frictions in the financial sector can influence the bank balance sheet and endogenously create an optimal bank capital structure.[9] RTF-TC research uses bank capital to mitigate asymmetric information frictions between lenders and borrowers (financial intermediaries). This endogenous resolution of the agency problem results in constraints on banks' leverage ratios and implies that equilibrium credit flows will depend on the banks' equity positions. Any unexpected movement in asset prices – either endogenously, via demand for investment, or exogenously via a financial shock – will affect the banks' balance sheet and risk premium. The shock will endogenously alter the demand for bank capital to attenuate the risk premium and the set of feedbacks that augment the initial change in investment and asset prices. Banks' endogenous demand for capital also interacts with the interbank market in determining loan supply.[10] In these models, the introduction of a binding regulatory constraint has important implications for the dynamics of the macroeconomic variables, because a costly trade-off arises between equity issuance and a decrease in lending.[11]

With these enhancements, DSGE models are better able to address fundamental policy issues, such as the overall importance of financial sector shocks in explaining the business cycle and the role of monetary policy and/ or prudential regulation to avoid or mitigate financial crises. For example, one RTF-TC study shows that, in the presence of financial frictions, aggressive interest rate cuts are required to offset adverse financial shocks.[12] Another RTF-TC study uses an enhanced DSGE model to assess the interaction between monetary and macroprudential policies and the design of an optimal mix of these policies. A comparison of the effects of countercyclical capital requirements, maximum loan-to-value ratios, and maximum leverage ratios with traditional monetary policy instruments shows that countercyclical financial-sector regulation may prove useful in mitigating the business-cycle fluctuations in the aftermath of a technological or a monetary shock, but might as well have an amplification effect if the banks' capital unexpectedly drops.[13]

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7 This is the case, for example, in Hirakata et al (2009, 2011) and Dib (2010). An alternative setting has been presented by Antipa et al (2010), where financial frictions arise from the fact that banks do not internalise the effect of excessive lending on the aggregate probability of default. This feature allows for excess credit which amplifies shocks.

8 Antipa et al (2010).

9 Research unrelated to the RTF-TC group made some promising advances in this field. In particular, see Gertler and Karadi (2011), Gertler and Kiyotaky (2010), and Gertler et al (2011).

10 Dib (2010) and Christensen et al (2011).

11 For example, in Angelini et al (2010, 2011) and Darracq Pariès et al (2010), banks accumulate capital (out of retained profits), as they try to maintain a capital-to-asset ratio as close as possible to an (exogenously given) optimal level that can be interpreted as a mandatory capital requirement. In Kiley and Sim (2010), banks find it costly to adjust their dividend payout in the presence of a capital constraint. In Tomura (2010), liquidity mismatch in banks' balance sheets leads to endogenous bank capital requirements that are used in preventing bank runs.

12 De Fiore and Tristani (2009).

13 De Fiore and Tristani (2009), Angelini et al (2011), Antipa et al (2010), Christensen and Meh (forthcoming 2012), Christensen et al (2011).

Even though DSGE models cannot be used to examine the endogenous creation of bubbles, an RTF-TC study attempts to model how the economy is affected by the life cycle of bubbles. The results suggest that ownership of the over-valued asset is an important issue. The boom-bust cycle is strongly amplified when the asset experiencing the price bubble is held by banks, but the economy is much less affected if the bubble asset is held by unleveraged agents.[14] Such research may help develop early warning indicators of dangerous bubbles, discussed further in Section 3, and an evaluation of credit conditions that may produce such bubbles.

The findings of many of the RTF-TC DSGE studies are preliminary and subject to further refinement. The studies tend to each focus on a particular financial shock in isolation (eg a shock affecting borrowers' net worth, asset prices, or banks' capital). Depending on the type of financial shock considered, its consequences and the transmission mechanism can be very different. Second, and perhaps more fundamentally, the work of the RTF-TC group has highlighted a key issue that macroprudential analysts must resolve when using DSGE models for policy analysis: they must strike a balance between simplicity and transparency on the one hand, and reality and completeness on the other hand. Perhaps, the answer lies in the specific purpose for which the model is used in a given instance. In fact, when the focus is on the quantification of the impact of shocks and the role played by banking regulation, a rich framework is needed in order to incorporate meaningful behaviour of the financial system and feedback effects to the macroeconomy. Some of the research conducted by RTF-TC introduced a banking sector in a complicated manner which makes it difficult to fully understand the forces driving the interaction between the real and financial sectors. In contrast, if the aim is to understand the transmission channels between the real and the financial sectors, then simpler models appear to be more desirable.

While the DSGE model findings reported in this summary are informative, further research and analysis is required. Since DSGE models assume forward-looking rational expectations equilibria, they must be modified to include some type of market or information imperfection before they can accommodate fads, bubbles or the market pricing imperfections that should be considered when analysing financial stability. Since the root causes of investment fads and market inefficiencies remain a mystery for the most part, there are potentially many ways that these features might be introduced into DSGE models and in some cases there is little empirical basis for the mechanism used to generate the financial sector inefficiency.

More generally, such studies and the corresponding models, both theoretical and empirical, are but one input into regulatory (and monetary) policymaking, in conjunction with qualitative judgements and analysing trends in a broad range of data.

The RTF-TC group has also highlighted several directions for future research on DSGE models:

- Appropriately enhanced, models can potentially be used to help assess the interactions (and the possible trade-offs) between macroprudential, monetary and fiscal policies, since all policies have a bearing on financial stability.[15]
- There is a need for a formal normative (welfare) analysis. What are the costs of a macroprudential policy (eg increased bank capital requirements) and how are they distributed among different agents? Can we compare the transition costs with the

[14] Aoki and Nikolov (2010).

[15] For a discussion on this topic, see Galati and Moessner (2011).

potential benefits in terms of decreased swings in the business cycle? Do we need to consider the accompanying fiscal policy?

- The very nature of financial intermediation is to assume financial risk due to balance sheet mismatch between assets and liabilities. The research of the RTF-TC group has modified and created models to incorporate a more accurate picture of the financial sector. However, maturity mismatch and the effects of market valuation on assets still need to be satisfactorily incorporated, especially since they represent an important aspect of the recent financial crisis.[16] More generally, future research needs to focus on endogenising the systemic-risk exposures of banks.[17]
- DSGE models can be useful for understanding the bank capital channel, but they are limited by their solution method. DSGE models equilibria are approximated around the model's steady state and such solutions may become inaccurate when considering large deviations from the steady path. These models also require a unique equilibrium and thereby cannot encompass models with multiple equilibria that allow movements between equilibria. It is an open issue whether local solution methods are useful for studying financial (in)stability and whether they are capable of producing reliable quantitative information in case of financial turmoil.
- Disaggregated models of the economy that include different degrees of borrower riskiness could help address questions such as: At any given moment, which sectors are at risk? How interdependent are the sectors (in other words, what is the correlation among sectors)? By contrast, current DSGE models only consider the net worth of the borrowers independently of the sector to which the borrowers belong and individual risks they might face. Several research papers of the RTF-TC group represent early attempts at including sectoral diversification and matching different degrees of riskiness in capital requirements.[18] More generally, there are a number of features that could potentially be useful to add to DSGE models (diversity of entities in the system and their interactions, risk appetite and expectations) that could help policymakers understand complex quantitative questions. Still, more research is needed in this area.

1.2 How can traditional macro stress testing models (those using a suite-of-models approach) be improved to better measure the transmission and the lasting effects of a macro-financial shock?

Macro stress testing refers to a range of analytical models and tools that are used by central banks and supervisory agencies to assess financial sector vulnerabilities to severe but plausible scenarios of widespread exogenous shocks. For many central banks and supervisors, the practice of macro stress testing was introduced as part of the Financial Sector Assessment Programs conducted by the IMF and the World Bank. As such, macro stress tests can provide valuable information on the potential negative effects on the financial sector that are imposed by severe real sector shocks, and thus help policymakers assess the soundness of the financial system. Ideally, macro stress tests could allow bank supervisors to identify institutions whose current financial condition poses risks under alternative macroeconomic scenarios.

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[16] Tomura (2010).

[17] For example, along the lines of Martinez-Miera and Suarez (2010).

[18] Angelini et al (2010, 2011) and Tomura (2010).

Central banks and supervisors typically use a suite of models and tools in a multi-stage process to conduct macro stress testing of credit risk.[19] The first stage involves projecting the dynamic paths of key macroeconomic indicators (such as GDP, interest rates, and house prices) under a certain stress scenario. The projections normally use some combination of structural macroeconometric models, VAR models and vector error correction models, or some other statistical approach. In the second stage, a credit risk satellite model is estimated using either loan performance data (such as non-performing loans, loan loss provisions, or historical default rates) or micro-level data related to the default risk of the household and/or corporate sector. The satellite or auxiliary model is then used to link a measure of credit risk to the variables from the macroeconomic model and to map the external macroeconomic shocks to a bank's asset quality shocks.[20] Finally, the last stage involves estimating the impact of the asset quality shocks on a bank's earnings and/or capital. One of the main limitations of traditional stress testing is that the satellite models that are used treat the macroeconomic variables as exogenous and ignore the feedback effects from a situation of distress in the banking system to the macroeconomy.

In conducting macro stress tests, the statistical relationship between macroeconomic variables and indicators of the banks' financial condition can change dramatically under stressed conditions. Therefore, if the focus is only on the conditional mean of a risk measure (as is typical of a traditional stress testing exercise), it can be an inadequate approach in assessing the impact of an aggregate shock. During periods of extreme stress, it is especially important to focus on unexpected losses in order to assess the tails of the loss distributions. The research of the RTF-TC group focused on the quantile regression (QR) method to address this issue.[21] The QR approach focuses on the tail events of conditional risk indicator distributions. It allows for the possibility of extreme events leading to changes in the statistical relationships between the risk indicators and macroeconomic variables across the quantiles of the distribution of a given stress indicator and by doing so, provides a more complete picture of covariate effects. For example, a covariates relationship with a stress factor can differ substantially at lower and upper quantiles of a dependent variable compared to its relationship at its mean or median values.[22] See Box 1 for a more complete explanation of QR.

RTF-TC research showed that the QR approach is robust to extreme events and can also be used to construct density estimates and forecasts of real activity and financial stress and expected shortfall measures of systemic real risk and systemic financial risk.[23] The QR approach produced more conservative results when compared with other approaches to modelling the macro-credit risk link.[24] The method is very flexible and could have a variety of

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[19] See the literature review prepared by the RTF-TC study group (Basel Committee on Banking Supervision (2011a)) and Foglia (2009), for an extensive discussion.

[20] Both the structural econometric and the VAR approaches typically do not include a measure of credit risk. Hence, they require satellite (or auxiliary) models to map macroeconomic variables into indicators that can be used to transmit the macroeconomic scenario to banks' balance sheets, ie, mapping external shocks to banks' asset quality shocks.

[21] De Nicolo and Luchetta (2010) and Schechtman and Gaglianone (2011).

[22] See Koenker and Hallock (2001) for a detailed discussion of quantile regression. Also, see Jones (2010), in work unrelated to that of the RTF-TC group, who provides an example of using quantile regressions to analyse the determinants of changes in thrifts' net interest margins. The CoVaR measure developed by Adrian and Brunnermeier (2010) is also based on the quantile regression approach.

[23] De Nicolo and Lucchetta (2010).

[24] Schechtman and Gaglianone (2011) conduct a macro stress test of system-wide credit risk in Brazil with a special focus on the tails of the credit risk distributions conditional on adverse macroeconomic scenarios. They found that the QR approach to modelling the macro credit risk produces more conservative results than the Wilson (1997) stress testing approach. The comparison is made on the vertical distances between the tails of the distressed and non-distressed credit risk distributions.

additional applications in the area of stress testing, such as forecasting interest income, fee income, profits, or loan loss provisions; or on probability of default (PD) estimates and loss-given-default (LGD) estimates which influence risk-weighted assets and capital adequacy ratios.

Box 1: Quantile regression

Ordinary least-squares (OLS) models the relationship between one or more covariates X and the conditional mean of a response variable (Y) given X = x. Quantile regression, first introduced by Koenker and Bassett (1978), models the relationship between X and the conditional quantiles of Y given X = x. QR is especially useful in applications where extremes in the response variable are important, because it allows the rate of change in the conditional distribution, measured by the regression coefficients, to depend on the quantile. As such, it provides a more complete assessment of the conditional distribution of Y given X = x when lower, upper, or all quantiles of the conditional distribution are of interest. QR makes no distributional assumption about the error term in the model. In contrast, OLS assumes that the covariates affect only the location of the conditional distribution of the response variable, and not its scale or any other feature of its distributional shape, such as skewness or long tails, and typically imposes a Gaussian distributional assumption about the error term in the model.(*)

QR generalises the univariate quantile concept to a conditional quantile given one or more covariates. For a random variable Y with probability distribution function

$$F(y) = Prob(Y \leq y),$$

the τ-th quantile of Y is defined as the inverse function

$$Q(\tau) = inf\{y : F(y) \geq \tau\},$$

where $0 < \tau < 1$. The median of Y is Q(1/2).

For a random sample $\{y_1, \ldots, y_n\}$ of Y, it is well known that the sample mean, which minimises the sum of squared errors, can be extended to the linear conditional mean function $E(Y \mid X = x) = x' \beta$ by solving

$$b = \operatorname{argmin}_{\beta \in R^p} \Sigma_i (y_i - x' \beta)^2, \; i = 1, \ldots, n.$$

Similarly, the general τ-th sample quantile, which minimises the sum of the asymmetric absolute errors, can be extended to the linear conditional quantile function $Q(\tau \mid X = x) = x' \beta(\tau)$ by solving

$$b(\tau) = \operatorname{argmin}_{\beta \in R^p} \Sigma_i \rho_\tau (y_i - x' \beta), \; i = 1, \ldots, n,$$

for any quantile $\tau \in (0,1)$ and where $\rho_\tau(\cdot)$ denotes the asymmetric absolute loss error function given by

$$L(e) = (1 - \tau) |e| \text{ if } e < 0$$

$$L(e) = \tau |e|, \text{ if } e \geq 0$$

where e denotes the error term.

The b(τ) denotes the τ-th regression quantile. The case where τ = ½, which minimises the sum of absolute errors, corresponds to median regression, which is also referred to as L_1 regression.

(*) See Koenker and Hallock (2001) for applications in economics and finance, including value-at-risk, risk management, and asset pricing. See also Chen (2005) for a technical discussion.

Recent stress testing exercises (eg the EU-wide stress test conducted in 2010 and the US SCAP exercise) typically use a stress time horizon of up to two years. The IMF and market participants are increasingly demanding stress testing exercises covering a longer stress time horizon (eg a period of five years). Over extended horizons, bank earnings can offset stress scenario losses which make it important to forecast the impact of stressed scenarios on banks' interest margins as well as on a bank's credit losses.

The RTF-TC research group also examined the importance of the type of data, aggregated versus granular, that should be used when conducting stress tests. They found that the use of more granular data may have advantages over aggregate data.[25] Stress tests that use only aggregate data must assume that the quality of all financial institutions' risk exposures in the financial sector are the same, despite the fact that some institutions might pursue riskier strategies and use very different business models. In current macro stress testing models, contagion effects are not explicitly modelled. Moreover, the modelling of these effects would require the use of granular data. Generally, it is likely that granular data is required for any realistic model of feedback effects both within the financial sector and from the financial sector to the real economy. One RTF-TC study shows that the use of highly granular exposure data is advantageous in conducting macro stress tests. The results of the macro stress tests differ when they are based on highly granular lending data (eg banks' own PD and LGD estimates for each exposure) compared to sector-averaged lending data.[26] However, another RTF-TC paper found that stress test results were robust in both cases of using either aggregate or granular data.[27]

Traditional macro stress testing approaches are rarely integrated in the sense that they model market, credit and liquidity risk using a consistent framework. Most stress tests focus on the profitability and solvency resilience of the banking system to macro shocks affecting (mostly) credit risk at banking institutions. In some applications, market risk shocks or the impact of funding problems on funding costs is added to the overall macro scenarios. Often these are not firm-wide stress test exercises in the sense that the credit, market, and liquidity risks are not consistently modelled. The RTF-TC made some progress in integrating liquidity risk into stress testing scenarios. Such models are discussed in further detail in Section 2.

The focus of traditional macro stress testing has been on borrower default, and has largely ignored less severe deterioration in borrower balance sheets even though such deterioration may result in a downgrade in a borrower's credit rating (credit migration). RTF-TC research addressed this limitation and accounted for both default risk and migration risk in its

[25] Bolt et al (2010), Coffinet et al (2009), Duellmann and Kick (2010), and van den End and Tabbae (2010).

[26] Duellmann and Kick (2010) examine the effect of a global credit crunch on the credit portfolios of 24 large German banks. The quantitative framework integrates the macro-perspective of the economy and the micro-perspective of the individual bank using a two-stage approach, accounting for default risk and migration risk after the first year and multi-sector stress.

[27] Bolt et al (2010).

analysis.[28] The results suggest credit losses could be substantially understated by analyses that only account for defaults.

The realistic modelling of feedback effects is one issue that the RTF-TC study group's current research did not manage to address in a satisfactory manner (see the discussion in the remaining gaps section below). The group looked at possible ways to incorporate feedback effects in the design of the macro scenarios. Currently, there is no agreement on what the accurate representation of the macroeconomic state-space should be in terms of, for example, the granularity of the data and the appropriate balance between macroeconomic and financial variables. Additionally, achieving an appropriate balance between the severity and likelihood of an exogenous, aggregate shock is also very difficult. One RTF-TC study which focuses on this issue obtains consistent macro scenarios by using a macroeconometric model that contains two financial accelerator mechanisms. This approach has advantages over DSGE models in that it is possible to directly shock the observed variables of interest (eg GDP, interest rate spreads, etc) that are used by the financial stability authorities for story telling when creating a stress scenario.[29]

RTF-TC research also examined the effects of macroeconomic and financial shocks on the three main subcomponents of a banks' income, namely net interest margin, fees and commissions, and trading income.[30] The results suggest that when conducting a macro stress test of banks' profitability during deep recessions, there is a much larger impact of output growth on bank profitability than commonly recognised in the literature.[31]

In sum, the stress testing research of the RTF-TC group made important methodological advancements in several areas. First, the quantile regression (QR) method was used in several papers to address the fact that, during periods of extreme stress, it is especially important to focus on unexpected losses in assessing the tails of the loss distributions. Second, research presented indicates that the use of more granular data can have advantages over the use of aggregate data in conducting macro stress tests. Third, while the attention of macro stress testing models has been on credit risk in the past, the recent global financial crisis has underscored the importance of looking at other risks, especially liquidity risk, and several papers addressed the issue of how credible stress tests of liquidity risk could be conducted. Fourth, the group considered the importance of credit migration as a source of stress loss and found that ignoring this effect will understate stress scenario losses. Fifth, some research extended stress test modelling to incorporate banks' income and profits. Finally, some recent research showed that when allowing for asymmetry (nonlinearity) in the co-movement of bank profits with economic activity during deep recessions, there is a much larger impact of output growth on bank profitability than commonly found in the literature.

There are several gaps that remain to be adequately addressed in the use of macro stress testing models.

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[28] Duellmann and Kick (2010).

[29] Hammersland and Traee (2010).

[30] Coffinet et al (2009) found, for a panel data set of French banks over the period 1993–2007, that fees and commissions and to a lesser extent trading income are much more sensitive to some adverse macroeconomic shocks than interest income.

[31] Bolt et al (2010). Existing empirical studies typically find only small effects of real output on bank profitability because they only consider a symmetric response of bank's profits to changes in economic activity during expansions and contractions. However, Bolt et al find that the effects are much larger when allowance is made for asymmetric effects through the business cycle. They show that the procyclicality of bank profits is stronger for deep recessions than for mild ones.

- First, and most important, the group notes the difficulty of realistically modelling feedback and contagion effects both within the financial sector and especially from the financial sector to the real economy.[32]
- Second, while RTF-TC research attempted to allow for asymmetry in the co-movement of bank profit with economic activity during deep recessions, more work needs to be done on capturing nonlinearities and structural instabilities in the statistical relationships among financial variables, macroeconomic variables, and financial health indicators.
- Third, more effort should be devoted to expand the risk types covered by macro stress tests and also to capture the effects of stress scenarios on off-balance sheet positions. In doing this, stress tests should attempt to capture the important interactions between different risk types, as these effects can involve compounding or magnifying effects.
- Fourth, macro stress test models typically only focus on banking institutions and ignore other types of financial institutions completely, such as those included in the non-banking financial sector. For some countries, inclusion of activities outside the regulated banking sector may be important when modelling the transmission of shocks both within the financial sector and from the financial sector to the real economy.

2. What is the impact of adverse liquidity shocks on the financial sector? How are they transmitted within the financial sector and to the real economy? What type of market environment is conducive to the creation of liquidity spirals?

The recent global financial crisis revealed the importance of the liquidity channel in determining both the ability and willingness of banks to extend credit and thereby affect the real sector. It has shown that financial frictions, high leverage ratios, large maturity mismatches in banks' balance sheets, the interaction between market and funding liquidity, and mark to market accounting are key elements in the propagation of liquidity shocks to the real sector. One clear lesson from the crisis is that financial stability authorities must assign much more importance to the systemic dimensions of liquidity risk in the future, drawing attention to important deficiencies in the standard toolkit in capturing financial instabilities.

Macroeconomic models developed before the global financial crisis demonstrated how asymmetric information, incomplete markets, and moral hazard could amplify business cycles and showed that the existence of collateralised borrowing could amplify shock propagation. While seminal, however, this work did not capture important aspects of the recent crisis, such as the interactions between market and funding liquidity risks, the role of the interbank market, or the international dimension of the crisis. This has led to the emergence of new contributions in the area of DSGE models that have been extended to capture important aspects of the crisis.

[32] De Graeve et al (2008) account for feedback effects from the financial sector to the real economy, by using a bank rating model that measures the probability of distress at the bank level and integrates this into a macroeconomic VAR model.

The research of the RTF-TC group that specifically looked at general equilibrium models with a liquidity channel can be classified along two lines. The first line builds upon the earlier developments and views the recent financial crisis in terms of an amplification mechanism whereby shocks impact the economy and, once in a while, the impacts of the shocks are unusually large. In this model, a crisis is a large shock or a shock with a large impact. In contrast, the second line of research considers financial crises as regime switches that reflect a dramatic change in agents' beliefs or the way in which the financial system operates.[33]

The first line of research is documented by two related modelling efforts that attempt to capture the importance of liquidity risk in the crisis. A substantial part of the recent turbulence played out in the financial sector through the complete freezing up of key wholesale financial markets, such as the interbank market and the asset-backed commercial paper market. To capture these effects, RTF-TC research included a DSGE model with a financial accelerator and financial frictions in the interbank market, composed of savers (with a large deposit base) and lending banks. Financial frictions were found to amplify and propagate the effects of exogenous technological shocks and financial intermediation shocks.[34]

Another aspect of bank liquidity is related to leverage and maturity mismatches. Very high leverage ratios combined with increased maturity mismatches in banks' balance sheets paved the way for liquidity spirals, which acted as a crucial amplification mechanism during the recent crisis. Liquidity spirals have the potential to exacerbate small equity losses, especially when the financial institutions hit by a shock are highly leveraged; their balance sheet maturity mismatch is large; and the amount of funds they are able to leverage on the market to meet margin requirements is sensitive to changes in asset prices. To capture these effects, RTF-TC studies included DSGE models where fluctuations in margin requirements over the business cycle play a crucial role.[35] Margin requirements are used as a disciplinary device to prevent bank runs when short-term debtors have limited information about the banks' asset quality. Bank runs are more likely and therefore, creditors require higher margins, when banks' equity falls in value during economic downturns. Moreover, one of the implications is that countercyclical capital regulation is not useful when the origin of a financial crisis involves a liquidity shock. Additionally, RTF-TC research investigated interrelationships between bank capital, the liquidity of bank assets, and the maturity mismatch in the banks' balance sheets. Illiquidity can arise from asymmetric information about asset quality. Therefore, in order to circumvent this financial friction, banks pool assets and issue liquid liabilities backed by the pooled assets in addition to increasing their capital holdings. The asymmetric information friction creates endogenous links between the dynamics of asset prices, asset market liquidity, and the capital required to prevent bank runs.[36]

A second line of RTF-TC inquiry focuses on regime shifts. One of the most striking features of the recent crisis was the sudden and complete freezing up of liquidity (ie liquidity black

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[33] The view that financial markets switched from one regime to another runs counter to the view that the recent financial crisis was triggered by a large exogenous shock, amplified by imperfect financial markets. It relies on the notion that agents' beliefs are self-fulfilling and reverse rapidly following the arrival of news or a change in economic fundamentals.

[34] Dib (2010).

[35] Tomura (2010).

[36] Tomura (2010).

holes) in key markets and the role that global financial imbalances played.[37] The sudden change in these markets was so remarkable that it resembles a model with two possible equilibria: one close to the perfectly competitive market and the other akin to Akerlof's adverse selection market, characterised by an absence of trade. RTF-TC research in this area focused on the international transmission of business cycles and how it is affected when leveraged investors are holding cross-border assets. This work focuses on: (i) the link between cross-border, intrabank transactions (ie lending between parent banks and their foreign branches and/or subsidiaries) and international financial crises; and (ii) the international transmission of business cycles. This issue of global imbalances was examined in a general equilibrium model where an interbank market improves the allocation of liquidity worldwide (both within the banking sector and from the banking sector to the real sector), but may also be subject to market runs.[38] This work suggests that excessive liquidity (eg capital inflows that often follow the financial integration of financially under-developed countries with large savings) can make the financial systems more fragile in the run up to the crisis. Overall, the RTF-TC findings show that foreign exposure through the interconnected balance sheets of leveraged investors can be a powerful propagation mechanism across countries.[39]

In addition to general equilibrium models, the RTF-TC also analysed other modelling tools that could help financial stability supervisors address the systemic dimension of liquidity risk. This analysis, discussed in Section 3, includes the so-called early warning models and the models of cascading defaults due to the network of interbank exposures.

In regard to early warning models – those that can be used to predict a financial crisis – RTF-TC research showed that these methods can be improved when the capital, asset, and liquidity positions of banks are explicitly taken into account. When the role of capital and liquidity is explicitly captured, the evidence shows that capital and liquidity are imperfect substitutes in a crisis; and, on top of the liquidity on the asset side of the banks' balance sheet, liability-side liquidity has a statistically significant predictive power for a potential financial crisis a few years ahead.[40]

Although interbank network analysis was well-developed before the crisis, it generally has little potential for evaluating systemic risk since interbank exposures and bank PDs are often

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[37] An important trigger of the recent crisis was the run on the liabilities of certain financial entities, such as special purpose vehicles and structured investment vehicles, which financed their holdings of long-term assets with short-term asset-backed commercial paper (largely denominated in US dollars). Most of the riskier entities were sponsored by large European banks, which provided them with backup liquidity facilities. As these entities became unable to roll over their outstanding commercial paper (largely denominated in US dollars) in August of 2007, they tapped into the backup lines of credit provided by their sponsors. In turn, the sponsoring banks had to seek additional funding in the interbank and other money markets. European banks with branches in the United States accessed the US money markets to satisfy their loan commitments, thereby causing sudden large-scale disruptions in these markets.

[38] Boissay (2010) develops a model with two possible states of the economy: a normal state, which is characterised by a deep wholesale financial market and highly leveraged financial institutions, and a crisis state, which is associated with a bank market run, which takes the form of a sudden increase in margin requirements and liquidity hoarding by banks' creditors. Bank runs are triggered by changes in creditors' beliefs about the riskiness of banks' asset portfolios, and are more likely to occur when banks start investing in lower-grade projects. This happens when savings are so abundant that all prime investment opportunities have been exhausted and banks start financing the credit demands of subprime borrowers.

[39] Correa et al (2011) and Dedola and Lombardo (2009). Correa et al use a two-country DSGE model with a local and a global bank in each country. In their model, the local bank raises domestic deposits and issues loans to domestic firms; whereas, the global bank, in addition to its domestic operations, also raises deposits from foreign households and issues loans to foreign firms, thereby having the ability to fund domestic loans with foreign deposits.

[40] Kato et al (2010).

small.[41] In order to address systemic liquidity risk, the group examined modelling enhancements that add market-wide bank runs and account for the fact that, during the crisis, funding liquidity risk arose endogenously from the interaction between market liquidity risk, maturity mismatch, and solvency risk.[42] This class of models can be used for various purposes, in particular for simulating the impact of a macro shock. By accounting for the network effect and the liquidity risk, it changes the assessment of the overall risk of the banking system following a shock. Since banks do not internalise the potential network effects, these models show that interbank exposures make runs more likely. Also, the risk of a bank facing a run increases with its maturity mismatch and diminishes with its short-term liquid assets, both of which determine a bank's capacity to resist and fend off potential runners.

Research conducted by the RTF-TC group on systemic liquidity risk suggests that higher, countercyclical capital, more liquid assets, and fewer short-term liabilities generate lower systemic risk in the financial system. In addition, it suggests that Basel III's regulatory requirements work to smooth business cycles and responses of the economy to exogenous shocks and reduce the probability of regime switches. However, research also shows the importance of accounting for the joint effects of the various regulatory requirements (notably of the capital and liquidity ratios) rather than examining each separately. In particular, RTF-TC research showed that capital has a decreasing marginal effect on systemic risk; the positive relation between systemic risk and short-term liabilities is much steeper at lower levels of liquid assets; and the negative relation between systemic risk and holdings of liquid assets is most significant at higher levels of short-term liabilities. Consequently, a regulatory framework that properly controls for systemic risk should consider capital, liquid asset holdings, and short-term liabilities in a holistic way. Treating any of them in isolation produces a misleading assessment of systemic risk and hence impairs the effectiveness of the new Basel III regulatory requirements.

In sum, the liquidity channel research presented at the RTF-TC workshops made important methodological advancements in several areas. First, attempts were made to model the sudden and complete drying up of liquidity in wholesale funding markets. Second, the issues of how funding liquidity risk can arise endogenously from the interaction between market liquidity risk, maturity mismatch, and solvency risk, and the link between global imbalances and financial fragility were addressed. Third, the important role that cross-border funding activities played in the crisis and the international transmission of business cycles was examined.

However, there are several gaps that remain for future work.

- First, work that addresses the shadow banking sector and the role it played in the recent crisis needs to be done. So far, work has focused on the banking sector, but other financial institutions such as money market mutual funds played an integral role in the drying up of liquidity in key markets during the recent crisis.
- Second, models of bank runs are still rudimentary and should be made more realistic.

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[41] An important reason for this finding is that the traditional network models downplayed the commonality of bank exposures. When banks are exposed to common or similar exogenous shocks, then their balance sheets tend to be weak (symmetrically, strong) at the same time. This was missed by the traditional model, which assumed low correlation of exogenous shocks across banks (see also discussion in Section 3).

[42] Gauthier, He and Soussi (2010).

- Third, more work is needed to address maturity mismatch between assets and liabilities and the maturity structure of liabilities on banks' balance sheets.
- Fourth, the link between global financial imbalances (capital flows) and financial fragility should be explored further.
- Finally, work should be conducted that incorporates contagion effects in funding markets.

3. How likely is a systemic shock? What is the probability that systemic vulnerabilities will be exposed in the near future? How is this probability affected by real sector developments?

Financial stability authorities have a mandate to oversee systemic risk, that is, the risk of experiencing an economy-wide shock that may impair the functioning of the financial system which in turn may cause further disruptions in the real economy. An event in which such a scenario plays out is often referred to as a systemic event. To successfully discharge this mandate, authorities must have a method for identifying systemic events as well as their likelihood and the associated consequences on the financial sector and the real economy. This means that financial stability supervisors and regulators need to form an *ex ante* view of the level of risk in the financial system that combines the probability aspect (ie how likely is a systemic event?) with the impact aspect (ie what is the expected magnitude of financial and real-economy losses in such an event?).

Currently, there is no widely accepted model for comprehensively measuring systemic risk. Instead, researchers have tended to use a wide range of models and methodologies to examine one or a few specific aspects of systemic risk. This heterogeneity is also reflected in the work of the RTF-TC group. The common denominator is that the health of the banking sector is critical for financial stability and therefore, systemic risk is consequently associated with an elevated likelihood that banks' capital and/or liquidity positions will deteriorate in the future.[43] Conditional on this premise, the analyses differ along various dimensions, including motivation (eg empirical vs theoretical justification) and coverage (eg individual banks vs financial sector vs whole economy).

Traditional macro stress testing exercises, discussed in Section 1.2, are typically concerned with impact assessment. In contrast, this section focuses on the probability that the financial sector will show signs of severe distress in the future and whether this likelihood is affected by changes in the real sector. These RTF-TC studies contribute to the literature on indicators for early detection of systemic risk. The section ends with a presentation of first attempts at joint modelling of both the probability and the impact aspect. Models and methods are broadly ranked by increasing complexity and the ability to capture interactions within the financial sector and between the financial sector and the real sector.

A first approach to measuring systemic risk consists of "early warning" systems, namely simple indicators based on aggregate data, such as the ratio of credit to GDP, or key asset

[43] The role of non-bank financial institutions is almost universally ignored. A partial exception is Carlson et al (2011) who calculate a distance-to-default indicator including both commercial banks and investment banks. This appears to be one of the most serious gaps in the literature and the RTF-TC studies offer little improvement.

prices, such as housing, commercial real estate, and equity price indices.[44] These indicators are typically calculated by examining the deviations of these variables from their long-run trends. Large deviations are interpreted as evidence that underlying financial market developments are not sustainable and potentially subject to sharp reversals. In general, these indicators provide helpful warning signals of financial stress, as they capture the most systematic and general signs of the build-up of vulnerabilities across sectors, countries and policy regimes. But their lack of specificity means that such indicators can serve only as the starting point for a fuller analysis. As such, although these indicators are extremely popular, there are some concerns regarding their reliability in out-of-sample forecasting. These concerns were addressed in some research examined by the RTF-TC group. One study provides new cross-country evidence on the empirical performance of equity, house price, and credit indicators in predicting macroeconomic outcomes and further casts doubt on the usefulness of these indicators.[45]

A different type of indicator that was examined supplements aggregate data with sector- or institution-specific information (ie asset prices, such as banks' equity valuations, or balance-sheet data, such as banks' capital/liquidity positions). This method was employed by several RTF-TC papers which developed systemic risk indicators based on distance-to-default measures using asset prices.[46] An advantage of this type of indicator is that they are based on readily available real-time data. The indicators can be constructed at various levels of granularity (eg using bank- or country-level data) and then aggregated using simple statistics (eg the mean or median) to construct a single measure of systemic risk.

In a similar manner, another RTF-TC paper uses monthly bank-specific, balance-sheet data to construct aggregate time-varying indicators of banks' responses to the liquidity shocks observed during the recent global financial crisis.[47] Using micro data, the cross-sectional dimension of banks' responses (measured by the correlation across exposures) was analysed, as well as the time dimension (measured by size/direction of the overall balance sheet adjustment). These indicators are shown to capture important behavioural characteristics of banks taken as a whole, rather than individually. Moreover, if this type of indicator is calculated accurately, it could have the ability to predict financial stress as it mounts.

An important general problem in the empirical work on systemic risk is the very large number of data series that may be potentially relevant to the measurement of financial health and

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[44] The "early warning" label typically refers to econometric models where these indicators are explicitly used to predict the probability of a crisis (however defined); here we interpret the term in a broader sense, and use it irrespectively of whether the indicators are used for forecasting or not (see the ECB December 2010 Financial Stability Review for a related discussion). Note also that we focus on indicators that are meant to work *ex ante* – that is, prior to any manifestation of financial distress. Coincident indicators (based for instance on funding spreads) can be seen as complementary insofar as they provide a useful way to track and quantify financial distress in real time. Kato et al (2010), discussed in Section 2, builds on the traditional early warning models.

[45] Assenmacher-Wesche and Gerlach (2010), who provide a critical view on the indicators studied by Borio and Drehmann (2009) and Alessi and Detken (2011). Alessi and Detken (2011) analyse early warning indicators for asset price booms, whereas Borio and Drehmann (2009) construct early warning indicators for financial crises. Alessi and Detken (2011) to some degree address the out-of-sample criticism of standard early warning models. Besides, even though Assenmacher-Wesche and Gerlach (2010) show that these indicators have a limited power for predicting adverse macroeconomic outcomes, they do not evaluate the performance of the indicators in the context of financial crises or asset price busts.

[46] Carlson et al (2011) and Jokipii and Monnin (2010) compute this measure using, respectively, US bank-level data and OECD country-level data. In addition, Jokipii and Monnin (2010) use a GARCH specification to account for endogenous price volatility.

[47] Van den End and Tabbae (2010).

macroeconomic outcomes. This issue is particularly problematic when using bank-level data. Some RTF-TC work investigated methods that can be used to avoid arbitrary and unsystematic selection or aggregation of relevant variables. Methods such as factor analysis and principal component analysis – particularly straightforward ways to extract latent factors – can be extremely useful when large datasets are available.[48] These statistical techniques deliver more robust risk indicators and are particularly valuable in forecasting, time series identification, and variable selection. In particular, factor methods are invaluable in combating omitted variable bias and overcoming degrees of freedom issues which are important when modelling the joint behaviour of risk indicators and macroeconomic aggregates.

If systemic risk indicators can be successfully integrated into broader macroeconomic analysis, policymakers may be able to detect systemic risk earlier and more accurately assess potential outcomes of exogenous shocks and policy interventions. The analyses of the RTF-TC group provide evidence of strong linkages between financial risk and macroeconomic outcomes. For example, there appears to be a high time-series correlation between distance-to-default measures – estimated using financial data – and investment, output growth, and inflation.[49] The evidence also suggests that compared to simple indicators based on aggregates, indicators based on latent factors have good forecasting power and are more responsive to changes in economic conditions. This is not surprising given that aggregate variables (eg total bank capital) implicitly rely on a very naive weighting scheme which in principle could be easily outperformed by a factor extraction process (where a bank strength index could be extracted from a large number of balance sheet indicators). An important advantage of factor extraction techniques is that they can reconcile the "micro" and "macro" aspects of risk measurement, because they provide a parsimonious way to take into account micro information when modelling macro dynamics.[50] In particular, these methods are very useful in addressing omitted variable bias and overcoming degrees of freedom issues.

An application of this approach examined the joint behaviour of real output growth and a financial risk indicator (the excess return on equity for a basket of large financial institutions) combining factor extraction with quantile regression techniques.[51] This makes it possible to forecast entire distributions for the two variables, allowing their co-dependence to change depending on whether the economy is in a normal or extreme stress state. The link between output and the bank equity premium is found to change significantly across the distribution. The estimated distributions can be used to compute the expected shortfall of these indicators, which provide theoretically superior measures of risk. The combination of factor models and quantile regression also allows for better quantification of the impact of prudential regulation and supervision on banks' health.[52]

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48 De Niccolò and Lucchetta (2010) and Jimborean and Mesonnier (2010).

49 Carlson et al (2011).

50 De Niccolò and Luchetta (2010) and Jimborean and Mesonnier (2010) use these methods to reduce a large number of economic and financial time series into a few factors that have superior forecasting properties. Carlson et al (2011) also apply this method in assessing the predictive power of their distance-to-default indicator.

51 De Niccolò and Lucchetta (2010).

52 De Haan and Klomp (2011) use quantile regressions to capture potential heterogeneities in the effect of the prudential measures on banks in different percentiles of the risk distribution. Capital regulations, restrictions on activities, supervisory control, and market entry regulations have a statistically significant effect on individual banks' health. This effect becomes more pronounced, as banks move higher up in the riskiness distribution.

Moving from a reduced-form forecasting exercise to a structural analysis (that is, identifying the causal mechanisms underpinning the observed correlation between risk and aggregate activity) is extremely challenging. Factor methods may also be useful in identifying structural shocks. One of the popular identifications strategies of empirical macroeconomists has long been to make assumptions that certain variables only respond to other variables with a lag. Factor methods allow making the application of this idea more encompassing by splitting large sets of variables into groups. This is done according to the perceived inertia of variables' responses to certain shocks, prominently the monetary shock.[53] Nevertheless, the attempts made so far (within the RTF-TC working group and in the research community at large) are still preliminary, and a credible identification strategy for the macro-financial nexus must still be developed.

Events associated with the recent global financial crisis have provided ample evidence of contagion across banks, markets, and whole economies. Indeed, the propagation of distress has made it clear that looking at the soundness of individual economic entities in isolation is not enough to rule out potential system-wide risks. To this end, a number of RTF-TC exploratory papers attempted to identify network aspects that make the system more prone to crisis transmission and systemic risk.

Among simple network characteristics, an obvious candidate for the attention of prudential regulators are the cross holdings of assets and liabilities, particularly among systemically important financial institutions. The work on this has grown in recent years, although current model developments suffer from data limitations.[54] At present, regulatory data submissions typically do not provide information on the distribution of gross cross-holdings. Still, the models have provided support for the intuition that large gross exposures serve as a catalyst for the propagation of shocks across sectors and individual banks, while mark to market accounting is a major driving force thereof.[55,56]

While the construction of a comprehensive stress test framework remains a work in progress, some research explored a prototype model that combines the necessary building blocks, including for the need to require systemically important financial institutions (SIFIs) to internalise the externalities they impose on the system by adjusting their capital requirements so that they better reflect an individual bank's contribution to the overall risk in the system ("systemic" capital requirements).[57] There is a static model of bank default driven by exogenous shocks to asset values, magnified by asset fire sales and propagated by interbank exposures. A Monte Carlo simulation of the idiosyncratic evolution of asset values allows quantification of the entire distribution of stress outcomes. The output of the model is the endogenous distribution of bank losses. This allows calculation of the optimal systemic capital requirements, also adjusted for the fact that capital requirements can alter the likelihood of individual bank default. It is shown that systemic capital requirements may differ

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[53] Using the identification scheme of Bernanke et al (2005), Jimborean and Mesonnier (2010) study the transmission of monetary policy with and without accounting for financial factors.

[54] See for example International Monetary Fund (2010) and the references therein.

[55] Castrén and Kavonius (2010) investigate the propagation of shocks to sectors linked by cross-holdings of mutual liabilities. These authors also apply market price-based Contingent Claims Analysis techniques to quantify total risk exposures by sector. Their results highlight how the increased volume of mutual leverage magnifies the associated volatilities of balance sheets.

[56] Gauthier, Lehar and Souissi (2010) embed a bank portfolio model in interbank exposures. Contagion and asset fire sales are the main propagation mechanisms of the exogenous macroeconomic shocks affecting banks.

[57] Gauthier, Lehar and Souissi (2010).

substantially from the requirements computed for individual banks taken in isolation. Moreover, the exercise yields implications for supervisory data needs. For example, restricting the analysis of interbank exposures to narrow classes of liabilities[58] leads to severe underestimation of default risk.

In sum, research examined by the RTF-TC project has several important findings. First, it identified a number of synthetic indicators that can be used to monitor system-wide risks and vulnerabilities. Second, in constructing these indicators, care was taken to avoid arbitrary and unsystematic selection or aggregation of relevant variables. Third, techniques based on factor extraction may allow reconciling the "micro" and "macro" aspects of systemic risk measurement because they provide a parsimonious way to take into account micro information when modelling macro dynamics. Fourth, quantile regressions are a useful tool for stress modelling. Fifth, systemic risk can arise from the propagation of individual stress in a network via interbank exposures. Finally, sixth, capital requirements for any given bank may matter for the stability of all other banks, particularly for systemically important financial institutions.[59]

There are still some remaining gaps.

- Bank behaviour is currently modelled in a very naive, mechanical fashion, or is ignored altogether.
- Systemic risk can arise from behavioural interactions that are currently not modelled. The general equilibrium literature discussed in Section 1.1 is potentially promising in this regard.
- Models that study the network aspect of the financial system are of use, but we believe that these models need to be made dynamic, as well as incorporate the behavioural response of banks to stress if they can be useful policy tools and informing liquidity regulation.

4. How to quantify bank behavioural responses to changing policies and macroeconomic conditions?

Variation in aggregate credit volume and/or interest rates results from changes in the behaviour of both borrowers and lenders. In order to disentangle the effects of the different behavioural responses empirically, more detailed granular data and plausible identification assumptions are needed. One approach to analyzing the aggregate credit changes is to use the opinions of borrowers and lenders from survey responses. These surveys (where and when available) can provide information on the external forces affecting the credit environment as perceived by agents at the micro level. Assuming that the survey responses are truthful and accurate, they can be used to provide insight into the relative intensity of the

[58] Excluding derivatives and cross shareholdings across banks.

[59] Research on SIFIs has progressed further after the conclusion of the RTF-TC's work. More specifically, the idea that negative externalities created by systemically important banks should be addressed by requiring additional capital was acknowledged by the Financial Stability Board and by the Basel Committee, see Basel Committee on Banking Supervision (2011b).

demand effects and the constraints on credit associated with borrowers' or lenders' balance sheets.[60,61]

However, it has been argued that survey respondents may merely report to the central bank what it wants to hear. An improvement over just using survey responses involves checking the survey responses against regulatory data, such as credit registers.[62] Research of the RTF-TC group shows that micro data on actual loan applications can be used to avoid the subjectivity biases or measurement errors of surveys. Conditional on the complete set of applications, any variation in the loans granted would represent changes in credit supply. To the extent that this variation can be explained by borrower and lender balance sheets, it can be used to measure the absolute and relative influence of the balance-sheet and the bank lending channel.[63]

In the absence of loan application data, the identification of supply and demand effects can still be achieved by using observations of credit outcomes across different categories of loans (conditional on a particular lender) or across different lenders (conditional on a given loan). For example, if borrowers can draw freely on their pre-committed credit lines, at least in the short run, then changes in commitment lending will reflect only variation in demand. Under the additional assumption that the demand for spot loans and the demand for commitment loans respond identically to macroeconomic conditions, changes in spot lending further identify the separate impact on loan supply.[64] In addition, it is also possible to make use of the fact that interest rates on loans often differ across banks at a single point in time. As a result, the imperfect substitutability of loan contracts could be exploited to provide a necessary exclusion restriction in order to identify loan supply. As such, the interest rates charged by a bank's competitors can be viewed as being exogenous variables, shifting the demand for a bank's loans independently of a bank's own pricing, thus supplying a valid instrument in the econometric sense.[65]

It is not appropriate to discuss explicit gaps in this area. A range of approaches has been used to deal with the issue of identifying and measuring loan supply and loan demand. However, all are imperfect and there is still a need for additional, more convincing approaches for identification.

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[60] Ciccarelli et al (2010) assume that banks' senior loan officers' responses reflect market conditions truthfully. The survey includes answers regarding the reasons behind banks' decisions to change their lending standards. This allows a straightforward decomposition of changes in credit according to demand, bank lending, and bank balance-sheet channels.

[61] Berrospide and Edge (2010) use the net fraction of loan officers reporting a tightening of credit standards in a VAR model. They effectively identify the bank lending channel by assuming that this proxy for lending standards does not affect contemporaneously bank capital ratios or loan growth rates, while the latter may affect lending standards.

[62] Foglia et al (2010) use borrower survey responses to identify credit-constrained firms, but check the validity of responses against the data on credit actually granted. They find 15 percent incidence of self-reported "constraints" uncorroborated by the lending records.

[63] Jiménez et al (2010) find that the bank lending channel strongly affects corporate lending, while lending to households varies more substantially due to changes in borrowers' characteristics.

[64] This identification strategy is implemented by Black and Rosen (2009). They find that firm size influences the amount of credit granted, possibly reflecting balance-sheet considerations. They also provide evidence that banks adjust their desired asset positions by changing the maturity of new spot loans.

[65] Havro and Vale (2011) use this idea to identify the loans supplied by Norwegian banks.

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Appendix

Workshops of the RTF-TC Group

Rome Workshop, July 2009

hosted by Bank of Italy

Session 1: Empirical analysis of the financial-real links

Session chair and discussant: Katherine Samolyk (Federal Deposit Insurance Corporation)

"Bank risk-taking, securitisation, supervision, and monetary policy: evidence from the euro area bank lending survey", José Luis Peydró (European Central Bank) and Angela Maddaloni (European Central Bank)

"Firm default and aggregate fluctuations", Jesper Lindé (Sveriges Riksbank)

"An empirical model of subprime mortgage default from 2000 to 2007", Sean Chu (Board of Governors of the Federal Reserve System)

Session 2: Macro implications of banks' capital requirements

Session chair and discussant: Leonardo Gambacorta (Bank for International Settlements)

"Regulation, capital and credit supply in the UK banking industry: an empirical investigation and simulation of countercyclical capital requirements", Matthew Osborne (Financial Services Authority)

"The stabilising effects of risk-sensitive bank capital", Frederic Boissay (European Central Bank)

"Mitigating the procyclicality of Basel II", Jesús Saurina (Bank of Spain)

Session 3: Macro modelling of the transmission channels between the financial and the real sector

Session chair and discussant: Stefano Neri (Bank of Italy)

"Distress in the financial sector and economic activity", Thomas King (Board of Governors of the Federal Reserve System)

"Optimal monetary policy in a model of the credit channel", Fiorella de Fiore (European Central Bank) and Oreste Tristani (European Central Bank)

"Capital injection, monetary policy and financial accelerators", Naohisa Hirakata (Bank of Japan)

Paris Workshop, June 2010

hosted by the Bank of France and the French Prudential Supervisory Authority

Session 1: The credit channel of monetary policy

Session chair and discussant: Benoit Mojon (Bank of France)

"Credit availability: identifying balance-sheet channels with loan applications and granted loans", Gabriel Jiménez (Bank of Spain), Steven Ongena (Tilburg University and CEPR), José-Luis Peydró (European Central Bank) and Jesús Saurina (Bank of Spain)

"The effect of monetary policy on the availability of credit: how the credit channel works", Lamont Black (Board of Governors of the Federal Reserve System) and Rich Rosen (Federal Reserve Bank of Chicago)

"Trusting the bankers: a new look at the credit channel of monetary policy and hints for the crisis", Matteo Ciccarelli (European Central Bank), Angela Maddaloni (European Central Bank) and José-Luis Peydró (European Central Bank)

Session 2: The risk-taking channel of monetary policy

Session chair and discussant: Itai Agur (Netherlands Bank)

"Does monetary policy affect bank risk-taking?", Yener Altunbas (Bangor University), Leonardo Gambacorta (Bank for International Settlements) and David Marques-Ibanez (European Central Bank)

"Fuzzy capital requirements, risk-shifting and the risk taking channel of monetary policy", Simon Dubecq (Bank of France and CREST), Benoit Mojon (Bank of France) and Xavier Ragot (Bank of France and Paris School of Economics)

Session 3: Analyses of current policy proposals

Session chair and discussant: Carmelo Salleo (Bank of Italy)

"Countercyclical loan-to-value ratios and monetary policy", Ian Christensen (Bank of Canada) and Cesaire Meh (Bank of Canada)

"The cyclical impact of capital requirements: Evidence from French banks' panel data", Jerome Coffinet (FPSA), Virginie Coudert (Bank of France), Adrian Pop (University of Nantes) and Cyril Pouvelle (Bank of France)

Session 4: Financial institutions and macroeconomic dynamics

Session chair and discussant: Bent Vale (Central Bank of Norway)

"Banks' financial conditions and the transmission of monetary policy: a FAVAR approach", Ramona Jimborean and Jean-Stéphane Mésonnier (Bank of France)

"Financial stability and monetary policy – the case of Brazil", Benjamin M Tabak (Central Bank of Brazil), Marcela T Laiz and Daniel O Cajueiro

"The impact of banking sector stability on the real economy", Pierre Monnin (Swiss National Bank) and Terhi Jokipii (Swiss National Bank)

London Workshop, September 2010

hosted by the Financial Services Authority, London

Session 1: The macro costs of financial crises

Session chairs and discussants: Christian Castro, Mette Nielsen and Paul Collazos (Bank of England)

"The crisis as a wake-up call: Do banks tighten lending standards during a financial crisis?", Neeltje van Horen (Netherlands Bank) and Ralph de Haas

"Modelling a housing and mortgage crisis", Charles A E Goodhart (London School of Economics), Dimitrios P Tsomocos (University of Oxford) and Alexandros P Vardoulakis (Bank of France)

"Liquidity transformation and bank capital requirements", Hajime Tomura (Bank of Canada)

Session 2: Calibrating capital requirements and macro considerations

Session chair and discussant: Laurent Clerc (Bank of France)

"Revisiting the macroeconomic costs and benefits of prudential standards: additions to the FSA/NIESR impact assessment framework", Matthew Osborne, Michael Straughan, Zanna Iscenko and Sebastian de Ramon (Financial Services Authority)

"Calibrating the level of capital: the way we see it", Ryo Kato, Shun Kobayashi and Yumi Saita (Bank of Japan)

"The long-term economic impact of higher capital levels", Bank of England Research Team

Session 3: The bank capital channel of lending supply

Session chair and discussant: Alastair Milne (Cass Business School)

"Capital requirements and credit rationing", Itai Agur (Netherlands Bank)

"The importance of the bank balance sheet channel in the transmission of shocks to the real economy", Antonella Foglia, Francesco Piersante and Roberto Santoro (Bank of Italy)

"The effects of bank capital on lending: What do we know? And, what does it mean?", Jose Berrospide and Rochelle Edge (Board of Governors of the Federal Reserve System)

Ottawa Workshop, October 2010

hosted by the Bank of Canada and the Office of the Superintendent of Financial Institutions Canada

Session 1: The use of DSGE models for macroprudential policy

Session chair and discussant: Gregory de Walque (National Bank of Belgium)

"Bank leverage regulation and macroeconomic dynamics", Ian Christensen, Cesaire Meh (Bank of Canada) and Kevin Moran (Laval)

"Dynamic effects of bank capital in general equilibrium", Michael Kiley and Jae Sim (Board of Governors of the Federal Reserve System)

"Capital requirement and financial frictions in banking: macroeconomic implications", Ali Dib (Bank of Canada)

Session 2: Tools for macroprudential supervision

Session chair and discussant: Prasanna Gai (ANU)

"When liquidity becomes a macroprudential issue: empirical evidence of bank behaviour", Jan Willem van den End and Mostafa Tabbae (Netherlands Bank)

"Balance sheet interlink ages and macro-financial risk analysis in the euro area", Olli Castrén and Ilja Kavonius (European Central Bank)

"Macroprudential regulation and systemic capital requirements", Celine Gauthier (Bank of Canada), Alfred Lehar (Haskayne School of Business, University of Calgary) and Moez Souissi (Bank of Canada)

Session 3: Macro stress testing

Session chair and discussant: Thomas Kick (Deutsche Bundesbank)

"Macro stress testing of credit risk focused on the tails", Wagner P Gaglianone and Ricardo Schechtman (Central Bank of Brazil)

"Stress testing French banks' income subcomponents", Jérôme Coffinet, Surong Lin and Clément Martin (Bank of France)

Washington Workshop, December 2010

hosted by the Office of the Comptroller of the Currency

Session 1: Macro stress testing

Session chair and discussant: Til Schuermann (Federal Reserve Bank of New York)

"Stress testing German banks against a global credit crunch", Klaus Duellmann and Thomas Kick (Deutsche Bundesbank)

"The financial accelerator and the real economy", Roger Hammersland and Cathrine Bolstad Træe (Cental Bank of Norway)

Session 2: Tools for macroprudential supervision

Session chair and discussant: Andrei Sarychev (UK FSA)

"Systemic real and financial risk: measurement, forecasting and stress testing", Gianni de Nicolò (IMF) and Marcella Lucchetta (University of Venice)

"Banking risk and regulation: does one size fit all?", Jakob de Haan (Netherlands Bank) and Jeroen Klomp (Netherlands CPB)

Session 3: Liquidity channel and systemic risk

Session chair and discussant: Michael Gibson (Board of Governors of the Federal Reserve System)

"Understanding systemic risk: the trade-offs between capital, short-term funding and liquid asset holdings", Céline Gauthier, Zhongfang He and Moez Souissi (Bank of Canada)

"Global imbalances and financial fragility", Frederic Boissay (European Central Bank)

Session 4: The use of DSGE models for macroprudential policy

Session chair and discussant: Matteo Iacoviello (Board of Governors of the Federal Reserve System)

"Would macro-prudential policies have avoided the crisis?", Pamfili Antipa, Eric Mengus and Benoît Mojon (Bank of France)

"Macroeconomic propagation under different regulatory regimes – evidence from an estimated DSGE model for the euro area", Matthieu Darracq Pariès, Christoffer Kok Sørensen and Diego Rodriguez Palenzuela (European Central Bank)

Oslo Workshop, January 2011

hosted by Central Bank of Norway

Session 1: Bank lending shocks and the macro economy

Session chair and discussant: Jean-Stéphane Mésonnier (Bank of France)

"Are bank lending shocks important for economic fluctuations?", Jørn I Halvorsen (Central Bank of Norway and Norwegian School of Management) and Dag H Jacobsen (Central Bank of Norway)

"Housing cycles, household credit performance, and economic activity", Robert Avery, Ken Brevoort (Board of Governors of the Federal Reserve System) and Katherine Samolyck (Federal Deposit Insurance Corporation)

Session 2: Transmission of shocks

Session chair and discussant: Skander van den Heuvel (Board of Governors of the Federal Reserve System)

"Bank lending channel during an exogenous liquidity shock", Bent Vale and Gøril Havro (Central Bank of Norway)

"Stock market volatility, consumption and investment: an evaluation of the uncertainty hypothesis using post-war US data", Burkhard Raunig (Austrian National Bank) and Johann Scharler (University of Linz)

Session 3: Macro-conditions, credit risk and bank profitability

Session chair and discussant: Henrik Borchgrevink (Central Bank of Norway)

"Bank profitability during recessions", Wilko Bolt, Leo de Haan, Marco Hoeberichts, Maarten van Oordt and Job Swank (Netherlands Bank)

"Bubbles, bank and financial stability", Kosuke Aoki (Bank of Japan) and Kalin Nikolov (European Central Bank)

Session 4: International real-financial transmission channels

Session chair and discussant: Benjamin Tabak (Central Bank of Brazil)

"Running for the exit: international banks and crisis transmission", Ralph de Haas (European Bank for Reconstruction and Development), Neeltje van Horen and Jeromin Zettelmeyer (Netherlands Bank)

"Financial frictions, financial integration and the international propagation of shocks", Luca Dedola and Giovanni Lombardo (European Central Bank)

"International banks and the cross-border transmission of business cycles", Ricardo Correa, Horacio Sapriza and Andrei Zlate (Board of Governors of the Federal Reserve System)