



# IMF Working Paper

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## Macrofinancial Modeling at Central Banks: Recent Developments and Future Directions

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**Abstract**

This paper surveys dynamic stochastic general equilibrium models with financial frictions in use by central banks and discusses priorities for future development of such models for the purpose of monetary and financial stability analysis. It highlights the need to develop macrofinancial models which allow analysis of the macroeconomic effects of macroprudential policy tools and to evaluate elements of the Basel III reforms as a priority. The paper also reviews the main approaches to introducing financial frictions into general equilibrium models.

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## I. INTRODUCTION

1. Most models used by central banks prior to the international financial crisis were in the New-Keynesian style and implicitly assumed perfect and complete financial markets.<sup>1</sup> In these models financial frictions arising from information asymmetry and non-convex transaction costs were missing. Financial markets were assumed to be frictionless and without contract enforcement problems. Based on these assumptions, the standard model was characterized by a single risk-free interest rate and all non-monetary assets were aggregated into government bonds.

2. The recent financial turmoil underscores the need to understand the role of financial frictions in the monetary policy transmission mechanism and to develop approaches to embedding these frictions in central banks' macro models. Credit channels and financial intermediaries embedded in macroeconomic models help to explain dynamics of the business cycle capturing the inherent procyclicality of the financial system. Similarly, the composition of households' balance sheets and assets such as housing play a significant role shaping the transmission mechanism.

3. This paper aims to contribute to this effort by surveying the current state of development of dynamic stochastic general equilibrium (DSGE) models with financial frictions in use in forecasting and analysis by central banks, and reviews the main approaches to introducing financial frictions into such models. The paper also offers a view on priorities for future development of such models specifically for the purposes of monetary policy and financial stability analysis.

4. The plan of the paper is as follows. Section II provides an overview of DSGE models with financial features in use by central banks prior to the crisis as well as model developments since the crisis. The Section III then seeks to identify the main weaknesses in existing models and priorities for development in models to be used in forecasting and policy analysis. An appendix reviews the principal approaches to introducing financial frictions and modeling of banking sectors in DSGE models.

## II. MACROFINANCIAL DSGE MODELS IN USE BY CENTRAL BANKS

5. The standard macroeconomic models used by most advanced country central banks for forecasting and policy analysis prior to the international crisis typically modeled inter-linkages between the financial system and real economic activity in a very simplified

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<sup>1</sup> The financial sector is characterized as perfect if it is frictionless, fully competitive and without barriers to entry or exit. The completeness of markets refers to a financial system with instruments to efficiently clear all financial risks. Assuming a perfect and complete financial market the structure of agents' balance sheets is irrelevant to the behavior of the real economy—the Modigliani-Miller theorem.

manner. The central bank policy interest rate and the exchange rate were generally considered to be the financial variables of over-riding importance linking domestic and foreign macroeconomic policies with economic activity. Implicitly this approach assumed perfect and complete financial markets characterized by risk-free financial contracts, reflecting the absence of asymmetric information and non-convex transaction costs. Although approaches to incorporating financial frictions existed, the assumption that financial markets are complete and efficient seemed to be a reasonable approximation of reality, at least in countries with well-developed financial systems. Moreover, this assumption helped to keep models, especially the DSGE models, tractable and computationally feasible.

6. The limited attention paid to macrofinancial linkages also likely reflected institutional arrangements common to many central banks. In particular, macroeconomic modeling for forecasting and analysis related to monetary policy formulation has usually operated quite separately from modeling and analysis relating specifically to financial system stability or prudential supervision. In cases where financial stability analysis is housed within the central bank, it is a relatively recent addition to central bank analysis and typically undertaken in a different department from the traditional macroeconomic analysis and forecasting, and such institutional arrangements may have inhibited effective collaboration. Moreover, the kinds of data and models used in financial stability analysis and in macroeconomic analysis are generally quite dissimilar, which makes it difficult to integrate them into the central bank's regular forecasting cycle. Institutional obstacles to collaboration on developing macrofinancial analysis are likely to have been even greater in situations where financial stability analysis took place largely outside the central bank.<sup>2</sup>

7. Even had there been very close integration between macroeconomic forecasting and financial stability analysis units, however, the latter were not ringing alarm bells sufficiently far in advance of the crisis for monetary or prudential policies to take adequate steps to forestall or significantly reverse the buildup of systemic vulnerabilities. Consequently, it is not obvious that macroeconomic analyses and forecasts, and the associated policy recommendations, would have been substantially different. This suggests that it was not only the workhorse central bank forecasting and analysis models that were lacking, but also those of the financial stability units.

8. In this section of the paper the focus of attention is on the DSGE models used by advanced central banks prior to the crisis as well as on more recent developments. The aim is not to provide a comprehensive overview of the state of modeling but an indicative perspective on where things stand, with particular emphasis on DSGE models. This emphasis

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<sup>2</sup> See Čihák (2006a, 2006b) for a survey of institutional arrangements of financial stability units within central banks.

reflects the fact that DSGE models are increasingly used in forecasting and policy analysis in central banks, and may well become the standard type of model used for these purposes, replacing more traditional semi-structural neo-Keynesian models. Beyond their greater versatility in addressing policy issues, the increasing use of DSGE models can be attributed to a significant extent to advances in estimation methods, notably the use of Bayesian estimation techniques, together with improvements in forecasting performance.<sup>3</sup>

9. The paper does not cover the incorporation of financial features or frictions in semi-structural models. Unquestionably many central banks have begun to incorporate such features into non-DGSE models, but such modifications are generally ad hoc and not published, making it very difficult to conduct a survey of them. Similarly, while many central banks may have been developing DSGE models, it is not feasible to survey models whose details have not yet been published. The coverage of the survey, therefore, is limited to those published by central banks in working papers or other publications.

#### **A. Models in Use Before the Crisis**

10. Prior to the financial crisis the main forecasting and policy analysis models—including DSGE models—used by most central banks almost all lacked financial frictions and credit channels and the scope for analyzing macrofinancial interactions and shocks.<sup>4</sup> In a few central banks, including the Bank of England, Bank of Japan, and the United States Federal Reserve, some attention was paid to the effects of financial wealth on household consumption, and housing prices in particular were incorporated into their DSGE forecasting models (Table 1). Nonetheless, these models still lacked credit channels and financial frictions related to the banking sector.

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<sup>3</sup> See Christiano and others (2011) for an overview of DSGE modeling for monetary policy purposes, including a discussion of estimation methods. Tovar (2009) also reviews the use of DSGE models by central banks, including discussions of the need to incorporate financial features, as well as estimation issues.

<sup>4</sup> Based on papers describing core models of major central bank published up to 2010.

**Table 1. Central Bank Forecasting and Policy Analysis Models Prior to 2008**

| Central bank          | Model  | Reference                              | Financial Frictions and Assets   |
|-----------------------|--------|--|--|
| Bank of Canada        | ToTEM  | Murchison and Rennison (2006)          | --   |
| Bank of England       | BEQM   | Harrison et al. (2005)                 | Housing as a financial asset with wealth effects on consumption. However, there are no financial imperfections.                              |
| Bank of Japan         | JEM    | Fujiwara et al. (2004)                 | Housing as a financial asset with wealth effects on consumption and a financial intermediary. However, there are no financial imperfections. |
| European Central Bank | AWM    | Fagan et al. (2005)                    | --   |
| US Federal Reserve    | EDO    | Edge et al. (2007)                     | Residential capital providing housing services. However, there are no financial imperfections per se.  |
| Sveriges Riskbank     | SIGMA  | Erceg et al. (2006)                    | --   |
|                       | RAMSES | Adolfson et al. (2007)                 | --   |
|                       | ?      | Christiano et al. (2007) <sup>1/</sup> | The financial accelerator framework.   |

Source: IMF Staff.

1/ The paper extends Adolfson et al. (2007), but it is not clear if this version of the RAMSES has been used for forecasting and policy analysis at the Riksbank.

11. The absence of financial frictions in their main forecasting models does not necessarily imply that central banks overlooked financial developments or shocks as a source of business cycle fluctuations.<sup>5</sup> Macrofinancial interactions and shocks emanating from the financial sector could be taken into account indirectly using other “satellite” models incorporating more detailed treatment of financial structure and its role in the transmission mechanism, as well as through the use of expert judgment. For example, stress-testing models or other partial equilibrium models of the financial sector or particular markets could be used to help inform the main macroeconomic forecasting models. Similarly, the macroeconomic forecasts could be used to inform the financial sector models.

12. Nonetheless, neither monetary policy reports nor financial stability reports of central banks or financial stability authorities of any major country suggest that there was close and systematic integration between macroeconomic forecasting and financial stability analysis prior to the financial crisis. To an important extent, as noted earlier, this may have reflected a

<sup>5</sup> Many central banks began publishing financial stability reports well before the financial crisis; see e.g., Čihák (2006a) for a survey.

combination of institutional barriers to collaboration, as well as the modeling complications of including financial sectors in the transmission mechanism. Additionally, data issues are likely to have played a role; whereas macroeconomic forecasting for monetary policy purposes is almost always quarterly (reflecting the typical frequency of national accounts data), much data relevant to financial stability (notably balance sheet information for many financial and non-financial entities) has typically only been available on a lower frequency. Moreover, financial stability analyses have typically been based on a “snapshot” approach, geared towards assessing current risks in the financial system, rather than a more dynamic, forward-looking approach needed for effective incorporation into macroeconomic forecasting.

13. In short, both institutional and practical considerations weighed against close integration of financial stability analysis with macroeconomic forecasting for monetary policy purposes. This failure almost certainly reflected an under-appreciation of the possible risks and consequences of financial crises. In the wake of the crisis, both central banks and financial stability authorities are now giving high priority to incorporating theoretical advances in understanding of financial intermediation processes and frictions into forecasting and policy analysis frameworks.

### **B. Model Development since the Crisis**

14. The development of DSGE forecasting models with embedded financial frictions is very much a work in progress. The ECB, the U.S. Federal Reserve, and the Reserve Bank of New Zealand appear to be the only central banks that, as of end-2010, have introduced such features into their main forecasting models (Table 2), but several other central banks are moving in the direction of incorporating financial frictions into their forecasting frameworks.<sup>6 7</sup> In some cases this may involve modifying existing models to add some financial features. In some other cases completely new models incorporating financial frictions are being built. Generally, models with such features appear to be mostly in the developmental phase or used for research purposes rather than used directly in forecasting. In a number of cases, such models may be used alongside the main forecasting model during a break-in period before beginning to use them as the main forecasting model.

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<sup>6</sup> Based on working papers published by central banks between 2008 and end-2010.

<sup>7</sup> The EDO model encompasses financial shocks and asset prices, but endogenous financial frictions are still absent.



**Table 2. Central Bank DSGE Forecasting Models Since 2008**

| Central banks               | Model             | Reference                  | Financial frictions and assets   |
|-----------------------------|-------------------|----------------------------|--|
| European Central Bank       | NAWM              | Christoffel, et al. (2008) | --   |
|                             | CMR <sup>1/</sup> | Christiano, et al. (2010)  | The financial accelerator and financial intermediaries. Financial assets with different degrees of liquidity.  |
| US Federal Reserve          | EDO               | Chung et al. (2010)        | Residential capital providing housing services, exogenous risk premium, and financial shocks. However, there are no endogenous financial imperfections per se. |
| Reserve Bank of New Zealand | KITT              | Lees (2009)                | Households borrowing against housing; collateral constraints on foreign borrowing.   |

Source: Authors.

1/ The CMR model includes features developed in Christiano et al. (2004) and (2008). Smets et al. (2010) give the first official indication that that this model is used for policy analysis at the ECB.

15. Consultations with central banks, together with a survey of central bank working papers published through to end-2010 suggests that around half a dozen countries have DSGE models with financial features in operation (Table 3). A number of other countries, including Czech Republic, Singapore, and Switzerland are also known to be developing or modifying models to incorporate financial frictions, though details of work underway has not been published and, therefore, cannot be included in this survey. Besides financial frictions, these models incorporate the standard set of nominal and real rigidities ensuring non-neutrality of monetary policy in the short run. Financial imperfections are introduced mostly by using the financial accelerator or collateral constraint frameworks, together with an explicit banking sector. This modeling strategy is aimed at capturing both the credit channel of transmission as well as frictions related to the banking sector.

**Table 3. Published Central Bank DSGE Models with Financial Frictions**

| Central bank    | Reference                           | Financial frictions  | Financial intermediaries   | Banks balance sheets   |
|-----------------|-------------------------------------|--|--|--|
| Bank of Canada  | Beaton, Lalonde, and Snudden (2010) | Multi-country model with international financial flows. Each country features a heterogeneous banking sector following Dib (2010b). The credit channel is introduced via the financial accelerator framework | Monopolistic deposit and lending banks exchange resources in an interbank market. No cross-border interbank borrowing; international financial flows introduced via cross-border loans.  | <p><i>Deposit banks:</i><br/> <i>Assets:</i> Net interbank position and government bonds.<br/> <i>Liabilities:</i> deposits.</p> <p><i>Lending banks:</i><br/> <i>Assets:</i> Loans.<br/> <i>Liabilities:</i> Net interbank position and bank capital.</p>   |
|                 | Dib (2010a,b)                       | The financial accelerator framework along with a heterogeneous banking sector.<br>Lending banks face capital requirements.   | Two types of banks—deposit and lending banks. Resources are exchanged via an interbank market. Banks have monopolistic power to set interest rates on deposits and loans; and they can default on interbank borrowing and capital returns.<br>Capital accumulated by the lending banks facing penalty costs whenever they deviate from the required level. | <p><i>Deposit banks:</i><br/> <i>Assets:</i> Net interbank position and government bonds.<br/> <i>Liabilities:</i> deposits.</p> <p><i>Lending banks:</i><br/> <i>Assets:</i> Loans and government bonds.<br/> <i>Liabilities:</i> Net interbank position, bank capital, and central banks injections.</p> |
|                 | Meh and Moran (2008)                | A double moral hazard framework—an agency problem between banks and their creditors (lenders); and between banks and entrepreneurs (borrowers).  | Capital position of banks determines their ability to obtain funds—the bank capital channel.   | <p><i>Assets:</i> Loans.<br/> <i>Liabilities:</i> Deposits and bank capital.</p>   |
| Bank of England | Markovic (2006)                     | The financial accelerator framework with an external financing premium enriched by banks capital costs. The banking sector faces adjustment costs in capital accumulation—the capital channel.               | A representative bank facing non-zero costs of raising new capital. Costs of bank liabilities (capital and deposits) affect the external finance premium.  | <p><i>Assets:</i> Loans.<br/> <i>Liabilities:</i> Deposits and bank capital.</p>   |
| Banco de Espana | Andres and Arce (2009)              | The collateral constraints framework, tied to house prices;<br>An explicit banking sector collecting deposits and issuing loans.<br>Assumption of imperfect competition in the banking sector.               | Imperfectly competitive banks introduced assuming Salop's circular-city model.<br>Steady-state lending spreads depend negatively on banks' market shares—the degree of banks' competitiveness.   | <p><i>Assets:</i> Loans to entrepreneurs.<br/> <i>Liabilities:</i> Deposits.</p>   |

| Central bank                | Reference   | Financial frictions   | Financial intermediaries   | Banks balance sheets   |
|-----------------------------|---|---|--|--|
| Banque de France            | Dellas, et al. (2010)   | An assumption that households need to hold deposits to purchase consumption goods; Firms finance their production via bank loans. A time-varying default rate on loans. | An explicit banking sector exhibiting monopolistic competition. Banks accumulate capital retaining profits and smoothing dividend policy. Banks face costs issuing equities and securing their portfolios through risk-free government bonds. Banks hold reserve to manage liquidity of deposits.                | <i>Assets:</i> Loans to firms and reserves.<br><i>Liabilities:</i> Deposits, banks capital and risk-free securities.   |
| Bank of Italy               | Gerali et al. (2010)  | The collateral constraints framework; Costly accumulation of banking capital shifting interest rate margins; Banks are subject to capital requirements.                 | <ul style="list-style-type: none"> <li>• A wholesale bank and monopolistic competition of retail branches.</li> <li>• Bank profits are used to accumulate capital assuming fixed dividend policy.</li> <li>• A capital to loans ratio has to be followed by banks, otherwise they face penalty costs.</li> </ul> | <ul style="list-style-type: none"> <li>• <i>Assets:</i> Loans to households and entrepreneurs.</li> <li>• <i>Liabilities:</i> Deposits and banks capital.</li> </ul> |
| Croatian National Bank      | <ul style="list-style-type: none"> <li>• Bokan et al. (2009)</li> </ul> | <ul style="list-style-type: none"> <li>• Costly banking, sticky interest rates on loans and deposits, and foreign currency borrowing.</li> </ul>                        | <ul style="list-style-type: none"> <li>• Wholesale banks have to follow loan to deposits ratio otherwise they face penalty costs.</li> <li>• Wholesale banks and monopolistic competition of retail branches.</li> </ul>   | <i>Assets:</i> Loans to households and entrepreneurs.<br><i>Liabilities:</i> Deposits and foreign borrowing.   |
| ECB                         | Angeloni and Faia (2009)  | Banks are exposed to runs with probability increasing with banks' leverage ratio—the bank capital channel.  | Heterogeneous banks assuming relationship banking. Holding of capital endogenously motivated by liquidity risks arising from runs on banks.  | <i>Assets:</i> Loans.<br><i>Liabilities:</i> Deposits and banks capital.   |
|                             | Christiano et al. (2010)  | The financial accelerator enriched by an explicit banking sector providing liquidity services.  | Representative banks using capital, labor and reserves to provide liquidity services—deposits. A bank production function is used to capture non-zero interest rate spreads in steady state.   | <i>Assets:</i> Reserves and loans.<br><i>Liabilities:</i> Deposits and securities.   |
| Reserve Bank of New Zealand | Lees (2009)   | Households borrow against housing; collateral constraints on foreign borrowing.   | --   | --   |
| Sveriges Riksbank           | Christiano et al. (2007)  | The financial accelerator framework.  | --   | <ul style="list-style-type: none"> <li>• --</li> </ul>   |

16. The models surveyed in Table 3 are fully structural. A number of central banks may also employ semi-structural macroeconomic models with important elements of financial

transmission. The Norges Bank, for example has a semi-structural model including house prices, credit, and equities, allowing house prices affect real economic activity.<sup>8</sup>

17. The relatively small number of central banks with core models incorporating financial frictions reflects a number of factors. Perhaps first and foremost is the absence of a generally agreed “workhorse” model akin to the New-Keynesian setup with a fairly standard set of frictions. As is discussed in greater detail in Appendix I, current modeling approaches are unable to characterize financial channels and risks comprehensively.<sup>9</sup> Moreover, there is also uncertainty about the relative importance of different sources of financial frictions and transmission channels. A second factor impeding incorporation of financial frictions is the substantial increase in complexity that this generally entails. In particular, introducing financial frictions into structural models requires abandoning the assumption of representative agents. Such heterogeneity adds significant computational burdens and costs to the use of DSGE models with financial frictions in policy analyses. Non-linearities and occasionally binding constraints add further complications to model specification and solution and the practical use of such models in forecasting and policy analysis.

18. Financial frictions stem either from information asymmetries between lenders and borrowers, or from difficulties in enforcing contracts. A fuller discussion of these financial frictions is contained in Appendix I. The most common are the introduction of a financial accelerator, in which borrowers (usually firms) face a risk premium that is decreasing in their net worth,<sup>10</sup> or a collateral constraint, in which borrowing is quantity constrained by the availability of suitable collateral—typically housing in the case of households, and physical capital in the case of firms.<sup>11</sup> These frictions provide an avenue for procyclical interactions between asset prices, the balance sheet positions of households and firms, and real economic activity through changes in access to borrowing.

19. Additionally, the models introducing an explicit banking sector broadly seek to capture (i) a bank capital channel of macrofinancial interaction, particularly the role of bank capital in shaping the business cycle; (ii) the role of interest rate spreads in transmission and business cycle dynamics; or (iii) the transmission effects of interbank borrowing and related risks. Most of models surveyed in Table 3 tend to concentrate on the bank capital channel,

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<sup>8</sup> Akram and Eitrheim (2008).

<sup>9</sup> See also the ECB (2010) survey of modeling approaches, which illustrates the wide variety of approaches being taken currently.

<sup>10</sup> See, e.g., Markovic (2006), Christiano, et al, (2007, 2010), and Dib (2010).

<sup>11</sup> See, e.g., Andres and Arce (2009), Lees (2009), or Gerali, et al (2010).

partly reflecting the interest in the macroeconomic implications of Basel III changes in regulatory requirements.

20. Modeling of the bank capital channel requires providing for a demand for capital that is linked to bank lending, and ensuring that capital is costly to obtain, particularly in the short term. The assumption that banks have limited access to equity markets, at least in the short term, means that increases in capital need to be achieved through accumulation of retained earnings (involving cuts in dividends or increases in revenues). Regulatory requirements are used to motivate the holding of costly capital by banks in Gerali, et al. (2010), Dellas, et al. (2010), and Dib (2010). Alternative approaches assume that holding of capital is motivated by an agency problem (Meh and Moran (2008)); or to mitigate liquidity risks, as in Angeloni and Faia (2009).

21. Modeling of the deposit and lending interest rate spreads relative to policy or interbank rates typically assumes that banks are characterized as having a specific “technology” for transforming deposits and other factor inputs such as labor into loans. Even when banks are assumed to be homogenous, interest rate margins of the representative bank will reflect intermediation costs and therefore vary over the business cycle.<sup>12</sup> However, most models assume a monopolistically competitive banking sector, e.g., Andres and Arce (2009), exhibiting non-zero steady-state margins and lagged transmission of policy rates into loan and deposit rates. Incorporating stickiness in (average) interest rates also helps the models to reflect the maturity structure of bank balance sheets.

22. In current models, the balance sheets of banks are kept very stylized. On the liability side are bank deposits and capital, while assets are loans. A crucial implication of the stylized representation of balance sheets is that the composition and riskiness of bank portfolios is generally exogenous rather than determined as part of a bank optimization problem. Christiano, et al. (2010) allow several types of loans and distinguish between deposits and securities on the liability side. In Angeloni and Faia (2009) banks decide about their level of capital and thus about the risk of runs. In almost all models, interbank borrowing or lending is ruled out. An exception is Dib (2009), which distinguishes between two types of banks—lending and saving—which interact in an interbank market.

23. Most models with an explicit banking sector assume that only domestic banks operate in the local financial market. Cross-border borrowing is not allowed and banks also collect funds only through the domestic money market. Cross-border borrowing is allowed in Beaton, et al. (2010). The model used in the paper is a multi-country framework with financial frictions and assumes a constant share of cross-border borrowing on firms’ loans.

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<sup>12</sup> Christiano, et al. (2010).

### III. CHALLENGES AND PRIORITIES FOR MODEL DEVELOPMENT

24. The incorporation of basic elements of financial structure and behavior into DSGE models is still at an early stage. While the financial frictions and features introduced recently represent an improvement on earlier models, there is a long way to go before the models are able to substantially meet central banks' policy analysis and forecasting needs. Most models focus on a small number of frictions or constraints on intermediation and ignore other important features of the financial transmission mechanism. They also include only a very limited range of financial assets. And the representation of financial intermediaries in almost all cases is highly simplified. Their objectives and instruments are generally characterized in a rudimentary fashion, and heterogeneity within the financial sector is, with few exceptions, ignored.

25. Addressing these and other shortcomings will take time and require careful prioritization. Many of the features which need to be added to DSGE models are already present in partial equilibrium models. However, they usually require heterogeneity of agents and/or financial assets. As a consequence, adding even a few financial frictions to DSGE models increases their complexity substantially, making them more difficult not just to operate, but also less readily understood by their users. This is especially important in a policy formulation and communication context, since a good understanding of the intuition or story behind the forecasts is essential for making and explaining policy trade-offs and choices.

26. These considerations point to the need to keep the incorporation of financial frictions and shocks into mainstream forecasting models parsimonious and focused on the most important transmission mechanisms. However, a general consensus has not yet emerged as to what the minimum representation of the financial sector should include. Some elements, including the financial frictions constraining lending to households and firms are likely to become standard, but other features are likely to be added only gradually, and are likely to vary across countries, reflecting differences in the structure of financial systems.

27. An additional key consideration likely to shape the development of macrofinancial models is the need for policymakers to understand the macroeconomic effects of the use of macroprudential policy tools and their implications for monetary policy formulation. Consequently, models will need to incorporate features which allow the main elements of the Basel III reforms to be taken into account.

28. Issues to be addressed in current models include:<sup>13</sup>

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<sup>13</sup> See also the useful discussion in ECB (2010).

### **Representation of non-financial agents and their behavior**

- Households and firms both borrow and save, in order to manage liquidity risk, but this behavior is generally not well-captured by current models. Such behavior should be built into the standard model as this would have important consequences for the dynamics of these agents' responses to shocks affecting perceived income risks.
- Although the financial accelerator framework presupposes default risks, the realization of these risks and the losses do not create distress in financial institutions.<sup>14</sup> Explicit representation of default probabilities and associated losses—and linked to macroeconomic developments—should be incorporated into models, partly because it would provide a more complete representation of the intermediation process. In addition it would provide an important link between the macrofinancial model framework and more detailed financial stress testing frameworks.
- The financial balance sheet of the public sector is typically left out of current models, although government bonds are often included among the few financial assets represented. Recent events have shown that doubts about fiscal sustainability can have an adverse impact on the financial sector, both through the impact on sovereign risk premiums and through the impact on the collateral value of government securities. Models would benefit from more complete representation of public sector financial positions and linking these to the sovereign risk premium.

### **Representation of financial agents and markets**

- The financial sector is comprised of quite different kinds of institutions. However, with few exceptions, current models use a representative monopolistically competitive “bank” to represent the financial sector. Although these stylized financial institutions may be generic enough to encompass banks, shadow banks, and some other non-bank financial institutions, more explicit differentiation among them will be needed.
- While it is unlikely that a realistic representation of the heterogeneity of financial institutions can be achieved any time soon, it will be important from both a modeling and empirical perspective to determine the domain of financial institution types to be included in core forecasting and analysis models and the institutions which should be represented only in satellite models informed by and informing the core macrofinancial models.

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<sup>14</sup> An endogenous time-varying default risk is absent in the collateral constraints framework, but an exogenous default risk can be added.

- Current models of the banking sector do not include an interbank market, with the exception of Dib (2010a, b). This is an important omission, since, as the financial crisis highlighted, the interbank market played a central role in magnifying the severity and extent of the crisis. A way forward in incorporating interbank markets may be offered by the framework developed by Gertler and Kiyotaki (2009). In this framework, moral hazard constrains the ability of banks to borrow from households or, though an interbank market, from other banks. In this case, idiosyncratic liquidity shocks to banks can lead to market segmentation, with spillover effects on the real economy.
- Incorporation of wholesale or interbank markets as a source of funding for banks will also be needed to assess the impact of Basel III reforms aimed at reducing the vulnerability of financial institutions and systems to liquidity disruptions (including through increased liquidity requirements and net stable funding ratio requirements). Additionally, explicit incorporation of an interbank market into mainstream forecasting and analysis models will provide an extremely useful complement to more detailed financial sector models used in financial stability analysis and in stress testing.
- One of the key roles of the financial sector is in maturity transformation between short-term deposits and longer-term loans. For this role to be incorporated into macrofinancial models, deposit and loan contracts of different maturities to be introduced through multi-period contracts or mimicked through different degrees of inertia in interest rates on different types of loans, deposits and other financial instruments. Introduction of such differences would, of course, have reciprocal implications for counterparty lenders and borrowers.
- Introduction of greater differentiation in the maturity structure of both lending and borrowing can potentially add great complexity to existing models. Yet some movement in this direction is essential to be able to properly address the issue of liquidity risk, the full impact of liquidity requirements, and the implications of stable funding requirements. Introduction of maturity mismatching will also influence the cyclical behavior of lending spreads. In many current models, spreads are procyclical (dampening the real cycle). Maturity mismatching could reverse this, so that spreads become counter-cyclical, in line with empirical evidence.
- The valuation of financial assets plays a key role in the dynamics of macrofinancial models. In the collateral constraints framework, the response of housing prices to demand shocks and, consequently, the collateral value of housing, is crucial to amplification of the business cycle through the housing market. The valuation of firms' net worth plays a corresponding role in the financial accelerator framework. Modeling of the determination of house prices and firm net worth will therefore play



a critical role in governing the strength of these transmission channels in macrofinancial models.

- The valuation of liquid assets plays a similar role in the interbank market, providing the basis for liquidity “spirals” to amplify the adverse effects of liquidity shocks. Calibrating the response of such asset prices to liquidity shocks will consequently largely determine the importance of this channel of financial transmission.
- Most current macrofinancial models are either closed economy models or only allow domestic currency borrowing. Going forward, it will be important to add open economy aspects, including to the financial sector. In particular, allowance will need to be made for borrowing and lending in foreign currencies, together with associated currency risks and risks of sudden stops.
- Current models have very simplified representations of the decision making and optimization processes of banks (or other financial institutions). Even in the current models many choice variables are exogenized. For example, if a bank’s current capital adequacy ratio deviates from desired or required capital, the method of adjusting the capital ratio is not determined endogenously within current models.
- Adding more variety in the riskiness and maturity characteristics of financial assets and liabilities available to financial institutions will significantly complicate the task of endogenizing their behavior. With institutions having multiple objectives and instruments, it is unlikely that models will be able to make substantial advances in endogenizing decision-making in the near future. In such circumstances, the best approach may be to impose a minimal set of optimization criteria and then to address other behavioral responses as alternative scenarios.

29. The “shopping list” of model improvements outlined above is surely not exhaustive, but even so is well beyond what can reasonably be expected to be achieved within the coming year or two. Yet there is a pressing need to have models with which to examine the implications of forthcoming decisions on elements of Basel III. Additionally, central banks and financial stability authorities have an urgent need to begin putting in place the substance of integrating financial stability concerns into monetary policy analysis and vice versa.. In order to move forward efficiently and fairly quickly, two important sets of issues need to be borne in mind. The first concerns the purposes for which the model or models are likely to be used. The second concerns the modeling “architecture;” that is, the organization and relationship between different models.

### **Model objectives**

30. DSGE models may be developed with somewhat different purposes in mind, and these differences should influence the priority accorded to incorporation of different features and frictions into the model. Three somewhat different purposes can be distinguished:

- Macrofinancial analysis and forecasting. The objective here is not to forecast financial crises. However, the incorporation of financial frictions should enrich the transmission mechanisms in the model, and allow for financial shocks to be introduced. It is not clear how much further it is important to go beyond adding credit frictions via collateral constraints or the financial accelerator, as well as adding assets such as housing. The models should be fleshed out sufficiently to provide forecast-consistent paths for important financial variables such as lending spreads, housing prices, and bank lending, to facilitate macrofinancial monitoring. This would provide the central bank with evidence on whether financial developments were consistent with the fundamentals, or showing evidence of bubbles or other developments warranting closer analysis.
- Macroprudential analysis. For this purpose, it is important to be able to examine the impact of changes in macroprudential instruments and regulations on the macroeconomy. The top priority should be on providing a basis on which key elements of Basel III reforms can be incorporated into the framework of model analysis. In practical terms this means, at a minimum, developing models able to take into account the impact of changes in bank capital and liquidity requirements, imposition of leverage ratios and net stable funding ratios. Clearly this implies the introduction of an explicit banking sector with financial liabilities and assets with differing degrees of liquidity or maturity, as well as introducing interbank markets, together with the regulatory constraints and the behavior of banks in observing those constraints. Such models would also be useful in assessing how the conduct of monetary policy should change in response to the use of macroprudential instruments. It could become apparent that the use of some instruments, such as countercyclical capital requirements, should be incorporated into the main macrofinancial forecasting model, but that is not certain ex ante.
- Stress-testing analysis. The key requirement for stress-testing purposes is for the macroeconomic model to be able to provide inputs to “satellite” models which represent the financial system at a more disaggregated level, and which can allow for crises. In this context, it may be especially important to have the interbank market represented in the macroeconomic model, together with model-consistent determination of asset prices.

31. The distinct priorities associated with different model purposes suggest that, instead of seeking to develop a single, all-purpose DSGE model, central banks and financial stability authorities might consider developing several versions of a model with at least some basic financial features and frictions built in as a common denominator. The more complex versions of the model would probably be needed for macroprudential analysis and stress-testing.

## Modeling architecture

32. While DSGE models have important advantages over ad hoc modeling approaches, they are not necessarily ideal under all circumstances. Most central banks still use semi-structural models as their core model in forecasting and policy analysis.<sup>15</sup> In such circumstances, extending the semi-structural models in place may be more expedient than developing DSGE models from scratch. Expanding semi-structural models to incorporate financial features and frictions can borrow from existing DSGE models to guide the specification and calibration of modified semi-structural models.

33. Additionally, even where DSGE models are used in mainstream analysis, it may be more efficient to conduct some aspects of analysis in satellite models which are linked to the core model.<sup>16</sup> This avoids increasing the size and complexity of the core model, keeping it easier to understand, solve, and simulate.

34. As already noted, for stress-testing purposes, it may be most sensible to conduct the stress-testing in a disaggregated and detailed modeling framework linked to, but largely outside, the core forecasting macroeconomic model. Of course, this approach requires thinking carefully about the design of both models in order to ensure that the necessary links and procedures are put in place to ensure that the system works efficiently.

35. In some other cases, even if it is feasible to incorporate some features into the DGSE model, it may still be preferable to address these features within a satellite framework due to technical aspects of model solution and simulation. Two particular examples where this may be the case are the treatment of non-linearities and the incorporation of interbank activity within mainstream forecasting models.

36. A common criticism of DSGE models, as well as most other macroeconomic models is that they do not incorporate non-linearities that may play a major role in triggering or even defining financial crises. Most DSGE models are linearized around the steady state. For small disturbances this is reasonable, at least as long as the current state of the financial system is not close to a point where non-linear effects are likely to kick in. For forecasting in the vicinity of such critical points, or in the event of large shocks, non-linearities are problematic.

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<sup>15</sup> Tovar (2009), for example, points to limitations of DGSE models in a number of respects.

<sup>16</sup> Satellite models are models, typically of specific blocks of the economy, that are substantially driven by variables determined in the core model, but which do not have simultaneous feedback loops affecting the solution of the core. In some cases, there may be feedback loops, but the interaction between the core and satellite models is iterative rather than simultaneous.

37. One approach to dealing with non-linearities is to incorporate them explicitly into the main analysis and forecasting framework the existence of occasionally-binding constraints (OBC).<sup>17</sup> Currently, the OBC approach has only been used in research models, but it could well be incorporated into models designed for current policy analysis and forecasting. However, this approach is likely to be most useful in dealing with constraints that are (i) likely to have a sufficiently high likelihood of being binding to warrant the additional modeling complications; and (ii) sufficiently well-defined to model at an aggregate level, such as those associated with regulatory requirements. A more disaggregated and less explicitly model-based approach may be more appropriate to deal with rarely binding constraints, or where constraints may bind quite differently across the financial system.

38. An alternative approach to dealing with non-linearities that bind only infrequently or at a relatively disaggregated level is to leave them completely outside the core model, but to address them in more detailed, but partial equilibrium, satellite models. This approach has the advantages that the regular analysis and forecasting process would be kept relatively simple both analytically and computationally, while the satellite models could provide very detailed information on the characteristics of the non-linearities as needed. For this approach to work well, however, financial satellite models would need to be well integrated into the forecasting and analysis frameworks used in central banks, which would often entail not only modifications to the models being used, but also to institutional relationships and procedures.<sup>18</sup>

39. It is also not entirely clear whether workhorse forecasting models should incorporate explicitly an interbank market. Although it is feasible to do so, it adds complexity—heterogeneity—which may be unnecessary and unhelpful to understanding the model on most occasions. From time to time, of course, shocks affecting the interbank market may be very important. In such circumstances, the best bet may be to model the interbank market outside the core model, but to ensure that there are necessary linkages between the two models so as to be able to incorporate the effects of interbank market developments into the core model as needed. Before a judgment can be made on whether this approach is sensible, however, it first needs to be determined whether the presence of frictions within the interbank market alters the transmission mechanism in a way that needs to be fully incorporated in the core model. Effective use of satellite models in policy analysis and forecasting requires developing procedures and a corporate culture of close integration between the macroeconomic analysis and forecasting teams and the financial stability analysis teams. The appropriate form of collaboration between macroeconomic analysis

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<sup>17</sup> See IMF (2010); Mendoza, (2010); Benigno, et al (2011); and references therein.

<sup>18</sup> For example, while the macroeconomic models are likely to be quarterly in frequency, with well-specified dynamics, the models used in financial stability analysis may be annual, with very little dynamics built in.

financial stability analysis teams and procedures should depend importantly on the focus of the analysis.

40. In the case of macroeconomic forecasting, for example, financial stability considerations would normally feed into the macroeconomic forecasts in an iterative fashion, or might be used to shape particular scenarios. For stress-testing purposes, alternative macroeconomic scenarios would be used to feed into the more detailed financial stability analysis models. Appropriate procedures will differ between these two types of analysis, though both are likely to require a higher degree of collaboration than has often been the case in the past.

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## **APPENDIX I: APPROACHES TO EMBEDDING FINANCIAL FRICTIONS, TRANSMISSION CHANNELS, AND RISKS IN DSGE MODELS**

1. This appendix reviews the incorporation of various financial frictions, transmission channels and risks into DSGE models from three different perspectives. In the first part, three main approaches to incorporating financial frictions are discussed. The financial accelerator and collateral constraints approaches are relatively common, and are increasingly being coupled with frictions associated with explicit modeling of financial intermediaries, including costly intermediation, bank capital constraints, and risk management behavior of banks. Modeling of occasionally binding constraints is also noted. The second part of the appendix discusses the main channels of financial transmission in current models, including the balance sheet channel associated with borrowers' balance sheet positions, the bank lending channel associated with bank capital positions, and the risk taking channel associated with bank response to changes in asset returns. The third part focuses on the main kinds of risk, including market risks, exchange rate risk, credit or default risk, and, lastly liquidity risk.

### **A. Approaches to Embedding Financial Frictions**

2. There are three basic approaches used extensively in the literature to embed financial frictions into DSGE models—the financial accelerator framework, the collateral constraints framework, and via explicit modeling of financial intermediaries. Each of these approaches has its own strengths and weaknesses and the properties of the many variants on each approach continue to be investigated, with the result that a consensus approach has not yet emerged.<sup>19</sup>

3. To introduce financial frictions two crucial changes to the standard New Keynesian model framework are required. The first is to replace the representative agent framework with heterogeneous agents. This provides a basis for motivating borrowing and lending as agents differ in their consumption preferences, productivities, or financing constraints. The second is to introduce information asymmetries between agents. The presence of ex-ante information asymmetries induces adverse selection; ex-post asymmetries imply agency costs for assessing creditworthiness and monitoring costs, which lead to an external financing premium.

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<sup>19</sup> The implications of collateral constraints for business cycle dynamics have been discussed extensively in the literature concluding that the effects vary with the design of constraints and with the kind of shocks affecting the economy.

### **The financial accelerator framework<sup>20</sup>**

4. The financial accelerator framework assumes an ex-post information asymmetry giving rise to an external finance premium reflecting the difference between the costs of externally borrowed and internally generated funds. The external borrowing premium varies inversely with borrower net worth and limits agents' borrowing.<sup>21</sup> In good times, borrowers have higher net worth, raising their creditworthiness and lowering external funding costs. Conversely, in bad times, lower net worth reduces creditworthiness, raising borrowing costs. The premium on external borrowing, therefore, is countercyclical.

5. The financial accelerator framework traditionally focuses on the lending relationship between households and entrepreneurs. Entrepreneurs are armed with production technologies and undertake risky projects, but are assumed to be dependent on external funding for projects. Entrepreneurs are assumed to be risk neutral, and experience idiosyncratic shocks to outcomes of their projects. They are able to observe project outcomes costlessly, whereas lenders (households) face monitoring and auditing costs. The ex-post information asymmetry implies a costly state verification problem for lenders.<sup>22</sup> In such circumstances optimal incentive compatible contracts are characterized by a non-negative external financing premium induced by monitoring costs and uncertainty about project returns.<sup>23</sup>

6. The countercyclical behavior of the external finance premium is the mechanism amplifying and propagating responses of real output and investment to shocks. For example, the initial response of output to a technology shock is amplified by an associated increase in asset prices. The rise in asset prices increases borrower net worth, leading to a decline in the external finance premium, and a further boost to spending. The financial accelerator helps to explain observed large swings in investment and hump-shaped output responses to moderate interest rate changes.

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<sup>20</sup> In this paper the label "financial accelerator" refers to the framework introduced by Bernanke, et al. (1999) into a DSGE setup.

<sup>21</sup> Borrowers' net worth is defined as the value of assets minus outstanding obligations.

<sup>22</sup> The costly state verification framework was introduced by Townsend (1979) and Gale and Hellwig (1985); and embedded into a general equilibrium model by Bernanke and Gertler (1989).

<sup>23</sup> Borrowers facing a positive external financing premium tend to accumulate wealth to finance projects internally. To ensure a positive external premium a non-zero probability of death may be imposed. Alternatively, a high discount rate by borrowers assures an incentive to consume today instead of saving. Carlstrom and Fuerst (2001) compare these approaches.

7. Empirical evidence on the financial accelerator mechanism is provided by Bernanke, et al. (1996), who examined cross-sectoral implications of the framework. The authors found that the access of small firms and consumers to credit varies over the business cycle and the evolution of their balance sheets in a manner consistent with the financial accelerator. Similarly, Christiano, et al. (2004) found the financial accelerator and financial shocks significant explaining the Great Depression; and Christensen and Dib (2008) claim the importance of the financial; accelerator in fitting U.S. data.

8. The strength of the financial accelerator mechanism varies with the nature of the shocks driving asset prices. Effects are strong for financial shocks directly affecting asset prices, but may be relatively moderate in response to supply shocks such as productivity or price mark-up shocks. The specification of debt contracts also influences the strength of the accelerator mechanism. Nominal (non-indexed) debt contracts, as in Christiano, et al. (2010), dampen the accelerator in the event of productivity and price markup shocks. Unexpected productivity increases lower consumer prices, raising the real cost of debt repayments when contracts are set in nominal terms.

9. Embedding the financial accelerator framework in a standard DSGE model with investment and capital accumulation is relatively straightforward so long as the conditions outlined in Bernanke, et al. (1999) are fulfilled. The main steps involve adding equations for an external financing premium, entrepreneurs' consumption and wealth accumulation.

### **The collateral constraints framework**

10. The collateral constraints framework provides another approach to incorporating financial frictions into DSGE models. Like the financial accelerator asset prices movements interact with credit market imperfections to amplify the effects of shocks. However, in contrast with the financial accelerator, borrower net wealth directly affects borrowing limits instead of indirectly through an external finance premium. The borrowing limits arise from the assumption of limited contract enforceability, such that lenders cannot force borrowers to repay their debts. In order to provide borrowers with an incentive to repay and for lenders to lend, contracts need to be secured by collateral. Durable assets as land, housing, or capital usually serve as collateral.

11. Following Kiyotaki and Moore (1997) the collateral framework assumes groups of impatient agents to motivate borrowing. These agents have a lower discount factor than other agents, so that they would prefer to borrow at the current interest rate to finance current consumption. However, impatient agents are constrained by credit limits which are

determined by the value of collateral, and the credit limits are assumed to be always binding (i.e., there is always a scarcity of collateral).<sup>24</sup>

12. Similarly to the financial accelerator framework the interaction between credit limits and asset prices is the key mechanism which amplifies shocks and makes them more persistent. A negative shock to asset prices lowers the value of collateral, leading to a reduction in credit limits. As a consequence, spending by impatient agents declines, lowering asset prices further.

13. Using a model with housing as collateral, Iacoviello (2005) and Iacoviello and Neri (2007) conclude that the framework helps to match an empirically observed co-movement of aggregate demand and housing prices in a case of asset prices shocks. Similarly, Liu, et al. (2010) find the collateral framework and asset prices shocks helps to account for empirical features of the business cycle.

14. As with the financial accelerator, the procyclical amplification effects in the collateral framework depend on the nature of the shocks involved, as well as on other assumptions. Amplification is very moderate for non-financial shocks with limited effects on asset prices. Hence, the collateral constraint framework is characterized by a weak amplification of supply shocks, particularly when debt contracts are nominal and not indexed.

15. Medicino (2008) and Kocherlokota (2000) claim that the importance of the amplification mechanism increases with the ratio of collateral to output, the share of output produced by credit-constrained agents, and with any productivity differential between constrained and unconstrained agents. Cordoba and Ripoll (2004), however, claim that amplification is very weak unless unorthodox assumptions on preferences and technologies are made. These include assuming an intertemporal elasticity of substitution significantly below one and a large ratio of collateral to GDP.

16. Introducing the collateral constraints into a DSGE model requires heterogeneity of agents including a group of impatient, credit-constrained agents. The credit constraint needs to be binding and durable goods as housing or capital are required as collateral.

### **Modeling of financial intermediaries**

17. The financial accelerator and the collateral constraint frameworks originally assumed that borrowers can obtain funds directly from lenders without any financial intermediaries. Introducing a banking sector into DSGE models provides an additional avenue for

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<sup>24</sup> Shocks hitting a model are assumed to be small enough to keep borrowing constraints binding. Occasionally binding constraints are discussed by Mendoza (2006).

incorporating financial frictions specifically linked to the costs of intermediation, financial intermediaries' balance sheets, and their risk management behavior. Although these intermediaries are typically called banks, the characteristics of the modeled institutions may include activities of non-banks fulfilling similar intermediation functions.

18. Modeling of financial intermediaries generally focuses on:

- Providing for endogenous determination of interest rate spreads over the business cycle consistent with observed behavior, and motivating a non-zero spread in the steady state;
- Modeling of a bank capital channel so that the balance sheet of the financial intermediary—and regulatory measures constraining the balance sheet—influences the transmission mechanism in addition to the balance sheet positions of nonbank agents; and
- Modeling of bank risk management.

***The costly banking framework***

19. Most approaches to explaining interest rate spreads and their behavior within the business cycle rely on a neoclassical banking framework assuming a representative bank operating within a perfect competitive environment and providing financial services—deposits and loans—to agents in the economy.<sup>25</sup> To play a non-trivial role, financial intermediation is characterized as a costly activity using resources to create and maintain debt contracts. Bank balance sheets are kept very stylized, usually assuming only deposits on the liability side and loans as assets.

20. The costs of financial intermediation give rise to a positive premium on loans—an interest rate spread—as in Edwards and Vegh (1997). However, if intermediation costs are positively related to the volume of intermediation, this implies that such costs, and their impact on spreads should be procyclical, which is at odds with empirical evidence.<sup>26</sup> The costly intermediation framework is usually combined with the accelerator or the collateral framework to improve the empirical consistency of the model.<sup>27</sup> Table 4 compares the financial accelerator, collateral constraints and costly banking frameworks with respect to their motivations and properties.

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<sup>25</sup> See, e.g., Diaz-Gimenez, et al. (1992) and Chari, et al. (1995).

<sup>26</sup> See, e.g., Borio, et al. (2001) for empirical evidence.

<sup>27</sup> See e.g., Goodfriend and McCallum (2007).

**Table 4. Approaches to Modeling Financial Frictions**

|  | The financial accelerator framework  | The collateral constraints framework   | The costly banking framework  |
|--|--|--|---|
| The source and nature of financial frictions | Ex-post information asymmetry—an external finance premium sensitive to net wealth of agents.   | Limited contract enforcement environment—lending constrained by the value of agents' collateral.   | Non-convex production technologies—increasing costs of financial intermediation with the volume of financial services.  |
| Motivation for borrowing and lending         | Heterogeneity of agents—households are net savers and entrepreneurs are net borrowers.   | Heterogeneity of agents in the form of different non-stochastic discount factors.  | Need to finance production in advance or an assumption of a constant share of lending for investment.   |
| Key variables                                | External finance premium.  | Credit limits and spreads.   | Interest rate spreads   |
| The transmission mechanism                   | Fluctuations of agents' net worth affect costs of external financing.  | Fluctuations of asset prices affecting the value of collateral and consequently the tightness of credit constraints.   | Interest rate spreads reflecting the amount of lending.   |
| Implications of financial frictions          | Amplify asset price shocks. Relatively moderate amplification of non-financial shocks. The strength of amplification is highly sensitive to model assumptions. | Amplify asset price shocks. Relatively moderate amplification of non-financial shocks. The strength of amplification is highly sensitive to model assumptions. | Dampen the transmission of shocks due procyclical interest rate spreads unless combined with sticky interest rates or other approaches introducing financial frictions. |
| Financial intermediaries                     | No explicit financial intermediary.  | No explicit financial intermediary.  | An explicit banking sector.   |

Source: IMF Staff.

21. Alternatively, an assumption of an imperfect competition in the retail banking sector can be introduced along with costly banking. This helps to match an incomplete pass-through from a policy interest rate to deposit and loan rates in the short-run and the observed propagation of monetary policy shocks.<sup>28</sup> The monopolistic power of banks, entry costs to the sector, or relationship borrowing is used to motivate stickiness in interest rates.<sup>29</sup> The stickiness of interest rates is also a means of representing the maturity mismatch between deposits and loans, as the probability of an interest rate renewal can be considered as the duration of financial contacts. A high probability of re-optimizing the deposit interest rate

<sup>28</sup> See e.g., Andres and Arce (2008), who use Salop's circular-city model to introduce imperfect competition instead of Dixit-Stiglitz differentiated product framework.

<sup>29</sup> See e.g., Mandelman (2006).



implies a short duration of deposit contracts, while a lower frequency of re-optimizing the loan rate implies longer maturities for loans.

### ***Bank capital***

22. A second strand of financial sector modeling focuses on bank balance sheets, and especially the role of bank capital in the transmission mechanism. An important motivation for incorporating bank balance sheets with capital into the model framework is that it facilitates analysis of financial stability issues and assessing the implications of prudential regulatory measures affecting bank capital. Incorporating bank balance sheets can also be used to examine other measures such as liquidity, reserve, and leverage requirements, once the relevant set of assets and liabilities have been built into the model.

23. This approach generally requires that banks use capital together with deposits to extend loans. Monopolistic banks earn profits, which are either retained to build up capital or distributed as dividends to shareholders. A common assumption is that banks are unable to raise capital through new equity issues, so that capital can only be raised through retained earnings. This mechanism implies an imperfect equity market.<sup>30</sup>

24. The need for banks to hold capital may be motivated by either market incentives or by regulations. In the case of market incentives, banks themselves may be subject to credit constraints due to an agency problem between banks and their creditors. Meh and Moran (2010) and Dib (2010b) develop models with such double moral hazard, and show that bank capital can mitigate the agency problem. As a consequence, the amount of credit that banks can extend is constrained by their own capital position.

25. Alternatively, models may motivate the holding of bank capital with regulatory requirements. Gerali, et al. (2010), for example, assume that banks face non-zero penalty costs lowering their profits whenever they deviate from a regulatory target. The penalty cost function is usually exogenous—it is not derived from banks' optimization problem—and its calibration reflects an empirically observed speed of elimination of deviations of bank capital from the imputed target or required level of bank capital. An endogenous penalty function can be derived by solving the agency problem referred to earlier or by introducing uncertainty into financial contracts and defining a payout scheme as in Angeloni and Faia (2009). In this respect the market-based and exogenous regulatory requirements are quantitatively equivalent.

26. The implications of bank capital requirements for real variables vary across models reflecting underlying assumptions about banks behavior. Meh and Moran (2010) find that the

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<sup>30</sup> In addition to being constrained by an imperfect equity market, the maturity mismatch between deposits and loans banks have to face the maturity mismatch to introduce the bank capital channel.

bank capital channel amplifies and propagates effects of supply shocks on real economic activity whereas the amplification is very moderate for demand shocks. This finding reflects the countercyclical behavior of lending spreads arising from the agency problem faced by banks. However, if penalty costs for deviations of capital from the required or target level are procyclical, then interest rate spreads will be procyclical, dampening the cyclical impact of both supply and demand.<sup>31</sup>

### ***Bank risk management***

27. Finally, there is a strand of banking sector modeling that focuses on embedding bank behavior with regard to risk management. These approaches introduce uncertainty and defaults into financial contracts, and define bank incentives and payout schemes. Most approaches incorporate into the DSGE framework partial equilibrium setups originally developed in the theory of corporate finance.

28. The model of Angeloni and Faia (2009) provides an example of this approach. In this model banks face two kinds of risk. On the lending side, losses may arise on loans for projects with uncertain returns. Losses also occur if loans are recalled early, forcing termination of projects underway. On the deposit side, banks are exposed to bank runs. Runs arise from the payout scheme supposing that depositors are served sequentially following the rule first come first served. Depositors are not able to observe the riskiness of bank lending portfolios directly and therefore rely on the observed ratio of bank capital to loans—the leverage ratio—to estimate the risk that the bank will be unable to pay off its deposits. The risk of a bank run is increasing in the leverage ratio. Moreover, if a run occurs, forcing the bank to call in loans, terminated projects will generate losses. The endogenous challenge for banks is to find a leverage ratio that optimally balances greed—higher returns on capital from having high leverage—against fear—the increased likelihood of bank runs and capital losses associated with early termination of projects.

### **Occasionally binding constraints**

29. Most models employing credit frictions assume that they are always binding. Mendoza (2006) and Mendoza (2008) introduce occasionally binding constraints in order to explain sharp reversals of international capital flows—sudden stops. In this model credit constraints become binding only after a sequence of adverse shocks and induce a spiraling collapse of asset prices further dampening real activity. In order to allow occasionally binding constraints, these papers assume a cardinal utility function for agents and need to be solved numerically using a non-linear global approximation method.

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<sup>31</sup> See Gerali, et al. (2010), and Christiano, et al. (2010).

## B. Transmission Channels

30. The main approaches to incorporating financial frictions focus on credit channels—the balance sheet and bank lending channels.<sup>32</sup> The balance sheet channel, working through net wealth of borrowers, is well described by both the financial accelerator and collateral constraints frameworks.<sup>33</sup> In these frameworks, borrowers' net wealth is determined particularly by asset prices behavior and it affects either an external finance premium or credit limits. With these frameworks, monetary policy not only influences demand through the traditional impact of the policy interest rate on retail interest rates, but also through the impact of interest rates on collateral values and net worth, which then affect private sector access to credit.

31. The financial accelerator and collateral constraints frameworks abstract from the role of financial intermediaries in the transmission mechanism. The introduction of banks and bank balance sheets further modify the transmission of macroeconomic developments and monetary policy actions.

32. Bank capital plays a key role in the bank lending channel, adding an additional constraint on bank intermediation.<sup>34</sup> To motivate the role of banks and the rationale for holding capital, intermediation and capital accumulation are modeled as costly activities, and the holding of non-zero level of capital is motivated by regulatory requirements or an agency problem.<sup>35</sup> Because capital accumulation is costly, and bank recourse to equity financing is assumed to be constrained, lending spreads to play a key role adjusting bank capital in response to shocks or regulatory requirements. Although it is not clear whether adding bank capital to the intermediation process amplifies or attenuates procyclical tendencies, the incorporation of this feature is important for analysis of the interaction of monetary policy with regulatory requirements affecting bank capital, notably including the proposed countercyclical capital requirements under Basel III.

33. Nonetheless, modeling of bank capital is quite rudimentary in most models. In particular, in most models, the riskiness of bank loan portfolios and share of non-performing loans are treated as exogenous, and thus unaffected by bank leverage. This importantly limits the ability of such models to address the financial stability implications of increasing or

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<sup>32</sup> The taxonomy of transmission channels follows Mishkin (1996).

<sup>33</sup> The balance sheet channel captures an impact of monetary policy actions on a balance sheets position and net wealth of borrowers and consequently on credit limits.

<sup>34</sup> See, e.g., Van den Heuvel (2006) for discussions of the role of bank capital in the bank lending channel.

<sup>35</sup> See Zhang (2009) and Dib (2010b).

decreasing bank capital requirements. An exception in this regard is Angeloni, et al. (2010), which links the probability of bank runs to the degree of bank leverage.

34. Also missing from standard models is the so-called risk-taking channel, whereby the riskiness of bank portfolios is determined endogenously, and is sensitive to interest rates.<sup>36</sup> The basic argument is that in a low interest rate environment, intermediaries will increase the riskiness of their portfolios, as well as the degree of leverage, in order to increase the rate of return on capital. To begin to address this kind of issue, models need to incorporate assets with different degrees of risk and return, and then endogenize the determination of shares of such assets in bank portfolios.

35. Portfolios including assets with different risk characteristics are introduced by Roger and Vlcek (2011). In this model banks hold a standard risky portfolio consisting of loans to the private sector together with a portfolio of risk-free government bonds. However, the relative size of these portfolios is set exogenously and the riskiness of the overall portfolio is constant.

36. On the liability side, the endogeneity of funding decisions is also absent from most models, precluding analysis of the potential impact of such choices on transmission and financial stability. Of particular importance in this regard are the choices between domestic and foreign currency funding, and between retail deposit funding and wholesale interbank funding. Dib (2010a,b) and Meh and Moran (2010) allow for interbank funding of retail banks, but the models do not allow for any choice between retail and interbank funding.

### C. Risks

37. The frameworks embedding financial frictions into DSGE models focus primarily on market and credit risks. Market risks refer to fluctuations in the value of agents' portfolios due to changes in underlying factors as interest rates, asset prices and exchange rates, while whereas credit risks relate to risks of defaults. Current DSGE models pay much less attention to liquidity risks and contagion risks in the banking sector.

#### **Interest rate and asset price risks**

38. Market risks related to interest rates are relatively well described by models with financial frictions. Depending on the nature of the debt contracts in the models, costs of interest rate movements are borne either by borrowers or lenders. Fully indexed and state-contingent debt contracts, as originally assumed in the financial accelerator framework, imply that borrower bears all interest rate risks. When contracts are non-indexed, supply

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<sup>36</sup> Search for yield or collective moral hazard are usually mentioned as the mechanisms motivating such behavior.

shocks such as price markup shocks or productivity shocks give rise to real redistribution effects.<sup>37</sup> Since borrowers are usually assumed to have a higher propensity to consume than lenders, these wealth redistribution effects are usually considered likely to amplify the demand effects of the original shock.

39. To introduce market risks related to interest rate changes into bank balance sheets either maturity transformation or a difference between ex-ante and ex-post returns on loans needs to be embedded into models. Zhang (2009) modifies the original financial accelerator framework by introducing an explicit banking sector which shares aggregate risks with entrepreneurs. Unexpected aggregate shocks to projects outcomes affect balance sheets of both firms and banks.

40. Market risks related to asset prices are introduced by assuming shocks directly affecting asset prices or the value of agents' collateral. Reflecting the transversality condition, DSGE models do not allow for endogenous asset price bubbles. Deviations of relative asset prices from fundamentals are, therefore, modeled as standard shocks with high persistence. Alternatively, learning or confidence (expectation) shocks could be used.<sup>38</sup> An asset prices bubble as a temporary deviation from fundamentals values is suggested by Bernanke and Gertler (1999). They assume that the duration and amplitude of asset price shocks is stochastic and assess the implications for the conduct of monetary policy.

### **Exchange rate risk**

41. In an open economy context, the financial accelerator framework can be used to generate an explicit country risk premium when combined with the assumption that agents can borrow from abroad. In this case the external financing premium becomes a country risk premium which evolves endogenously with the balance sheet positions of agents and with asset prices.<sup>39</sup> In Choi and Cook (2004) the external financing premium is applied to banks rather than to entrepreneurs. Iacoviello and Minetti (2006) embedded the collateral constraint framework into a two country model enabling entrepreneurs to borrow either from domestic or foreign households.

42. In the open economy model, the currency denomination of assets and liabilities has an important influence on the wealth and cash flow consequences of exchange rate movements, analogous to the indexation or non-indexation of debt contracts. Liability dollarization, common in emerging market economies, implies that exchange rate depreciation raises debt

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<sup>37</sup> See e.g., Christiano, et al. (2004).

<sup>38</sup> See, e.g., Beaudry and Potier (2004).

<sup>39</sup> See Cespedes, et al. (2004) and Choi and Cook (2004).

service costs and worsens balance sheet positions of borrowers. These effects may potentially overshadow the usual substitution effects of exchange rate movements, with important consequences for the conduct of monetary policy. The effects of liability dollarization and credit constraints under different exchange rate regimes are discussed by Cespedes, et al. (2004) and Elekdag and Tchakarov (2007). Both these papers introduce credit frictions through the financial accelerator and resume full dollarization of liabilities.

### ***Default risk***

43. With regard to credit risks the financial accelerator framework is the only framework allowing endogenous defaults of debt contracts. With stochastic project outcomes, contract default is possible, but in the original setup default costs were borne by entrepreneurs so that lenders could not go bankrupt. In the collateral framework borrowers do not face idiosyncratic risks of project outcomes and consequently endogenous defaults are ruled out.<sup>40</sup>

44. An endogenous probability of defaults by firms and banks can be introduced into the general equilibrium framework following de Walque, et al. (2009). In their model defaulters are not excluded from the market, they just face higher costs to obtain new loans reflecting bad reputations. Firms decide how much of their loans they want to repay, taking into account the higher cost of borrowing associated with defaults, as well as the disutility from loss of reputation. Defaults by firms, in turn, can lead to banks defaulting on interbank debts. Dib (2010a,b) uses a similar set up in modeling the interbank market, finding that the interconnectedness of the financial system can amplify shocks, while higher capital buffers mitigate the effects of shocks. An alternative approach to determining defaults is simply to link the likelihood of project failure and loan default to the business cycle. In such a case the default rate is assumed to rise during busts and fall during booms.

45. Goodhart, et al. (2009) assume heterogenous agents and banks to motivate financial flows and non-zero default probabilities. In this setup, defaults arise as an equilibrium phenomenon affecting agents' borrowing costs. Zhang (2009) assumes that the default rate of banks on their liabilities is a negative function of their capital. A low capital position raises funding costs inducing adverse affects on credit supply.

46. Most models employing credit frictions assume that they are always binding. Mendoza (2006) and Mendoza (2008) introduce occasionally binding constraints in order to explain sharp reversals of international capital flows—sudden stops. In this model credit constraints become binding only after a sequence of adverse shocks and induce a spiraling collapse of asset prices further dampening real activity. In order to allow occasionally

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<sup>40</sup> The possibility of household default could be introduced by making household income stochastic.

binding constraints these papers assume a cardinal utility function for agents and need to be solved numerically using a non-linear global approximation method.

### ***Liquidity risk***

47. Liquidity risks have not been a priority for inclusion in central bank DSGE models until very recently. However, work on incorporating liquidity risks into models has been spurred by the evident importance of liquidity constraints, and their role in the contagion of financial distress during the financial crisis. Angeloni and Faia (2009) capture liquidity risks by assuming that banks face runs on deposits increasing with their leverage. To dampen liquidity risks banks must hold a non-zero level of capital. In Dib (2010a,b) lending banks choose between lending to entrepreneurs and holding risk-free government securities. Capital is held not only to satisfy regulatory requirements, but also signal creditworthiness in the interbank market. In Christiano, et al. (2010) excess liquidity is a production factor in the supply of financial transaction services. Roger and Vlcek (2011) introduce liquidity requirements as an exogenously determined share of banks' assets to be held in government bonds.