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Assessing macro-financial linkages: a model comparison exercise

Rafael Gerke, Magnus Jonsson,
Martin Kliem, Marcin Kolasa,
Pierre Lafourcade, Alberto Locarno,
Krzysztof Makarski, Peter McAdam

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Rafael Gerke - Deutsche Bundesbank
Magnus Jonsson - Sveriges Riksbank
Martin Kliem - Deutsche Bundesbank
Marcin Kolasa - National Bank of Poland and Warsaw School of Economics
Pierre Lafourcade - De Nederlandsche Bank
Alberto Locarno - Banca d'Italia
Krzysztof Makarski - National Bank of Poland and Warsaw School of Economics
Peter McAdam - European Central Bank

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Abstract

The recent global financial crisis has increased interest in macroeconomic models that incorporate financial linkages. Here, we compare the simulation properties of five medium-sized general equilibrium models used in eurosystem central banks which incorporate such linkages. The financial frictions typically considered are the financial accelerator mechanism (convex " spread" costs related to firms' leverage ratios) and collateral constraints (based on asset values). The harmonized shocks we consider illustrate the workings and mechanisms underlying the financial-macro linkages embodied in the models. We also look at historical shock decompositions of real GDP growth across the models since 2005 in order to shed light on the common driving factors underlying the recent financial crisis. In these exercises, the models share qualitatively similar and interpretable features. This gives us confidence that we have some broad understanding of the mechanisms involved. In addition, we also survey the current and developing trends in the literature on financial frictions.

JEL: E32, E44, E47, E52

Keywords: Financial Frictions, Credit Constraints, Financial Accelerator, Model Comparison, Eurosystem Central Bank Models.

> *... the biggest lesson of the financial crisis is that our models need to find a more meaningful role for finance. Episodes of financial stress are too frequent, and seem too costly, to be treated as events that are "bad luck" ...* (Cecchetti et al., 2009, p9)

1 Introduction

The global financial crisis (the "Great Recession") which began around the turn of 2007/2008 has prompted a fundamental re-evaluation of modeling strategies as regards financial linkages. It has long been known that financial markets were imperfect. This reflects information and risk-taking asymmetries and adverse selection between lenders and borrowers, costly verification of financial contracts, the possibilities of bankruptcies and contagions, etc. Consequently, a feature of financial markets is that lenders tend to demand a premium (or spread) over "risk-less" interest rates as compensation against such uncertainties and costs. The effect of that spread, moreover, is likely to be highly pro-cyclical, thus amplifying economic downturns. In addition, borrowers may also be restricted in the absolute amount of funds available to them, for example as in mortgage loans, and may therefore be required to provide collateral for those loans.

The strength of such "financial frictions" and the soundness of the financial system naturally have implications for how central banks conduct monetary policy and assess inflationary pressures and risks. The widening of spreads and deterioration in private lending from late 2007 onwards in many countries prompted a number of central banks to loosen monetary policy and engage in various forms of enhanced credit support.

Thus, recent episodes of financial-market turbulence have increased the demand for general equilibrium models that can account for the interaction between these markets, inflation and the real economy. Yet, many existing policy models largely assumed frictionless financial markets (with a few notable exceptions, such as Christiano et al. (2003)). This reflected, to some degree, academic and empirical controversy as to the importance of financial channels. Some analysis stress them as a key amplifier and source of business-cycle fluctuations (e.g. Bernanke et al. 1999) whilst others suggest their impact may be confined to periods of deep financial distress (see Meier and Mueller, 2006).

To illustrate, the spread between policy rates and commercial rates are typically small and have the same time-series properties, thus justifying modelers turning a blind eye. During periods of intense financial stress, however, this is unlikely to be the case (e.g., Gilchrist and Zakrajsek, 2011). The question then becomes how frequent are large financial crises. A recent and widely regarded historical analysis of over 600 years and almost 70 countries (Reinhart and Rogoff, 2009) suggests that financial crises are frequent and share many common characteristics: i) declines in real housing prices average 35 percent, stretched out over six years, while equity prices fall an average 56 percent over 3.5 years. ii) unemployment rises an average of 7 percentage points during the down phase (average length being four years); output falls more than 9 percent over a two-year period. iii) government debt tends to increase rapidly with its biggest driver the collapse in tax revenues; counter-cyclical fiscal policy efforts also contribute, as well as sharply increasing interest rates.

Against this background, our paper surveys the strength and nature of financial channels and frictions in a number of prominent central bank models of the eurosystem (hereafter, ESCB), when examined over common simulation and historical exercises. We proceed as follows. In the next section, we address the latest developments in modeling of financial frictions. This area has witnessed a dramatic increase in research seeking to address the causes of financial failures in general, the specificities of the most recent financial-led downturn and remedial policies. Section 3 takes a first look at the models (five in all) that we shall examine. They represent a useful cross section since three are estimated on the euro area data, one is estimated from Swedish data and one from Polish data – the latter two being interesting as examples of countries outside the single currency. In section 4 we present harmonized simulation evidence from the models. Such experiments or model comparison exercises are useful for a number of reasons:[1] first, if – for commonly scaled shocks – the models share qualitatively similar and interpretable features, this gives us confidence that we have some broad understanding of the mechanisms involved. Second, model development is a continuous process and so comparisons of model reactions allows us to build up robustness and common knowledge in the development and assessment of those models. The common shocks that we consider are: a standard monetary shock, an equivalent spread shock, a loan-to-value ratio shock, and a so-called valuation shock. In section 5, we use the same model families to show historical shock decompositions of GDP growth from 2005 in order to shed light on the common driving factors underlying the recent financial crisis. This is both instructive in itself and sheds light on whether robust cross-country, cross-model messages emerge. We finish the main part of the paper, by looking at future research direction in the field of modeling financial friction. Section 7 concludes.

[1] In the past many such exercises have appeared in and been sponsored by *Economic Modelling*.

2 Related Literature

The financial crisis of the past three years has spawned a wealth of papers attempting to model its main narrative lines, in particular the macro-financial feedback effects. Nevertheless, the profession did not wait for the onset of the crisis to try to embed financial frictions into a macroeconomic framework: a generation of models grew out of the Bernanke-Gertler (BG or BGG, 1989, 1999) financial accelerator and the Kiyotaki-Moore (KM, 1997) collateral constraint analyses, both developed more than a decade ago. Such models provided new channels to amplify and propagate real and financial shocks to the real economy. At the heart of these models are agency problems between borrowers and lenders that are solved with appropriate contracting schemes, which in turn introduce a role for leverage, risk and spreads. The BGG framework emphasizes the role of the external finance premium, the cost wedge between raising funds internally or externally; the KM framework highlights instead the importance of collateral constraints, which restrict borrowing to a fraction of assets. In both cases, variations in asset prices are key in determining borrowing behavior, as they affect either the price (via the finance premium) or the quantity (via collateralization) of funds available to borrowers.

In the following, we highlight some contributions in the literature on these two channels that have made their way into central banks' modeling apparatus, and in particular the five country models that we analyze in the next sections. We also document similarly relevant advances in integrating banking sectors into DSGE models. Admittedly, these advances do not necessarily reflect the current frontier in research. This is not so much a reflection of central banks' lack of interest or resources than an incompressible delay from theory to application in the policy world. Models have to be probed, tested, and validated before they can be put online, at the risk of being quickly obsolete. Much work is being done in central banks to integrate the latest research developments into the policy sphere, but the analysis presented below rests on an established modeling core. The final section of this paper, section 6, will provide more details on future directions for central bank models.

2.1 Collateralized Debt and Business Cycle Fluctuations

In their seminal paper, Kiyotaki and Moore (1997) show that relatively small and temporary shocks to productivity are amplified and propagated into the economy when debt is fully collateralized. Ex-ante heterogeneity in the time-preference profile of agents ensures that, in equilibrium, patient agents lend funds to impatient ones, generating credit flows in the economy. Furthermore, physical assets are used both as a factor of production and as collateral for loans. The dynamic interaction between the price of the asset and the credit limits acts to amplify the effect of productivity shocks on output and make it more persistent.

Collateral constraints and discount factor heterogeneity à la KM have become popular features in business cycle models, as they have proved useful to explain macro-financial linkages via housing market dynamics. Iacoviello (2005) first highlighted how nominal debt contracts and collateral constraints tied to housing values were crucial to match the positive response of spending to a housing price shock and the sluggish response of real spending to an inflation shock. More recently, Iacoviello and Neri (2009) quantify the contribution of the collateral effect on household borrowing to explain the empirical dynamics of household consumption. They find that shocks to housing demand and supply and to monetary policy account for most of the dynamics of residential investment and housing prices, and that spillovers from housing markets to consumption are empirically relevant. Using a model with similar KM features, Campbell and Hercowitz (2005) assess the contribution of the financial reforms of the early 1980s to the reduction in macroeconomic volatility, finding that lower down payment requirements and amortization rates for durable goods purchases, as implemented in the early 1980s, explain a large part of the actual decline in the volatility of output, consumption, and hours worked. Collateral constraints of the Campell-Hercowitz type can reproduce the response of durable and non-durable spending to monetary policy shocks, as shown by Monacelli (2009). Collateralized household debt is a crucial feature in explaining the monetary-policy induced co-movement of durable and non-durable spending. Calza et al. (2009) use collateral constraints to show that the transmission of monetary policy shocks to residential investment and consumption is stronger when down-payment rates are low and mortgage contracts are set with variable rates, in line with empirical evidence. In sum, collateralized household debt is critical to replicate several business-cycle facts related to consumption spending, housing prices and housing investment.

2.2 The External Finance Premium

The Bernanke-Gertler financial accelerator mechanism has also spawned a large literature emphasizing financial frictions on the corporate side. The mechanism relies on blending production technologies and asymmetric information. The acquisition of capital is financed from both entrepreneurial net worth and external funds. Using a "costly state verification" approach à la Townsend (1979, 1988), BGG assume that capital goods producers can easily observe the returns to their individual projects, but lenders must incur a cost to do so. This inherent agency problem is solved with an optimal contract that trades off monitoring costs and default probabilities, and implies an external finance premium that depends on the entrepreneur's leverage ratio. It therefore represents a novel amplification and propagation mechanism of productivity shocks.

Using a quantitative model with a BGG-style financial accelerator mechanism, Christiano et al. (2003) argue that the borrowers' balance sheet channel was a major contributor to the amplification and persistence of the Great Depression, much of which owed to an exogenous rise in households' liquidity preference. Indeed, a shift in preference for accumulating currency instead of time deposits crimps investment by reducing the availability of external funds to entrepreneurs. The accelerator effect, working through the fall in entrepreneurial net worth, exacerbates the impact of the shock on the aggregate economy. Estimating a variation on the BGG model, Christensen and Dib (2008) show that the financial accelerator improves quantitative models' fit of US data. Moreover, the nominal aspect of financial contracts greatly amplifies and propagates the effect of demand shocks on investment, while it dampens the effect of supply shocks—a result also obtained by Iacoviello (2005) in a model with collateral constraints and nominal debt contracts. Christiano et al. (2009) develop a large scale, BGG-style model estimated on US and Euro data with two new financial disturbances capturing time-varying risk profiles of entrepreneurs and their survival probabilities. The authors find that these two shocks account for roughly a fifth of the variability in the business cycle component of output in the EU and the US. Moreover, the risk shock is the most important source of fluctuation for GDP growth in the EU and the second most important shock in the US. Dib et al. (2008) add an international dimension to the framework adopted in Christensen and Dib (2008) and estimate their model on Canadian data. Financial shocks to the domestic credit market explain a large fraction of variability in investment, GDP, real exchange rate, hours and consumption, while international financial disturbances account for around 10 percent of variations in GDP, investment and the real exchange rate, and slightly less of the variability in consumption and asset prices. These studies, along with many other papers, underscore the empirical importance of the financial accelerator in business-cycle analysis.

KM-style agency costs and BGG-style financial accelerators need not be confined to the household and corporate decision problem, respectively. As a case in point, Carlstrom et al. (2010) integrate collateral constraints on the corporate side, by assuming that labor demand must be partly financed by borrowing, which is itself constrained by entrepreneurial net worth and profits. This set-up generates a feedback loop between asset prices and productive inputs, with interesting amplification and propagation features. Similarly, Aoki et al. (2004) introduce the financial accelerator in a framework with housing investment, where home buyers are the ones to face an external finance premium. This mechanism amplifies and propagates the effect of monetary policy shocks on housing investment, housing prices and consumption. Cúrdia and Woodford (2010) also play the same mixing game, by introducing a time-varying wedge between the interest paid on household debt and earned on household saving. The set-up yields two sources for a credit-spread: financial intermediation requires real resources and intermediaries must cover losses from loans that will be defaulted upon. The spread may be endogenous or exogenous, depending on the parameterization of the model.

2.3 Banking in DSGE models

Most of the recent analysis on financial frictions in DSGE models–including those described above—tends to assume that investors lend directly to borrowers, without the intervention of financial intermediaries. In reality, a large fraction of financial flows are channeled by banks. The following section summarizes recent work that analyzes how the banking sector affects economic fluctuations in a general equilibrium environment.

A first strand of the literature considers perfectly competitive banking sectors in which the production processes of loans and deposits are costly and interest rates are determined by zero-profit conditions. Prominent examples of this approach are Christiano et al. (2007), and Goodfriend and McCallum (2007). The former integrate a neoclassical model of banking into a fully-fledged DSGE model estimated on Euro Area data, and find that banks play a relatively minor role, whether as source of shocks or as propagation mechanism. The latter consider banks that produce loans using collateral and monitoring, and identify the external finance premium with the marginal cost of loan production. They emphasize the role of money in facilitating transactions by considering a cash-in-advance constraint that ties spending to the amount of bank deposits. The presence of collateral in the production function generates a "banking accelerator" similar to the financial accelerator: monetary expansions that increase the value of the collateralizable assets reduce the external finance premium for given bank deposits. It also generates a "banking attenuator", by which the increase in spending increases demand for bank deposits and the premium for given collateral. Which effect dominates depends on the calibration.

A number of papers have analyzed the implications of imperfect competition in the banking sector on economic fluctuations. In Aliaga-Diaz and Olivero (2007), market power of banks is due to switching costs. When setting interest rates, banks face a trade-off between higher current profits and lower future market share. This generates counter-cyclical spreads which amplify the effects of TFP shocks on the economy. In Mandelman (2006), entry in the retail banking sector entails sunk costs, forcing banks to enter at a minimum efficient scale. In expansions, incumbent banks face stronger competitive pressure from outsiders, which generates countercyclical mark-ups and amplifies business cycle fluctuations. Stebunovs (2008) provides a model of spatial monopolistic banking competition with endogenous entry of goods-producing firms, in which new entrants borrow from banks to finance start-up costs. He finds that stronger monopoly power in the banking industry increases the financial burden faced by borrowers, thus reducing the number of firms in the market and the aggregate level of output. In these circumstances a positive technology shock has a proportionally higher effect on total production than in a perfectly competitive banking environment. Finally, Andrés and Arce (2008) consider a monetary economy where spatial monopolistic competition à la Salop in the banking sector interacts with collateral constraints on borrowers. Stronger banking competition affects cyclical fluctuations through two channels: higher leverage ratios (which increase short-run volatility of housing prices, consumption and output) and lower lending margins (which weaken the transmission mechanism). As the authors show, the leverage effect dominates the lending margins effect following a monetary policy shock, but the opposite is true in the case of credit-crunch shocks.

Finally, Hülsewig et al. (2006) and Gerali et al. (2009) analyze the effects of sluggish adjustment in nominal loan and deposit rates on cyclical fluctuations. Both papers propose economies where a continuum of banks compete à la Dixit-Stiglitz and are subject to costly adjustment of nominal loan rates (either Calvo- or Rotemberg-style). In Hülsewig (2006) et al.'s framework, banks shelter firms from monetary policy shocks by smoothing lending rates, which weakens the cost channel. Gerali et al. (2009) study the contribution of banking shocks (in the form of shocks to banks' balance sheet and to loan rates) to the business cycle. They find that shocks originating in the banking sector account for the larger share of the output contraction in the Euro Area in 2008.

The models at the core of the analysis in the next section all exhibit at least one form of financial frictions as described above: collateral constraints and financial accelerator on the household or corporate side, or both. As was argued at the start of this literature review, much progress has been made in DSGE-modeling of financial frictions in general, and the banking sector in particular, since the start of the financial crisis. The final section will highlight the major routes undertaken to push this research frontier.

3 An Initial Examination of the Models

3.1 Broad Model Characteristics

We use five different models in this study - from the National Bank of Poland (*NBP*: Brzoza-Brzezina & Makarski, 2011), Sveriges Riksbank (*Riksbank*: Ramses II model of Christiano et al. 2011), Banca d'Italia: Darracq-Pariès & Notarpietro, 2008), the ECB (*ECB*: Fin model of Lombardo & McAdam, 2012) and the Bundesbank (*Bundesbank*: Buzaushina et al., 2011.).

3

The BdI model is a two-country economy (Euro area and the US), the Bundesbank is a two-country monetary union model (Germany and the rest of the euro area) supplemented with an exogenous foreign sector while the other three are small-open economies supplemented with an exogenous foreign sector.

The models are mainly used for policy simulations and research while the Riksbank's model is also used in the forecast/projections process. All models are estimated on quarterly data, although these tend (with the exception of the BdI and ECB models) to include relatively short samples from the mid 1990s. Monetary policy is modeled with a Taylor rule. **Table 1** summarizes their main features.

The models feature the two common financial frictions described in the previous section: collaterally constrained agents (households and/or firms) and a financial accelerator mechanism à la BGG. The NBP and BdI models have collaterally-constrained agents: the NBP-model has both collaterally constrained households and firms, while the BdI-model only has the former. The Riksbank and Bundesbank models have a BGG-friction. The ECB model is the only one that combines both collaterally constrained households with respect to housing and with a BGG-friction for firms.

Data on various financial variables have been used when estimating the models. The models that feature the BGG-friction have used data on firms' spread, i.e. the spread between a measure of a market-wide corporate bond and a riskless bond. Models that incorporate collateral constraints have used data on the spread on household deposits, loans to households and firms, property prices, and residential investments among other things. In all the estimations, the riskless policy rate has been included.

3.2 Key Parameter Comparisons across Models

We now focus on a comparison of the models' key parameters. By "key" we mean parameters most likely to affect model dynamics: parameters of adjustment costs and nominal inertia; the Taylor response coefficients; and the size and persistence of technology, monetary and financial shocks. An overview is given in **Table 2**.

The parameters are comparable only to a certain degree: while the BdI and ECB columns represent deep parameters for the whole EMU, the Bundesbank parameters are related to Germany, and finally the Riksbank and NBP parameters are related to Swedish and Polish cases, respectively.

Monetary policy is modeled with an augmented Taylor-rule, as is standard in most DSGE-models. That is, the central bank also put some weight on (i.e., smooths) variations in the interest rate in addition to setting targets in inflation and output. This smoothing parameter is estimated to be around 0.8 in all models. The estimate of the coefficients on inflation and output (or output growth) is also similar among the models. The reaction coefficient on inflation is around 1.5 and on output around 0.2.[2] Furthermore, the standard deviation of the policy innovation is also in the same ballpark in all models, at about 0.1-0.2. Consequently, the monetary policy rules appear relatively similar.

The nominal rigidities consist of both price and wage stickiness. The average wage contract length is about 1 year in all models, except the BdI-model where it is around 2 years. The average duration of the price contract length ranges from 2 quarters (the NBP model) to around 9 quarters (the Riksbank model). Indexation values in the model are relatively modest, between 0.2 to 0.4.

The real adjustments costs consist of investment adjustment costs.[3] The ratio of investment-to-non-residential investment adjustment costs (where applicable) is around 2 in the ECB model, calibrated to be common in the BdI model, but is around 0.1 in the NBP model (reflecting the substantial higher adjustment costs in the residential sector). Values of around two are slightly lower than standard estimates in the literature.

The steady state spread varies between about 100 basis points in the Bundesbank model (calibrated) and around 200 basis points in the NBP and Riksbank models. The estimate in the ECB model lies somewhere in between, at about 130 basis points.

The models that have collateral constraints – the NBP, BdI and ECB models – include a calibrated loan-to-value ratio and a share of "patient" households. The loan-to-value ratio is about 0.75 in the three models for households. The NBP-model also includes a firm loan-to-value ratio of 0.2, reflecting survey evidence. However, there is less variation in the share of "patient" households. The share is calibrated

[2] An exception is the BdI-model where the coefficient on inflation is 0.91; in an open-economy setting fulfilling the Taylor principle is not a necessary requirement for determinacy/stability, as the real interest rate is no longer the only variable influencing the output gap and hence inflation. In an open economy monetary policy impulses are transmitted to aggregate demand and inflation through channels that are absent in a close economy, e.g., Svensson (2000).

[3] There are usually other real adjustment costs like for example, habit formation and capacity utilization, in the models but they are not at issue here.

to about 0.7 in the NBP model and around 0.8 in the ECB and BdI models.

The models include a broad range of shocks. They include standard disturbances such as neutral and investment-specific technology shocks. These two shocks are in general quite persistent, with the former being somewhat more so than the latter. It is notable that the persistence of the neutral technology shock in the NBP-model is quite low, at about 0.6. The standard deviation of the investment-specific shock varies substantially between the models, from about 0.2 in the Riksbank model to above 5 in the Bundesbank model.

The models incorporate four different financial friction shocks, namely shocks to net worth, the financial premium, the loan-to-value ratio and housing demand. The net worth shock is included in the models with a BGG-friction (the Riksbank and Bundesbank models). The persistence is somewhat higher in the Riksbank model, about 0.8 compared to about 0.7, while the standard deviation is slightly higher in the Bundesbank model.

There is a financial premium shock related to firms in the models with collateral constraints (the NBP, BdI and the ECB models). This shock is quite persistent in the latter two at about 0.9, while it is only about 0.5 in the NBP-model. It is notable that the standard deviation of this shock is above 3 in the Bundesbank model while it is only about 0.07 in the model from ECB.

The other two financial shocks – to the loan-to-value ratio and housing demand – are related to households in the three models with collateral constraints. Both shocks are rather persistent (in effect borderline stationary). In particular in the BdI-model where the loan-to-value shock has a persistence of 0.97 and the housing demand shock a persistence of 0.99.

4 Simulation Analysis

We now come to our main set of exercises: model comparisons across common shocks that relate to financial mechanisms in the various models. The shocks that we analyze are the following:

1. A standard monetary policy innovation whereby the policy rate increases in the initial simulation period by 25 bp;
2. An initial shock to the spread or premium faced by firms of 25 bp;
3. A "net worth" shock meant to increase spreads;
4. An increase in loan-to-value ratios;
5. A negative "valuation shock" à la Gertler and Karadi (2009);

All shocks are temporary and, in general, highly persistent. Moreover, a common reporting framework is employed: output, consumption, investment, employment, the price of capital, capital stock, inflation, spreads and the policy rate.

Overall, we can say that models tend to share qualitatively similar and interpretable features and thus give us confidence in understanding the mechanisms involved. Cross-country and cross-model differences can be mapped back – to varying degrees – to specific modeling choices and differences in key parameters, as well as observed differences in country experiences and structures.[4]

4.1 Monetary IRFs in the Models

Figure 1 shows impulse responses to a monetary shock in five models used in the five central banks models. The simulations are harmonized in such a way that they imply the same impact reaction of the quarterly policy rate, i.e. 25 bps.

In qualitative terms, the model responses are similar and very much in line with consensus views on how such a shock propagates (e.g., Christiano et al. (1999)). Following an unexpected monetary policy tightening, domestic demand and output contract (a relatively small decline of investment in the NBP model can be attributed to the smaller financial sector in Poland, and is consistent with other studies on the

[4] Note, we have not included a housing demand shock although this was done in some of our earlier work (Jonsson et al., 2010). This shock though, recall, is interesting since on the household side, collateral constraints help match the positive response of spending to a housing demand shock, and generate a correlation between consumption and real house prices that is close to the data (Christensen et al. (2008)) but absent in models without financial frictions.

Polish economy). This translates into a decrease in inflation. The contractionary effect of the policy shock is amplified by a fall in the net worth and housing collateral.

However, there are some important differences across the models concerning the shape of the impulse responses. In particular, the speed of return of investment to the steady state is markedly lower in models based on the external finance premium specification in firms' investment (Bundesbank, Riksbank and ECB). Also, models stressing collateral constraints in financing housing investment (BdI, ECB) usually do not deliver a distinct hump-shape pattern in the response of consumption. As only the NBP model imposes sluggish adjustment in the pass-through to retail rates (via a Calvo scheme), it is also the only one producing a decrease in spreads following an increase in the policy rate.

The models also differ in the amplification effect of financial frictions. To illustrate these differences, we show in **Table 3** the ratio of the nadir response of output and inflation in models with financial frictions to the respective nadir responses of these variables in the models' frictionless versions. In all models, incorporating financial frictions deepens the fall in output following a contractionary monetary policy shock. As for the inflation response, the picture is more mixed, with some of the models featuring virtually no difference between their variants with or without financial frictions.

4.2 Spread shocks

Clearly, one of the advantages of incorporating financial frictions into DSGE models is to analyze the economy's response to shocks specific to the financial sector. The first shock we consider affects spreads on loans paid by investing firms. We demonstrate its effect in **Figure 2**.

This disturbance is defined as a positive innovation to the volatility of idiosyncratic shocks faced by entrepreneurs in the models based on the BGG setup (ECB, Bundesbank, Riksbank). Hence it is sometimes referred to as a riskiness shock. In contrast, in the NBP model, which is based on collateral constraints, the spread is shocked directly. The size of the shock is normalized so that it results in an increase in the quarterly lending spread of 25 basis points on impact.

As Figure 2 reveals, this type of shock can have qualitatively different implications in various models. In all of them, a rising premium makes lending more expensive, encouraging agents to cut investment. As a result, the price of capital falls as well. As regards other variables, there are a number of striking differences across the models. In particular, some of them show a short-lived increase in output and employment (e.g., the NBP results), reflecting either the resource cost of more monitoring, or increased external demand following depreciation of the exchange rate. The effect on inflation can be either positive or negative, hence the policy is either accommodating or tightening.

4.3 Net Worth shocks

Another financial shock that can be analyzed within DSGE models currently in use among our model set captures exogenous changes in borrowers' balance sheets. In the external finance premium setup, this shock increases the mortality rate of entrepreneurs, lowering the stake the borrowers have in investment projects, and effectively limiting their ability to attract funds. We present the impulse responses in **Figure 3**, normalizing them so that the peak reaction of the quarterly lending spread in each model is 25 bps.

In many respects, the qualitative effects of this shock are very similar to a riskiness shock. However, the degree of similarity across the models is much higher. All of them show a sharp contraction in investment, which is not fully offset by an increase in consumption (exiting entrepreneurs transfer their resources to households so an increase in the mortality rate boosts households' income), so aggregate output falls, except for a short-lived increase in the ECB model. The shock resembles a demand shock since output and inflation move in the same direction, so the monetary policy is accommodating. Interestingly, in two out of three models considered (ECB and Bundesbank), the spread continuously rises for a couple of quarters before it starts dying out. This reflects the fact that with a significantly higher proportion of firms going bust (compared to before), the contraction of output and investment is deep. Since firms' net value decreases for a prolonged period reflecting the protracted decline in output and investment, this implies that the spread stays on a rising trend. This reinforces the contraction.

4.4 LTV Shocks

We use the fact that in two of the five analyzed models, we can stochastically perturb the share of assets that can serve as collateral, i.e. the loan-to-value ratio. The responses are presented in **Figure 4**, in which the initial increase in LTV is normalized to 10 percent. Since in the NBP model collateral constraints concern not only households but also firms, we additionally show for this model the responses to an increase in the LTV ratio relevant to financing housing only.

A positive shock to the LTV ratio corresponds to an exogenous temporary increase in the availability of funds to the borrowers and is clearly expansionary. The borrowing households thus increase consumption. The response of investment and real house prices can be positive (BdI model) or negative (NBP), depending on whether relaxing the credit constraint is mostly used to increase consumption or housing purchases. As can be seen from the two variants of the NBP model, there is little spill-over from relaxing collateral constraints in one sector to the other. In particular, an increase in the LTV affecting firms has hardly any effect on house prices. Similarly, a shock to the LTV ratio in the households sector barely moves the price of capital.

4.5 Valuation Shocks

Some recent contributions to the literature study the impact of a 'capital quality' shock, so as to capture in a simple way an exogenous source of variation in the value of assets held by intermediaries (Gertler and Karadi 2009, Gertler and Kiyotaki 2010 and Brunnermeier and Sannikov 2010). This exogenous trigger will be amplified by the fact that the market price of capital is endogenous. To mimic a broadly similar effect, we report the response across models of variables to a 10 percent increase in the capital depreciation rate (followed by a 0.9 auto-regression). This depreciation shock is best thought of as capturing some form of accelerated economic obsolescence rather than actual physical wear-&-tear. What matters in thinking about how this shock maps into the narrative of the crisis is that the supply curve of capital is shifted inwards in an exogenous and persistent way.

The rough picture of responses (see **Figure 5**) across models is as follows. A positive shock to the depreciation rate corresponds to a temporary increase in the user cost of capital, which naturally depresses demand for capital. Input substitution raises employment and households cut down on spending to rebuild the capital stock. The higher rental rates of capital, coupled with sticky prices, imply higher marginal costs which push up inflation (with various lags corresponding to the models' different degrees of nominal rigidities). Where the models differ is in the response of the price of capital and investment, and by extension output, given the consumption pattern. For example, in the Riksbank's model consumption, investment and output falls somewhat more than in the other models. In all models, Tobin's q drops, as the persistently low depreciation rate reduces the incentive to accumulate capital. The shock in these models has the distinct flavor of a supply disturbance pushing output and prices in opposite directions.

5 Historical Decompositions

Historical decompositions involve taking observables and decomposing them into the contribution associated with the structural shocks. In this way, we can observe what have been their driving forces, and, in particular, how important financial shocks have been for business-cycle fluctuations. The figures below (**Figures 6a to 6e**) show contribution charts for real GDP growth.[5] We have performed similar decompositions for inflation, the spread and housing prices, but for brevity, we suppress them.[6] In the decompositions, we omit the effect of initial conditions and measurement errors for convenience.

Given that the number of structural shocks can be relatively high (around 20 typically for a medium-sized DSGE model, recall Table 1), we group them into the following convenient and logical categories with (across the models) the following typical components:

Financial: Net Worth; Premium; Housing Demand; Residential Productivity.

Foreign: external risk premium; export preference; import price; foreign variables (demand, interest rate).

Mark-Ups: All mark-up shocks.

Demand: Domestic Risk Premium Shocks; Government Expenditure Shocks; Preference Shocks; Import Demand Shocks.

Technology: Permanent neutral technology shock; Transitory neutral technology shock; Investment-specific technology shock.

Monetary Policy: Innovation on Taylor rule

External Risk Premia: NBP only.

Note, that this distinction of shocks is by no means unique (investment-specific shocks could equally be considered among financial shocks), but it does illustrate well the workings of the model. For instance, the financial block is deliberately intended to isolate shocks which would not be found in more standard models without financial frictions. One caution is that decomposing shocks may give a misleading impression of the relative importance of shocks. For example, the number of shocks included in the technology and foreign block tends to be high. Accordingly, these shocks – by their very size – will tend to appear dominant compared to, say, the monetary block which usually comprises a single shock, unless that latter shock was unusually large. Thus, ranking shock types need not be informative. What may be of more interest is how shock types move over the cycle and whether, in particular periods, they make an unusually strong or weak contribution, relative to other times.

[5] These are measured in deviation from a mean growth rate that needs to be added to obtain the realized values.

[6] Naturally, these omitted results are available on request.

Moreover, given that quarterly decompositions can be quite noisy, we report annual cumulated results: $\sum_{j=0}^{3} X_{t-j}$.[7] The reporting horizon is from 2005:1 until the end of every particular model's estimation sample, capturing the neighborhood around the financial crisis.

5.1 The Real GDP Growth Rate

In the context of growth, we first notice that financial shocks are strongly pro-cyclical: when the economy contracts (expands), financial shocks tend to make a negative (positive) contribution. A visually quite clear example of that is from the NBP decompositions. Second, though financial shocks played some small (i.e., around 10%) role in the cumulated downturn in real GDP, they were by no means dominant. That said, in the Riksbank and NBP models the contribution of these shocks can on occasion be extremely large, at around a third. Although their overall effect was not dominant, a notable feature is that when countries' growth fell below zero, the defined contribution of financial shocks to the real economy widened over time. A good example of that is the Riksbank profile where financial shocks go from a GDP contribution of around 5% in 2008:4 to almost 20% in subsequent quarters.

5.2 Overall Summary

As earlier indicated we performed historical decompositions for a number of variables and not solely real GDP growth. This was done for brevity. However for reference, we can draw common lessons and interpretations about the effect of financial shocks and frictions across many variables, as follows:

1. Financial shocks are markedly pro-cyclical. For instance, when real output growth or house prices are high relative to their historical mean, financial shocks tend to be "supportive", and vice versa.

2. Financial frictions are both source and propagator of business-cycle fluctuations. In terms of GDP growth and inflation, financial shocks per se are not dominant. However, since we know that financial frictions were important during the Great Recession; this is simply another way of saying that financial frictions also represent a strong propagation mechanism within the economy. We need only look back on our simulations, to remind ourselves of the amplification effects of all shocks under financial frictions.

[7] NBP is the only model which reports quarterly decompositions; GDP decompositions are expressed in annual terms but not annualized cumulated terms.

3. Financial shocks mostly affect financial variables.

4. A discussion of both the pattern of structural shocks and monetary outturns suggest that monetary policy was in general restrictive around the downturn, but supportive thereafter.

5.3 Growth and Monetary Policy

An interesting story to draw out is the contribution of monetary policy shocks to growth. Mostly, we see that the role of such shocks is small compared to say technology and foreign shocks (although this would be true in general). However, this masks a subtle but important narrative. Monetary policy shocks (with the notable exception of Poland) appeared restrictive around the downturn: this is likely to have reflected the fact that short-term nominal monetary policy rates were on a tightening cycle in the run up to the crisis and although policy rates corrected themselves rapidly (see the positive contribution to GDP growth after the nadir), the contribution was muted reflecting perhaps the lower-bound constraint as well as the past effect of monetary tightening, and perhaps (to the extent that we can meaningfully capture non-credit effects), the enhanced credit support of the central bank. In the following section we make a further highly stylized interpretation of the effect of monetary-policy outcomes on the real economy.

5

5.3.1 Structural Shocks and Monetary-Growth Outcomes

Our analysis suggested that going into the crisis, euro-area monetary policy innovations were restrictive but became supportive of growth as the crisis hit its nadir. However, it is worth recalling that such decompositions show the contribution of structural shocks. In the context of Taylor rules, that reflects the “unsystematic” rather than “systematic” component of monetary policy. It remains to be seen whether we can talk in a more general sense about the contribution of monetary policy to growth. Nonetheless, since models are partly story-telling devices it may be illustrative to examine the narrative mapping between decompositions and the data.

To that end we examine (see **Figure 7**) euro-area data series from 2005 for real output growth, the policy rate (the 3-month euribor) and the spread (the difference between the rate of Monetary Financial Institutions loans to Non-Financial Companies – of maturity up to one year). Thus, the actual representative borrowing rate was the euribor plus the spread – although given credit scarcity during periods of the Great Recession, the true (shadow) borrowing rate would have been higher.

The euro area experienced strongly negative growth from 2008:2 to 2009:3 (as indicated by the vertical lines). Interestingly, the policy rate was on a tightening cycle going into that downturn. From 2008:3 onwards, though, monetary policy rates fell to below one hundred basis points. This pattern would have been expected to have supported output growth. However, two caveats are worth noting. First, that short-term monetary policy rates cannot fall below zero may have constrained monetary policy makers' ability to make a stronger positive growth contribution. Second, the gestation lags between monetary policy changes and the real economy is known to be long and variable: in effect, the policy relaxation would have needed time to wind in to economic decisions and the previous tightening time to wind out. The impact of policy changes may also be state dependent (i.e., monetary changes may be more or less powerful depending on when they are implemented); if so, linear models would be at a disadvantage in capturing that feature.

Regarding firms' financing costs, spreads were roughly stable before the Great Recession at just over 100 bp. Thereafter, this spread almost doubled and seemed immune (if not orthogonal) to the otherwise accommodative monetary stance. Seen in this light, the pattern of structural shocks maps very well to the actual pattern of growth and interest rates over the crisis period.

6 Wither macro-financial models?

The analysis in this paper has rested on a suite of first-generation models of macro-financial linkages. As the previous sections has shown, these models have proven useful along a number of dimensions, but they have been found wanting on other crucial aspects of the current financial crisis. This section highlights the current research frontier, so as to point where central banks are headed in their modeling efforts.

The crucial aspect of this first generation of models with financial frictions is that they did not formally require a banking sector: financial flows could be channeled directly from lenders to borrowers. The crisis emphasized the need to characterize banks as badly-incentivized agents inserted in the borrower-lender relationship for the models to match the widely-held view that the impulse, amplification and propagation all originated from the banking sector itself. One can view the next generation of macro models with financial frictions as trying to integrate this extra layer of agency problems within DSGE models. That is, costly state verification (the BGG framework) and limited enforceability (the KM framework) can potentially bite twice: in the relationship between banks and depositors, and in that between banks and borrowers.

The benchmark papers of this new generation, which are described below, follow roughly two different paths. The first group of models introduces agency problems in the borrower-lender-banker triangle while remaining in the paradigm of linear models, so that these models remain amenable to quantitative analysis and possible estimation. The second group fully takes on board the contingency inherent in imperfect contracting worlds but pays the high price of abstraction or requires new techniques that preclude their use (for the time being) for policy purposes.

6.1 Non-contingent banking models with asymmetric information

Within the first group, three papers capture the essence of the borrower-lender-bank triangle. They model formally a banking sector in a standard dynamic New Keynesian framework, but go about different ways to generate financial constraints, with different antecedents in the banking and finance literature.

Gertler and Karadi (2010) model financial constraints in the spirit of Hart and Moore (1994), as an agency problem arising from financial intermediaries' incentive to divert funds from intended projects on which they earn a risk-adjusted premium. The associated participation constraint for potential lenders takes the form of a 'skin-in-the-game' requirement which ties bankers' assets to their equity capital, generating endogenous leverage. The link between the premium and leverage goes both ways: the premium justifies leverage as a behavioral control device, while leverage justifies the premium as the marginal cost associated with the participation constraint.

Gertler and Kiyotaki (2010) build on the same premise and introduce an extra layer of agency problems in the inter-bank market, where banks may be constrained in obtaining funds from each other for the same moral hazard reasons. Angeloni and Faia (2010) take a different tack and model the banking sector in the spirit of Diamond and Rajan (2000, 2001): banks are 'relationship lenders' to otherwise illiquid entrepreneurs and develop a comparative advantage in extracting value from projects they fund. Loans are therefore illiquid because banks cannot commit to extracting the maximum surplus from the projects to satisfy the liquidity needs of those for whom they intermediate. Deposits play the role of a commitment device: the possibility of a run, should the bank threaten to shirk, would wipe out its rents. The paradox is therefore that financial fragility enables liquidity creation. The optimal deposit ratio, or leverage, will trade off the probability of bank runs with the ability to obtain better returns for the bank's depositors and equity-holders. Meh and Moran (2010) build their banking sector yet differently, on the double moral hazard framework of Holmstrom and Tirole (1997), as both entrepreneurs and banks are tempted to shirk their obligations vis-à-vis their respective providers of funds. Higher bank capital increases the ability to raise funds and facilitates bank lending, so that the dynamics of bank capital affect the propagation of shocks. The model structure delivers a channel through which both entrepreneurs' and banks' net worth affect investment, thus enhancing the traditional financial accelerator mechanism. Furthermore, leverage is endogenously determined as the product of market discipline which forces banks in a downturn to finance a larger share of investment projects out of their own wealth.

One reward for the added complexity of modeling the banking sector is the potential for a new impulse to set off new amplification and propagation mechanisms. In Gertler and Karadi's model, the pressure on bank leverage starts off asset fire-sales, resulting in a decline in asset prices and an increase in borrowing costs (spreads). The ensuing downturn on the real side launches a second round of falling asset prices and deteriorating balance sheets. The mechanism is similar in the Meh and Moran model, where endogenous leverage sets the stage for second-round effects in which lower investment leads to lower bank earnings and net worth, further limiting banks' ability to attract funds and provide external financing. The Angeloni-Faia model provides another mechanism whereby monetary easing will increase leverage and systemic fragility which in turn will amplify the real effect of monetary shocks over and above the standard transmission mechanism.

Another reward is that these models are suitable for banking-sector-oriented policy analysis, which for many was their justification in the first place. For example, Gertler and Karadi set up their model specifically to analyze quantitative easing policies, where supply of public funds generates a government multiplier on the private leverage ratio which can loosen the aggregate balance sheet when the private one tightens. Angeloni and Faia focus instead on the interaction between monetary and Basel-type prudential policy, which plays out via the supply of bank capital. With its extra layer of inter-bank intermediation, the Gertler and Kiyotaki framework can shed light on policies geared towards inter-bank market frictions.

A third, potential reward is the prospect of quantitative policy analysis of these agency issues. A common feature of all these papers is that they seek to develop tractable quantitative models that are only moderately more complex than the New Keynesian model at the core of central banks' modeling apparatus. The next step would to be to estimate these currently calibrated models. This is a priori manageable given that they are all linearized, a feature that makes them suitable for estimation with standard toolboxes (Dynare, YADA, Iris).

In fact, linearization is the crucial common step that these models take to simplify the integration of agency problems in infinite-horizon models. Indeed, in all cases, inequality constraints that arise from the incomplete contracting space (participation, feasibility, and incentive constraints for borrowers, lenders, and banks) are all set to equalities by suitable choice of parameters and functional forms, so that the models can be linearized. The upside is that shadow values, reflected in various leverage or loan-to-value ratios, generate multiplier effects and amplification and propagation channels such as asset fire-sales and de-leveraging cycles as described above. The downside is that by forcing inequalities to bind at all times, contingency is swept under the rug. For example, leverage or loan-to-value ratios are always at the maximum allowable, never less so. Yet, the occasional switch from binding to non-binding states brings about interesting dynamics. Indeed, valuation of contingent claims – of occasionally binding constraints – leads to features that are by nature excluded from linear models, but are prevalent in the data, namely non linearities (threshold effects), asymmetries, volatility and possible multiple equilibria. Several papers take a promising step in that direction.

6.2 Models with Occasionally-Binding Constraints

In a recent and important contribution, Brunnermeier and Sannikov (2010) develop a macro model which highlights several non-linear features of macro-financial linkages in a single framework. Their starting point is a standard economy populated by borrowers and lenders (but no banks) facing collateral constraints and default risk. Where they depart from the existing literature is in the solution technique, which enables them to tackle up front the occasionally binding constraints inherent in the imperfect contracting space of the model. Pricing 'max' operators, which is what occasionally binding constraints translate into, is the backbone of real option theory. Brunnermeier and Sannikov bring this aspect to the fore and chapter four major results on the interplay between the real and financial sectors.

First, by solving the model globally rather than locally, they show that the unconditional distribution of the model's state variable is bimodal. Thus, while the economy rests most of the time around a steady state with normal growth, it is prone to instability, suffering occasional bouts of high volatility. This arises endogenously, as a result of agents valuing assets with occasionally binding constraints, such as skin-in-the-game or haircut conditions. Second, risk is endogenous, as time-varying asset price volatility reflects again the response to potential future binding constraints. This feature increases asset price correlations in volatile episodes. The intuition is that when constraints bind for some assets, feedback and amplification effects eventually affect the prices of all assets, who lose their value as diversification or hedging vehicles. Third, a pecuniary externality arises from the fact that borrowers do not realize that in bad times, their asset sales will affect the price of other assets, thus affecting other agents' collateral constraints and incentives. Borrowers will therefore choose higher leverage than necessary in good times, increasing systemic instability. Fourth, securitization makes the financial system less stable because it leads to greater leverage and systemic risk, even though it enables agents to smooth idiosyncratic shocks.

He and Krishnamurthy (2009) obtain similar features in a model of aggregate liquidity à la Holmstrom and Tirole. The model is one of limited market participation, but where financial specialists (bankers) offer households exposure to excess returns, at the risk of diverting part of the reward for themselves. The incentive compatibility constraint again reflects the need for sufficient 'skin in the game' on behalf of bankers. But it is not forced to bind at all times. Accordingly, the economy exhibits two regimes, depending on whether the constraint is slack or not. In the constrained region, bankers bear the greater bulk of risk exposure precisely when they are undercapitalized, so that the risk premium and the volatility of the risky asset rise. The volatility of bankers' wealth also increases as their wealth itself falls, prompting them for precautionary reasons to re-balance to the safe asset at the same time households do, thus lowering the equilibrium interest rate and causing the market for the risky asset to dry up. Furthermore, when the constraint binds, the common component of returns on different assets is magnified, increasing their correlations.

Jeanne and Korinek (2010) construct a model of debt deflation spirals with the same flavor: debt accumulation and asset prices interact to amplify booms and busts endogenously. The model is essentially the original Kiyotaki-Moore with occasionally binding constraints (recall that KM use linear utility and different discount rates across agents to ensure borrowers are always taking on maximum debt). Insiders have a comparative advantage in holding an asset that can be used as collateral to borrow from outsiders. Specialized skills and attendant moral hazard entail KM-style incentive compatibility constraints. These generate a feedback loop: borrowing capacity is increasing in the asset price, while the asset price increases with consumption and borrowing capacity, leading to endogenous amplification and possibility of multiple equilibria. The model also entails systemic externalities as in Brunnermeier and Sannikov: borrowers do not realize that taking on debt affects asset prices, thus other agents' constraints. They undervalue savings as precautionary liquidity and borrow too much. Hence the scope for public intervention (a Pigou tax on borrowing), as a social planner would internalize the contribution of precautionary savings to reducing systemic risk.

These aspects of models with occasionally binding constraints have been also explored in the literature on sudden stops, and the current financial crisis has strikingly similar features to the episodes of financial stress and deep recessions experienced by emerging economies. Mendoza (2010) proposes a model of sudden stops which strongly highlights this parallel, using as common element the Fisherian debt-deflation mechanism. The model imposes a ceiling on the leverage ratio of an economy. When it binds, the economy is characterized by current account reversals, precipitous declines in output and absorption and asset price collapses. When it doesn't, the economy follows normal business cycle patterns. The non-linear features of the debt-deflation mechanism enable sudden stop episodes to co-exist with regular business cycles without requiring a different set of large, unexpected shocks. This suggests the same type of regime-switching characterization of the economy as in Brunnermeier and Sannikov.

The upshot of these models is that they uncover insights that linearized models by definition cannot reveal. The downside is that they are much more difficult to solve and to take to the data. They remain very stylized and making them more realistic may substantially affect some of their results. Unfortunately for central banks, most of these models also overlook the impact of nominal rigidities, or fail to underline the fact that financial frictions can generate monetary non-neutrality even in the absence of sticky prices . Furthermore, there is no formal role for intermediaries: contracts are between borrowers and lenders directly. The curse of dimensionality is such that there is a very limited set of stochastic disturbances shocking the models. These models are therefore unsuitable for quantitative analysis beyond basic calibration. Extensions to a larger state space are certain to be prohibitively expensive given current computing power. However, given the importance of the features these models uncover, more resources are being devoted in central banks to make quantitative headway along these research avenues.

7 Conclusions

Integrating financial frictions into large, institutional macro models is an ongoing agenda. It remains to be seen whether this class of models can generate sufficient internal propagation to reflect financial crises, whether they can be of use in real time in analyzing financial distress, and how far they can inform policy in terms of analyzing asset bubbles and non-standard policy responses. Many model features – passive banks, minimal default characteristics etc – remain unsatisfactory. None of our models, for instance, endogenously generate financial crises with abrupt, sudden real contractions. And in the current climate, one of the problems with existing models is that risk is located in real returns at the level of firms and consumers, even though it is widely recognized that the recent crisis originated in the financial system.

Our models, moreover, are linear business-cycle frameworks. Financial crises, particularly large ones, can have highly non-linear and highly persistent effects – they may for example lead to a permanent reduction in trend growth. Furthermore, financial crises (at least of the recent kind) are necessarily rare. In other words, they are not the essence of normal business-cycle fluctuations.

That said, whilst the models surveyed capture financial frictions and shocks through an imperfect lens but they do nonetheless possess the lens. They do allow a richer interpretation of the data and the ability to track and rank financial phenomena and shocks over time. Indeed, one might argue that in the recent current crisis, the most important problem for policy makers was their limited understanding of the qualitative interactions among relevant variables (let alone, quantitative effects). The models described here can definitely fill this gap. The models surveyed here share qualitatively similar and interpretable features. This gives us confidence that we have some broad understanding of the mechanisms involved.

Essentially, we use models to provide a quantitative and coherent evaluation of various effects and outcomes. Because they are inevitably imprecise, their simulation results should be taken as illustrative of the signs and (relative) sizes of responses, rather than as a definitive guide to real-world behavior. They are a tool for helping to tell coherent, quantitative stories about how and why financial instabilities arise and manifest themselves.

As described, new approaches to modeling financial frictions and linkages are on stream. Many of these approaches attempt to deal with many of the issues and weaknesses identified in this report. However, the basic mechanisms (collateral constraints, convex premia) are likely to continue to dominate these frameworks. New models that emerge from this research should deepen our understanding of policy-relevant issues such as the interaction between real and financial sides of the economy;

the optimal mix and feed-back between monetary and macro-prudential policies; the pass-through of policy rates to lending rates during “crisis” and “normal” periods. We expect the theme of macro-financial linkages to remain a fruitful area for research and policy analysis. But to be successful in structural models their implementation must be tractable and transparent.

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Table 1: Broad Model Characteristics

NBP		RiksBank	BdI	ECB	Bundesbank
Coverage	Poland	Sweden	Euro Area + US	Euro Area	Germany + Rest of Euro Area
Nature of Financial Friction	Collaterally Constrained Firms & HHs	BGG	Collaterally constrained HHs	BGG + Collaterally Constrained HHs	BGG
Open Economy	Appended Foreign VAR		Two-country model (euro area +US)	Appended Foreign VAR	
No. of Observables	13	19	24	21	20
… of which "financial"	1 Policy Rate (home; foreign) 2 Loans to HHs & firms 3 Spread on loans to HHs & firms, 4 Spread on HH deposits	1.Policy Rate (Home; Foreign) 2.Firms' Spread	1.Policy Rate (Home; Foreign) 2.Residential Inv. (Home, Foreign) 3.Property Prices (Home, Foreign) 4.Household debt (Home, Foreign)	1. Policy Rate (Home; Foreign) 2. Firms' Spread 3. Residential Inv. 4. Property Prices	1. Firms' spread (Germany) 2. Policy Rate (EMU; Foreign) 3. Investment (Germany and REA) 4. firms' credit (Germany)
Estimation Sample	1997:1 – 2009:2	1995:1 – 2010:3	1980:2 – 2010:1	1980:1 – 2010:2	1995:1 – 2009:4
Monetary Rule	Taylor		Taylor + Ramsey optimal rules	Taylor	
Model Use	Research; policy simulations	Forecasting; policy simulations	Research	Policy Simulations	

Table 2: Key Parameter Comparisons across Models

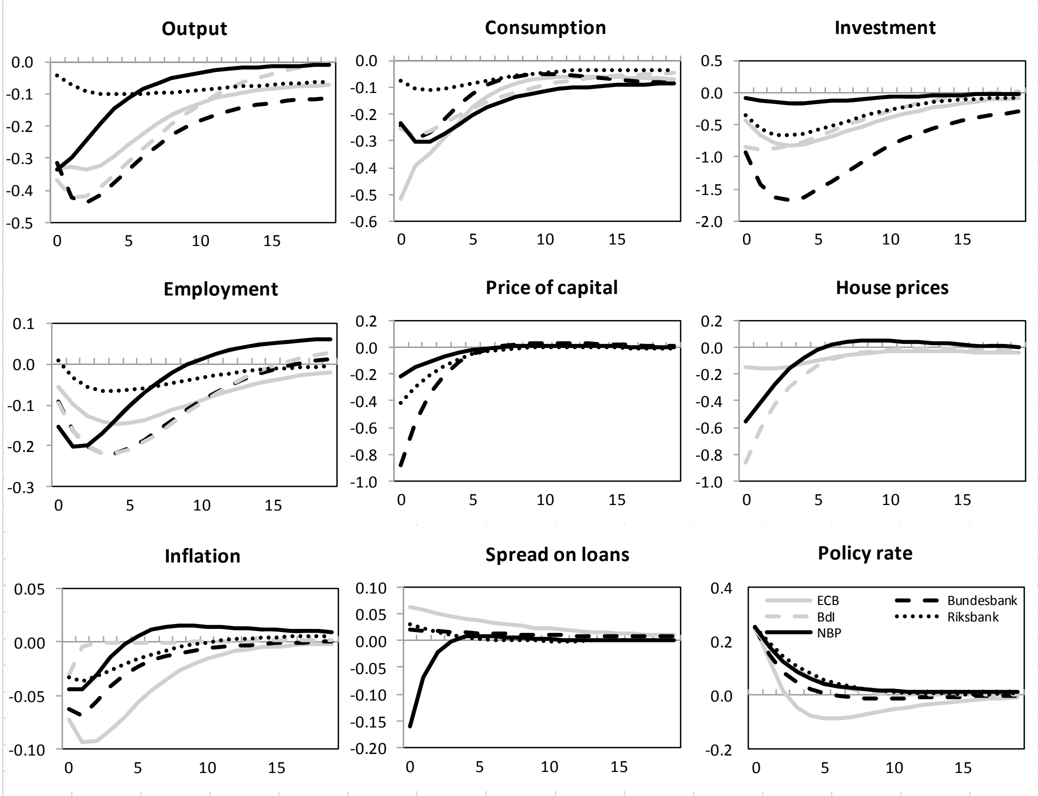
	NBP	RiksBank	BdI	ECB	Bundesbank
	Monetary Policy				
Smoothing, Infl., ΔInfl., O. Gap, Δ O. Gap	0.81, 1.55, –, 0.48, –	0.82,1.91 – ,0.023, –	0.81,0.91,0.17,0.2 (Output), 0.14 (Δ Output)	0.86,1.6,0.19, –, 0.22(Δ Output)	0.72, 1.64, –, , 0.19 (Δ Output)
Policy Innovation (σ, ρ)	0.2%, iid.	0.12, iid	0.11, iid	0.13, iid	0.15, iid
	Nominal Adjustments				
Wage Contract Length (NR, R)	4, –	4, –	7, 9	3.40, 3.40[c]	3.16, –
Wage indexation (NR, R)	0.44, –	0.43, –	0.23, 0.47	0.46, 0.46[c]	0.18, –
Price Contract Length (NR, R)	2	8.85, –	14, 0[c]	5.02, –	2.82, –
Price indexation (NR, R)	0.42	0.14, –	0.44, 0[c]	0.39, –	0.20, –
	Real Adjustments				
Inv Adj. Costs (NR/R ratio)	5.2/50	2.58 (NR)	1[c]	2.64	2.02 (NR)
Temporary Neutral Tech. Shock (σ, ρ)	1.5, 0.6	0.47, 0.84	0.58, 0.94	1.22, 0.84	0.66, 0.94
Inv.-Spec. Tech. Shock (σ, ρ)	–	0.23, 0.62	0.42, 0.96	3.0, 0.66	5.23, 0.53
	Financial Terms: Firms				
Elasticity of Financial Premium	0.0012	–	–	0.017	–
Steady-state Premium (bp)	200	232		128	106
Financial Premium shock (σ, ρ)	0.3, 0.55	–		0.072, 0.87	3.14, 0.95
Spread Contract Length	2			–	–
Loan-to-Value ratio	0.2 [c]				0.5 [c]
Loan-to-Value Shock (σ, ρ)	10.1, 0.75				–
Net worth shock (σ, ρ)	–	0.35, 0.82			0.92, 0.66
	Financial Terms: Households				
Share of "Patient" HHs	0.66[c]	–	0.85	0.80[c]	–
Loan-to-Value ratio	0.70 [c]		0.80	0.75[c]	
Loan-to-Value Shock (σ, ρ)	7.5, 0.73		0.62, 0.97	–	
Housing Demand Shock (σ, ρ)	2.3, 0.72		1.48, 0.99	9.5, 0.94	
Transitory Residential Productivity (σ, ρ)	–		0.86, 0.99	–	

Notes:
NR, R indicates non-residential and residential. "–" indicates not applicable. "c" indicates calibrated. Nominal contract lengths quoted are in quarters.

Table 3: Derived Amplification effect of financial frictions

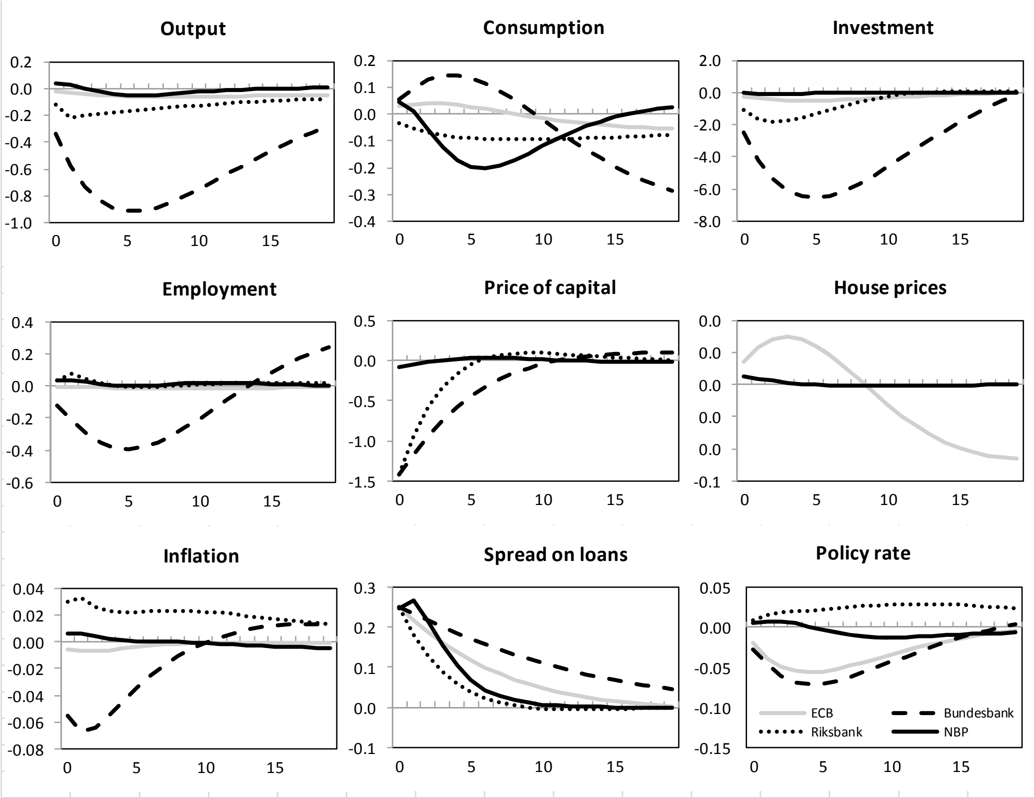
	Riksbank	BdI	ECB	Bundesbank
Output	1.29	1.14	1.48	1.11
Inflation	0.88	0.99	1.48	0.95

Figure 1.
Responses to a monetary shock in ESCB models with financial frictions



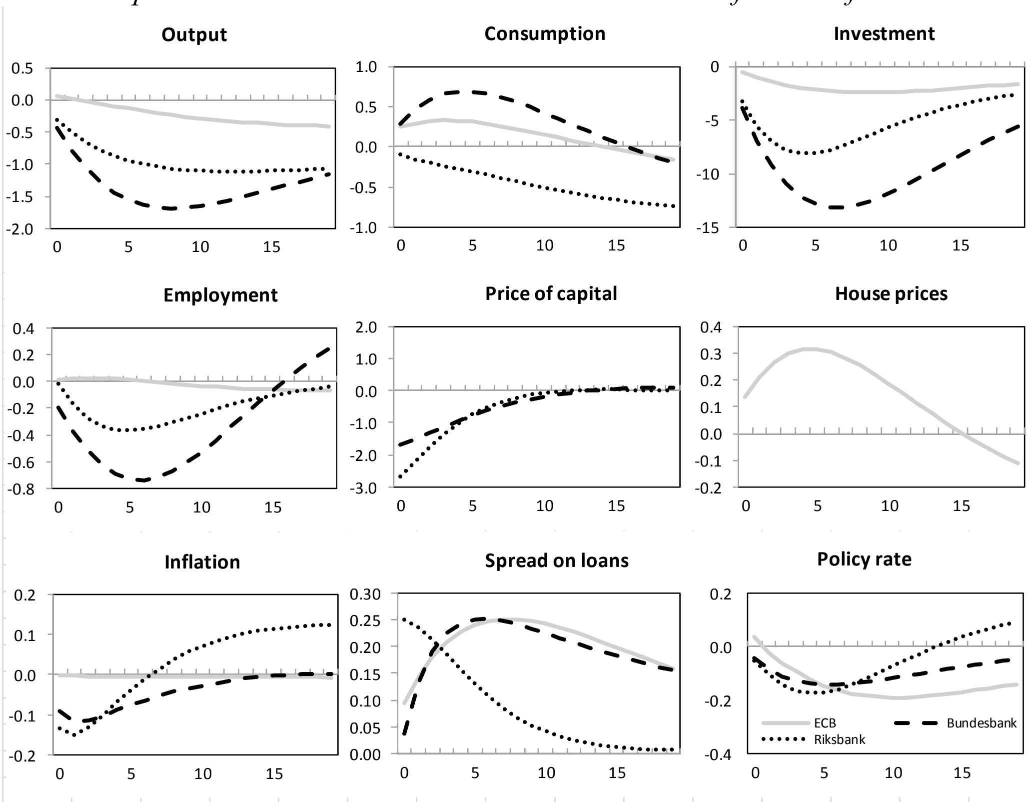
Note: This figure shows the impulse responses of selected variables to a temporary monetary policy shock of 25 bp in the first period. All responses are reported as percentage deviations from the non-stochastic steady, except inflation and interest rates.

Figure 2.
Responses to a lending spread shock in ESCB models with financial frictions



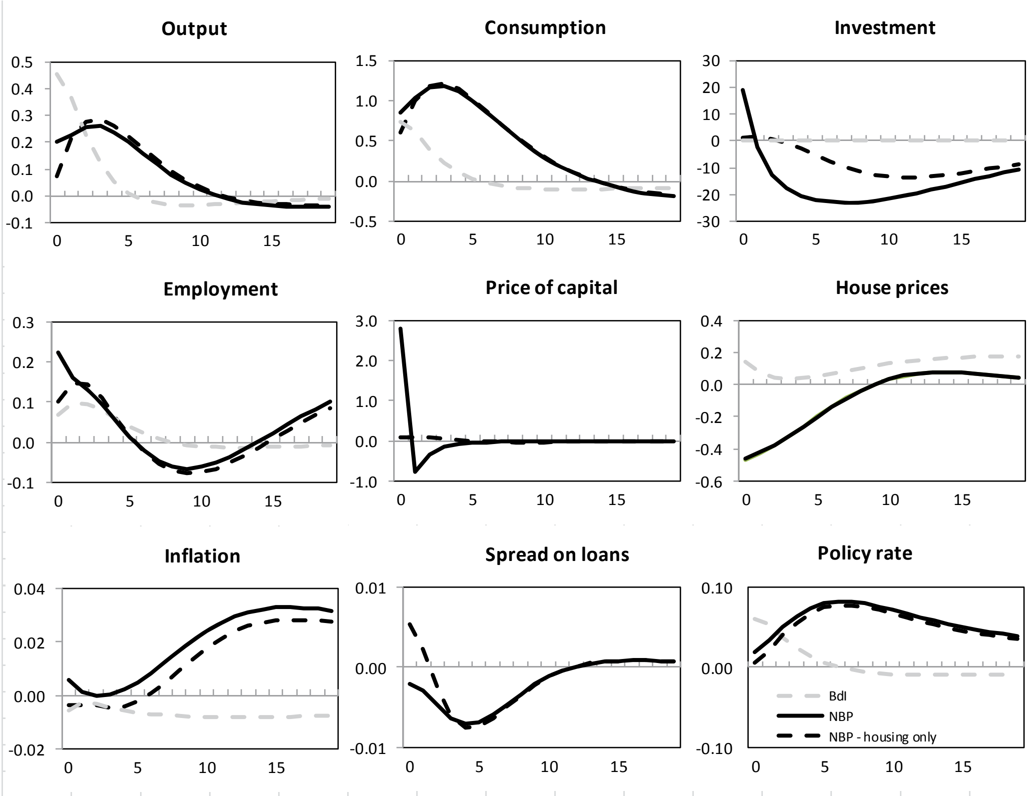
Note: This figure shows the impulse responses of selected variables to a temporary shock to the spread of 25 bp in the first period. All responses are reported as percentage deviations from the non-stochastic steady, except inflation and interest rates.

Figure 3.
Responses to a net worth shock in ESCB models with financial frictions



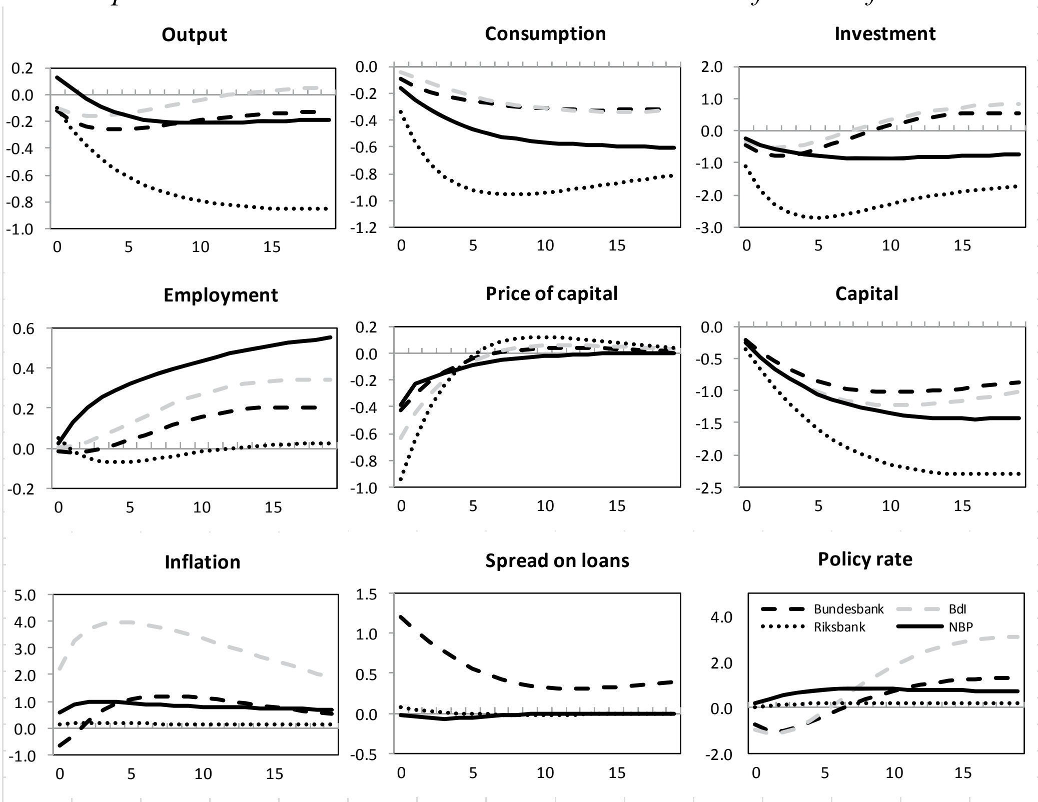
Note: This figure shows the impulse responses of selected variables to a temporary shock to net worth one standard deviation such as to impose an initial increase in spreads of 25bp. All responses are reported as percentage deviations from the non-stochastic steady, except inflation and interest rates.

Figure 4.
Responses to an LTV shock in ESCB models with financial frictions



Note: This figure shows the impulse responses of selected variables to a temporary shock to the loan-to-value ratio one standard deviation. All responses are reported as percentage deviations from the non-stochastic steady, except inflation and interest rates.

Figure 5.
Responses to a "Valuation Shock" in ESCB models with financial frictions



Note: This figure shows the impulse responses of selected variables to the depreciation rate of capital. All responses are reported as percentage deviations from the non-stochastic steady, except inflation and interest rates.

Figure 6a. Historical Decomposition of Quarterly Real Output Growth (NBP)

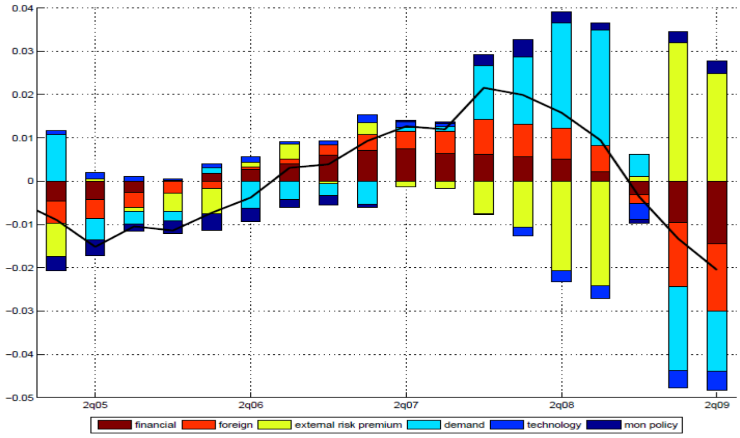


Figure 6b.Historical Decomposition of Annualized Real Output Growth (Riksbank)

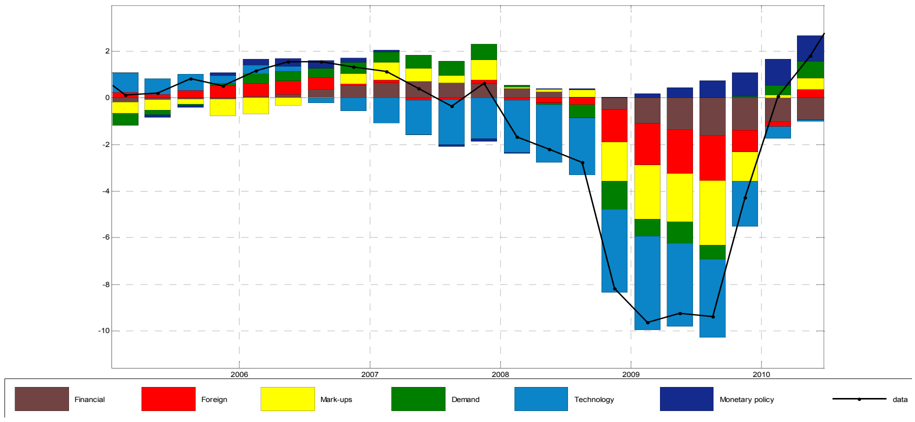


Figure 6c. Historical Decomposition of Annualized Real Output Growth (BdI)

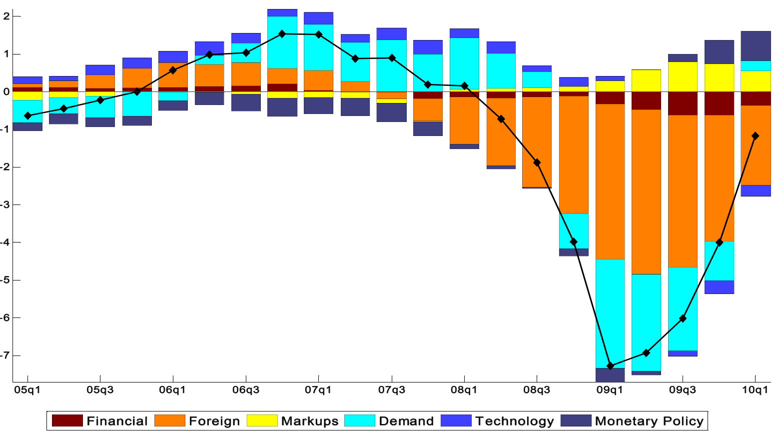


Figure 6d. Historical Decomposition of Annualized Real Output Growth (ECB)

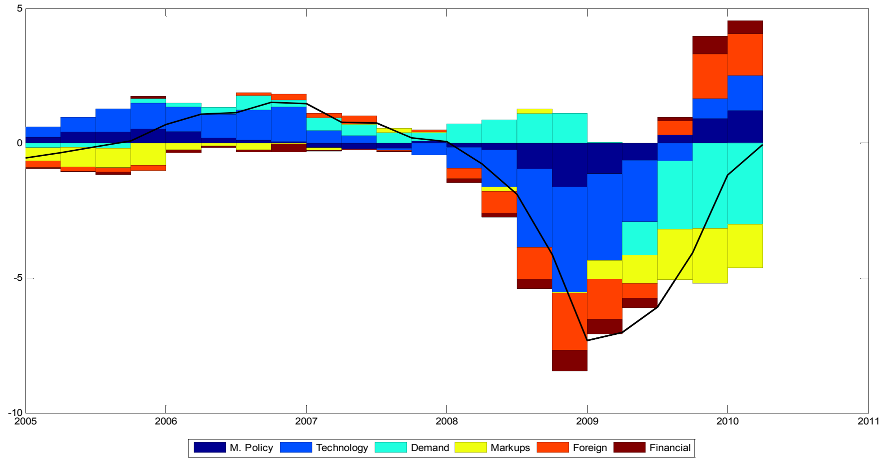


Figure 6e. Historical Decomposition of Annualized Real Output Growth (Bundesbank)

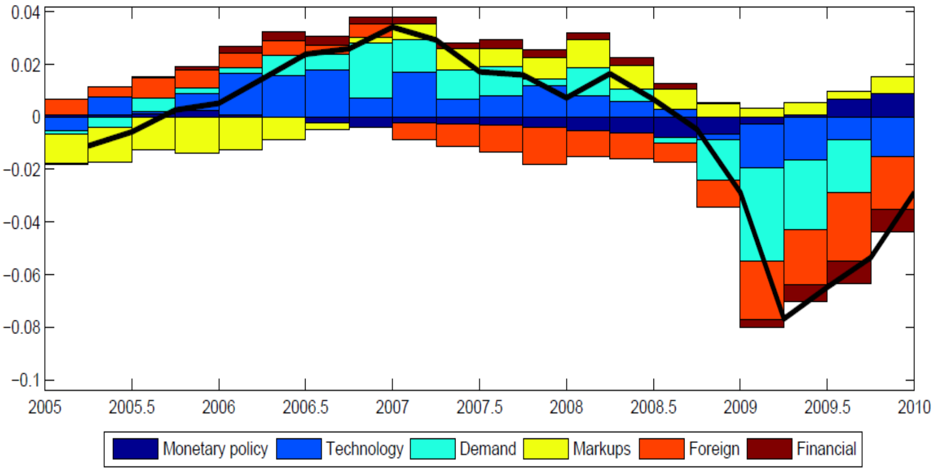


Figure 7. Euro area output growth and interest rates.