National Institute of Economic and Social Research

IMPLEMENTING MACROPRUDENTIAL POLICY IN NIGEM

Oriol Carreras*
E. Philip Davis**
Ian Hurst
Iana Liadze
Rebecca Piggott
James Warren*

*Formally of NIESR
**NIESR and Brunel University

NIESR Discussion Paper No. 490

Date: 26 March 2018

About the National Institute of Economic and Social Research

The National Institute of Economic and Social Research is Britain's longest established independent research institute, founded in 1938. The vision of our founders was to carry out research to improve understanding of the economic and social forces that affect people's lives, and the ways in which policy can bring about change. Seventy-five years later, this remains central to NIESR's ethos. We continue to apply our expertise in both quantitative and qualitative methods and our understanding of economic and social issues to current debates and to influence policy. The Institute is independent of all party political interests.

National Institute of Economic and Social Research
2 Dean Trench St
London SW1P 3HE
T: +44 (0)20 7222 7665
E: enquiries@niesr.ac.uk
niesr.ac.uk
Registered charity no. 306083

This paper was first published in March 2018

Implementing Macroprudential Policy in NiGEM

Oriol Carreras, E. Philip Davis, Ian Hurst, Iana Liadze, Rebecca Piggott, James Warren

Abstract

In this paper we incorporate a macroprudential policy model within a semi-structural global macroeconomic model, NiGEM. The existing NiGEM model is expanded for the UK, Germany and Italy[1] to include two macroprudential tools: loan-to-value ratios on mortgage lending and variable bank capital adequacy targets. The former has an effect on the economy via its impact on the housing market while the latter acts on the lending spreads of corporate and households. A systemic risk index that tracks the likelihood of the occurrence of a banking crisis is modelled to establish thresholds at which macroprudential policies should be activated by the authorities. We then show counterfactual scenarios, including a historic dynamic simulation of the subprime crisis and the endogenous response of policy thereto, based on the macroprudential block as well as performing a cost-benefit analysis of macroprudential policies. Conclusions are drawn relating to use of this tool for prediction and policy analysis, as well as some of the limitations and potential further research.

Keywords: Macroprudential policy, house prices, credit, systemic risk, macroeconomic modelling

JEL Classification: E58, G28

Acknowledgements

We thank Ray Barrell and Jagjit Chadha for helpful comments.

Contact details

E. Philip Davis: e_philip_davis@msn.com and p.davis@niesr.ac.uk; Iana Liadze: i.liadze@niesr.ac.uk; Rebecca Piggott: r.piggott@niesr.ac.uk; Ian Hurst: i.hurst@niesr.ac.uk ;National Institute of Economic and Social Research, 2 Dean Trench Street, London SW1P 3HE

[1] The three EU countries where NiGEM has banking sector models incorporated

1 Contents

2 Introduction

Since the global financial crisis, there has been increasing interest among authorities in both advanced and developing countries in introducing macroprudential policy. Macroprudential policy can be defined as being focused on the financial system as a whole, with a view to limiting macroeconomic costs from financial distress (Crockett 2000), and with risk taken as endogenous to the behaviour of the financial system. However, as noted by Galati and Moessner (2014), "analysis is still needed about the appropriate macroprudential tools, their transmission mechanism and their effect". Theoretical models are in their infancy and empirical evidence on the effects of macroprudential tools is still scarce, although our recent work (Carreras et al. 2016) and its references do show promising results for the effectiveness of macroprudential policies. A primary instrument for macroprudential policy has not yet emerged. Meanwhile, for authorities, targets of macroprudential policy are typically house prices, credit and the credit-GDP gap or judgemental assessments based on a range of macroprudential indicators. This leaves aside potential for use of systemic risk indicators based on early warning models for banking crises as a complementary target for macroprudential policy, on which there is a rich literature (see for example Davis and Karim (2008) and Barrell et al. (2010a)).

We contend that extant model-based work often either omits feedback from the macroeconomy to the financial sector, in particular a macroprudential reaction function, and/or would find disequilibrium hard to manage, and that both of these difficulties can be improved in our semi-structural global macroeconomic model NiGEM. Accordingly, in this paper we seek to introduce macroprudential considerations to an established global macromodel (NiGEM), initially by instruments of variable bank capital adequacy and mortgage loan-to-value ratios. The former will impact the economy by acting on the spread between borrowing and lending of corporate and households while the latter will transmit through its impact on the housing market.

A systemic risk indicator will keep track of the likelihood that a financial crisis takes place. Based on the work by Karim et al. (2013), the systemic risk index will be a function of banking sector capital adequacy and liquidity ratios, house price growth and the current account to GDP ratio. We shall enable users to trigger macroprudential policy directly or enable policy to be triggered endogenously as the systemic risk indicator reaches critical levels, which can itself vary between countries or be set by the user.

The paper is structured as follows: in Section 3 we present a brief taxonomy of macroprudential tools. In Section 4 we review some of the extant theoretical work on macroprudential in the macroeconomy. Section 5 introduces NiGEM and Section 6 looks at some earlier work on macroprudential policy in NiGEM. Section 7 outlines the specific extensions to NiGEM that we are introducing and Section 8 concludes.

3 Taxonomies

Authorities around the world are implementing a macroprudential pillar to economic policy, to complement microprudential, monetary and fiscal policy. Such a pillar is aimed to prevent financial crises by limiting systemic risk – the danger that there arises widespread disruption to provision of financial services that impact in turn on the real economy. In order to appropriately calibrate such measures, there is a clear need for a forecasting and simulation tool to assess appropriate triggers for macroprudential intervention, the effect of such interventions and their relationship to monetary and fiscal tools. Such a tool should also allow for global interactions and trends in financial and economic quantities and prices and cross border spillovers. NiGEM, extended to allow for user driven as well as endogenous macroprudential interventions, is ideally suited to such a role.

In this context, bear in mind that macroprudential policy may vary across time, where the policy seeks to limit the procyclical build-up of risk during a credit-driven upturn, or may be implemented at the cross-sectional level, whereby the aim is to maximise the resilience of the financial system to shocks arising from failure of large institutions or markets. The following table (from Bennani et al. 2014) shows how some tools are used to dampen the expansionary phase while others target the contractionary phase. Others again focus on contagion between systemic institutions and they aim to control risk via capital, assets or liquidity. Our own approach will focus largely on time series tools (marked in bold), although the cross sectional elements will also be reflected in any impact of such policy on aggregate actual or target capital adequacy.

Table 1: The time and cross-sectional dimensions

	Time dimension	Cross-sectional dimension
Capital	**Countercyclical capital buffer**	G-SII and O-SII buffer
	Dynamic provisioning	Systemic risk buffer (SRB)
	Sectoral capital weights	[Leverage ratio]
	[Countercyclical leverage ratio]	
Assets	**Loan-to-value (LTV) caps**	Large exposure measures
	Loan-to-income (LTI) caps	Concentration limits
	Debt-to-income (DTI) caps	
Liquidity	Limits on loan-to-deposit ratio	Systemic liquidity surcharge
	[Time varying] liquidity ratios	Liquidity coverage ratio (LCR)
	[Time varying margin requirements]	Net stable funding ratio (NSFR)
		Minimum haircuts/margin floors
		Reserve requirements

Source: Bennani et al. (2014).

General versus specific is another taxonomy of macroprudential tools. General macroprudential instruments are notably capital or provisions held by institutions (either in time series or cross-section) not specific to sectors they lend to. An example is the countercyclical buffer of 2.5 percentage points for banks, which should be raised when times are good and lowered when they are bad. Dynamic provisioning across bank balance sheets as in Spain also fits into this category. These are tools specifically developed to mitigate systemic risk. There are additional tools that may be relevant at times such as reserve requirements, liquidity regulations, capital controls and limits on system wide currency mismatches.

There are also specific tools targeted to sectors such as housing. These were often not originally developed with systemic risk in mind, but can be modified to target systemic risk. Whereas macroprudential surveillance focused on house prices as a key indicator is common across many countries, attempts to regulate house purchase lending were historically less widespread in advanced countries, but is becoming more common in the light of the sub-prime crisis (CGFS (2010), Darbar and Wu (2014), Kuttner and Shim (2016)). Examples of such tools are the loan-to-value ratio which we shall use in our own work, debt-service to income, housing related taxes, limits on exposure to housing, risk weights on housing loans and loan loss provisioning requirements linked to housing loans. A further breakdown in specific tools is between supply side credit policies (limits on exposure to housing, risk weights on housing loans and loan loss provisioning requirements linked to housing loans), demand side credit policies (loan-to-value ratio and debt-service to income ratio) and housing related tax policies that affect house prices directly, see Kuttner and Shim (2016).

In this context, according to empirical work (as summarised and extended in Carreras et al. (2016)), effective tools of macroprudential policy include loan-to-value ratios, debt-to-income limits and bank capital requirements (which may be sectoral or general). We have scope, as discussed below, for implementing loan-to-value and capital requirements in NiGEM. We note that these tools are effective in the time series dimension and at most indirectly in the cross-sectional one.

4 Macroprudential policy in theoretical macroeconomic models

Before discussing NiGEM per se, we highlight some recent work in the field of macroprudential policy and macroeconomics as background. Galati and Moessner (2014) give a helpful breakdown of progress in macroprudential modelling, into three areas: banking/finance models, three-period banking or DSGE models, and infinite horizon general equilibrium models, which we follow in this paper.

Banking/finance models, in the tradition of Diamond and Dybvig (1983) highlight how financial contracts are affected by various incentive problems related to information asymmetry and commitment that can entail default. Then, there can be self-fulfilling equilibria generated by shocks, leading to systemic financial instability. They accordingly seek to explain the interaction of borrowers and lenders. For example, Perotti and Suarez (2011) look at price based and quantity based regulation of systemic externalities arising from banks' short term funding. Accordingly, current liquidity regulation could be justified, together with a Pigovian tax on short term funding. However, such models tend to be cross section and omit the time series dimension and thus cannot be used to address procyclicality. Furthermore, they tend to be partial equilibrium and thus omit key general equilibrium effects.

Such effects are included in three period general equilibrium models of the interaction of asset prices and non-financial and financial sector systemic risk. Such models assess risk taking by heterogeneous agents in an economy vulnerable to such systemic risks. For example there may be financial amplification during booms and busts that have external effects as in Goodhart et al. (2012) and Gersbach and Rochet (2012a and b). Individual agents take decisions without allowing for the general equilibrium effects of their actions, in particular the effects of asset sales caused by excessive borrowing on asset prices. Accordingly, they generate patterns of feedback loops entailing falling asset prices, financial constraints and fire sales. Then, macroprudential tools can be shown as helpful in preventing fire sales and credit crunches, including loan-to-value ratios, capital requirements, liquidity coverage rations, dynamic loss provisioning and margin limits on repos by shadow banks (Goodhart et al. 2013).

Further results of interest are provided by models that focus on the functions of banks in the economy such as improving liquidity insurance, risk sharing and raising funding, which as shown by Kashyap et al. (2014) can then be used to analyse weaknesses underlying the global financial crisis, notably excessive risk taking by underfunded banks relying on short term funding and exploiting the safety net. Horvath and Wagner (2013), meanwhile, show that macroprudential regulations can lead savers and banks to alter other portfolio choices. Countercyclical regulation can worsen cross sectional risk for example, although tools to reduce cross sectional risk may reduce procyclicality.

Infinite horizon DSGE models with financial frictions build on the insights of papers such as Bernanke et al. (1999) on the financial accelerator. Such models (e.g. Goodfriend and McCallum 2007) were traditionally linear, so found it hard to deal with non-linearities implicit in systemic risk and changes in regulation. They tended to assume complete markets and that defaults either do not occur or are exogenous. And furthermore they tended to ignore endogenous leverage. So a crisis is modelled as a big negative shock that gets amplified rather than a credit boom that gets out of control (Boissay et al. 2013).

More recent models have sought to overcome these problems, with multiple equilibria, non-linearity, externalities and amplification mechanisms being more sophisticated. Hence macroprudential policies can be better assessed, although the models have to remain small due to the difficulty of the solution methods (Galati and Moessner 2014). Borrowers may, for example, face occasional binding endogenous borrowing constraints in times of crisis as in Fisher's (1933) debt deflation paradigm, linked to falling asset prices and declining net worth, see for example Benigno et al. (2013). Meanwhile models such as Brunnermeier and Sannikov (2014) look at global dynamics in continuous time models with financial frictions. The financial sector does not internalise the costs associated with excessive risks, so there is high leverage and maturity mismatch. Securitisation allows risk to be offloaded by the financial sector but raises overall risk taking. The economy has low volatility and adequate growth in steady state but the steady state is unstable due to large shocks provoking endogenous leverage and risk taking with feedback loops from the financial to the real economy. The model features a pattern of rising leverage and amplification when aggregate risk declines, as in the great moderation.

Antipa and Matheron (2014) review potential tensions between monetary and macroprudential policies given overlapping impacts. They use a DSGE model calibrated to Euro Area data with a financial friction manifested in a collateral constraint. Macroprudential policy affects this constraint cyclically and the work entails investigation of the zero lower bound (ZLB). Results include the following: macroprudential policies act as a useful complement to monetary policy during crises, by attenuating the decrease in investment and, hence, output; forward guidance is very effective at the ZLB, by providing a substantial boost to demand and reducing the costs of private deleveraging at the same time; overall, countercyclical macroprudential policies do not undo the benefits of forward guidance, but rather sustain them.

In general, such models highlight the transmission mechanism of real and financial factors, with the combination of macroeconomic boom, credit boom and low interest rates being dangerous, with consumption smoothing and precautionary saving being key underlying factors in financial imbalances' build-up. Model calibrations can help with understanding how macroprudential regulation can reduce the risk of crisis. State contingent taxes can also play a role, as can Pigovian taxes and an optimal mix of macroprudential policy and bailouts.

5 The NiGEM model

This section provides a succinct non-technical exposition of the National Institute's Global Econometric model, NiGEM which we use in our research. Where relevant to the analysis, details of the model will be presented in the text to follow, but an in-depth discussion falls beyond the scope of this paper.[1]

NiGEM is a global econometric model, and most countries in the EU and the OECD as well as major emerging markets are modelled individually. The rest of the world is modelled through a set of regional blocks so that the model is global in scope. All country models contain the determinants of domestic demand, export and import volumes, prices, current accounts and gross foreign assets and liabilities. Output is tied down in the long run by factor inputs and technical progress interacting through production functions. Economies are linked through trade, competitiveness and financial markets and are fully simultaneous.

Agents are presumed to be forward-looking, at least in some markets, but nominal rigidities slow the process of adjustment to external shocks. The model has complete demand and supply sides and there is

[1] For further details, the reader is referred to the NiGEM website: https://nimodel.niesr.ac.uk/ .

an extensive monetary and financial sector, together with household and government sectors. As far as possible, the same theoretical structure has been adopted for each country. As a result, variations in the properties of each country model reflect genuine differences emerging from estimation, rather than different theoretical approaches.

Policy reactions are important in the determination of speeds of adjustment. Nominal short-term interest rates are set in relation to a forward looking feedback rule. Long-term interest rates are the forward convolution of future short-term interest rates with an exogenous term premium. An endogenous tax rule ensures that governments remain solvent in the long run; the deficit and debt stock return to sustainable levels after any shock, as is discussed in Blanchard and Fisher (1989). Exchange rates are forward looking and so can 'jump' in response to a shock.

Within NiGEM, labour markets in each country are described by a wage equation (see Barrell and Dury, 2003 for a detailed description) and a labour demand equation (see, for example, Barrell and Pain, 1997). The wage equations depend on productivity and unemployment, and have a degree of rational expectations embedded in them – that is to say the wage bargain is assumed to depend partly on expected future inflation and partly on current inflation. The speed of the wage adjustment is estimated for each country. Wages adjust to bring labour demand in line with labour supply. Employment depends on real producer wages, output and trend productivity, again with speeds of adjustment of employment estimated and varying for each country.

NiGEM allows the macroeconomy to be affected directly by financial regulation and financial instability. When banks increase the spread between borrowing and lending rates for individuals it changes their incomes, and can also change their decision making on the timing of consumption, with the possibility of inducing sharp short term reductions. The volumes of deposits and lending that result are demand determined. Changing the spread between borrowing and lending rates for firms may change the user cost of capital and hence investment, and the equilibrium level of output and capital in the economy in a sustained way.

6 Earlier work introducing macroprudential policy in NiGEM

To incorporate macroprudential policy in NiGEM for a project commissioned by Sveriges Riksbank, Davis et al. (2011) undertook a number of modifications of the existing Swedish model. First, housing wealth was included in the consumption function; second, household liabilities were allowed to be driven by housing wealth (previously it had been driven by income); and third, the house price equation incorporated an income, wealth and mortgage effect as well as an effect of long real rates and the household sector lending spread (the previous equation had included only the interest rate terms). Hence, the effect of banks on the economy via lending spreads is broadened from fixed investment, the stock of capital and consumption to also include house prices, which affects consumption via housing wealth.

Besides standard simulations, Davis et al. (2011) imposed three macroprudential ones. One is for a 3 percentage point rise in the bank spread for mortgages only, to show the effect of higher countercyclical capital requirements on mortgages for 2 years. Subsequently, they apply the same shock to all bank lending so it also affects the spread for the corporate sector, showing the effect of rising general capital requirements for banks. Finally a fall in regulated loan-to-value ratios was proxied by shocking the implicit user cost of housing by 3 percentage points for 2 years. The main difference between the bank spread for household lending and the user cost of capital is the effect of the household lending spread on personal income which is absent for the user cost of capital shock.

Evidence from these NiGEM simulations suggests that macroprudential policies, focused on the housing market, can have a distinctive impact on the economy which could helpfully complement monetary policy at most points in the cycle. These results are in turn broadly consistent with work assessing theoretically how macroprudential policies may affect the economy, as cited above.

Accordingly, a generalised rise in capital adequacy affecting all lending is shown to have a quite marked impact in GDP, mainly via investment rather than consumption, while a more focused capital adequacy rise for mortgage lending only or a loan-to-value ratio policy appear to have scope to reduce credit and house prices and hence consumption with less effect on the rest of the economy than other options, although the housing based policy may of course be more subject than capital adequacy based policies to disintermediation. Capital adequacy for mortgage lending affects GDP more than the loan-to-value ratio policy since it has more of an impact on personal income and hence consumption. Monetary policy does of course also affect housing market variables but also has a greater effect on the wider economy.

Catte et al. (2010) use the National Institute Global Econometric Model (NiGEM) for the US over the period 2002 to 2007. They perform a number of counterfactual simulations to investigate two central elements of the story, namely: (a) an over-expansionary US monetary policy and the absence of effective macro-prudential supervision, which permitted a prolonged expansion of debt-financed consumer spending; (b) the decision of China and other emerging countries to pursue an export-led growth strategy supported by pegging their currencies to the US dollar, resulting in a huge build-up of their official reserves, in conjunction with sluggish domestic demand in surplus advanced economies characterized by low potential output growth.

They assume in turn a policy was feasible that would influence spreads on mortgages and show that along with monetary policy tightening, this would have mitigated the housing cycle (reducing real house price rises by 1/3 over 2002-2007). However, growth would have been lower and the improvement in the current account deficit, though not trivial, would have presumably been too small to eliminate the risk of a disorderly correction. For that, a rebalancing of global demand via expansionary policies elsewhere would have been required.

7 Macroprudential policy in NiGEM

7.1 Systemic risk index

We extend NiGEM to include a systemic risk index which will identify when the financial system and economy show signs of needing macroprudential intervention owing to heightened risk of a financial crisis. This index drives the macroprudential policy levers (capital buffers and loan-to-value ratios) and is based on the work by Karim et al. (2013), where unweighted banking sector capital adequacy, the banking sector liquidity ratio, the change in real house prices and the current balance to GDP ratio drive systemic risk. Given the prominent role that the systemic risk function plays in our modelling of macroprudential policy in NiGEM, we briefly summarize in this section the work by Karim et al. (2013).

Karim et al. (2013) utilise a multinomial logit to model the probability that a financial crisis occurs at any point in time. The dependent variable is a binary banking crisis indicator that takes the value of one at the onset of the crisis and zero otherwise.[2] The dataset includes data on systemic and non-systemic banking

[2] An alternative approach would be to consider a binary variable that takes a value of one whenever a country is in a banking crisis. However, this might bias the results as policy actions implemented during a crisis may have a direct

crises from 14 OECD countries drawn from the IMF Financial Crisis Episode database and the World Bank database of banking crises.[3] The sample covers 1980-2007 with annual data.

Table 2: Nested testing of the crisis model, 1980-2006

NLIQ(-2)	-0.058 (0.242)	-0.061 (0.187)	-0.062 (0.183)	-0.064 (0.166)	-0.06 (0.181)	-0.064 (0.163)	-0.089 (0.163)	-0.082 (0.02)
CBR(-2)	-0.555 (0.004)	-0.555 (0.005)	-0.559 (0.004)	-0.568 (0.003)	-0.532 (0.003)	-0.555 (0.002)	-0.482 (0.004)	-0.454 (0.002)
RHPG(-3)	0.073 (0.124)	0.076 (0.066)	0.075 (0.066)	0.076 (0.06)	0.083 (0.028)	0.079 (0.038)	0.076 (0.038)	0.08 (0.037)
LEV(-3)	-0.804 (0.004)	-0.803 (0.004)	-0.795 (0.004)	-0.792 (0.004)	-0.726 (0.003)	-0.751 (0.002)	-0.685 (0.002)	-0.544 (0.00)
OBS(-2)	0.034 (0.278)	0.034 (0.269)	0.034 (0.257)	0.034 (0.259)	0.033 (0.25)	0.028 (0.333)	0.021 (0.333)	-
INFL(-2)	-0.115 (0.525)	-0.108 (0.537)	-0.088 (0.369)	-0.082 (0.384)	-0.081 (0.384)	-0.083 (0.385)	-	-
M2RES(-2)	0.00 (0.392)	0.00 (0.369)	0.00 (0.365)	0.00 (0.378)	0.00 (0.393)	-	-	-
YG(-2)	0.107 (0.575)	0.107 (0.573)	0.111 (0.555)	0.134 (0.42)	-	-	-	-
DCG(-2)	0.014 (0.824)	0.016 (0.802)	0.016 (0.799)	-	-	-	-	-
RIR(-2)	0.025 (0.852)	0.017 (0.89)	-	-	-	-	-	-
BB(-2)	0.016 (0.875)	-	-	-	-	-	-	-

Source: Karim et al. (2013).
Note: P values in parentheses.

Karim et al. (2013) test for the effect of up to eleven independent variables: current account balance to GDP ratio (CBR), real GDP growth (YG), inflation (INFL), change in real house prices (RHPG), the M2 to foreign exchange reserves ratio (M2RES), real domestic credit growth (DCG), unweighted bank capital adequacy (LEV), bank narrow liquidity to assets ratio (NLIQ), the real interest rate (RIR) and the fiscal surplus to GDP ratio (BB). They also include a proxy for off-balance-sheet activity of banks (OBS).

The nested testing of the variables, with sequential elimination of insignificant variables, is shown in Table 1 for 1980-2006.

Only four variables remained after the procedure: the current balance to GDP ratio and narrow bank liquidity ratio (both at lag 2), the change in real house prices and unweighted capital adequacy (both at lag 3). OBS was considered to be proxied by house prices for the 1980-2006 estimation period.

There is logic to the inclusion of each of these variables. For example, capital protects banks against losses (it acts as a "buffer"), so higher capital increases banks' resilience to shocks. Lower capital makes them both more vulnerable to shocks but also gives rise to incentives for risk taking due to the moral hazard, generated in turn by the mispriced "safety net" of lender of last resort and deposit insurance. Liquidity ratios show banks' robustness to sudden withdrawal by depositors. Increased house prices may give rise to

impact on some variables of the regression model. For further discussion on this point see Demirguc-Kunt and Detragiache (1998).

[3] The countries included in the analysis are: Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Spain, Sweden, UK and the US.

higher borrowing without major increases in leverage, but levels may be unsustainable. House prices are also correlated with commercial property prices, trends in which link closely to fragility in the banking sector (Davis and Zhu 2009); together they are key indicators of a credit-driven cycle.

A number of potential links can also be traced from current account deficits to risk of banking crises. Deficits may be accompanied by monetary inflows that enable banks to expand credit excessively and may link to economic overheating. Inflows may also both generate and reflect a high demand for credit, and boosting asset prices in a potentially unsustainable manner. Such patterns may be worsened by lower real interest rates driven by inflows. Inflows to finance deficits may be sensitive to the risk of monetisation via inflation, and such a cessation can disrupt asset markets and banks' funding.

OECD countries are usually seen as relatively less subject than emerging markets to such "sudden stops". However, as argued by McKinnon and Pill (1994), capital inflows in a weakly regulated banking system with a safety net may lead to booms in lending, consumption and asset prices as well as further increases in current account deficits. This pattern may lead on to exchange rate appreciation, loss of competitiveness and a slowdown in growth, as in the US in the middle of the last decade. It may also lead to a banking crisis, again much as we saw in the US in the late 2000s, although unlike for traditional "sudden stops" the currency did not collapse.

Using the estimated coefficients from Karim et al. (2013), the final model of the probability of a financial crisis can be written as follows:

$$Prob(crisis_t) = \frac{1}{1 + e^{-(-0.544LEV_{t-3} - 0.082NLIQ_{t-2} + 0.08RPHG_{t-3} - 0.454CBR_{t-2})}}, \quad (1)$$

With LEV denoting bank capital to total assets ratio, NLIQ - narrow liquidity to total assets ratio, RPHG - change in real house prices and CBR - the current account balance to GDP ratio. This equation provides a probability of crisis for each country based on differing levels of these variables, whereas being based on panel estimation the coefficients are the same across countries.

Subsequently, one needs to define a threshold value to indicate the point at which the probability of an economy suffering a financial crisis is large enough to warrant action from the authorities via macroprudential policy. The trigger point would lead to the authorities imposing loan-to-value ratio limits on the housing market via the mortgage demand function. There would then be an impact on house prices and in turn consumption via a wealth effect. There could also be an effect via flexible capital ratios, (countercyclical buffer (CCB)) as the authorities raise required capital at the trigger point of the systemic risk function. This would impact via a rise in spreads for corporate and household lending, driven by the capital adequacy headroom in countries (as discussed below). Investment and consumption would both decline.

We report in Table 2 the in-sample accuracy of the logit model developed by Karim et al. (2013). As can be seen, the model predicts the state of the economy (with or without a banking crisis) successfully in 3 out of 4 occasions:

Table 3: In-sample accuracy of early warning model (1980-2006)

	Dep=0	Dep=1	Total
P (Dep=1) ≤ 0.0357	240	3	243
P (Dep=1) > 0.0357	84	9	93
Total	324	12	336
Correct	240	9	249
% Correct	74.07	75	74.11
% Incorrect	25.93	25	25.89

Source: Karim et al (2013) Notes: Using the sample proportion of crisis years (0.0357) as a cut-off. Dep is the value of the binary dependent variable.

As an alternative, we have earlier estimates from Barrell et al (2010b) which used less up-to-date data but did include the subprime crisis in the estimation:

$$Prob(crisis_t) = \frac{1}{1 + e^{-(-0.34LEV_{t-1} - 0.11NLIQ_{t-1} + 0.08RPHG_{t-3} - 0.24CBR_{t-2})}}. \quad (2)$$

and which we in the current work have adopted for NiGEM. Using actual values for each country we calculate critical values for the probability of a crisis, which are used to trigger the macroprudential policies. These are[4] 0.05 for Germany, 0.03 for Italy and 0.01 for the UK.[5]

We did consider alternatives to a systemic risk index as outlined above, but found the index to be superior to the possible alternative triggers for macroprudential policy. For example, price based measures might be considered as an alternative trigger, and there is a literature for example on the credit quality spread of government to corporate bonds as a cyclical predictor. However, with respect to financial crises, their predictive power is limited: the "efficient markets hypothesis", whereby prices convey all necessary information, may not hold. The failure of markets to internalise the cost and probability of the 2007-2009 systemic crisis is a case in point (Bennani et al., 2014). Borio and Drehmann (2009) find that real asset price gaps (between actual indices and smoothed trends), especially property price gaps, proved useful in predicting banking crises; at the same time they stress that indicators focusing exclusively on stock market prices would have failed to signal the build-up of risk as it was not correctly priced. Furthermore, most of the measures capturing banks' risk-taking that have been used in the literature, such as the expected default frequency (EDF), idiosyncratic bank volatility, the so-called Z-score, or banks' Value-at-Risk (VaR), work reasonably well for assessing risks in the cross sectional dimension but not so well in the time dimension (Dufrénot et al., 2012).

As a more viable alternative, we note the Bank for International Settlements (BIS) work on credit-GDP gaps as a possible crisis predictor (see also Davis et al 2017). As argued by Bennani et al. (2014), the credit-to-GDP gap, as noted above, is particularly relevant for calibrating the CCB as it signals the build-up of risk sufficiently early, prior to financial crises (see, e.g., Drehmann et al., 2010; Drehmann et al., 2011). However, it may not be always a robust leading indicator of costly price booms or banking crises (Borgy et al., 2014). Repullo and Saurina (2011) argue that the credit-to-GDP gap ratio could exacerbate the inherent procyclicality of the risk-sensitive bank capital regulation. In addition, as the credit-to-GDP gap ratio

[4] We define the critical values as the probability of a crisis, according to equation 2, when LEV, NLIQ, RPHG and CBR are at their average levels over the sample period.

[5] The lag length of the right hand side variables is reduced in the model, to ensure a more timely response of a macroprudential tools to elevated probability of a crisis.

corresponds to the deviation from a filtered trend, its real-time use depends mostly on the reliability of the end-of-sample estimates of credit and GDP. Some authors argue that subsequent revisions of macroeconomic statistics could be as large as the gap itself (Edge and Meisenzahl, 2011), which can raise concerns about the robustness of the credit-to-GDP gap if used as the sole indicator for CCB implementation.

We note that the "horse race" of indicators in Basel Committee (2010) which found the credit gap superior, did not include the output of any systemic risk function as an alternative. For our own practical purposes, using the credit-to-GDP gap would require, in addition to household debt, inclusion of corporate and non-bank financial institution debt, which is not present in most country models in NiGEM. We do however retain it as an alternative option. Other possible triggers can include borrower leverage, lending standards, debt-to-income ratios for households and corporations and exposure of households and corporates to interest rate and currency risks. However, the systemic risk index is our preferred method of triggering macroprudential policy.

7.2 Modelling macroprudential policy in NiGEM

This section lays out the general form of the macroprudential block in NiGEM, following from Carreras et a (2017). We describe the macroprudential levers, how they interact with our systemic risk index and the effects that macroprudential tools have on the economy. Our approach will also consider the costs and benefits of macroprudential action.

A growing literature (extensively surveyed in Carreras et al., 2016) has pointed out that macroprudential tools are effective at curbing asset price and credit growth as well as ensuring minimum levels of bank capital or liquid assets to total assets. The work of Karim et al. (2013), among others, on modelling the probability of a financial crisis and the costs of financial instability (see also Barrell et al (2009), (2010c)) indicates that the aforementioned effects of macroprudential policy may indeed limit the likelihood of a costly crisis and subsequent recession taking place. However, the implementation of such policies is likely to increase the cost of financial intermediation. Thus, we will explicitly take into account the beneficial effects of macroprudential policy on limiting the risk of a crisis taking place, while incorporating the costs as captured by the impact of macroprudential tools on the borrowing and lending spread and on house prices and subsequently on real activity.

Before delving into the details, we introduce in an informal manner the main ingredients and channels of the model underlying the macroprudential block. We will consider two macroprudential variables: loan-to-value ratios on mortgage lending, and bank capital adequacy. The choice is based on work from FIRSTRUN Deliverable 4.7 (Carreras et al., 2016) that found loan-to-value ratios and variable bank capital adequacy to have a statistically significant impact on house price and household credit growth in advanced OECD countries. Loan-to-value ratios are specific to the housing sector and will impact the economy primarily via private consumption. By limiting the quantity of available credit for housing, this lever will have an impact on house prices, which in turn will impact the aggregate consumption equation via a wealth effect. Meanwhile, an important element of Basel III is discretion of the authorities in setting capital adequacy for macroprudential purposes, as discussed further below (Basel Committee 2010, 2015). Bank capital adequacy will act on the spread between borrowing and lending rates of households and corporates, subsequently having an impact on private sector investment via its effect on the user cost of capital and on private consumption via an impact on house prices and real personal disposable income (*rpdi*).

7.2.1 Macroprudential tools

The loan-to-value ratio (*ltv*) is the first macroprudential lever that we include in the model. It takes the form of a discrete function whose value depends on our systemic risk index (*sri*). While nothing constrains the number of values that *ltv* might take, in our benchmark specification *ltv* will be a binary variable that takes the value of zero or one, with unity representing a tightening of policy, which is triggered when *sri* exceeds a certain threshold value, $\overline{sri}$ (0.05 for Germany, 0.03 for Italy and 0.01 for the UK). Easing can accordingly take place after the *sri* is below crisis levels. We have defined the *ltv* function in NiGEM to return to 0 after *sri* has dropped below the critical value and remained below for 3 years. The 3 year lag is to prevent the policy being switched on and off if *sri* is fluctuating around its critical value and to ensure that easing does not occur prematurely.

We note there could be a more gradual adjustment whereby there are intermediate as well as maximum applications of the ltv policy (so, it might first rise to 0.5 at an intermediate level before attaining 1 at crisis levels of *sri)*. In addition, *ltv* can be set manually rather than being triggered by changes in *sri*, and in this case it may be set to values other than 0 or 1.

Target capital adequacy that banks will have to follow with their actual risk adjusted leverage will also be triggered by the systemic risk indicator and constitutes the second macroprudential lever of the model. The way in which *sri* triggers the reaction function would be different from the *ltv*, and occurs through the target risk adjusted bank leverage variable *levrrt*. We follow the approach of the countercyclical buffer in Basel III, whereby the increase in capital adequacy in response to concerns about systemic risk can be up to a maximum of 2.5 per cent, although as noted in Basel Committee (2015), authorities can exceed this if they see fit. Generally authorities allow up to 1 year for banks to adjust to a rise in the CCB, but falls can be taken immediately.

We have modelled target capital adequacy such that in simulation, once *sri* rises above its critical value, *levrrt* immediately jumps to a level 2.5 percentage points above its baseline. Similarly to *ltv*, once *levrrt* is triggered it remains 2.5 percentage points above baseline until *sri* has dropped below its critical value and remained there for 3 years, after which *levrrt* reverts to its baseline level. The risk-weighted capital-to-asset ratio, *levrr*, adjusts gradually in response to the change in *levrrt*. We consider our sri function to be a superior trigger to the credit/GDP gap that is recommended by the Basel Committee (2015), as discussed above.

Note that use of the risk adjusted capital to asset ratio (*levrr)* and its target (*levrrt)* are in line with the existing work on NiGEM such as Davis and Liadze (2012) as discussed further below, as well as with the current regulatory regime which focuses on risk weighted assets. This is accordingly distinct from the actual estimates of the *sri* set out above that used unweighted capital/assets. However, as shown in Barrell et al (2009), who adopted a similar approach to us, the correlation coefficient for weighted and unweighted capital ratios is 0.92.[6]

Finally, note that the inclusion of the capital adequacy ratio in the *sri* function means that the policy of increasing capital adequacy requirements has a direct effect of reducing systemic risk, while the effect of *ltv* on systemic risk is indirect, via house prices.

---

[6] They also noted “If we regress the weighted capital ratio on a constant and an unweighted capital ratio for the UK the coefficient on unweighted capital is 1.0007 with a standard error of 19.6 and hence there is no problem in linking our results in this section [banking sector modelling] with those in the section above on the causes of crises” (Barrell et al 2009, p26).

7.2.2 Modelling spreads

Spreads are assumed to be driven by capital (as a cost to banks) but not by *ltv*. The household lending wedge (*lendw*) is driven by the net wealth to household income ratio (*nwpi*), bank capital to risk-weighted total assets ratio (*levrr*) and the rate of household mortgage arrears (*arr*).

$$lendw = f(nwpi, levrr, arr) \tag{3}$$

A change in the capital adequacy target (*levrrt)* affects the household lending wedge (*lendw)* indirectly via its effect on *levrr*, which moves towards the target level.

The overall corporate lending wedge (*iprem*) is set equal to *corpw* assuming bond finance is priced similarly to bank finance; the wedge on bank lending to corporates will also be affected by inverse headroom (as discussed below) capital adequacy (*levrr*), the corporate insolvency rate (*insolr*) as well as the cyclical state of the economy denoted by the actual output to potential output ratio (*y/ycap*).

$$iprem = corpw = f\left(\frac{y}{ycap}, insolr, levrr, 1/headroom\right) \tag{4}$$

Headroom is the difference between banks' level of capital adequacy (*levrr*) and that required by the authorities (*levrrt*). The latter will be affected by the normal Basel level of 8 per cent of risk adjusted capital adequacy plus any additional requirements of the authorities, as in the UK, and further additions such as the Basel III countercyclical buffer as discussed above. These will all affect *levrrt* while losses and capital building, as well as assets and their composition, will affect *levrr*.

$$headroom = levrr - levrrt \tag{5}$$

The systemic risk indicator *sri* will feed directly into the target level of capital adequacy in the manner as noted above, which in turn will feed into both *iprem* and *lendw*. The working of this is as discussed above

$$levrrt = f_{levrrt}(sri) \tag{6}$$

7.2.3 Modelling house prices and credit

Each of the two macroprudential tools we include in the model affects sectors in the economy in a different way. Focusing first on the loan-to-value ratio (*ltv*), this tool primarily targets the housing market. In NiGEM, the housing market is described by a price (supply) equation, p_H, and a demand equation for mortgages. Loan-to-value ratios, by imposing a constraint on the quantity of mortgages supplied in the market, will potentially, through market clearing, affect house prices.

Household liabilities are split between consumer credit and mortgages, both of which are endogenously determined. Given that *lendw* already appears in the existing equation for mortgages, we consider a simple expansion of the existing mortgage equations to include *ltv*:

$$morth/ced = f_{p_H}(rpdi, lendw, lrr, rph, ltv) \tag{7}$$

where *morth/ced* denotes outstanding mortgage liabilities in real terms, *rph* denotes real house prices and the remaining variables have been defined previously. The nominal counterpart to *morth* then feeds into total household liabilities *liabs*. Consumer credit is not affected directly by *ltv* limits, which are specific to mortgage lending.

House prices are affected indirectly by macroprudential policy in terms of the lending spread to households (price effect of capital requirements) and by the loan-to-value ratio tool (quantity effect of *ltv*), again with the calibrated coefficient being based on the estimates in Carreras et al (2016). In addition, house prices are also determined by the long-run real interest rate (*lrr*) and the price level (ced) in order to control for supply side dynamics[7]. Note that besides its direct impact, the lending spread *lendw* will also impact indirectly via net interest income.

The existing equations in NiGEM for house prices and household liabilities were amended to incorporate the changes laid out in this section. Note that other asset prices (equity prices, bond yields, exchange rates) are not affected directly by the macroprudential tools.

$$p_H = f_{p_H}(lendw, lrr, ced, ltv) \tag{8}$$

7.2.4 Impacts on consumption and investment

The loan-to-value tool will affect consumption by reducing directly both lending and house prices. The capital adequacy tool will have an impact on private investment and consumption by acting on the lending spreads of corporates and households, as well as indirectly on consumption via house prices and credit as spreads adjust.

Consumption (*c*) is affected by housing wealth (*hw*), which in turn is driven by house prices, and by net financial wealth (*nw*) which is affected by total outstanding liabilities. As a result, macroprudential policy will have an impact on private consumption via the wealth effect coming through its impact on both house prices and household liabilities. It will also impact via net interest income generated by changes in the household lending spread *lend*w which affects *rpdi*.

$$c = f_c(rpdi, nw, hw) \tag{9}$$

Corporates are affected by capital adequacy as the movements in the corporate lending spread, *corpw*, triggered by *sri*, will have an impact on private sector investment via the user cost of capital. Investment is not affected directly by *ltv* policy, although there is impact on housing investment indirectly via falling house prices.

7.3 Modelling the banking sector in selected countries in NiGEM

Further channels of macroprudential policy are available in the UK, German and Italian models where the banking sector is explicitly modelled, and on which this paper focuses[8]. The modelling of banking sectors' influence in terms of spreads between borrowing and lending rates, in a global macroeconomic model, was pioneered by NIESR in its work on the impact of capital adequacy regulation (Barrell et al., 2009), where other influences on spreads besides capital include measures of borrower risk. Goodhart (2010) has argued that determining spreads is precisely the way that banks should be incorporated in macroeconomic models, and not either ignored or set out in terms of the "money multiplier", see also Woodford (2010).

As described in Davis and Liadze (2012), we model banking activity as a set of supply (or price) and demand curves. Demand depends on levels of income or activity, and on relative prices, whilst supply, or price, depends upon the costs of providing assets and on the risks associated with those assets. The banking sectors in the model have four main assets, secured loans to individuals for mortgages, (*morth*) with a

[7] The house price equation is backward looking by default. In forward looking mode, house prices are also affected by real personal disposable income (rpdi) and housing capital stock (kh).
[8] The banking sector is also explicitly modelled in the US (Davis and Liadze 2012), but this paper focusses on European economies.

borrowing cost (*rmort*) affected in part by the mark up applied to household loans by banks (*lendw*) as shown above, unsecured loans to individuals for consumer credit (*cc*) with a higher borrowing cost or rate of return (*ccrate*) again affected by the household margin. Then there are loans to corporates (*corpl*) with a rate of return or cost of borrowing (*lrr+corpw*) where *lrr* is the risk free long rate and *corpw* is the mark up applied by banks (*iprem* is set equal to *corpw,* as noted above). The whole balance sheet of assets (*bbal*) can then be derived by adding in liquid assets (*bra*) which are modelled as a fixed percentage of the balance sheet and other assets (*bbsoa*), which rise in line with total lending.

$$bbal = corpl + morth + cc + bra + bbsoa \tag{10}$$

This is the denominator of unadjusted capital adequacy. Given the balance sheet of assets we can also estimate the risk adjusted balance sheet (*brwa*) by applying broad risk weights to the different assets. This is then the denominator of *levrr* (risk adjusted capital adequacy). We assume that mortgages have a risk weight of 0.5, liquid assets 0.2, other assets 0.3 and consumer credit and corporate loans have a risk weight of 1.0.

$$brwa = corpl + 0.5 * morth + cc + 0.2 * bra + 0.3 * bbsoa \tag{11}$$

Assuming then that assets equal liabilities, we can calculate the components of liabilities, namely deposits (driven by M1), other liabilities (growing in line with nominal GDP), wholesale deposits (a residual, in line with the practice of banks to use this as a residual source of funds) and capital itself (driven by spreads, assets and losses as well as headroom, as shown in equation (12) below). The sum of these variables is liabilities which is set equal to assets. Accordingly, we can derive total on-balance sheet bank activity within the UK, Italy and Germany.

We go into more detail on the simple algebraic framework for capital adequacy. If there is a shock to any of the assets of the banking system then *levrr* will change, and banks will be obliged to adjust either their capital or their asset structure. Capital can either be raised by rights issues or by absorbing some of the gross operating surplus of the system.

$$bcap = bcap_{-1} + \left(1 - \frac{levrrt_{-1}}{levrrt_{-1}+3}\right) * 1.5 * 10 * \left(\frac{lendw_{-1}}{400} * (morth_{-1} + cc_{-1}) + \frac{corpw_{-1}}{400} * corpl_{-1}\right) \tag{12}$$

Using the example of the UK, which is also applied for Germany and Italy, the expression inside the first set of brackets in equation (12) gives the speed of adjustment for bank capital. As *levrr* is the risk weighted ratio of capital to assets, or *bcap* divided by risk weighted assets, *brwa*, we can calibrate the adjustment of *bcap* in line with the speeds of adjustment discussed in Osborne (2008). To achieve this we multiply the shortfall indicator by 1.5, as shown above. If *levrr* is below its normal level, given the desired level of headroom over 8 per cent, namely 3, some of bank income will be used to rebuild bank capital and increase headroom, and operating margins on consumer lending will be increased to speed up the process. The gross operating surplus of the banking system is the gross margin on the three types of lending multiplied by the total value of the stock of the particular category of lending, as illustrated in the expression inside the second set of brackets. Note that we do not assume that capital can be rebuilt simply by new capital issues, although we acknowledge that these occur at times, as do government recapitalisations in the wake of banking crises.

Changes in the speed of adjustment in this equation change the short run, but not the long run effects of changes in capital adequacy targets. Equation (12) is extended when there are endogenous arrears and insolvencies to reflect the losses imposed on bank capital by corresponding defaults. We have not incorporated this in the current exercise.

Then if regulation is tightened, for example via higher capital adequacy requirements as in Basel III, then increasing margins and reducing lending will both move banks back toward their desired capital ratio. If the capital adequacy target ratio (*levrrt*) rises then risk weighted capital adequacy (*levrr*) will increase and so will the cost of corporate and personal sector borrowing, raising the gross operating surplus that can be devoted to rebuilding capital, and reducing assets which raises *levrr* via a smaller denominator. In models where arrears and bankruptcies are endogenous, there can also be a deduction from capital for losses.

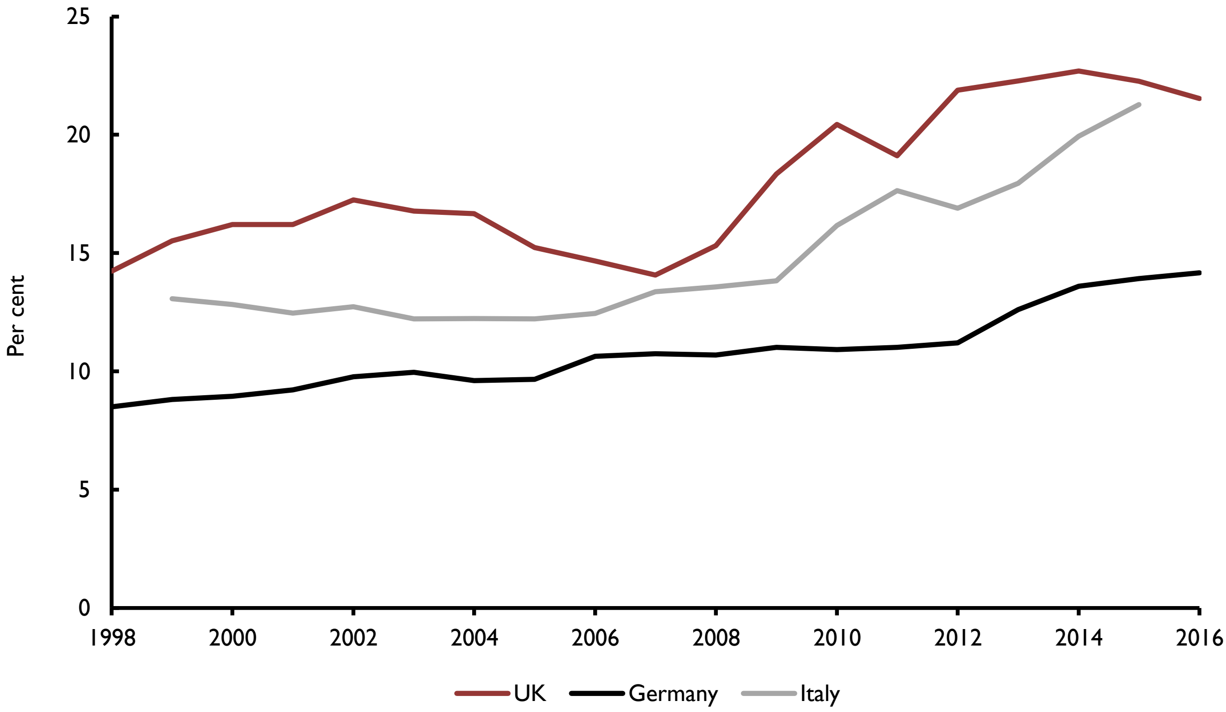
In the UK, for example, there has been a normal excess above the required minimum level of capital adequacy, which has averaged 3 percentage points in this sample, with a corresponding difference applied in Italy and Germany. As the difference between actual and target levels of risk weighted capital to asset ratios shrinks, we might expect banks to push up their borrowing charges. As headroom goes to zero we would expect there to be significant non-linear increases in borrowing costs. In order to capture this we included inverse headroom in the corporate wedge equations, as shown above.

8 Key variables

In this section we show and comment briefly on the variables that influence the systemic risk function over the period 1997-2016[9]. These are banking sector risk adjusted capital to asset ratio (*levrr*), banking sector liquidity ratio (*liq=bra/bbal*), the change in real house prices (*rhpg*) and the current account/GDP ratio (*cbr*).

[9]All variables referred to here come from the NiGEM database.

Chart 3.1: Bank risk adjusted capital adequacy (*levrr*)



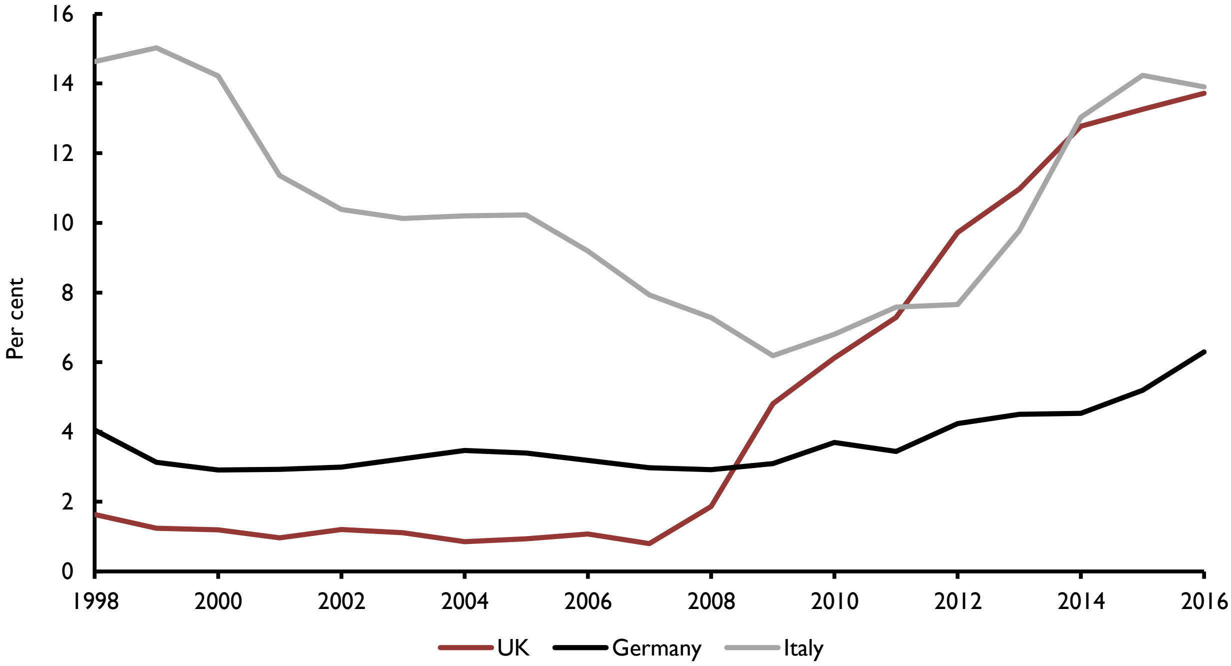
Source: NiGEM database

As shown in Chart 3.1, the risk-weighted capital to asset ratio was relatively flat from 1997-2007 despite the increasing risk of financial instability. A slight upward trend is apparent in Germany from around 8 per cent to just over 10 per cent while in the UK the ratio fluctuated around 15 per cent (reflecting partly the higher trigger ratios applied in that country bank by bank). Italian banks had ratios that were at an intermediate level of around 12.5 per cent.

Since 2007 the ratio has increased over time, in line with Basel III, but according to our data this is much more apparent for Italy and the UK than for Germany. The UK and Italian ratios are around 20-25 per cent in the period since 2015, whereas the German ratio rose only to around 14 per cent at the end of the period. It needs to be borne in mind in assessing these data that the risk adjusted ratio itself is an imperfect measure of bank risk, especially under Basel II, in the run-up to 2007, as subprime assets were given inappropriately low risk weights following generous credit ratings being obtained for them.

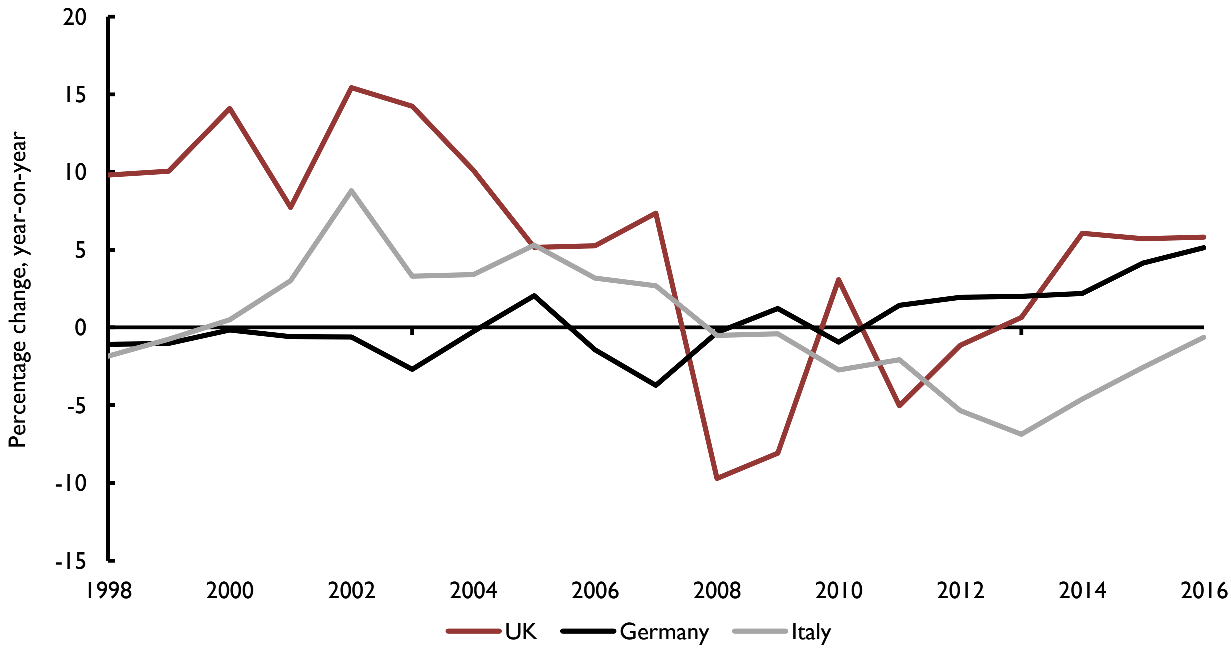
Turning to liquidity (Chart 3.2), the measure shown suggests marked cross-country differences. Prior to the crisis, the ratio in the UK and Germany was quite low, at around 3 per cent for the UK and 1 per cent for Germany. In contrast, Italian banks held high but declining liquidity according to this measure, falling from 15 per cent in the late 1990s to 8 per cent in 2007 and 6 per cent in 2009. Again in line with Basel III and banks and regulators' preparation for it, as well as in response to the crisis and the overreliance on unstable wholesale funding, the ratio rose sharply over 2009-2017. By the end of the sample, it reached 14 per cent in both the UK and Italy, while in Germany, the ratio climbed only to 7 per cent.

Chart 3.2: Bank liquidity ratio (*liq=bra/bbal*)



Source: NiGEM database and authors' calculations

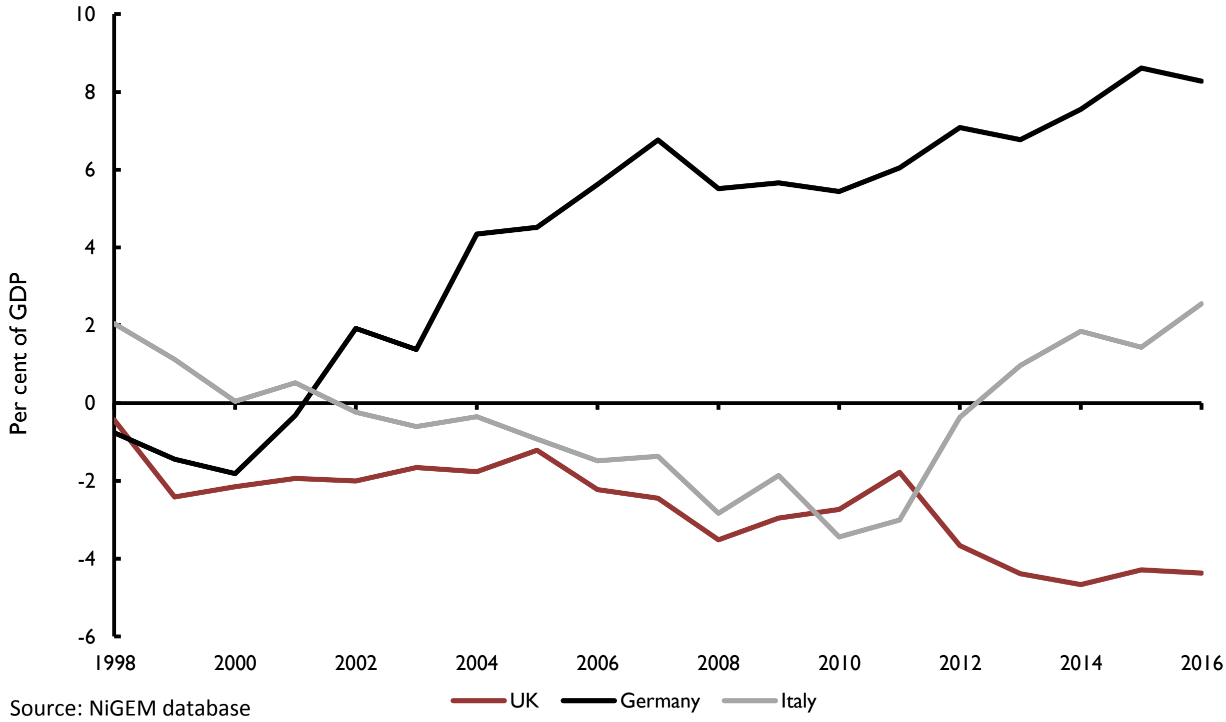
Chart 3.3: Real house price growth (*rhpg*)



Source: NiGEM database

House prices (Chart 3.3) show greater volatility in the UK compared to Italy and especially Germany where annual change fluctuated around zero prior to 2010, after which a steady rise was seen. There were noteworthy falls in the UK over 2008-9 and in Italy over 2009-16.

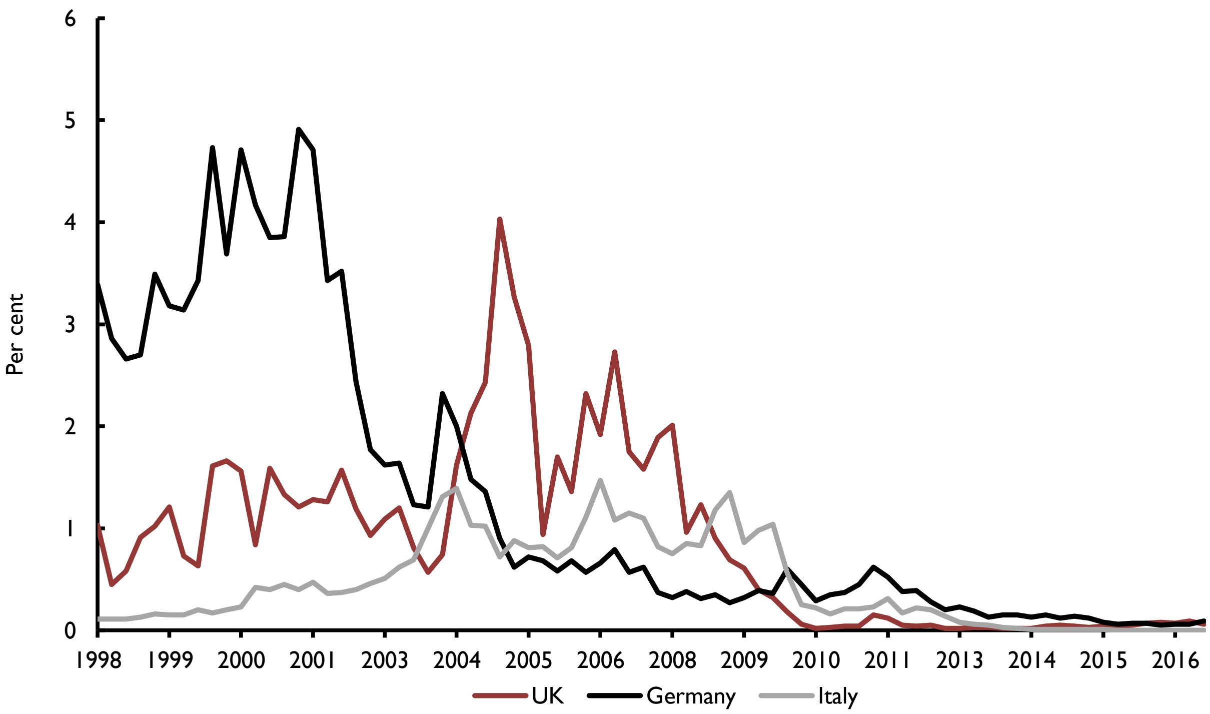
Chart 3.4: Current account/GDP ratio (*cbr*)



Source: NiGEM database

Current account imbalances (Chart 3.4) are greatest in Germany in respect of the surplus that prevailed from 2002 onwards. In the UK there has been a persistent deficit, likewise in Italy from 2002-2011, after which a surplus was achieved.

Chart 3.5: Patterns of systemic risk (*sri*)



Source: NiGEM database and authors' calculations

The pattern of the systemic risk indicator is influenced by all 4 variables shown above (Chart 3.5), but given the coefficients and the size of the variable, risk adjusted capital ratios have a particularly strong effect. The period prior to the 2007 crisis showed a strong rise in the ratio in the UK, and to a lesser extent in Italy, thus giving some advance warning. In the case of the UK this was driven particularly by house prices and the current account, since capital and liquidity did not change much, while in Italy the decline in liquidity had a marked effect, as did the current account and house prices. The very high levels in Germany in the late 1990s reflect the weak data for bank risk measures shown above, offset later by the improving current account and relatively stable house prices.

In the years since the crisis it is notable that for all the countries, this measure has been declining, and since 2015 has typically been close to zero per cent. This pattern largely reflects the improvement in banking risk measures following the regulatory tightening of the crisis and Basel III, as well as the lower rates of change in house prices.

9 Simulations

We undertook four sets of simulations for Germany, Italy and the UK - the EU countries with banking sectors in the NiGEM model.

1. Tightening of *ltv* policy - we assess the impact of imposing tighter loan-to-value limits on the housing market on a permanent basis.

2. Tightening capital adequacy policy – we permanently raise the target risk adjusted capital adequacy by 2.5 percentage points, which represents the effect of imposing Basel III countercyclical buffer fully.[10]

3. General macroprudential tightening – we combine the two policies, imposing higher *ltv* limits and raising the countercyclical buffer simultaneously.

4. Crisis mitigation – this is a historic dynamic simulation over the subprime crisis period. We allow the macroprudential policies to be triggered by the level of the systemic risk indicator over 2004-2032. As noted, critical values for *sri* are 0.01 in UK, 0.03 in Italy and 0.05 in Germany (derived from sample averages).

We show the responses of the economies of Germany, Italy and the UK in the charts below. Comments on the patterns follow. Note that we exogenise the monetary response, which means that interest rates do not react to the deviations from inflation and nominal targets (simulation results with endogenous monetary policy are presented in Appendix 1, showing the effects of endogenous monetary policy are relatively minor). Fiscal policy follows a default feedback rule which ensures that the deficit achieves an equilibrium trajectory by using the direct tax rate as an instrument. Simulations were done one country at a time, apart from the historic dynamic simulation, where we simulated the effects on all three countries simultaneously.

[10] Due to the forward looking nature of financial markets in the model, long term interest rates decline from the very first period of the simulation, which stimulates investment. To offset this, we increase the user cost of capital in the first period of the simulation.

By default, financial markets in NiGEM are forward looking, as are factor markets. All of these may be affected by changes in financial regulation. Changing the spread between borrowing and lending rates for individuals changes their incomes, and can also change their decision making on the timing of consumption. Changing the spread between borrowing and lending rates for firms may change the user cost of capital and hence the equilibrium level of output and capital in the economy in a sustained way. A further important effect is of lower expected inflation on long rates, which means that there is a partial offset to any increase in the user cost of capital on investment arising from the corporate wedge. Charts are at the end of Section 4.

9.1 Tightening of loan-to-value policy

The first simulation is the tightening of ltv policy. We see from Chart 4.1.1 that household liabilities decline in every country in the sample by around 2.0 per cent after 5 years. We note, however, that mortgage lending is not sizeable in Italy (or Germany) relative to GDP (around 60 per cent debt/income ratio for households) as compared to the UK (110 per cent). Equally, house prices fall in each country by around 3-3.5 per cent over the same period (Chart 4.1.2). These results are to be expected since we have applied a direct exogenous shock to *ltv* in each of the relevant equations, in line with estimates in Carreras et al (2016). On the other hand, the patterns of bank capital adequacy and GDP growth are more varied. We see from Chart 4.1.3 that the risk adjusted capital to asset ratio rises in each case, but only marginally in Germany, by about 0.04 percentage point and by 0.07 percentage point in the UK and Italy, respectively. This reflects the changing size and pattern of bank assets over the period following the shock.

The policy has a contractionary impact on GDP, albeit a fairly marginal one, with output falling by around 0.05-0.15 per cent at the trough. The components of this are shown in the subsequent charts. We see from Chart 4.1.5 that, after five years, consumption falls quite markedly by 0.2-0.5 per cent in all three countries, reflecting the wealth effect of falling house prices following the increase in *ltv* ratio and households' need to save for deposits. However, dynamic patterns differ, reflecting different speeds of adjustments to the shocks in the economies. The fall in output depresses investment and in the short term private investment drops by about 0.2 per cent (Chart 4.1.6). However, in the medium term there is a partial recovery in investment. The fall in consumption generates a marked rise in the saving ratio of up to around 0.3 percentage point (Chart 4.1.7), which is to be expected since the ltv policy requires households buying property to save more for a deposit. The current balance improves, largely due to fall in domestic demand, but also following improvement in competitiveness lead by a reduction in domestic prices (Chart 4.1.8). Given that monetary policy is deactivated in the simulations, exchange rates (vis a vis the dollar) do not change.

Looking at the banking and financial market effects of the policy, the lending wedges for corporates and households are relatively unaffected by the ltv policy so changes are quite small (Charts 4.1.9 and 4.1.10). This policy affects the volume of credit and not its price, and bank assets fall both on an unweighted as well as weighted basis by 1.5 and 1.4 per cent, respectively (Charts 4.1.12 and 4.1.13). The decline in risk adjusted assets is smaller than that of the unweighted measure, as mortgages have a relatively low risk weight.

Finally, the policy has a negative effect on the systemic risk indicator for the UK and Germany but not to a significant degree in Italy (Chart 4.1.14). The differences in *sri* are driven largely by the different effects on risk adjusted capital adequacy, which has a considerably greater effect than house prices or the current account (both of which also move favourably for financial stability) in the equation. However, it should be taken into account that the baseline *sri* in Italy is very low owing to the levels of capital and liquidity being high while house prices are stable. These means that the amount by which the Italian *sri* can improve is highly limited (zero is the lower bound to the *sri* index), and implies in turn that macroprudential policy is less needed for financial stability in that country as long as that configuration persists.

9.2 Increase in risk-adjusted capital adequacy target

Moving to the second simulation on the countercyclical capital buffer, Chart 4.2.1 shows that there is a decline in household liabilities, driven by the overall downturn in the economy (Chart 4.2.4) and the rise in the household lending wedge (Chart 4.2.10). House prices also decline, after rising initially, being affected by the increase in lending wedge, but by much less than in the ltv scenario (Chart 4.2.2). We see from Chart 4.2.3 that risk adjusted capital adequacy rises in line with the target set by the authorities, by 2.5 percentage points, with a lag, as is permitted by the Basel rules.

GDP falls in this scenario to a much greater degree than in the ltv case, with the declines after 5 years being greater in Germany and Italy than the UK where the decline is quite small (Chart 4.2.4). Looking at the components, we see that both consumption and investment decline. However, compared to the previous scenario, the impact on consumption is smaller, while on private investment the impact is markedly larger. Private investment falls less in the UK than Germany and Italy (Chart 4.2.6), in the light of rises in the corporate lending wedge (Chart 4.2.9) and declines in other components of GDP. The saving ratio falls as real personal disposable income declines more than consumption, again markedly so in Italy (Chart 4.2.7). Similar to the previous case, it is not surprising to see an improvement in the current account balance as domestic demand decreases following the introduction of higher capital requirements (Chart 4.2.8).

As regards the financial patterns, the corporate wedge rises in each country, stabilizing at around 0.5-0.7 percentage points above base after five years (Chart 4.2.9). The household wedge rises rather less, by around 0.15-0.2 percentage points (Chart 4.2.10). These patterns are driven by the higher levels of capital required for banks, which affect banks' costs and are present in the equations for the wedges. Corporate lending falls to a much greater extent than lending to households (Chart 4.2.11, compare Chart 4.2.12), by 6 per cent, in line with the greater rise in the wedge for companies. Bank assets fall to a greater extent than in case of implementation of tighter *ltv* policy, for all three countries but the falls is greater in Germany and Italy than the UK (Charts 4.2.12-4.2.13); the fall is comparable for both risk weighted and unweighted capital adequacy since the brunt of the shock is taken by corporate lending with a risk weight of 1. Finally the systemic risk indicator falls by more than in the *ltv* case for the UK and Germany, reflecting the key influence of bank capital adequacy on systemic risks (Chart 4.2.14), although again the ratio in Italy is little affected. Note that the scales on the *sri* charts 4.1.14, 4.2.14/4.3.14, and 4.4.14 differ.

9.3 Combined macroprudential tightening

Combining the two above mentioned policies as a third scenario gives a greater impact on financial stability and also on the macroeconomy and financial sector. We in effect see both patterns described above superimposed. We note highlights rather than going chart by chart. Both consumption and investment (Charts 4.3.5 and 4.3.6) fall markedly, although GDP is partly buoyed by the improvement in the current account (Chart 4.3.8). The saving ratio rises in the UK and Germany, showing a greater relative impact of the *ltv* shock, while it falls in Italy (as personal income is reduced more than private consumption) (Chart 4.3.7). Declines in bank assets and in the *sri* are correspondingly greater in the combined application of macroprudential policies (Charts 4.3.12-4.3.14). The *sri* pattern is however dominated by the impact of the capital adequacy tightening.

9.4 Historic dynamic simulation for the crisis period

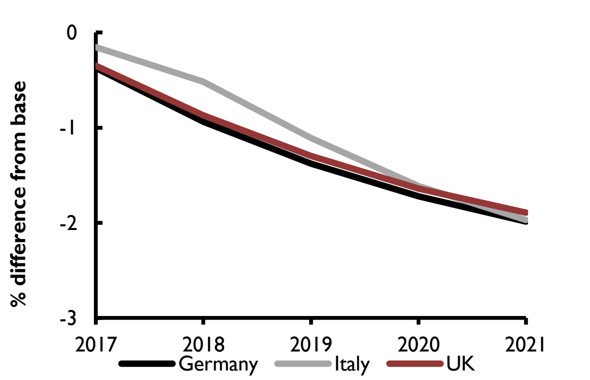
The final simulation, which covers the crisis period, is most relevant for the UK and Italy only, as the systemic risk indicator does not reach critical levels in Germany and hence the macroprudential tools are not triggered. German banks suffered from a crisis less due to domestic conditions than due to the US securitised bonds that they had purchased. The small impact on Germany reflects the differential effect of the macroprudential policy changes in the UK and Italy on its economy.

By triggering the macroprudential policies in 2004, the UK and Italy would have had lower levels of household debt (Chart 4.4.1) as well as slower house price growth (Chart 4.4.2) at the onset of the crisis. The capital adequacy of banks also would have been higher, most likely giving more resilience to the banking sector (Chart 4.4.3) (we note that the policy is retained for three years after the systemic risk indicator drops below its critical level). Note, however, that we do not give any offset for a possibly beneficial mitigation of the effect of the crisis on credit rationing and uncertainty relative to what actually occurred, which might have had a favourable effect on output. Hence the effect of the policy is largely negative on output (Chart 4.4.4) reflecting lower consumption and investment (Charts 4.4.5 and 4.4.6), while the current balance are markedly higher over the crisis period (Chart 4.4.8).

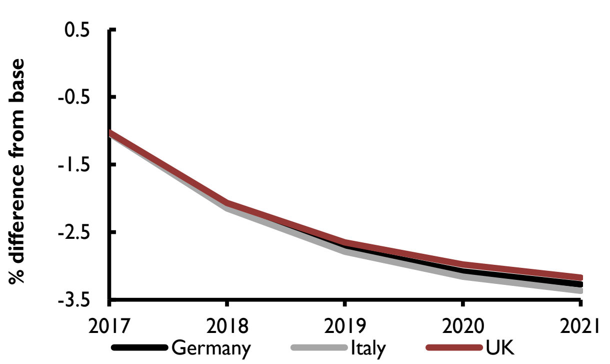
Lending wedges would have been boosted by the policies, thus somewhat dampening borrowing. Corporate lending would have been much lower as compared to the baseline case, which would have been favourable for financial stability (Chart 4.4.11). Lower levels of corporate lending would have lowered banking sector assets (Charts 4.4.12 and 4.4.13) - over 3 per cent lower in the UK at the onset of the crisis in 2007 Q3 and around 7% lower in Italy. Finally, a marked reduction in a systemic risk index suggests that the macroprudential policies would have reduced the possibility of the crisis occurring, or at least making it less severe (see the cost-benefit calculations in section 5) – again note the scale differs from the charts of *sri* in the earlier simulations.

Chart 4.1: Simulation output: tightening of loan-to-value policy

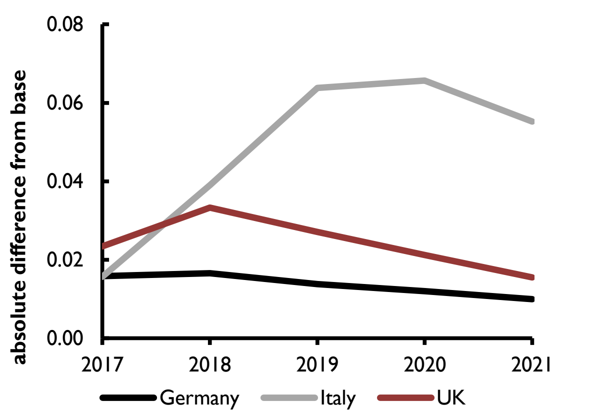
4.1.1 Household liabilities



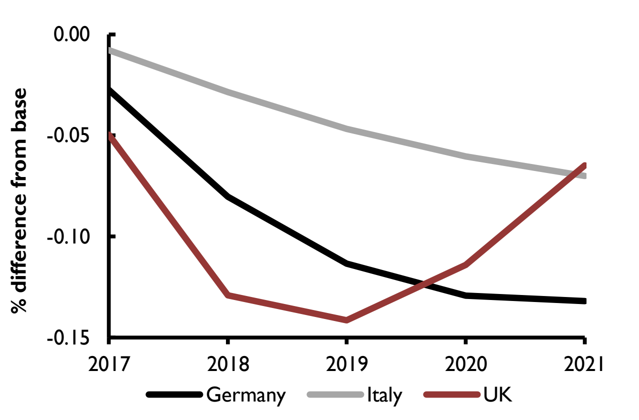
4.1.2 Real house prices



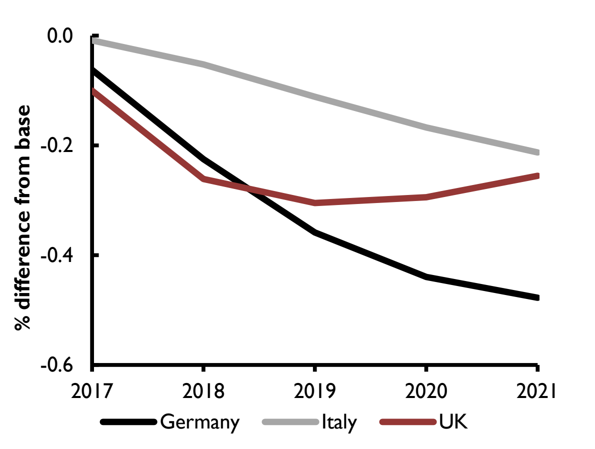
4.1.3 Risk adjusted capital adequacy



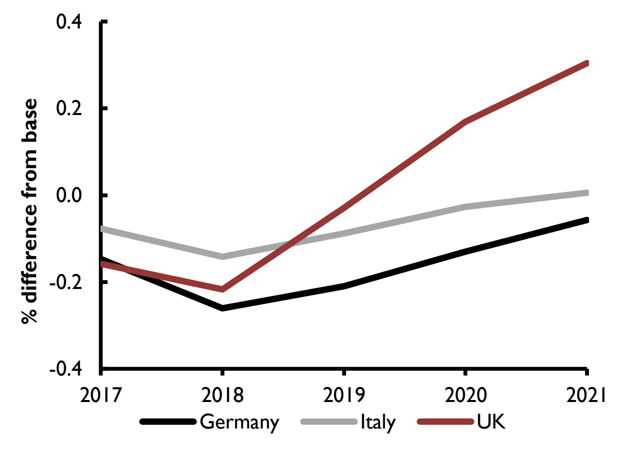
4.1.4 Output



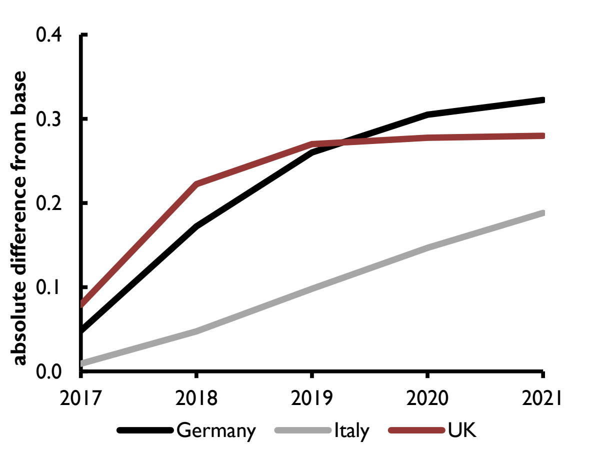
4.1.5 Household consumption



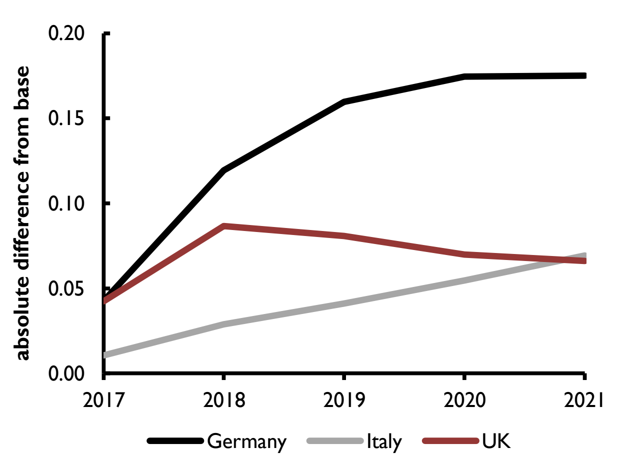
4.1.6 Private sector investment



4.1.7 Saving rate



4.1.8 Current account to GDP ratio (per cent)



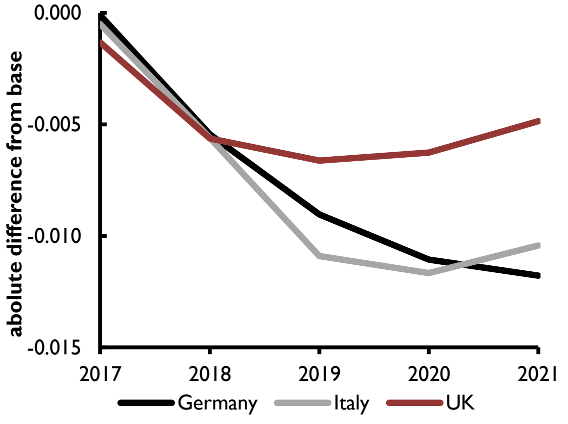
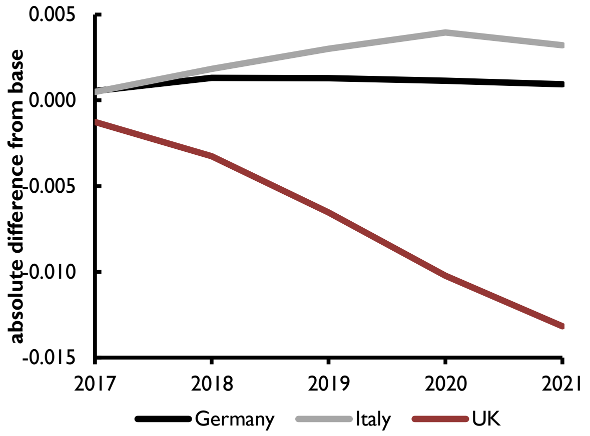
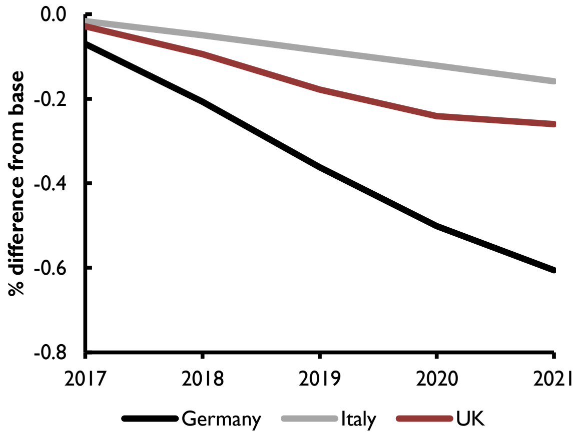
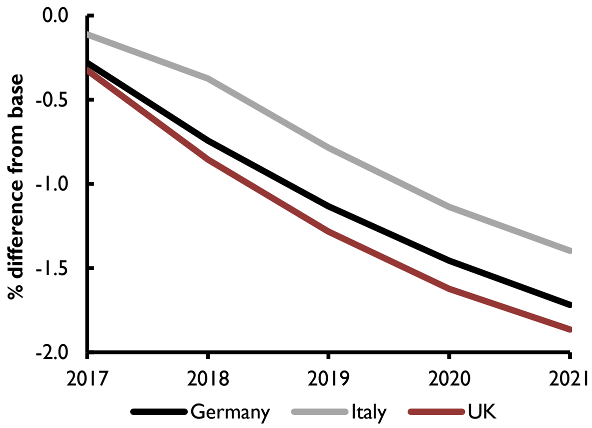
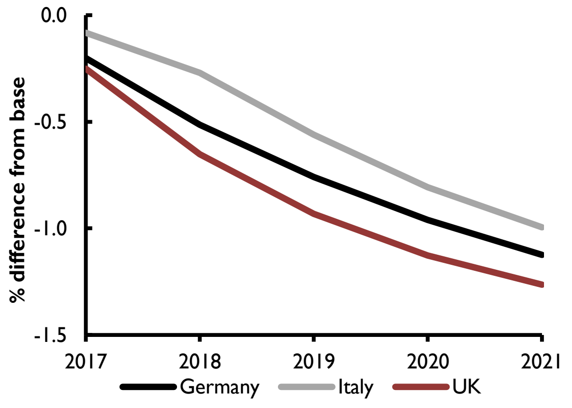
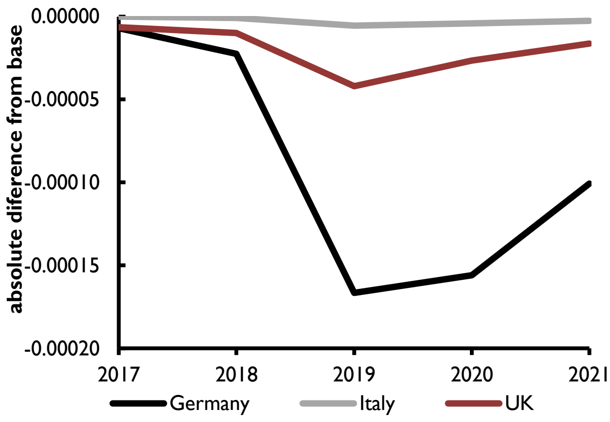
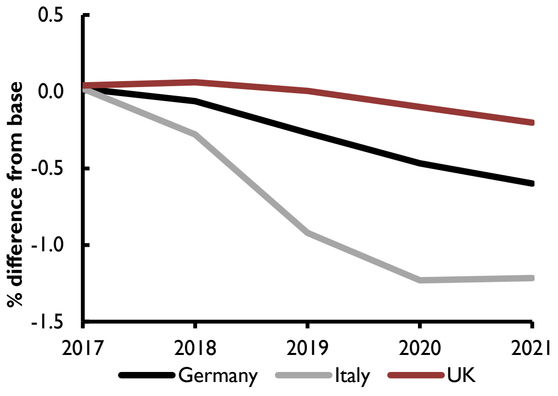
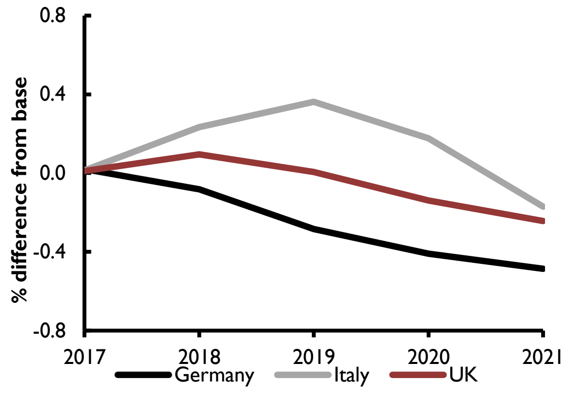
4.1.9 Corporate wedge	4.1.10 Household lending wedge
	
4.1.11 Corporate lending	**4.1.12 Banking assets**
	
4.1.13 Risk weighted banking assets	**4.1.14 Systemic Risk Index**
	

Chart 4.2 Simulation output: increase in risk-adjusted capital adequacy target

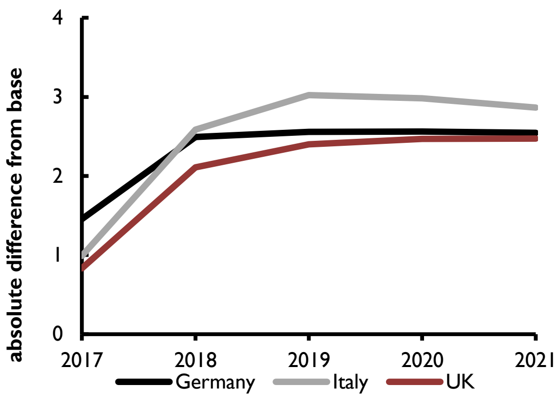
4.2.1 Household liabilities



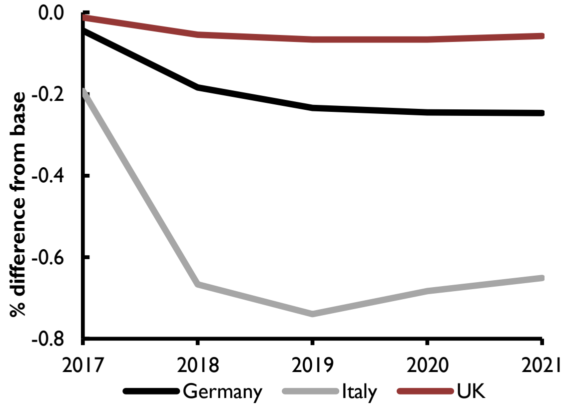
4.2.2 Real house prices



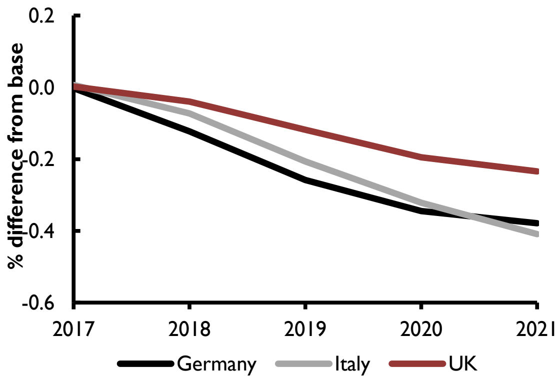
4.2.3 Risk adjusted capital adequacy



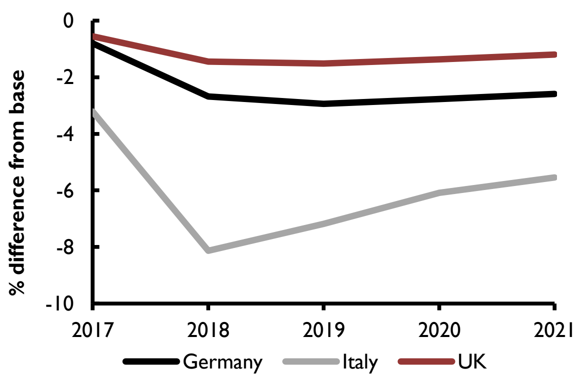
4.2.4 Output



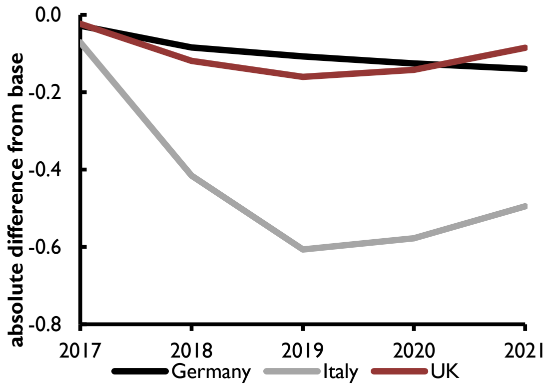
4.2.5 Household consumption



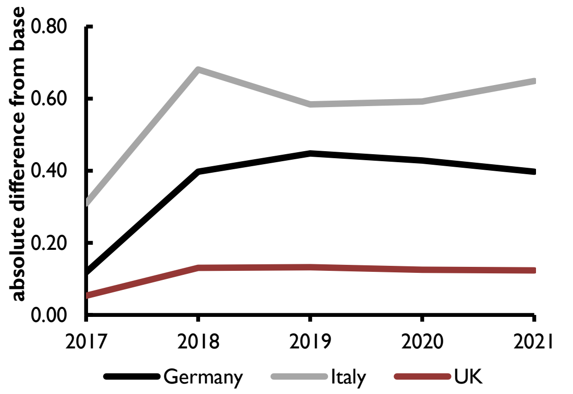
4.2.6 Private sector investment



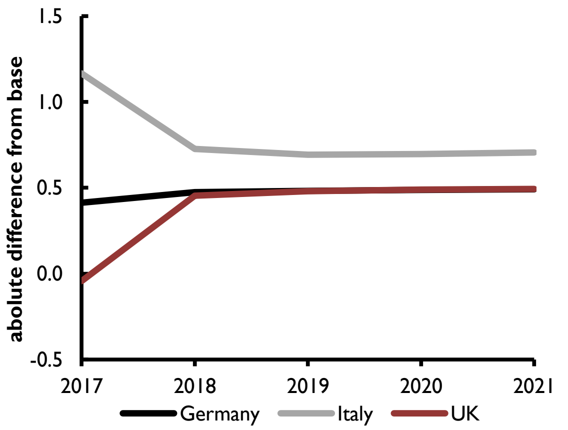
4.2.7 Saving rate



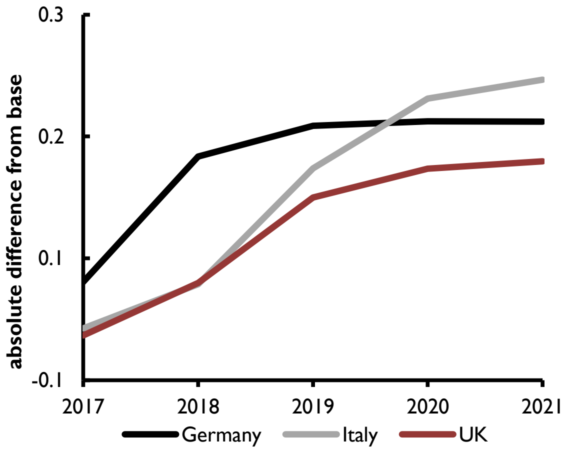
4.2.8 Current account to GDP ratio (per cent)



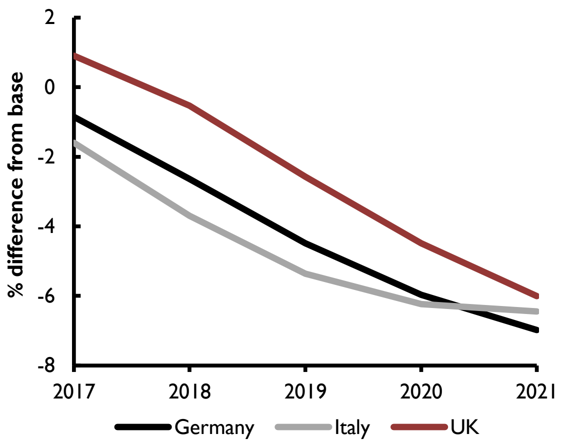
4.2.9 Corporate wedge



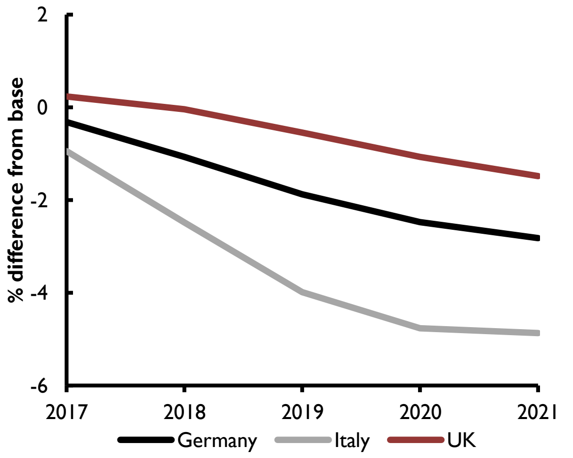
4.2.10 Household lending wedge



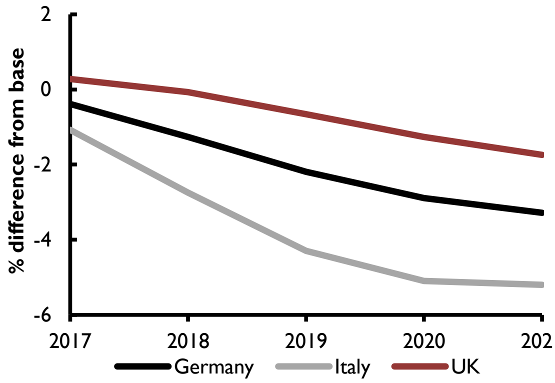
4.2.11 Corporate lending



4.2.12 Banking assets



4.2.13 Risk weighted banking assets



4.2.14 Systemic Risk Index

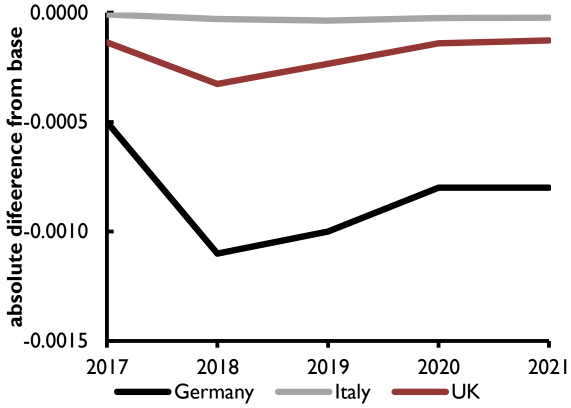
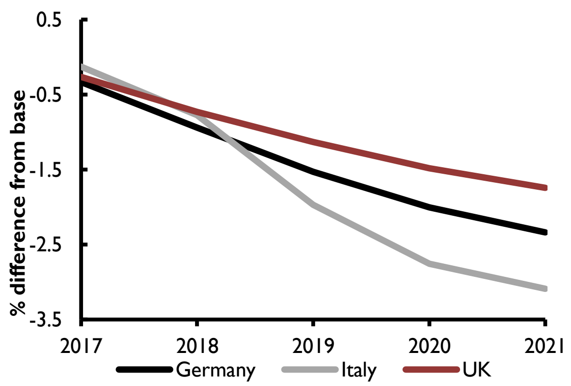
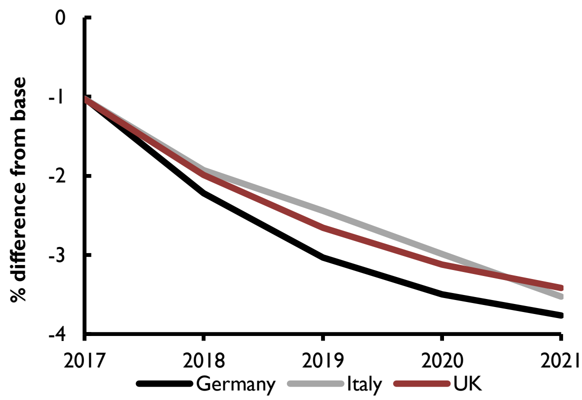


Chart 4.3 Simulation output: combined macroprudential tightening

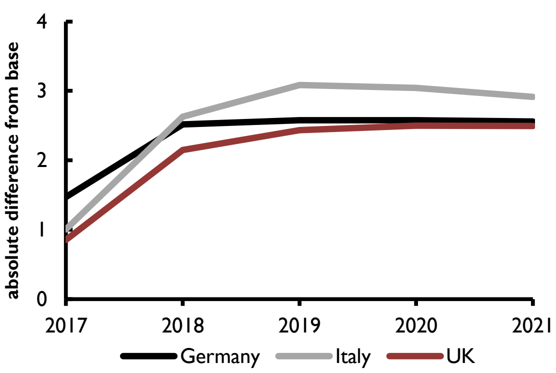
4.3.1 Household liabilities



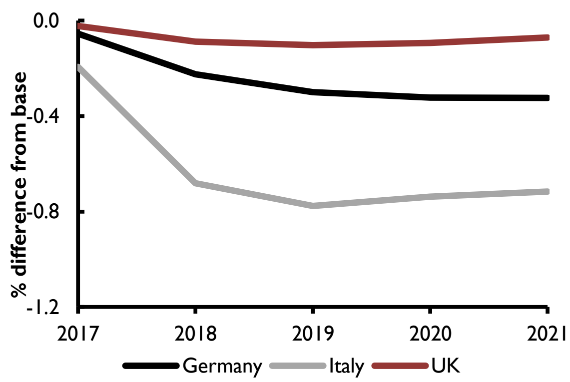
4.3.2 Real house prices



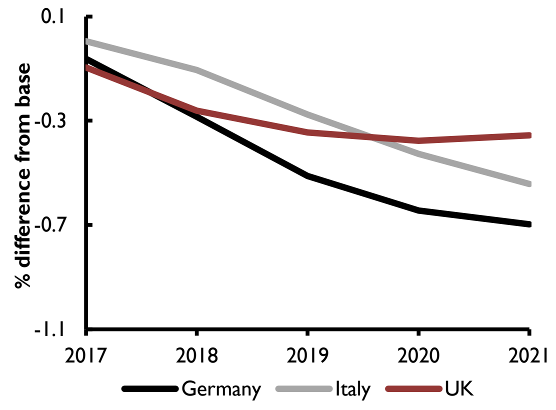
4.3.3 Risk adjusted capital adequacy



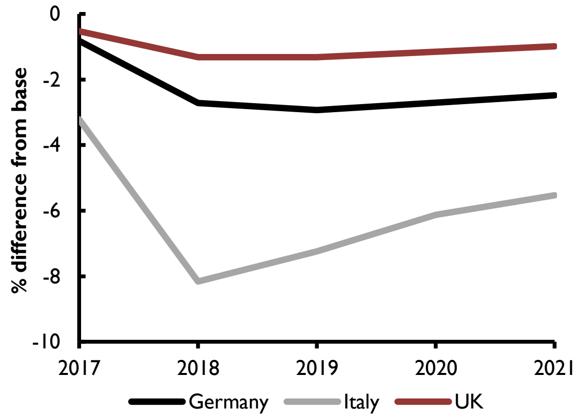
4.3.4 Output



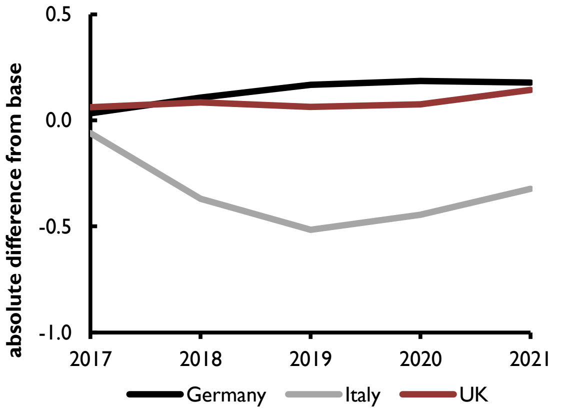
4.3.5 Household consumption



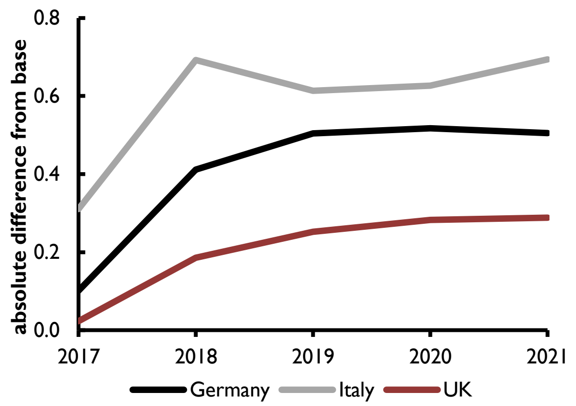
4.3.6 Private sector investment



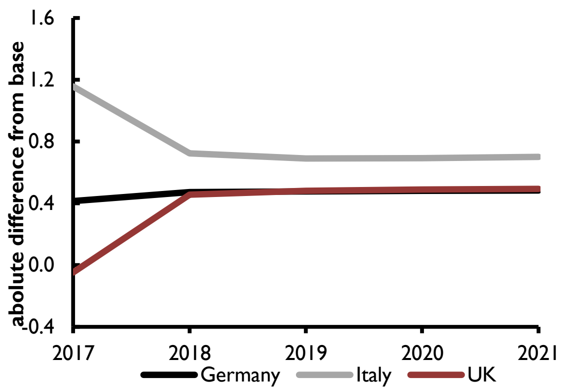
4.3.7 Saving rate



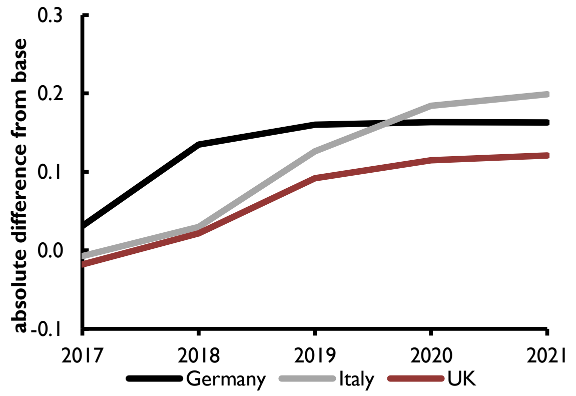
4.3.8 Current account to GDP ratio (per cent)



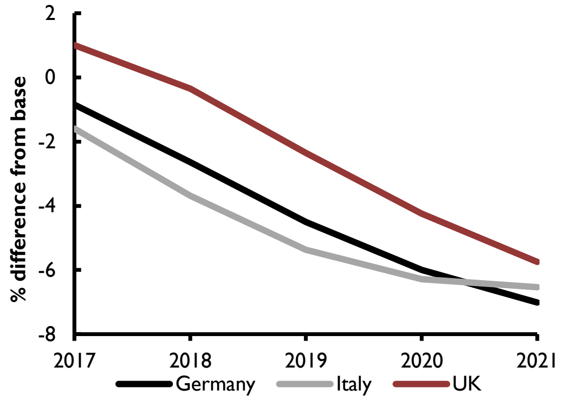
4.3.9 Corporate wedge



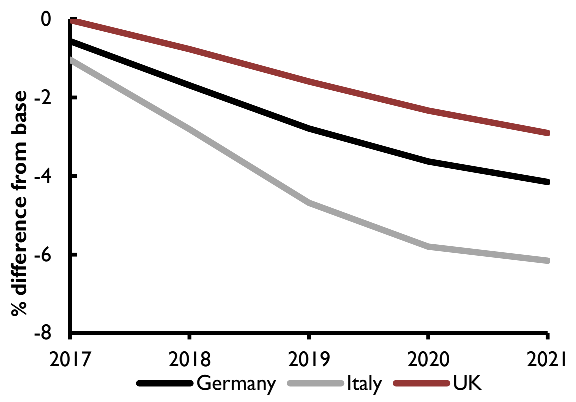
4.3.10 Household lending wedge



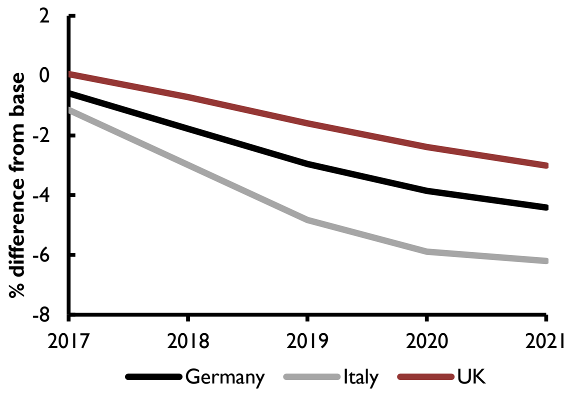
4.3.11 Corporate lending



4.3.12 Banking assets



4.3.13 Risk weighted banking assets



4.3.14 Systemic Risk Index

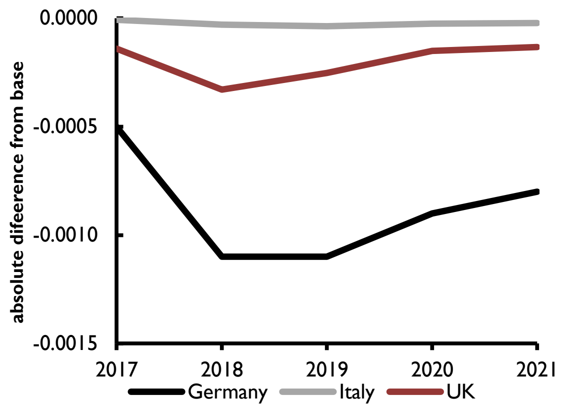
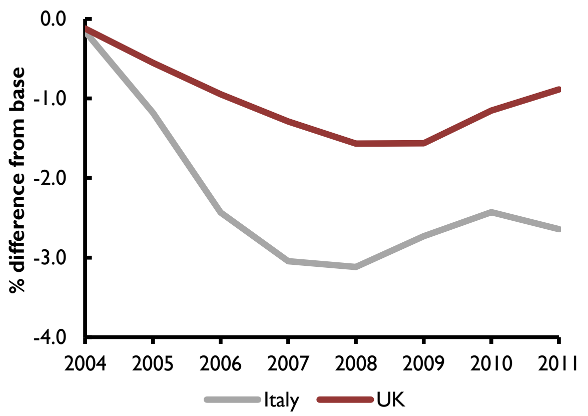
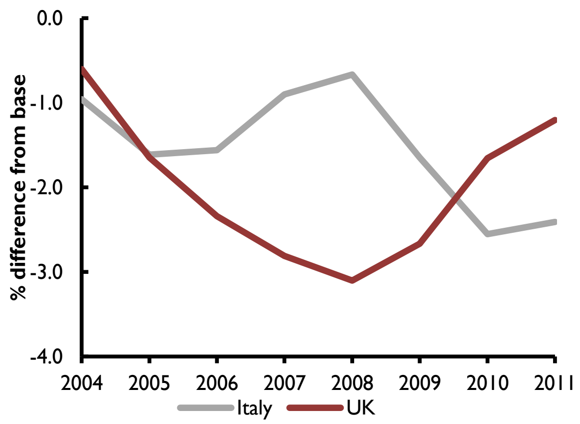


Chart 4.4: Historic dynamic simulation for the crisis period

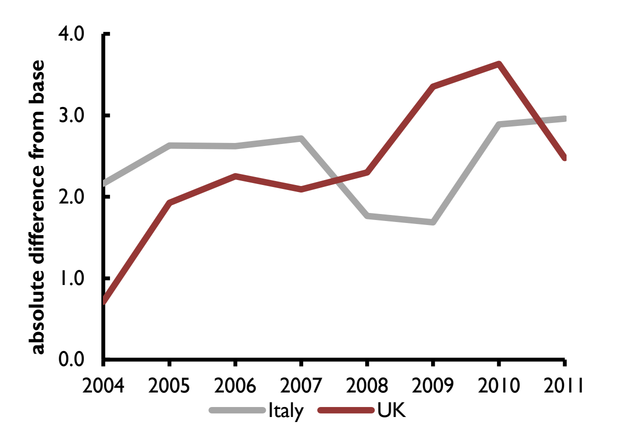
4.4.1 Household liabilities



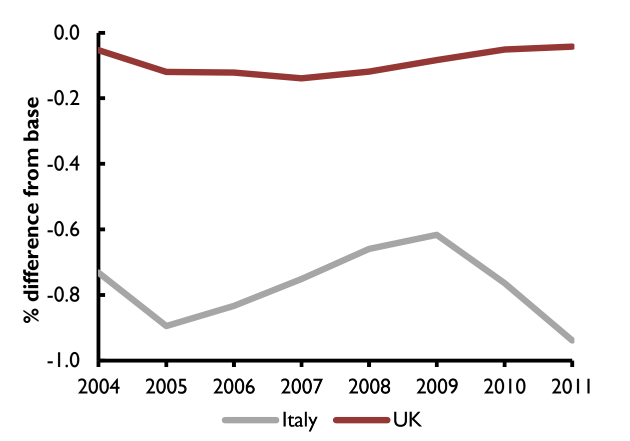
4.4.2 House prices



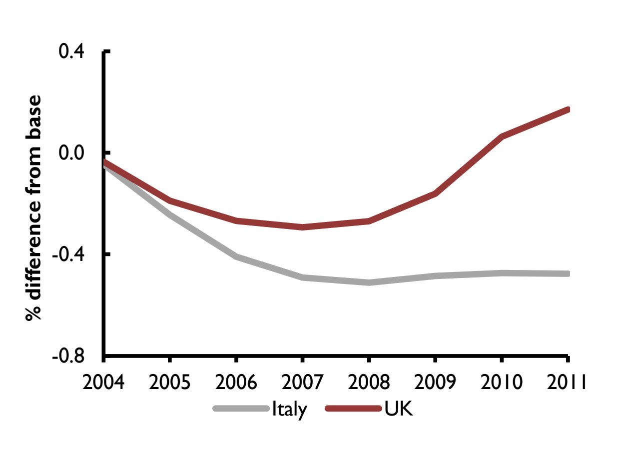
4.4.3 Risk adjusted capital adequacy



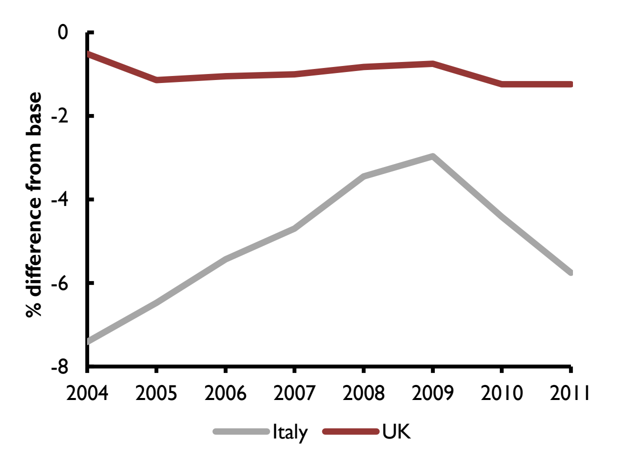
4.4.4 Output



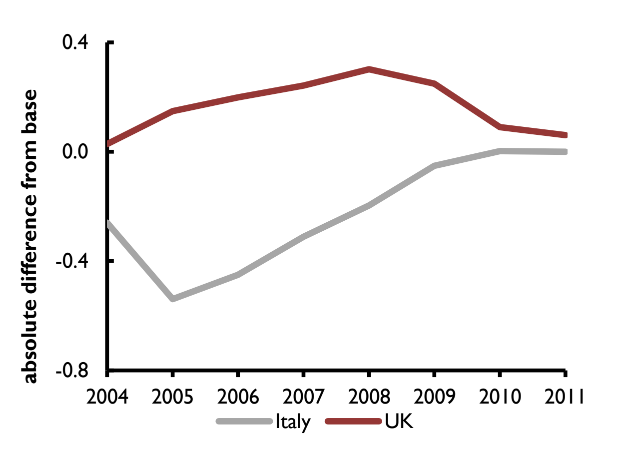
4.4.5 Household consumption



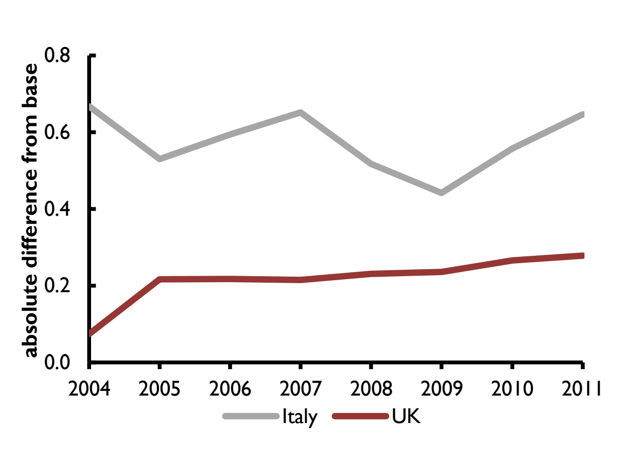
4.4.6 Private sector investment



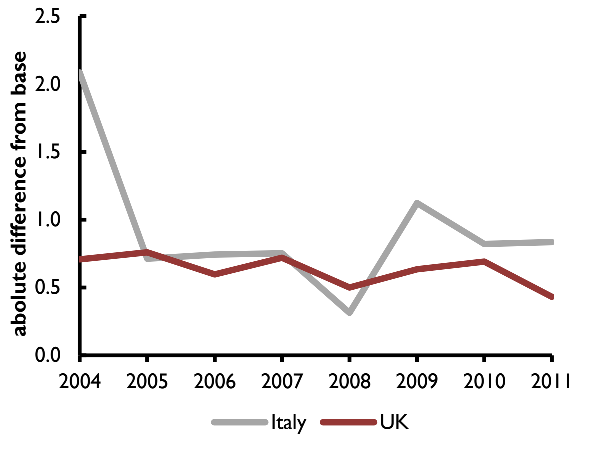
4.4.7 Saving rate



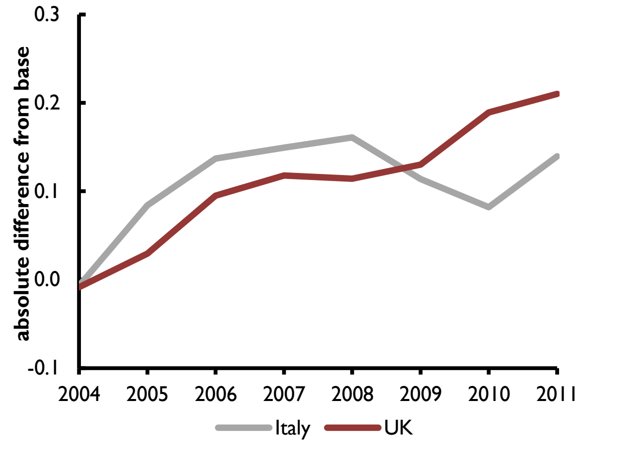
4.4.8 Current account to GDP ratio (per cent)



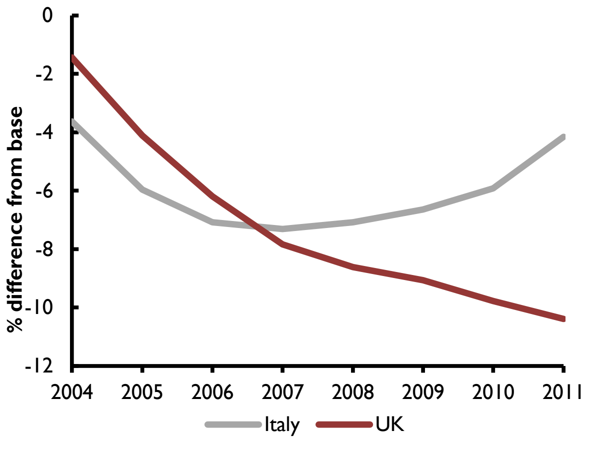
4.4.9 Corporate wedge



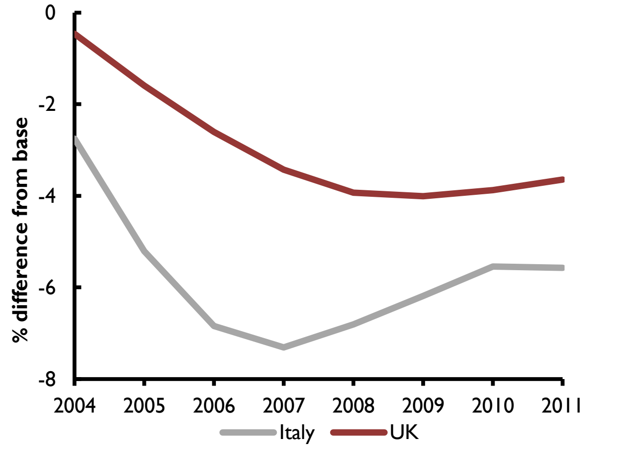
4.4.10 Household lending wedge



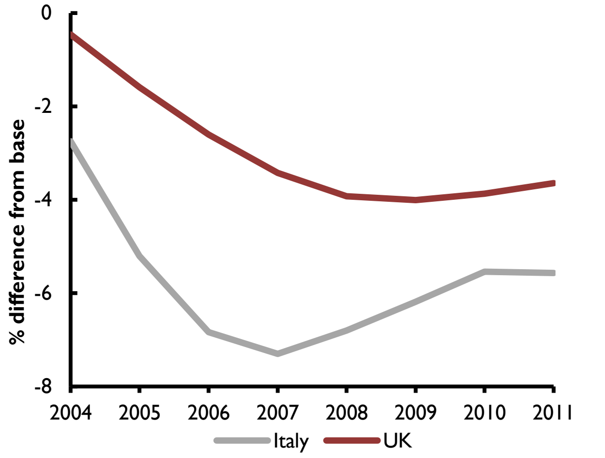
4.4.11 Corporate lending



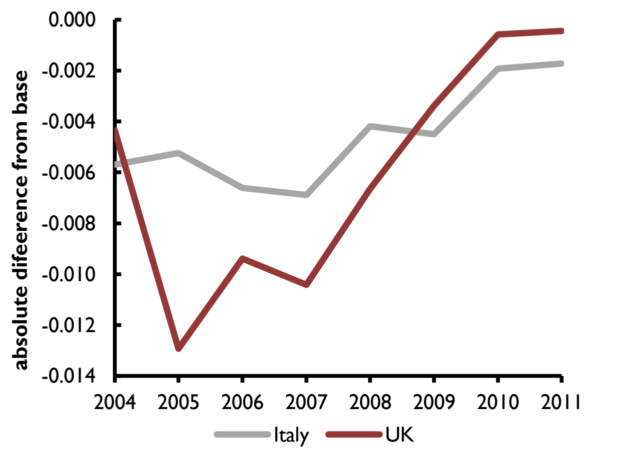
4.4.12 Banking assets



4.4.13 Risk weighted banking assets



4.4.14 Systemic Risk Index

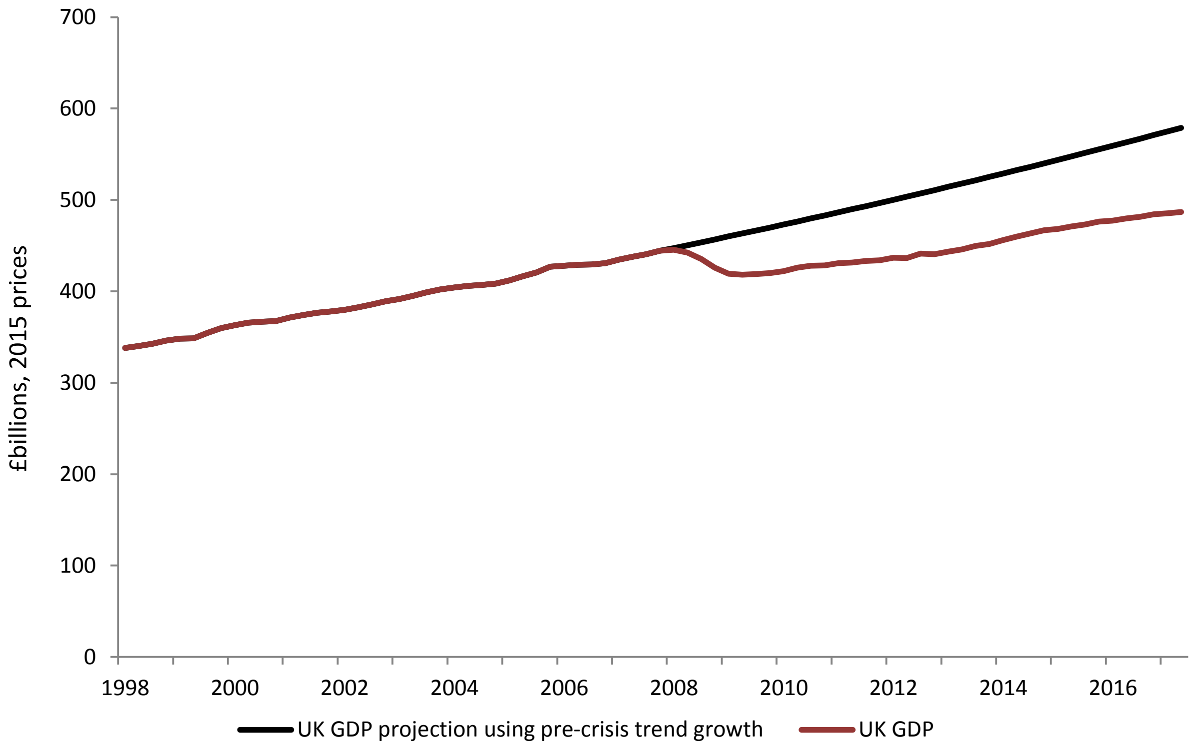


10 Cost-benefit analysis

As noted above, and discussed further in Barrell et al (2009), changing macroprudential policies change the probability of financial crises, and crises have clear costs for the economy. Hence we can calculate the expected gross gain from macroprudential policy implementation, and we can compare it to the gross costs in terms of output. If we were to take the net present value (NPV) of all costs and benefits from tighter macroprudential policies, we would have to take account of the costs incurred during a post crisis recession. This would require us to analyse the effects of changes in macroprudential policies on the path of GDP.

The short term costs of a crisis may be significant, and they are likely to be negative and could outweigh any other costs. The flow costs of the crisis may be written as the difference between our expectation of what output would have been at time t if there had been no crisis, versus the output if there was a crisis, and to obtain the policy benefits this is multiplied by the change in probability of the crisis owing to the policy action (lowering loan-to-value ratios or raising capital adequacy). We use estimates of the cost of the subprime crisis in the UK as a simple comparison of the actual path of GDP with what GDP would have been if growth had persisted at its average rate over the 10 years prior to the crisis, to provide a baseline for costs. The pattern is shown in the chart below:

Chart 5.1: UK GDP and pre-crisis trend



Source: NiGEM database and authors' calculations

Meanwhile, we can trace the effect of the macroprudential measures on the economy as set out above in a simulation with an application of macroprudential policies with no specific boom or bust (as in the GDP charts). We can also assess the impact of LTV and capital adequacy alone. We can then calculate the net present discounted value of the benefit-cost difference by subtracting the cost from the benefit and discounting. In line with Barrell et al (2009), we use a discount factor of 3 per cent.

A key question is then the way to calculate benefits. Absolute changes in probability may not be realistic bearing in mind that the average across the sample of Karim et al (2013) is 0.0357, and our chosen critical levels are 0.05 for Germany, 0.03 for Italy and 0.01 for the UK. Accordingly, besides calculating the benefit using changes in absolute probabilities of crises, we recalculated the present value based on the relevant critical level (using as a measure of benefit the proportion of the critical level accounted for by the change in sri due to the policy) and twice the critical level.

The results in table 3 illustrate that use of absolute probabilities always results in a negative NPV. For the UK and Germany, benefits are substantially positive at the actual critical level of crisis probability and at double that level, while for Italy the net benefits are still negative. This relates to the low base level of sri in Italy which means that the gain owing to the policy is very small over the simulation base. Finally for the historic simulation we show the NPV of the absolute gain from 2004-2016 from implementing the macroprudential policies as shown above, which for the UK is 4.3 per cent of GDP and -1.4 per cent for Italy.

Table 3: Cost benefit calculations (monetary policy reaction function off, per cent of 2016 GDP, based on 7-year projection)

SRI change	Tightening of loan-to-value policy	Tightening of the risk-adjusted capital adequacy target	Combined simulation	Historic simulation
UK				
Absolute probability	-0.5	-0.9	-1.3	4.3
Crisis probability of 0.01	0.8	11.5	11.6	
Crisis probability of 0.02	0.2	5.2	5.1	
Germany				
Absolute probability	-0.6	-1.4	-2.1	0.3
Crisis probability of 0.05	0.7	9.9	9.7	
Crisis probability of 0.10	0.0	4.0	3.5	
Italy				
Absolute probability	-0.3	-4.5	-4.9	-1.4
Crisis probability of 0.03	-0.3	-3.9	-4.3	
Crisis probability of 0.06	-0.3	-4.2	-4.6	

11 Conclusions

In this paper, we first illustrate our specific extensions to NiGEM for a macroprudential block, before going on to the results of counterfactual scenarios based on the macroprudential block. We also perform a cost-benefit analysis of macroprudential policies, whereby the benefit is captured by the diminished probability of a crisis and the cost by the impact of macroprudential policies on output. The policies are tested in the NiGEM models for the UK, Germany and Italy, all of which have a banking sector submodel in NiGEM. An explanation of the data sources is carried out in Appendix 3.

Concerning limitations, we note that macroprudential policy is more likely to be implemented in a discretionary manner, rather than be triggered by systemic risk in the model given current low levels of the latter, which in turn reflect Basel III improvements to capital adequacy. The systemic risk function is of course largely focused on banking sector risk and resilience, and accordingly the model will not forecast as it stands the types of crisis that have originated in the non-bank sector such as the 1998 Russian financial crisis or the recent European sovereign debt crisis. Consequently, an assessment of non-bank imbalances may be a further area for research.

Further research might focus on additional macroprudential tools such as the Debt-To-Income ratio for mortgages as well as taxes on financial institutions, both of which were shown to be effective in Carreras et al (2016). A further important issue is to implement feedback from the real economy to bank capital adequacy and lending in the form of mortgage arrears for households and insolvencies for companies. Relevant equations were estimated in Davis and Liadze (2012) for these quantities. We can also assess the impact of macroprudential policy when monetary and fiscal policy do not partly offset their impact, i.e. varying the policy mix, as is illustrated in Appendix 1, although effects of this are quite small (compare for example Chart 4.1.4 and Chart A.1.4 showing a small offset of *ltv* policy by monetary policy easing).

12 References

Antipa, P. and Matheron, S. (2014), “Interactions between monetary and macroprudential policies”, Banque de France Financial Stability Review, 18, pp. 225-239.

Barrell, R., Davis, E. P., Fic, T., Holland, D., Kirby, S. and Liadze, I. (2009), “Optimal regulation of bank capital and liquidity: how to calibrate new international standards” FSA Occasional Paper no. 38, October.

Barrell, R., Davis, E. P., Karim, D., Liadze, I., (2010a), “Bank regulation, property prices and early warning systems for banking crises in OECD countries”, Journal of Banking and Finance, 34, pp. 2255–2264.

Barrell, R., Davis, E. P., Karim, D. and Liadze, I. (2010b), " The impact of global imbalances: Does the current account balance help to predict banking crises in OECD countries?", NIESR Discussion Paper No. 351.

Barrell, R., Davis, E., Liadze, I., Karim, D, (2010c), “The Effects Of Banking Crises On Potential Output In OECD Countries” NIESR Discussion Paper no. 358,

Barrell R., and Dury, K. (2003) 'Asymmetric labour markets in a converging Europe: Do differences matter?' National Institute Economic Review No. 183, January 2003

Barrell, R., and N. Pain (1997), 'Foreign Direct Investment, Technological Change, and Economic Growth Within Europe', Economic Journal, 107, pp. 1770-1776.

Basel Committee (2010), “Guidance for national authorities operating the countercyclical capital buffer”, BCBS, Basel.

Basel Committee (2015), “Frequently asked questions on the Basel III countercyclical capital buffer”, BCBS, Basel.

Benigno, G., Chen, H., Otrok, C., Rebucci, A. and Young, E. (2013), "Financial Crises and Macro-Prudential Policies", Journal of International Economics, 89(2), pp. 453-470.

Bennani, T., Després, M., Dujardin, M., Duprey, T. and Kelber, A. (2014), “Macroprudential framework: key questions applied to the French case”, Banque de France Occasional papers, No. 9

Bernanke, B., Gertler, M. and Gilchrist, S. (1999), "The financial accelerator in a quantitative business cycle framework", Handbook of Macroeconomics 1 (1999), pp. 1341-1393.

Blanchard, O.J. and Fischer, S. (1989) “Lectures on Macroeconomics”, Cambridge: MIT Press.

Boissay, F., Collard, F. and Smets, F. (2013), "Booms and systemic banking crises", ECB Working Paper No. 1514.

Borgy V, Clerc L and Renne J-P (2014), “Measuring aggregate risk: Can we robustly identify asset-price boom–bust cycles?”, Journal of Banking & Finance 46 (2014) 132–150

Borio, C. and Drehmann, M. (2009), "Towards an operational framework for financial stability: ‘fuzzy’ measurement and its consequences", BIS Working Paper No. 284.

Brunnermeier, M. and Sannikov, Y. (2014), "A Macroeconomic Model with a Financial Sector", American Economic Review, 104(2), pp. 379-421.

Carreras O, Davis E P and Piggott R (2016) “Macroprudential tools, transmission and modelling”, Firstrun Deliverable 4.7, Horizon 2020

Catte, P., Cova, P., Pagano, P. and Visco, I. (2010), "The role of macroeconomic policies in the global crisis", Bank of Italy Occasional Papers No. 69.

CGFS (2010), “Macroprudential instruments and frameworks: report published by the Committee on the Global Financial System” 21 May 2010, Basel.

Crockett, A. (2000), "Marrying the micro- and macro-prudential dimensions of financial stability", Remarks before the Eleventh International Conference of Banking Supervisors. Bank for International Settlements. Basel, 20-21 September 2000.

Darbar, S. M. and Wu, X. (2015), “Experiences with macroprudential policy, five case studies”, IMF Working Paper 15/123.

Davis, E. P., Fic, T. M. and Karim, D. (2011), “Housing Market Dynamics and Macroprudential Tools”, in “RUTH, the Riksbank’s inquiry into the risks in the Swedish housing market” pages 219-298, also Brunel Economics and Finance Working Paper 11-07.

Davis E P and Karim D (2008), “Comparing early warning systems for banking crises”, Journal of Financial Stability, 4, 89-120

Davis E P and Liadze I (2012), “Modelling and simulating the banking sectors of the US, Germany and the UK”, NIESR Discussion Paper 396

Davis E P and Zhu H (2009), “Commercial property prices and bank performance”, Quarterly Review of Economics and Finance 49, 1341–1359

Demirguc-Kunt, A. and Detragiache, E. (1998), “The Determinants of Banking Crises in Developed and Developing Countries”, IMF Staff Paper, Vol. 45, No.1.

Diamond, D. and Dybvig, P. (1983), "Bank runs, deposit insurance, and liquidity", Journal of Political Economy, 91(3), pp. 401–419.

Drehmann (M.), Borio (C.), Gambacorta (L.), Jimenez (G.) and Trucharte (C.) (2010) “Countercyclical capital buffers: Exploring options”, BIS Working Paper, No. 317.

Drehmann (M.), Borio (C.) and Tsatsaronis (K.) (2011) “Anchoring countercyclical capital buffers: The role of credit aggregates”, International Journal of Central Banking, 7(4), pp. 189-240.

Dufrénot (G.), Klaus (B.), Malik (S.) and Vardoulakis (A. P.) (2012) “Credit standards and financial institutions’ leverage”, mimeo.

Edge, R.M., Meisenzahl, R.R., (2011). The unreliability of credit-to-GDP ratio gaps in real time: implications for countercyclical capital buffers. International Journal of Central Banking 7 (4), 261–299.

Fisher I (1933) “The Debt-Deflation Theory of Great Depressions”, Econometrica, 1, 337-357

Galati, G. and Moessner. R. (2014), “What do we know about the effects of macroprudential policy?” DNB Working Paper No. 440.

Gali. J, (2009), “Monetary policy, inflation and the business cycle”, Princeton University Press.

Gersbach, H. and Rochet, J. C. (2012a), "Capital Regulation and Credit Fluctuations", CEPR Discussion Paper No. 9077.

Gersbach, H. and Rochet, J. C. (2012b), "Aggregate Investment Externalities and Macroprudential Regulation", Journal of Money, Credit and Banking, 44, pp. 73-109.

Goodfriend, M. and McCallum, B. (2007), "Banking and interest rates in monetary policy analysis: a quantitative exploration", Journal of Monetary Economics, 54, pp. 1480–1507.

Goodhart, C. A. E. (2010), “Money, credit and bank behaviour: need for a new approach” National Institute Economic Review, 214.

Goodhart, C., Kashyap, A., Tsomocos, D. and Vardoulakis, A. (2012), "Financial Regulation in General Equilibrium", NBER Working Paper No. 17909.

Goodhart, C., Kashyap, A., Tsomocos, D. and Vardoulakis, A. (2013), "An Integrated Framework for Analyzing Multiple Financial Regulations", International Journal of Central Banking, 9(1), pp. 109-143.

Horváth, B. and Wagner, W. (2013), "The Disturbing Interaction between Countercyclical Capital Requirements and Systemic Risk", Mimeo, Tilburg University.

Kashyap, A. K., Tsomocos, D.P. and Vardoulakis, A.P. (2014), "How does macroprudential regulation change bank credit supply?", NBER Working Paper No. 20165.

Karim D, Liadze I, Barrell R and Davis E P (2013), “Off balance sheet exposures and banking crises in OECD countries”, Journal of Financial Stability, 9, 673-681

Kuttner, K, N., and Shim, I. (2016), “Can non-interest rate policies stabilise housing markets? Evidence from a panel of 57 economies,” Journal of Financial Stability, 26, 31-44.

McKinnon, R. I., H. Pill, (1994), “, Credible liberalizations and international capital flows; the overborrowing syndrome”, Stanford University, Stanford.

Osborne, M. (2008), “Preliminary results from FSA research project on bank portfolio dynamics”, mimeo, Financial Services Authority, London.

Perotti, E. and Suarez, J. (2011), "A Pigovian Approach to Liquidity Regulation", International Journal of Central Banking, 7(4), pp. 3-41.

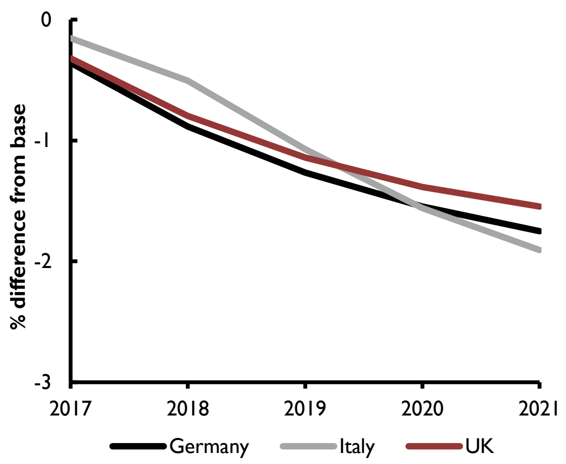
Repullo R. and Saurina J. (2011) “The Countercyclical Capital Buffer of Basel III: A Critical Assessment”, CEPR Discussion Papers, No. 8304.

Woodford, M. (2010), “Financial intermediation and macroeconomic analysis”, Journal of Economic Perspectives, 24(4), pp. 21–44.

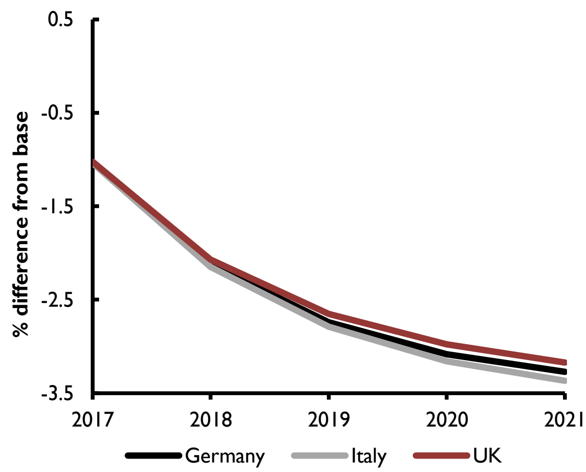
Appendix 1 – Simulations with endogenous interest rates

Chart A.1: Simulation output: tightening of loan-to-value policy

A.1.1 Household liabilities

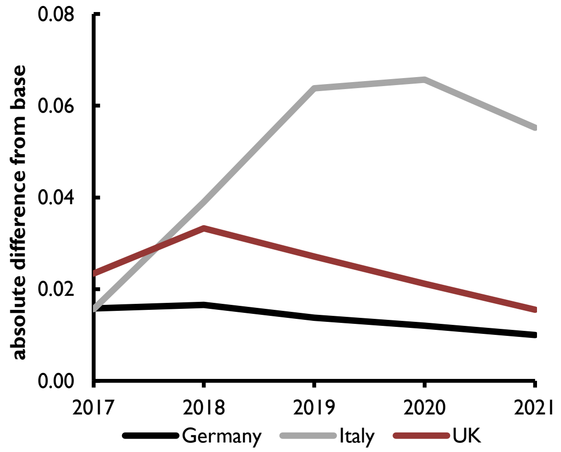


A.1.2 Real house prices

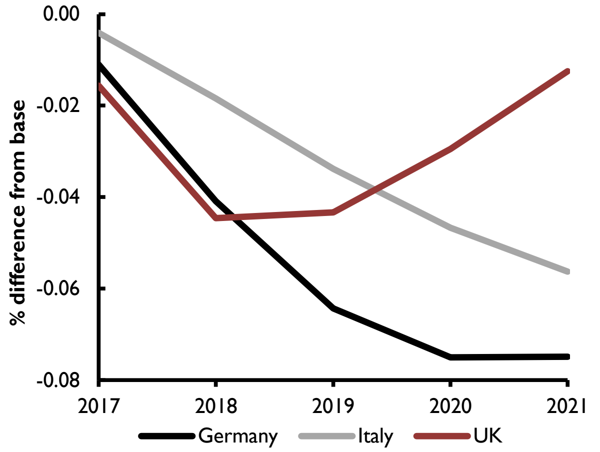


A.1.3 Risk adjusted capital adequacy

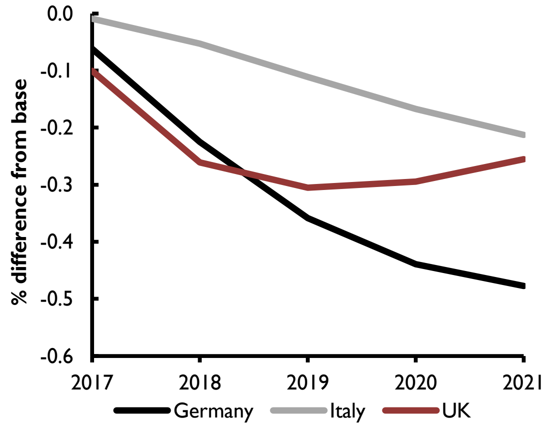
A.1.4 Output



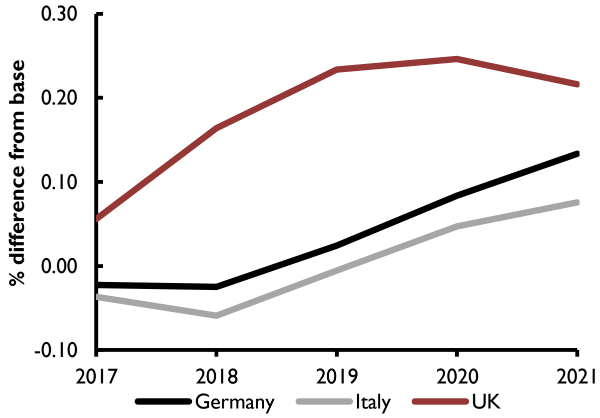
A.1.5 Household consumption



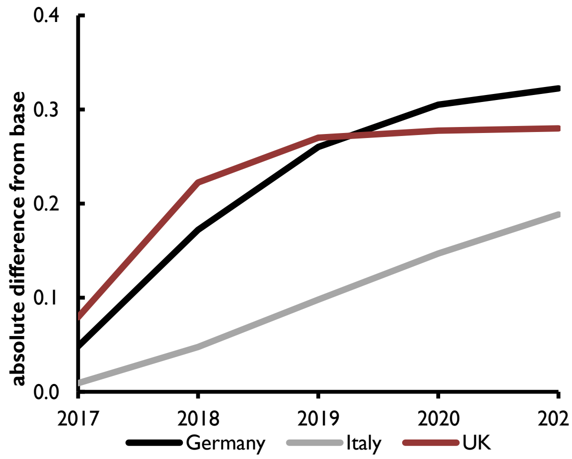
A.1.6 Private sector investment



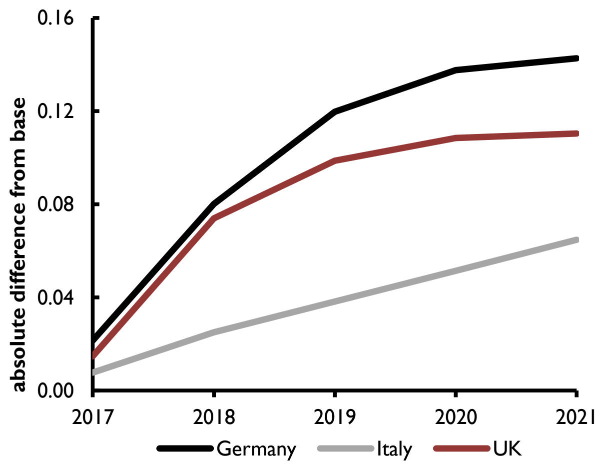
A.1.7 Saving rate



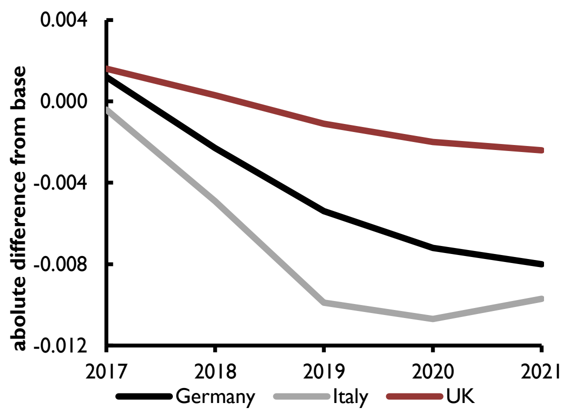
A.1.8 Current account to GDP ratio (per cent)

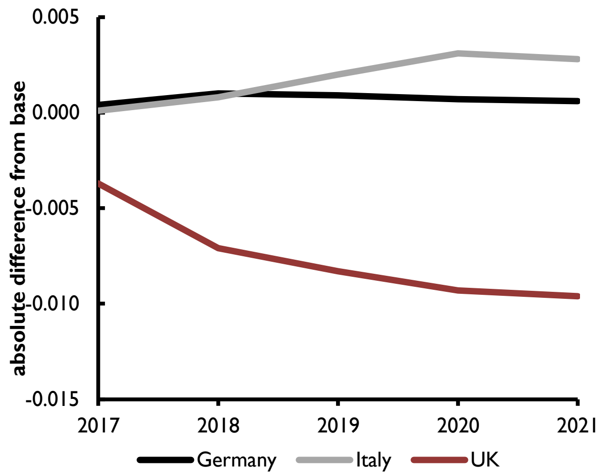


A.1.9 Corporate wedge



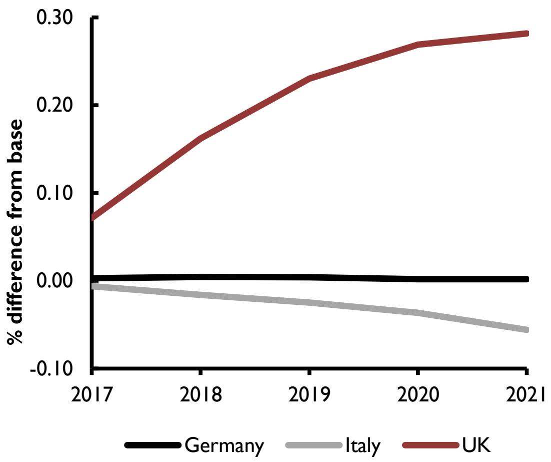
A.1.10 Household lending wedge

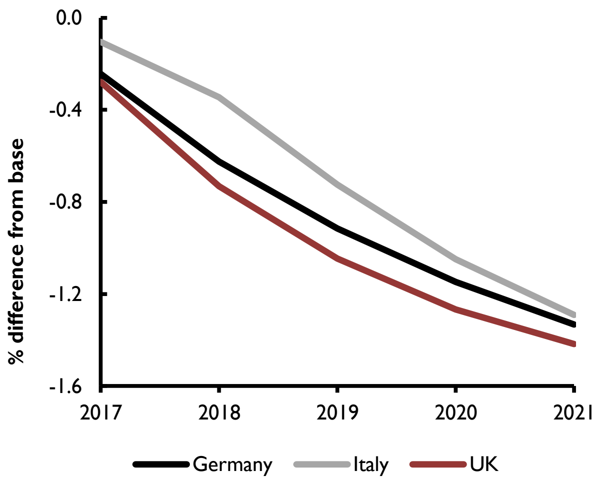




A.1.11 Corporate lending

A.1.12 Banking assets





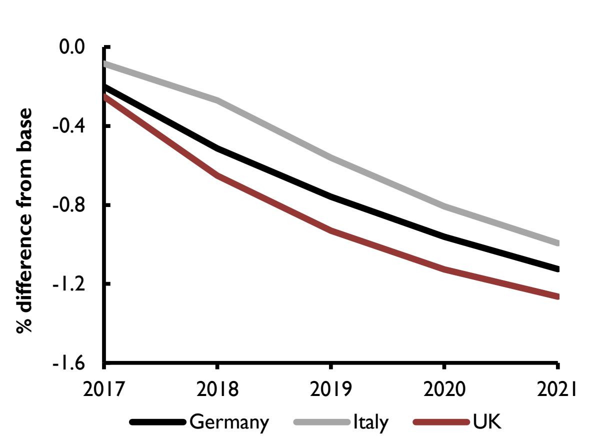
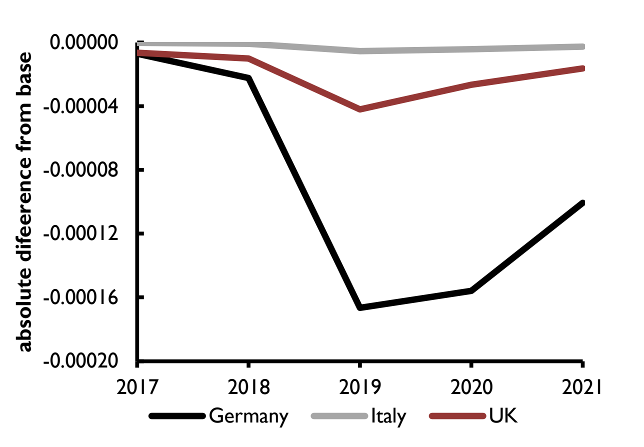
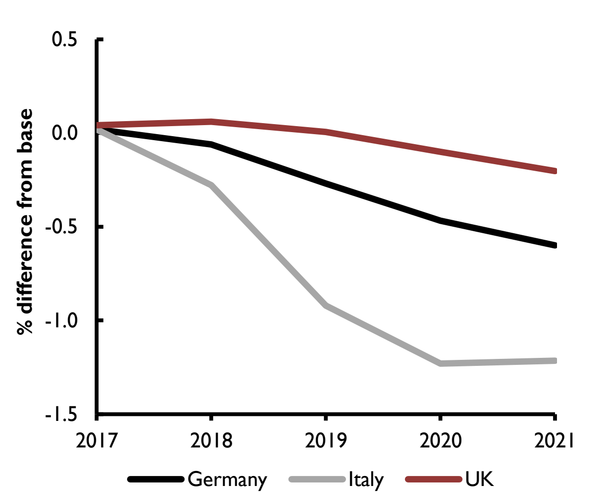
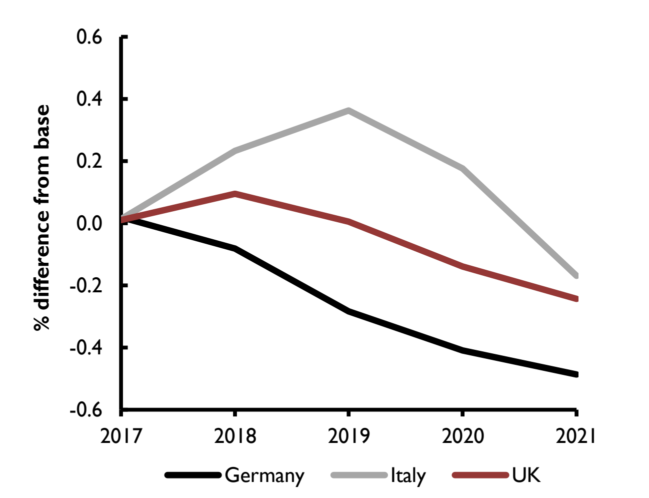
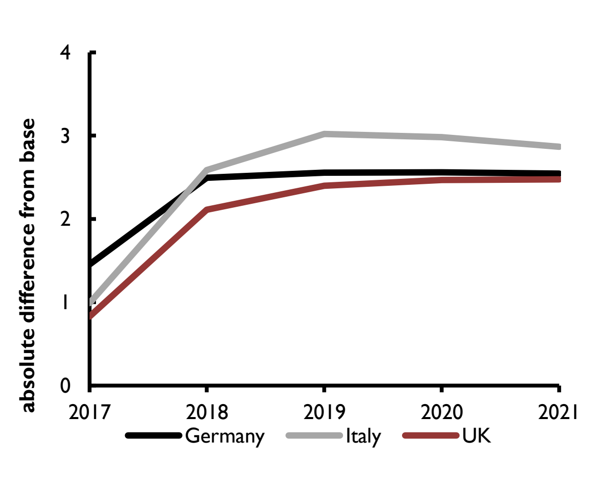
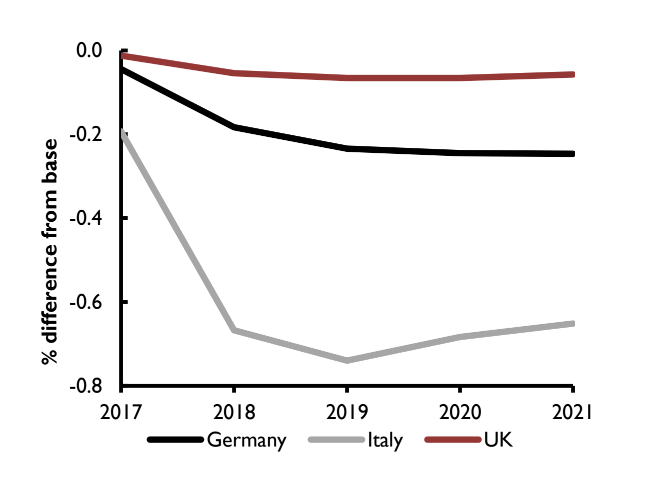
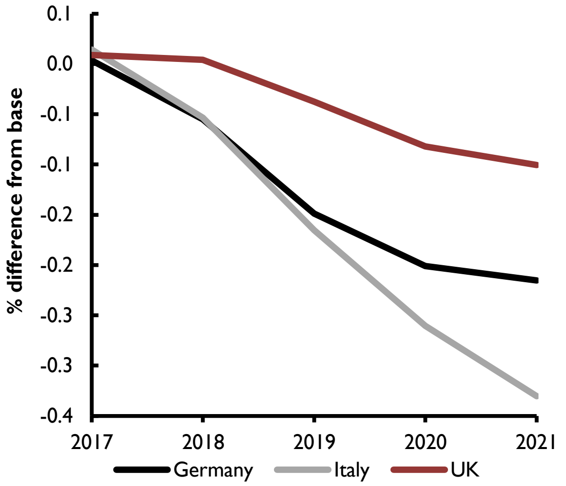
A.1.13 Risk weighted banking assets	A.1.14 Systemic Risk Index
	

Chart A.2: Simulation output: tightening of the capital adequacy target

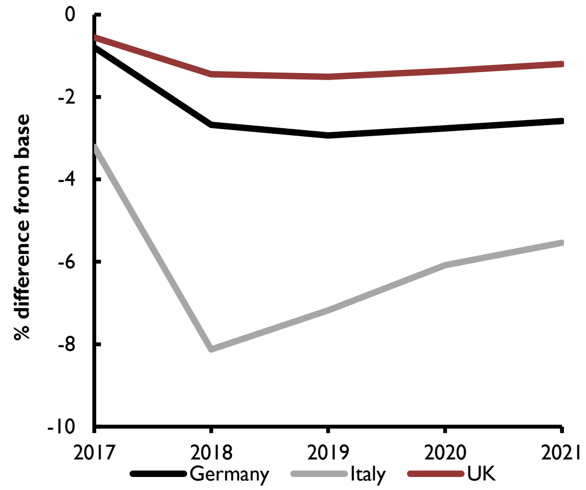
A.2.1 Household liabilities	A.2.2 Real house prices
	

A.2.3 Risk adjusted capital adequacy	A.2.4 Output
	

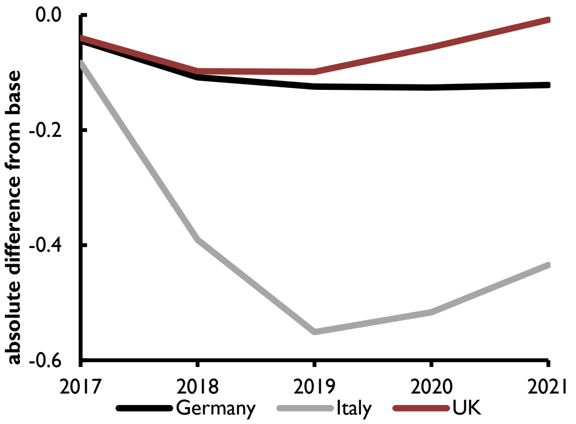
A.2.5 Household consumption



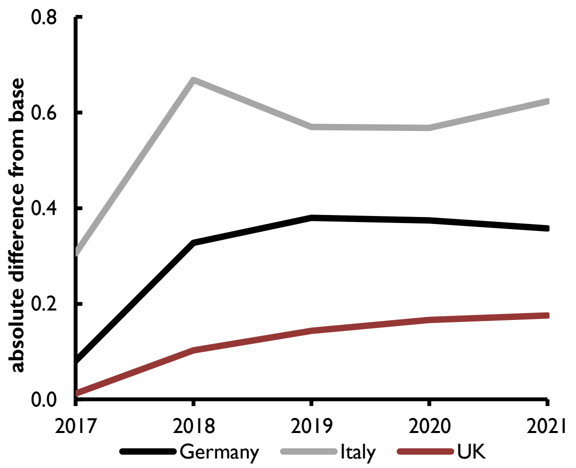
A.2.6 Private sector investment



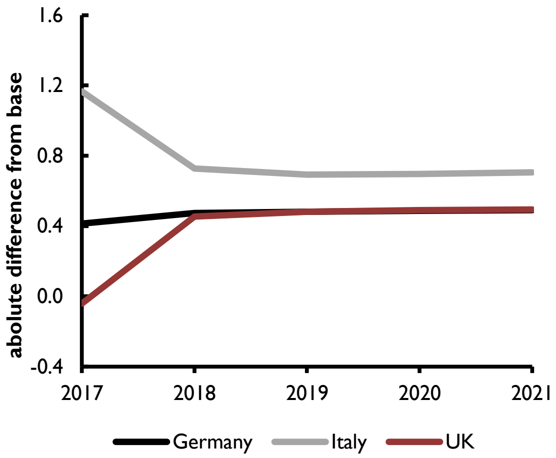
A.2.7 Saving rate



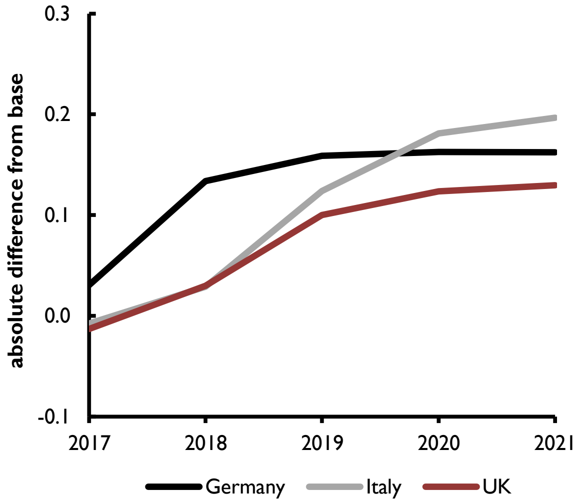
A.2.8 Current account:GDP



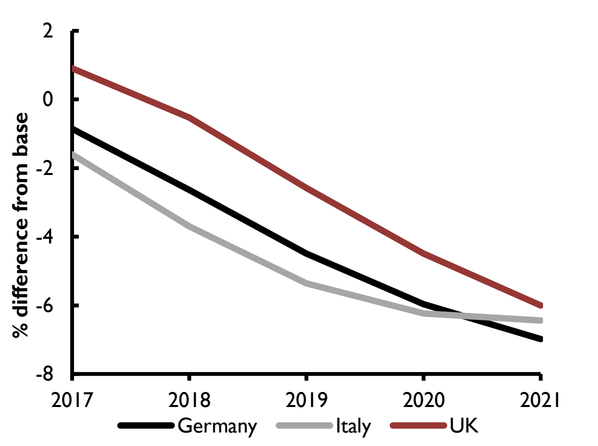
A.2.9 Corporate wedge



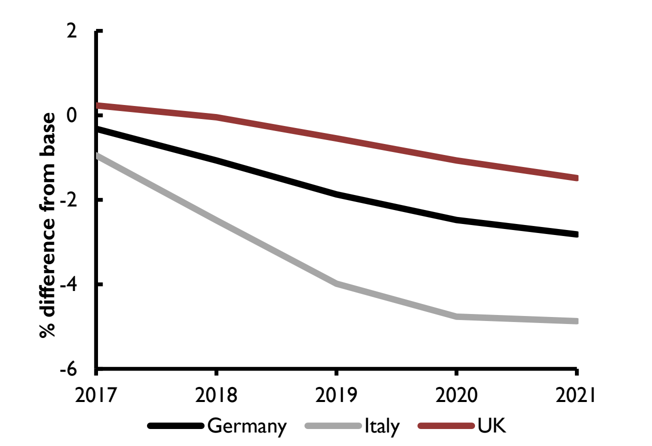
A.2.10 Household lending wedge



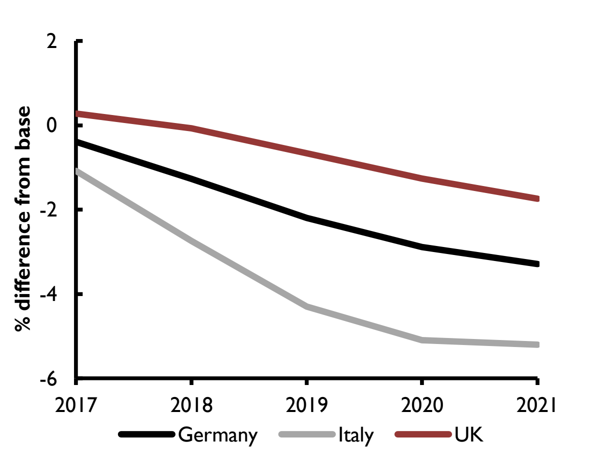
A.2.11 Corporate lending



A.2.12 Banking assets



A.2.13 Risk weighted banking assets



A.2.14 Systemic Risk Index

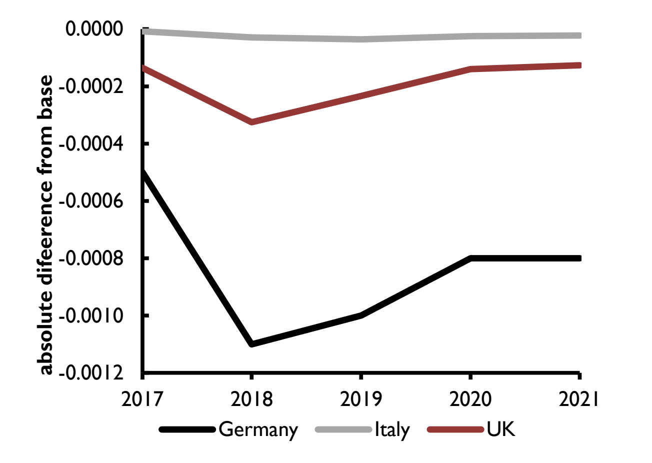
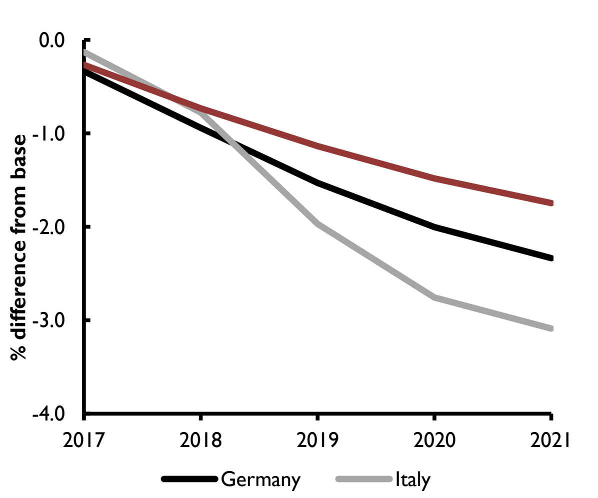
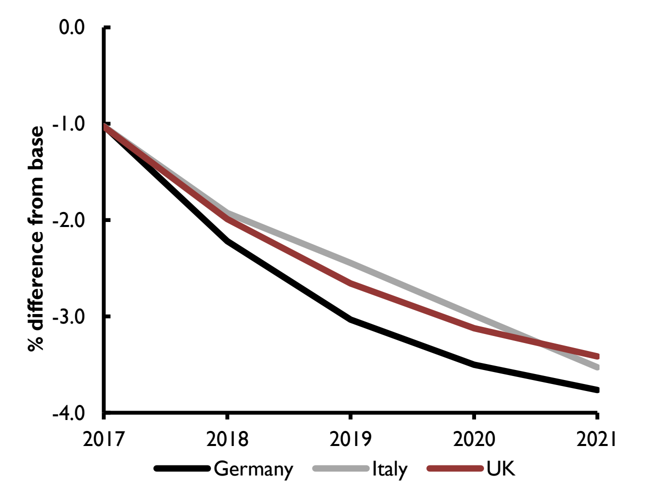


Chart A.3 Simulation output: combined macroprudential tightening

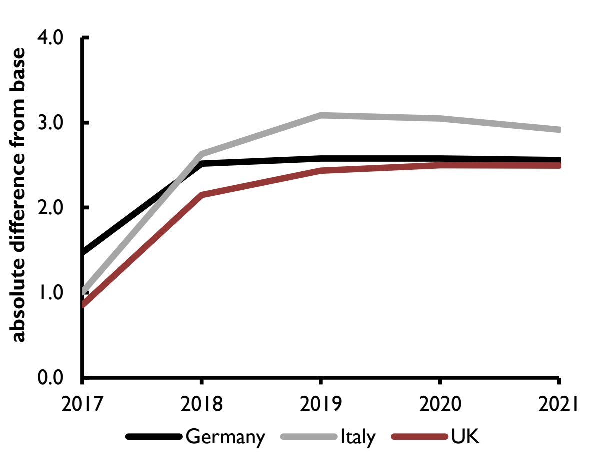
A.3.1 Household liabilities



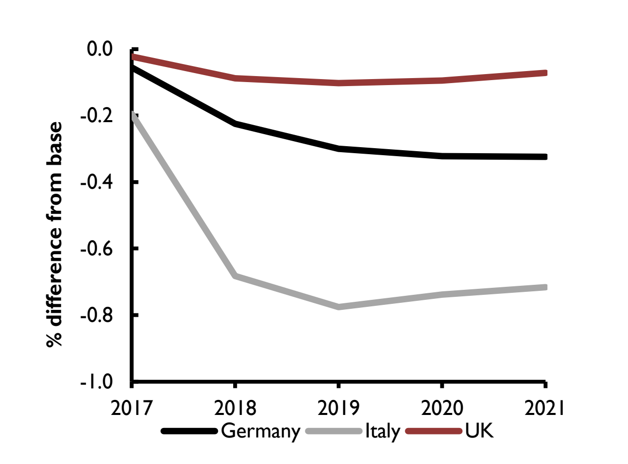
A.3.2 Real house prices



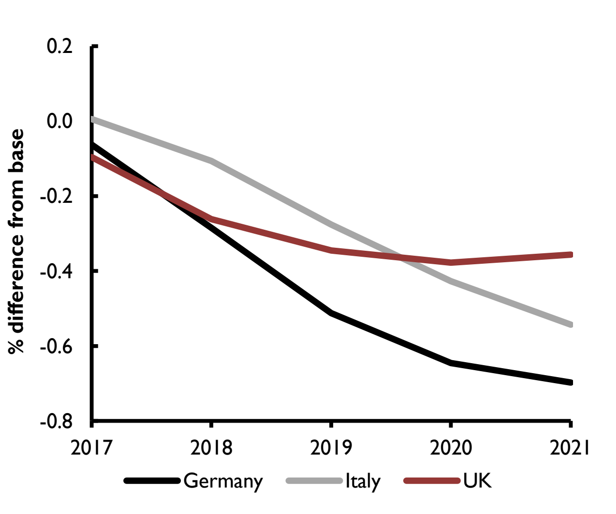
A.3.3 Risk adjusted capital adequacy



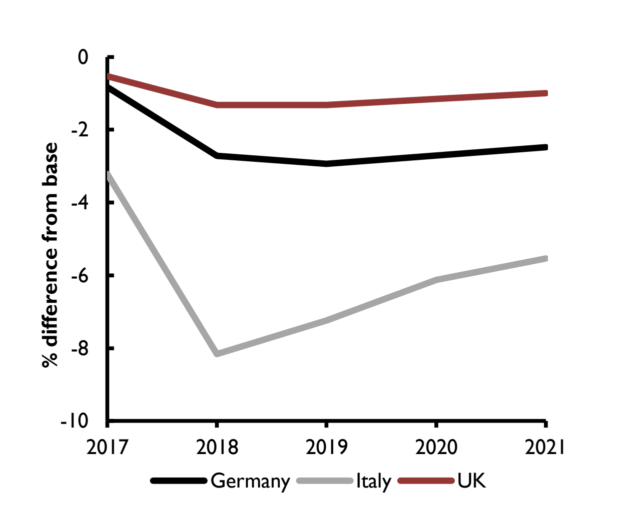
A.3.4 Output



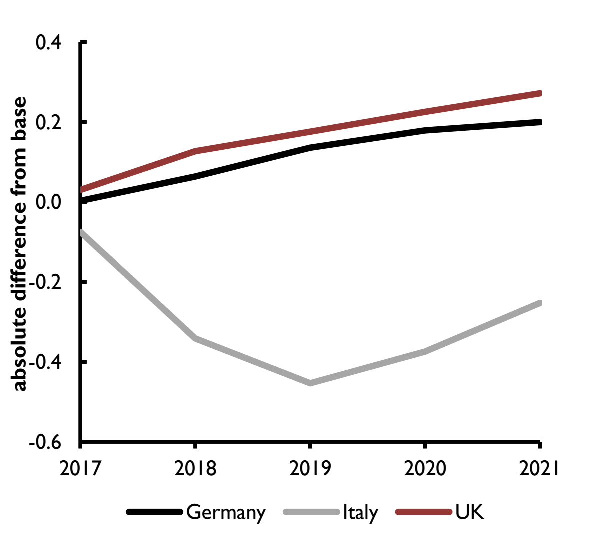
A.3.5 Household consumption



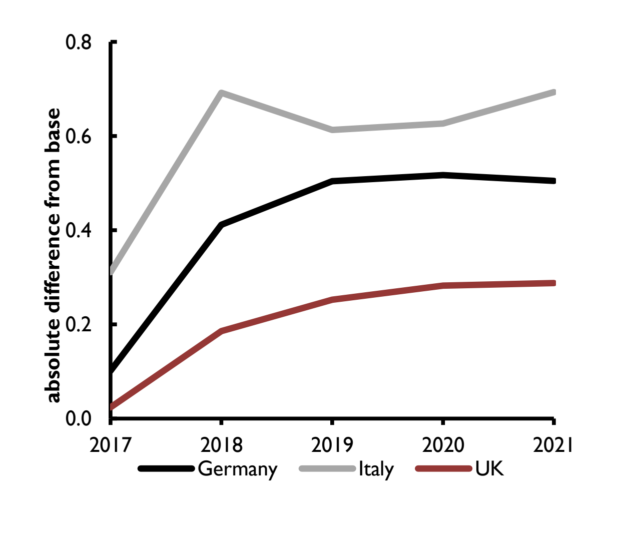
A.3.6 Private sector investment



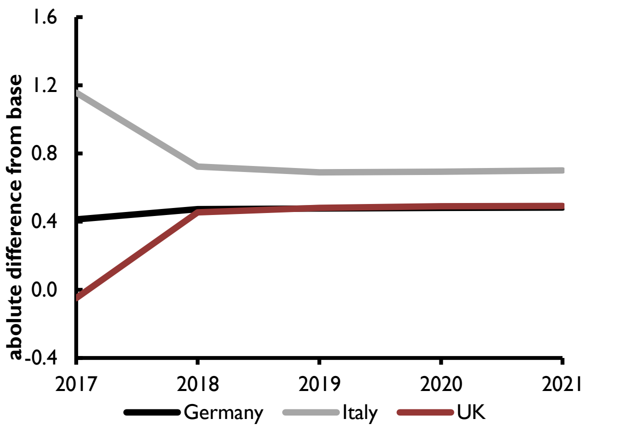
A.3.7 Saving rate



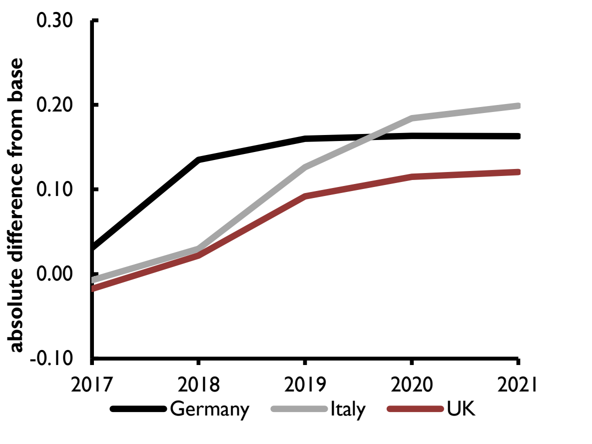
A.3.8 Current account to GDP ratio (per cent)



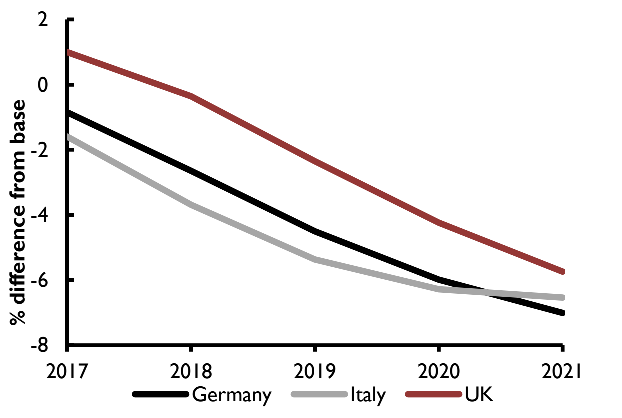
A.3.9 Corporate wedge



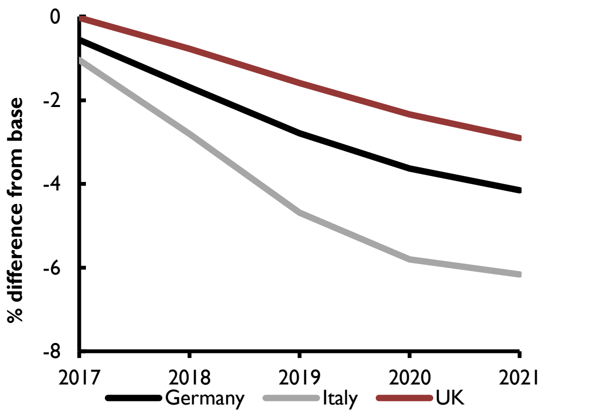
A.3.10 Household lending wedge



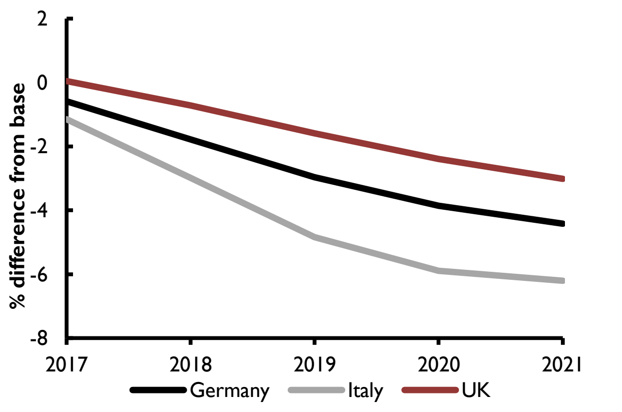
A.3.11 Corporate lending



A.3.12 Banking assets



A.3.13 Risk weighted banking assets



A.3.14 Systemic Risk Index

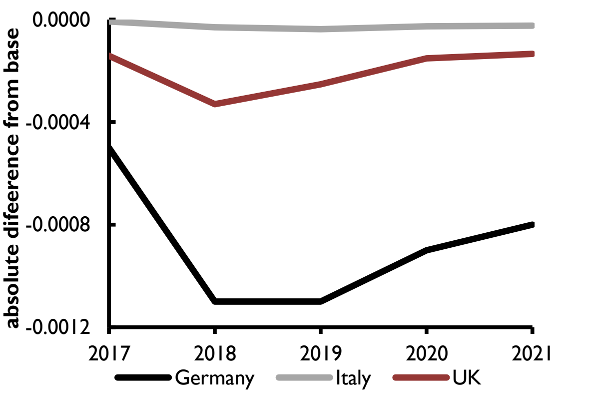
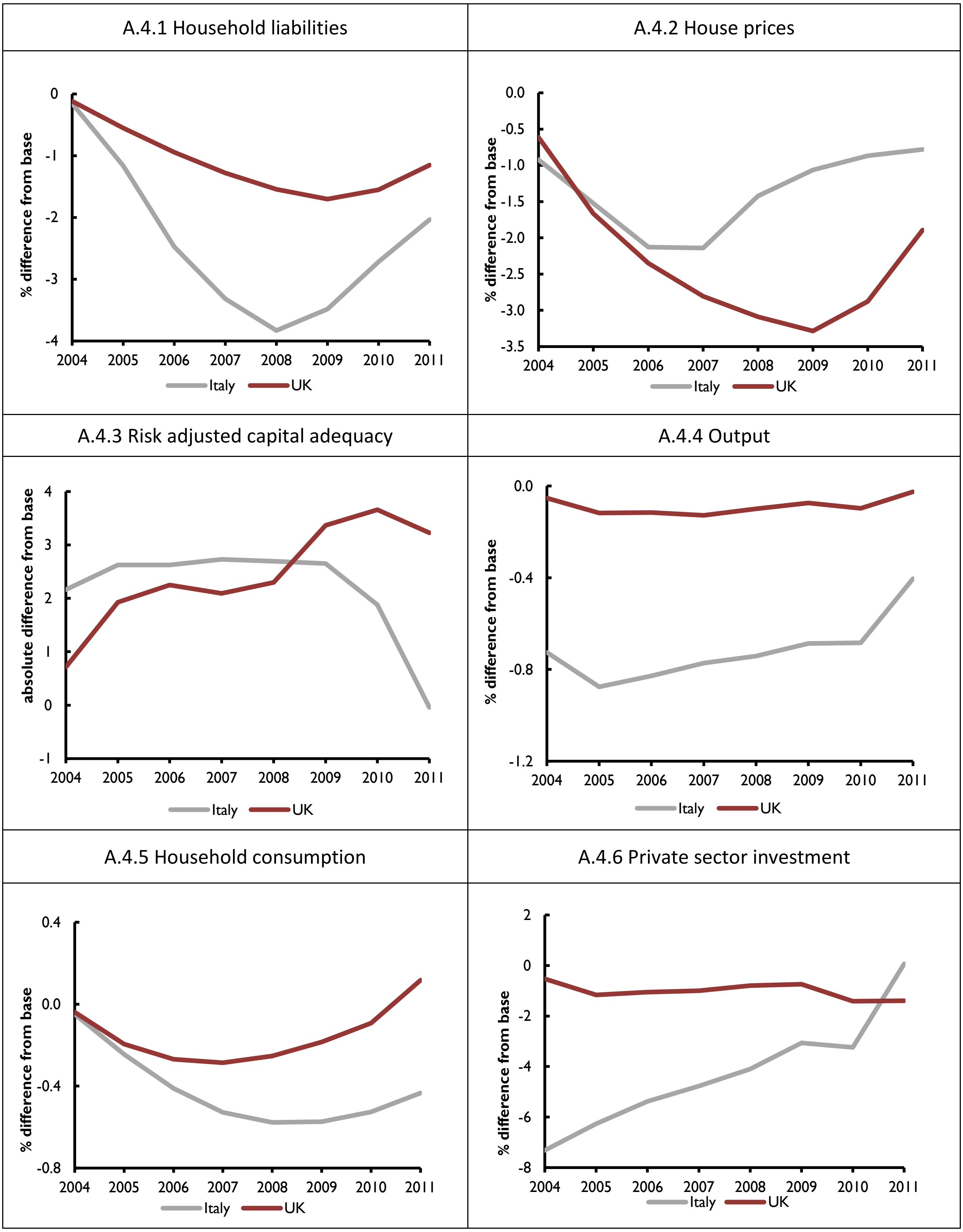
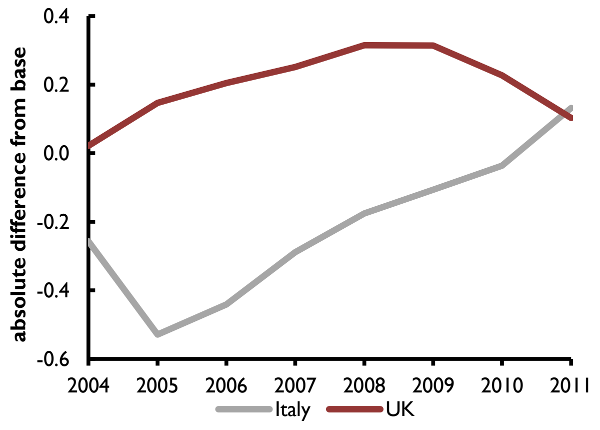


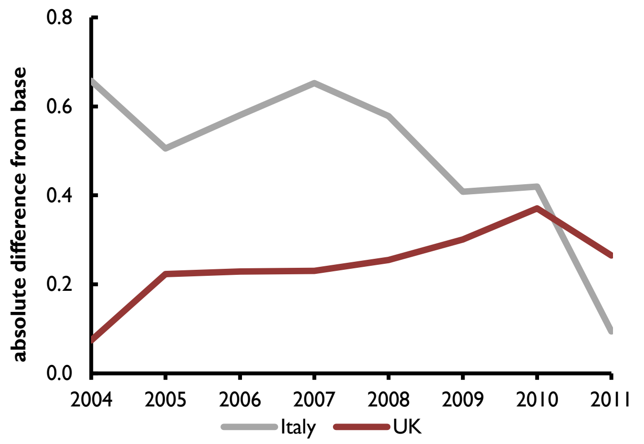
Chart A.4: Historic dynamic simulation for the crisis period



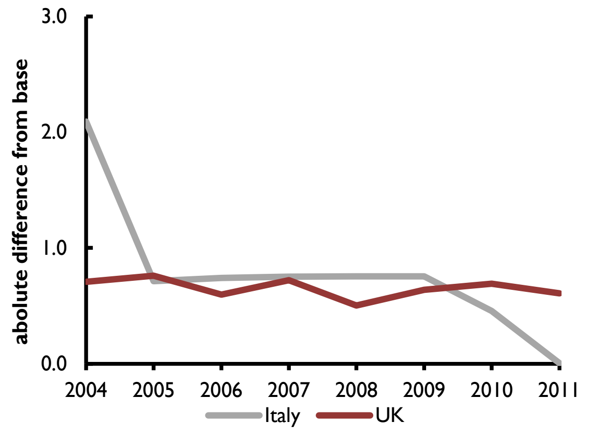
A.4.7 Saving rate



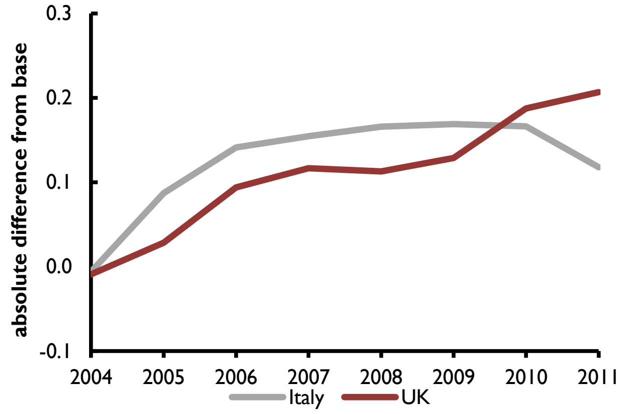
A.4.8 Current account to GDP ratio (per cent)



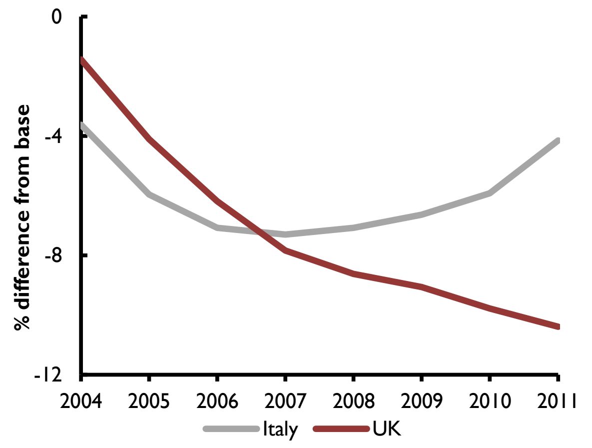
A.4.9 Corporate wedge



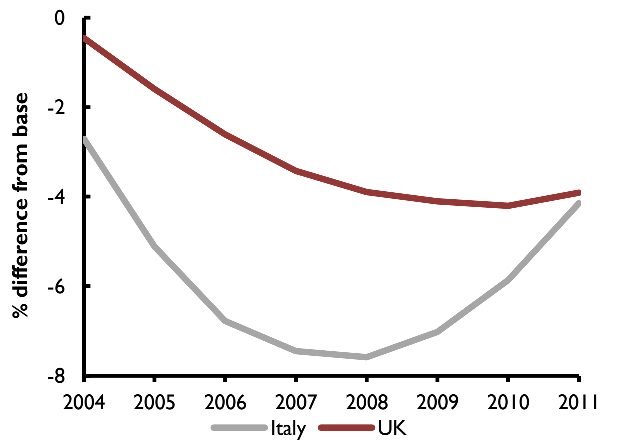
A.4.10 Household lending wedge

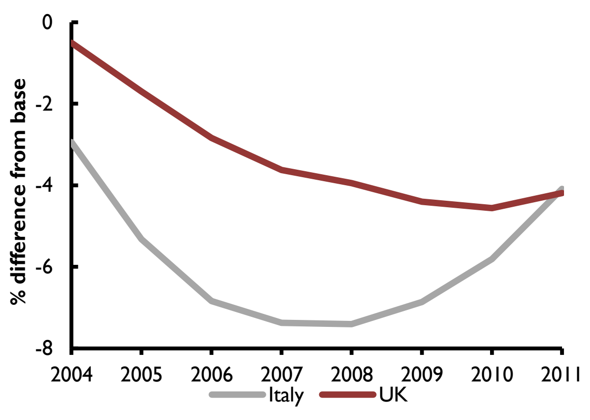
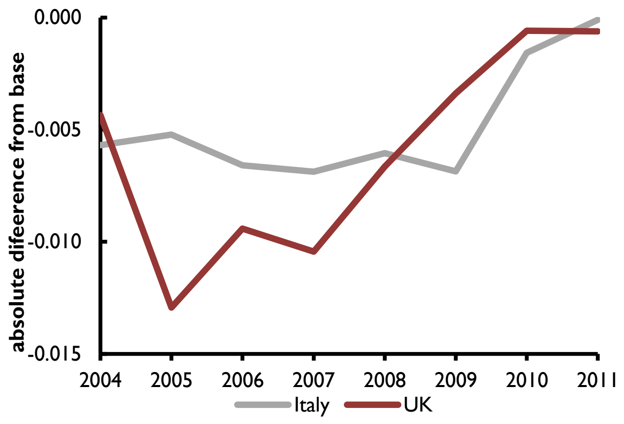


A.4.11 Corporate lending



A.4.12 Banking assets



A.4.13 Risk weighted banking assets	A.4.14 Systemic Risk Index
	

Appendix 2– Modelling macroprudential regulation for countries without a banking sector sub-model

For those countries where there is no banking sector in NiGEM, the corporate and household lending spreads are modelled as random walks. For these, we can simply introduce a wedge to the existing equations to account for the higher cost of financing imposed on credit institutions by a tightening of capital requirements, driven by *sri*.

$$iprem = f_{iprem}(sri) \tag{1}$$

$$lendw = f_{lendw}(sri) \tag{2}$$

where *iprem* denotes the overall corporate lending wedge and *lendw* the household lending wedge. This needs to follow a pattern as set out above, depending on whether or not there is a banking crisis.

For those countries that do not have a banking sector model, the existing equation relates household credit (*liabs*) with disposable income. To accommodate the presence of macroprudential policies, we expand the equation as follows:

$$liabs = f_{liabs}(di, lendw, lrr, p_H, ltv) \tag{3}$$

Household liabilities are affected by disposable income (*di*), the household lending spread (*lendw*), the long-run risk free rate (*lrr),* house prices (p_H) and the loan to value ratio, *ltv*. As noted, this implies that *ltv* has a quantity effect (also on house prices, see below) and not a price effect via spreads, which is consistent with our estimates for spreads in Carreras et al (2016). The calibrated coefficient on *ltv* is derived from the estimates in that paper. Meanwhile capital as shown above has a price effect on borrowing via *lendw* but not a direct quantity effect.

For those countries that do not have a banking sector model, the existing equation relates household credit (*liabs*) to disposable income. To accommodate the presence of macroprudential policies, we expand the equation as follows:

$$liabs = f_{liabs}(di, lendw, lrr, p_H, ltv) \tag{4}$$

Household liabilities are affected by disposable income (*di*), the household lending spread (*lendw*), the long-run risk free rate (*lrr),* house prices (p_H) and the loan to value ratio, *ltv*. As noted, this implies that *ltv* has a quantity effect (also on house prices, see below) and not a price effect via spreads, which is consistent with our estimates for spreads in Carreras et al (2016). The calibrated coefficient on *ltv* is derived from the estimates in that paper. Meanwhile capital has a price effect on borrowing via *lendw* but not a direct quantity effect.

Appendix 3 – Data list

Variable names	Definitions
ARR	Rate of household mortgage arrears
BBAL	Banking sector assets (total)
BBSOA	Banking sector other assets
BCAP	Banking sector capital
BRA	Banking sector liquid assets
BRWA	Risk-weighted banking assets
C	Consumption
CBR	Current account to GDP ratio
CC	Consumer credit held by households
CCRATE	Household unsecured borrowing rate
CED	Consumer expenditure deflator
CORPL	Non-financial corporate debt
CORPW	Non-financial corporate sector lending wedge
HW	Value of personal sector housing stock (FOF)
INSOLR	Rate of company liquidations
IPREM	Investment premium
KH	Capital stock (housing)
LENDW	Rate Spread - household (borrowing - lending)
LEVRR	Risk-weighted capital to asset ratio
LEVRRT	Risk-weighted capital to asset ratio target
LIABS	Household liabilities (total)
LRR	Long real rates
LTV	Loan-to-value ratio
MORTH	Mortgage debt of households
NW	Net wealth, personal sector

NWPI	Net wealth to personal income ratio
PI	Personal income
R3M	3 month interest rates
RHPG	Change in real house prices
RMORT	Average offered mortgage rate
RPDI	Real personal disposable income
SRI	Sytemic risk index
Y	Real gross domestic product
YCAP	Trend output for capacity utilisation