The Impact of Quantitative Easing on UK Bank Lending: Why Banks Do Not Lend to Businesses?

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Abstract

The growing proportion of UK bank lending to the financial sector reached a peak in 2007 just before the onset of the Global Financial Crisis (GFC). This marks a trend in the dwindling amount of bank lending to private sector non-financial corporations (PNFCs), which was exacerbated with the Great Recession. Many central banks aimed to revive bank lending with quantitative easing (QE) and unconventional monetary policy. We propose an agent based computational economics (ACE) model which combines the main factors in the economic environment of QE and Basel regulatory framework to analyse why UK banks do not prioritize lending to non-financial businesses. The lower bond yields caused by QE encourage big firms to substitute away from bank borrowing to bond issuance. In addition, the risk weight regime of Basel I/II on capital induces banks to favour mortgages over business loans to small and medium enterprises (SMEs). The combination of lower bond yields and Basel II/III capital requirements on banks, which, respectively, impact demand and supply of credit in the UK, plays a role in the drop of bank loans to businesses. The ACE model aims to reinstate policy regimes that form constraints and incentives for the behaviour of market participants to provide the causal factors in observed macro-economic phenomena.

Keywords: Monetary policy, quantitative easing, bank lending, agent-based modelling, gilt yields, capital adequacy requirements, risk weighted assets.

JEL Classification: E51, E52, E58, G02

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1. Introduction

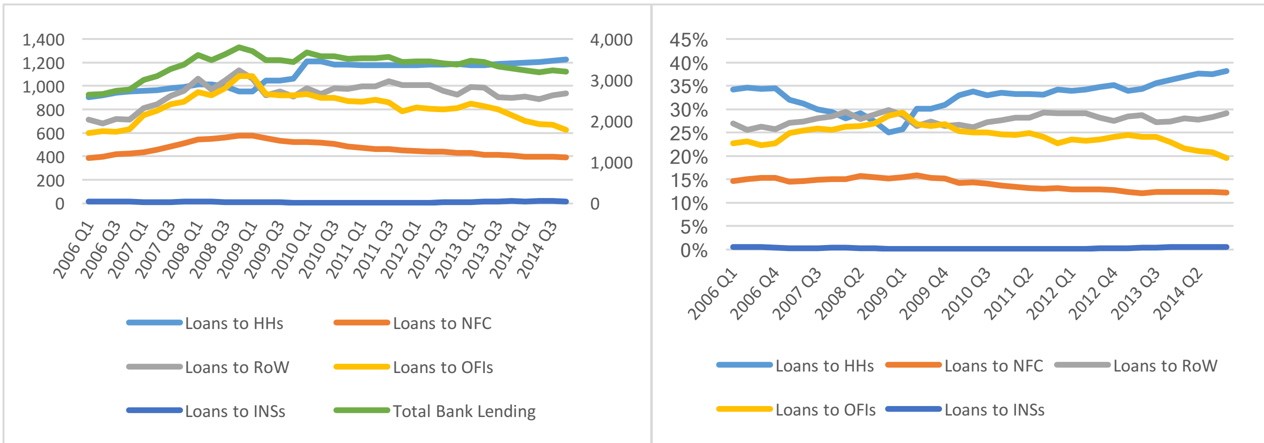
The great financial crisis (GFC) of 2007 produced severe recessions in major economies and raised the threat of a total collapse of the global financial system. The crisis had major repercussions for the UK economy that witnessed an increase in unemployment and severe contraction in GDP BoE by about 4.7% in the last 3 quarters of 2008.Like the monetary authorities of other countries, the Bank of England (BoE)reduced its short-term policy rate to exceptionally low levels from 5.75% to 0.5%, over the period from July 2007 to March 2009. However, lowering interest rates proved not to be sufficient to support aggregate demand and help in the economic recovery to pre-crisis levels. Consequently, following the precedent first set by the Bank of Japan in 2001, and more recently by the US Federal Reserve (Fed) Large Scale Asset Purchase (LSAPs) programs of November 2008, the BoE Monetary Policy Committee (MPC) launched an open-ended asset purchase program (APP) in March 2009. Unlike conventional open market operations involving short term assets, central banks make outright purchases of longer term securities (see, Haldane et al, 2016) under these asset purchase programs, also referred to as quantitative easing (QE).

As the APP was to be subsumed under the 1997 Monetary Policy Framework, priority was given to the necessity of "*increasing nominal spending growth to a rate consistent with meeting the inflation target in the medium term*"[4].In addition, the MPC minutes of March 5 2009 note that APP "*would also mean that the banking system would be holding a higher level of reserves in aggregate, which might cause it to increase its lending to companies and households*". At the same time, it was also anticipated by the MPC that APP will enhance "*functioning of corporate credit markets, that should make it easier for some types of companies to raise finance, reducing their reliance on the banking sector*" (*Ibid*.) The mechanics of QE aimed at asset purchases from non-bank financial institutions involves new electronic central bank money credited to the reserve account of the seller's bank which, in turn, creates a deposit of the same amount favouring the seller. This, so called bank lending channel, which is now replete with bank reserves, is expected to increase bank lending to households and businesses[5]. To what extent were these anticipated outcomes of QE borne out?

[4]This is reported in the letter from the Chancellor of the Exchequer of 3 March 2009 and also in the MPC minutes of March 5 2009(http://webarchive.nationalarchives.gov.uk/20091204142322/http://www.hm-treasury.gov.uk/d/chxletter_boe050309.pdf,andhttp://www.bankofengland.co.uk/publications/minutes/Documents/mpc/pdf/2009/mpc0903.pdf). The assets purchases are also seen to be critical to the strategy "to ease the flow of corporate credit… increase liquidity and trading activity in some UK financial markets and stimulate issuance by corporate borrowers and the resumption of capital market flows" (*Ibid)*.

[5]Regarding the targeting of non-bank financial institutions, especially Insurance Companies and Pension Funds, see point 42 in the minutes of the MPC meeting for the 4 and 5 March 2009 available at:http://www.bankofengland.co.uk/publications/minutes/Documents/mpc/pdf/2009/mpc0903.pdf

Figure 1: UK Bank Lending to Different Sectors 2006 to 2014 (Quarterly; £Billion, RHS, Totals)



(a) Amounts Bank Lending (£Billion) **(b) Proportions of Total Lending**

Source: UK ONS Flow of Funds Project: Financial Accounts Excel Sheet 3.2

Notes: UK Bank lending refers to lending by Monetary and Financial Institution; RoW: Rest of World; HHs: Households; PNFCs: Private non-Financial Corporates; OFIs: other financial institutions; INSs: insurance companies and pension funds.

As shown in **Figure** 1: UK Bank Lending to Different Sectors 2006 to 2014 (Quarterly; £Billion, RHS, Totals), UK total bank lending which saw an average growth of 5.5% per quarter between 2007 Q1 and 2008Q1, with the latter standing at £3.61 Trillion, suffered falls in the 4%-6% range in the period between 2008Q2-2009Q2. Within a year from the start of the APP, total bank lending jumped 7% in 2010Q1 and the lending to households and private non-financial corporates (PNFCs) peaked at £1.74 Trillion. However, over the next 3 years, total bank lending fell by 1%-3% annually. It showed a fall or little to no growth in every quarter except for 2013 Q1, probably because of funding for lending scheme (FLS) (Churm et. al (2013), Badeley-Chappell (2013)). It should be noted that when bank lending to rest of the world (ROW) is accounted for, domestic lending fell by over £200 billion. Further, lending has been found to be skewed in the direction of mortgage lending to households with its share of total bank lending rising from 25.69% in 2009Q1 to 38.18% by the end of 2014. In contrast, non-financial businesses (non-financial corporations and SMEs) faced a fall in bank loans with their share of total bank lending falling from 15.91% to 12.16% over the same period. We also examine the extent to which non-financial firms substituted away from bank loans to bond issuance through the portfolio rebalancing channel.

A number of studies investigate how QE policy influences the real economy through the portfolio rebalancing and other channels. Gagnon et al. (2010) emphasize the impact of the Fed LSAPs programs on the yields of the longer-term assets purchased under the programs. They point out that the programs appear to be successful in decreasing the term premiums by 30 to 100 basis points. More comprehensively, Joyce et. al. (2011) specify five transmission channels of the impact of QE. This includes policy signalling, portfolio rebalancing, liquidity, broad money, and confidence. They claim that while the effects of QE can spread directly into the wider economy through the confidence factor leading to larger aggregate expenditure, asset prices and returns represent the path of transmission for the other four channels. By lowering asset yields, QE can boost aggregate spending through decreasing the cost of borrowing for firms and consumers, Joyce et. al. (2011).Joyce et. al. (2014) have also investigated the specific mechanics of portfolio rebalancing by the non-bank financial institutional investors such as Life Insurance and Pension Funds which substituted the assets purchased by the BoE by bonds issued by PNFCs. Equities price growth caused by a combination of portfolio rebalancing and falling interest rates also boosts the value of legacy assets held by financial institutions, a phenomenon that is referred to as "stealth recapitalization" (see, Brunnermeier and Sannikov (2012) and Chodorow-Reich (2014)) that can help banksto remain buoyant. Hence, whatever the controversy surrounding the accumulation of 'excess' reserves at the central bank from APP (see, Reis, 2016)[6], and concerns about such extremely loose monetary policy conditions for a prolonged period(see, Rajan (2010), Bean et.al. (2015)) in the post GFC period, this paper investigates a specific misdirection of bank lending away from the real economy in the context of QE.

Thus, while Office for National Statistics (ONS) data in **Figure 1**: UK Bank Lending to Different Sectors 2006 to 2014 (Quarterly; £Billion, RHS, Totals) shows that domestic lending by UK banks fell by more than £218.6 billion in four years after APP was introduced early in 2009, the worrying trend is the shrinkage in the amount of loans to UK nonfinancial businesses falling to as low as 12% of total lending when compared to a 50% share of financial companies and rest of the world. The latter two was as high as 59% in 2008Q1.Indeed, this is part of a bigger problem of "why banks do not lend to the real economy". This has being discussed by several authors under the rubric of excessive growth of the financial sector in advanced economies and ,in particular, growing bank activities relating to trading assets and financialization[7]as these have a bearing on low GDP growth and its extreme volatility (Blundell-Wignall,Roulet (2013),Bezemer and Hudson (2016), Cecchetti et al (2011), Arcand et. al. (2011),Stockhammer (2004), Easterly et. al (2000)). The latter study by Stiglitz and his co-authors was one of the first to signal the negative impact of the

[6]Between March 2009 and August 2012, the total amount of bank reserves on the liabilities side of the BoE increased from about £31.5 billion to £251.9 billion. This increase in bank reserves at the BoE accounts for about 59% the size of APP by the end of 2012. The same phenomena of increasing bank reserves at the central bank appears in the US where the reserve balances with Federal Reserve expanded massively after the launch of large scale asset purchase (LSAP) programs in 2008. The Fed data shows that bank reveres expanded by about 812% between October 2008 and August 2012. (**Source**: Data Download Program (DPD):http://www.federalreserve.gov/datadownload/).

[7]Partnoy and Eisinger (2013) analyse the financial statements of big banks and find that the majority of their income and also outsized losses come from traded assets.

excessive growth of the financial sector. Though related, the focus of our analysis is not on this wider problem, which also relates to banks' chase for yield and carry trades associated with cross-border bank lending triggered by prolonged low interest rates. Instead, this paper aims to reinstate at a micro-level the role of financial regulation which Stiglitz (2011) raised as an urgent issue for incorporation into macro-economic models to test out systemic and systematic impacts from the incentives and constraints inherent to regulation.[8]

While the fall in bank lending during recessions has a long legacy, including the theories on liquidity trap where close to zero interest rates cannot stimulate investment (for example Krugman et al. (1998) and Krugman (2000)), a relatively new strand of literature on the impact on bank lending from capital adequacy requirements has evolved since the 1990s. The diverse justifications for the decreases in bank lending during recessions in the presence of capital adequacy requirements have been based either on the lower supply of credit by banks or the lack of demand for loans. The supply-side explanations can be grouped into two main categories. Studiesin the first category (such as Thakor (1996), and Borio and Zhu (2012)) attribute the decrease in bank lending to the changes in the risk perception of the banks. The other category of explanations (for example, Watanabe (2007),Repullo and Suarez (2013), and Repullo (2013)) refers to the shortage of bank capital (the *capital crunch* hypothesis) as the main driver of credit rationing in the downturn especially in the presence of *pro-cyclical* capital regulations (see Brunnermeier et al. (2009)).[9]Further, the seminal work of Jones (2010) implicates banks' regulatory capital arbitrage for prompting an individually rational but destabilizing and socially deleterious response to Basel capital requirements for which Jones claims econometric models may not be best suited to analyse. The perverse incentives of Basel II has been implicated for the large increase in leverage in banks with the use of credit default swaps (CDS) in addition to mortgage securities on bank balance sheets (Blundell-Wignall-Smith and Roullet (2013) and Markose et. al. (2012)) and of sovereign debt to reduce capital from the implied risk weighting, respectively, in the carry trades associated with the GFC and in the Eurozone crisis (Acharya and Steffan (2014)). Following the Jones (2020) precedent, we argue that an agent based model of bank lending is needed to show how the constraints and

[8]Stiglitz (2011), in the context of fixing macroeconomics in the post GFC era, had noted that certain 'perverse' incentive structures especially in the financial sector were instrumental for the destabilizing events of the GFC. Stiglitz (*ibid*) concludes that .. "*the standard macroeconomic models neither incorporated them nor provided an explanation for why such incentive structures would become prevalent—and these failures are failures of economic science*."

[9]The reliance of capital regulations on the mark-to-market valuations of assets and the market-based measures of risk makes these regulations *pro-cyclical* and increases the volatility in asset markets. That is, the rises in market value of equity during booms accompanied with fixed costs of bank regulations induce banks to expand their lending. In contrast, during busts equity prices become low decreasing the ability of banks to provide loans. For a further discussion of the *pro-cyclicality* of bank regulations see Brunnermeier et al. (2009).

incentives of the risk weighted capital requirements of Basel II and III have a direct bearing on the direction of the bank lending, favouring mortgages and penalizing, in particular, SMEs.

In summary, our agent based model brings together the supply and demand sides of bank lending in granular detail. On the demand side, the influence of APP on gilts and corporate bonds yields represents the starting point of our ACE model. Asset purchases by BoE reduce the supply of gilts remaining for the private sector (local supply effects) leading to lower yields on gilts and corporate bonds (McLaren et al (2014)). The lower bond yields induce BFs to substitute parts of their bank borrowing with security debt (bonds). On the supply side, influenced by the capital requirements, that assign different risk weights for different types of loans, banks respond to the drop in big firms borrowing, by expanding mortgages and decreasing the amount of loans granted to SMEs, which carry a higher risk weight. The mortgage market of UK households is also modelled in detail. The distinction between big firms (BFs) and small and medium enterprises (SMEs) is important in the context of this paper because the accessibility to debt financing is different for the two types of firms. BFs have access to security debt (bond) market, whereas borrowing from banks represents the sole source of debt financing for SMEs. In the standard perspective of the fall in the demand for loans, for instance, Bikker and Hu (2012) argue that the lack of demand for bank loans rather than supply is the key factor in the fall in bank borrowing during slumps.[10] However, in this context, little consideration has been given to the impact of lower bond yields (and hence the wider use of security debt) which is caused by QE, on the demand for bank loans by big nonfinancial firms. This represents a vital element in our explanation of the fall of bank lending to nonfinancial businesses.

Methodologically, we propose a data driven formulation of the ACE model of the developments in the UK bank lending markets since APP was introduced along with the regulatory capital constraints on banks. The ACE model of the paper follows the data driven approach described in Markose (2013) in requiring that the distributional characteristics of the different economic sectors, such as households, nonfinancial businesses and banks, are based on empirical foundations. We implement an important empirically determined scale factor to specify the numbers of agents in each class in order that they represent the UK economy. This also permits the outputs of the ACE model to be scaled back up to give simulated results that can be validated against actual UK data. We use Windrum, Fagiolo and Moneta (2007) method for model validation.

The relevant balance sheet items of each of the 10 biggest UK banks is part of the initial conditions for the simulation of UK bank lending decisions for mortgages and to SMEs. The use of micro-level data sets is similar to the BoE agent based model of the UK mortgage market , Baptista et. al (2016) in that granular

[10] See also, Berger and Udell (1994).

institutional details and data are included to investigate implications of specific macro-policy relevant measures that can alter behaviours of market participants by using the simulation model for scenario analysis and comparative statics. However, while the BoE ACE focussed on the buy to let rental market, we consider a wider loan portfolio decision model of UK banks.The important difference in banks' behaviour with the introduction of Basel capital constraints in their portfolio allocation decision, comes about only when in addition to the direct costs of the credit risk of default on loans, the different categories of bank loans invites an institutionalized cost of capital implied by the Basel risk weighted rule. We use extant average bank write offs on the categories of loans to proxy for the probability of default in all the scenarios. The simple 8% capital ratio of Basel I, results in exactly the same optimal lending policy for households as in the case of no regulatory capital requirements with the former only implying an overall upper limit on leverage for the total loan book without distinction between the asset classes. In contrast, one of the main findings is that what was a less than rigid preference among banks in favour of mortgages and against loans to businesses, especially SMEs, has become a veritable mecca of what Schularick et. al (2014) have called 'mortgaging up' after the introduction of favourable risk weights on mortgages in Basel II. Ofcourse, there has not been the aggressive capital arbitrage by banks either through remote or synthetic securitization (see, Blundell-Wignall-Smith and Poulet (2013)) in the post 2009 period of APP. Our results are consistent with the empirical findings that during the course of APP, the assumption that banks extended mortgages only in response to the slack caused by big firms reducing bank loans as bond yields fell, is a good one. However, the growth of UK mortgage lending was not sufficient to counter the decline in business loans , therefore representing the main cause of the shrinkage in total bank lending. It is envisaged that the data driven agent based model of the UK banking sector will be extended in a modular fashion to encompass a more explicit characterization of the Brunnermeir and Sannikov (2012) stealth recapitalization of banks in low interest rate regimes and also the search for yield carry trade financing by UK banks to the rest of the world. Ideally, a fuller incorporation is needed for big PNFC behaviours regarding their option to use funds from bond issuance to buy back shares. As explained in the literature survey, though not fully exploited yet, ACE models can implement the endogenous/exogenous demarcation better than other modelling techniques with the modeller creating exogenous data feeds into the model agents in a time specific way.

The reminder of the paper is structured as follows. Section 2 surveys the relevant literature. The agent-based approach used in the paper is outlined in Section 3 along with a full description of the model agents and their behaviours. Section 4 summarizes the ACE model initial conditions followed by the simulation outcomes and model validation results. Section 5 contains concluding remarks of the paper.

2. The Related Literature

This literature survey is divided into three subsections. The first gives a brief survey of the QE literature including that related to the Japanese QE introduced in 2001. The second section examines some of the main papers in the field of the impact of capital adequacy requirements on bank lending, especially, in recessions. In the last section, the literature of agent-based computational macroeconomics (ACME) is reviewed.

2.1 The Impact of Quantitative Easing on Bank Lending

Quantitative easing (QE) has been stimulating the academic literature since its introduction by the Bank of Japan (BoJ) in 2001,in particular post GFC when the monetary authorities of the US, UK and EU started to pursue unconventional monetary policies. The main studies on QE focused on the influence of the massive asset purchases on asset yields and less so on the macroeconomic consequences and the impact on bank lending. First, while authors agree that asset purchases under QE have decreased the yields of government bonds (Kimura and Small (2004) for Japan, D'Amico and King (2011) for the US, and Daines, Joyce and Tong (2012) for the UK), the evidence on the impact on other assets yields has been mixed. Kimura and Small (2004) point out that BoJ asset purchases led to lower premiums on higher grade corporate bonds. This conclusion is supported by McLaren et al (2014) who argue that asset purchases under APP reduced gilts yield and, through local supply effects (asset purchases by BoE reduce the supply of gilts remaining for the private sector), the yields of corporate bonds. They claim that the expected asset purchases had a significant impact on yields after each announcement in March 2009, August 2009, and February 2012. Similar results for Fed's LSAP programs are revealed by Gagnon et al. (2010). They show that the programs led to dropsof 30 to 100 basis points in the risk premium component (rather than expectation component) of the longer-term yields. Conversely, Oda and Ueda (2005) show that the BoJ monetary policy at close to zero interest rate was effective in lowering the expectations component of interest rates. However, the portfolio rebalancing effects on the risk premium component were not significant. The papers that analyse the effects on the wider economy generally specify a positive influence of QE on the real economy. For instance, Honda, Kuroki, and Tachibana (2007) and Harada and Masujima (2009) indicate that BoJ QE increased aggregate output through asset prices and bank reserves. This conclusion is supported by the results for US QE (Chen, Cúrdia, and Ferrero (2011) and Baumeister and Benati (2010)) and UK QE (Kapetanios *et al.* (2012)). Lastly, the response of bank lending to QE program has received relatively lower attention. For example, Bowman *et al* (2011) identify a positive but small impact of BoJ QE on bank lending. Joyce and Spaltro (2014) show similar outcomes for the BoE APP program. They claim that the effects were more important for smaller banks.

2.2 Bank Lending and Capital Adequacy Requirements

The influence of capital requirements on bank lending and bank behaviour has been investigated since the introduction of Basel rules in the late 1980s. Thakor (1996) inspects the role played by Basel capital rules in the developments in the US banking system in the early 1990s including the fall in aggregate bank lending and the increase in the share of government debt securities holding in the portfolios of US banks. He indicates that an expansionary monetary policy in the presence of capital requirements may either increase or decrease bank lending depending on the impact of the increasing money supply on the term structure of the interest rates. Hans et al. (1999) point out that weakly capitalized banks tend to substitute away from assets with higher risk weights and to cut their total lending to enhance their capital ratios. These findings are supported by several authors[11] including Gambacorta and Marques-Ibanez (2011) who specify that banks with weaker capital ratios and greater dependence on market funding and non-interest income sources strongly decreased their lending during the crisis. Moreover, Heid, Porath and Stolz (2004) results show that a fall in capital buffers induces banks to rebuild them by raising capital and lowering risk-weighted assets by investing more in the safer assets and less of the riskier assets. However, although most of the literature focuses on the role of the supply of credit, some studies attribute the decreases in bank lending in recessions to demand factors. Berger and Udell (1994) investigate the causes of the reallocation of credit by U.S. commercial banks from loans to securities in the early 1990s. Their results indicate that while risk-related credit crunch hypotheses are not salient reasons of the fall in bank lending, demand-side impact on lending tend to be strong. More recently, Bikker and Hu (2012) argue that credit rationing in a cyclical downturn is not driven by a shortage in bank capital as the *capital crunch* hypothesis suggests. They show that while the demand factors dominate the market, the preeminent loans supply variables (bank capital and reserves) tend to be insignificant determinants of bank lending.

As many of these papers rely on econometric analysis, conclusions such as weakly capitalized firms switch to lower risk weighted assets is highlighted as an individually rational thing to reduce capital requirements, few papers take this forward as part of the macro-economic framework. Despite an influential survey of Furfine et.al (1999) that asked hard questions regarding whether the Basel regulatory framework led to systematic trends in bank lending and in particular the role of perverse incentives

[11]For example, Gambacorta and Mistrulli (2004), Rime (2001), and Furfine (2000).

flagged out in detail in Jones (2010) in the form of capital arbitrage, few macroeconomic models aim to include the incentives and constraints posed by Basel rules for the macroscopic implications of this for the wider problem that banks are lending less and less to non-financial corporations, especially to SMEs. As noted in the introduction, this paper follows this route. In Markose et. al. (2012),an agent based model similar in the data driven formulation of the model in this paper, found that the big US banks were involved in a CDS carry trade in the run up to the 2007 GFC, but without the favourable 20% risk weights from synthetic securitization that permitted banks to reduce capital from 8% on bank assets to 1.2% with the adoption of credit risk transfer by holding of CDS from AAA guarantors (like AIG), the observed extremely high levels of leverage on balance sheets of US FDIC big banks could not have been achieved. Likewise, Acharya and Steffan (2013) gives the following analysis for the Eurozone crisis as a case of regulatory capital arbitrage due to Basel II regulations, which assign a zero-risk weight for investments in sovereign debt. They argue that governments themselves could have had incentives to preserve the zero-risk weight in order to increase demand for high risk sovereign debt. Acharya and Steffan (2013) state that "Undercapitalized banks, that is, banks with low Tier 1 capital ratios, have incentives to increase short-term return on equity by shifting their portfolios into the highest-yielding assets with the lowest risk weights in an attempt to meet regulatory capital requirements without having to issue economic capital (regulatory capital arbitrage)". As will be pointed out in the next section, an ACE model is well placed to test out perverse incentives that lead to destabilizing effects of policy.

2.3 Agent-Based Computational (ACE)Macroeconomics

The study of the economy by means of ACME and network analysis is a relatively new field. It also represents a suitable approach to respond to the criticisms of the generic representative agent model of mainstream macroeconomic models[12]. Macroeconomists have been accused of a heavy dependence on dynamic stochastic general equilibrium (DSGE) models that are built around special cases where market inefficiencies are not possible (Stiglitz (2011)) and institutional details and financial interconnections in the provision of liquidity, capital adequacy, solvency and contagion based negative externalities are ignored (Markose (2013)). Critics of the standard macro models have targeted the assumption of equilibrium that nets out all private credit and simply cannot incorporate herd behaviour and network effects , Akerloff (2002), and also carry trades from perverse incentives that result in destabilising phenomena in the real world, Colander et. al (2009).

[12]Delli Gatti et. al. (2008,2010),Arthur (2006), Buiter (2009)Wieland (2010), Stiglitz (2011), Kirman (2006, 2010), Collander et. al (2009),among others.

For our purposes existing ACME models can be classified into two main categories: those that produce qualitative results and those that are data driven. The bulk of the ACME are qualitative models in which stylized boom bust dynamics are produced. This can be done by relaxing rational expectations and using adaptive learning or explicit herding behaviours (see Gaffeo et. al. 2008). Lengnick (2011) gives a simple baseline model. For a recent survey of the ACEME is given in Dawid and Delli Gati (2018). In the second category of ACME we have those purported to represent massive real economy models. Models such as EURACE and ASPEN projects (Chan and Stiglitz (2008))attempt to simulate the entire EU and US economies, respectively. These models have been used to investigate the impact of policy interventions in the US and the Euro Area. For example, Teglio, Raberto and Cincotti (2013) use the EURACE environment to assess the impact of capital adequacy requirements on the wider economy. They perform simulations over a 40-year period and examine the short, medium and long run implications of different levels of capital adequacy ratios. Their results show a non-trivial impact of capital adequacy ratios on GDP, the unemployment rate and the aggregate capital stock on banks. They also point out that this influence of the capital adequacy ratios arises from the credit channel, and varies significantly depending on the time span of the evaluation period.

The subset of the data based ACE and the most recent category,including the model of this paper, follow the data driven approach suggested by Markose (2013) and it is closest in spirit to the BoE agent based model for the UK mortgage market of Battista et. al (2016).The specificity of institutional details and policy conditions are finely modelled to analyze the responses of the relevant economic agents. Micro level data sets for the economy are used to calibrate the model agents and flow of funds constraints are strictly adhered to. In other words, the endogenous/exogenous demarcation can be made in ACE models with the relevant exogenous actual data that be specified as a 'data agent' that feeds into or informs the model agents in ways specified by the modeller. In Markose et. al (2012), the ACE model was used to see the consequences of the credit risk transfer rule in Basel II that gave a 20% risk weight to bank assets that had AAA guarantors providing CDS cover. It is argued that rule following behaviour as in complying with the regulation and availing of the full extent of its incentives, and also the conduct of carry trade activities are relatively easy to implement in ACE. This is because unlike fully fledged adaptive behaviour, agents' strategies, intelligence and autonomy are limited to following the letter of the law and strictly verifying conditions for which the most profitable arbitrage applies and also tracking the resulting self-reflexive deterioration of the risk in bank assets as agents herd into them. Stress tests for perverse incentives of policy are among the easiest of multi-agent exercises and as with it must be *de rigueur* in macro-prudential policy in order that flawed policies do not get perpetuated.

3. Methodology of Data Driven Agent-based Model of UK Bank Lending

3.1 Data Characteristics of Agents

We model the developments in bank lending in the UK after the introduction of APP in 2009 using an ABM with four classes of agents: households (HHs), big firms (BFs), small and medium enterprises (SMEs) and banks (Bs)). The UK economy data for each of these classes of agents around the launch of APP in 2009, given in Appendix A, is used as empirical basis of theinitial conditions both for the numbers of agents in each class and also for relevant balance sheet data of agents for the ACE model.The latter is purported to simulate agents'interactions in the UK bank lending markets on a monthly basis for a period of 50 months from the advent of the BoE APP in 2009.

Our approach can be divided into five main steps. Firstly, our data driven ACE methodology is innovative in proposing a scale factor for the ABM and the real economy. The size of agent classes is set in a way that replicates the actual sizes of agent populations in the UK based on data from the ONS, BoE financial statistics, Nationwide, and The Money Charity around the launch of APP in March 2009. We implement a proportional scaling factor calculated using the actual sizes of the UK households and nonfinancial business populations as follows. The number of households with at least one adult working in 2009 was 21.46 million[13]. Additionally, there were 4.923 million businesses 99.9% (i.e. 4.918 million) of which were SMEs[14] and the remaining (i.e. 0.005 million) were BFs. This indicates proportions of 0.229 and 0.00024 between the number of SMEs and BFs, respectively, and the number of HHs. Hence, since the number of HHs in the ABM is set to 100,000, the numbers of SMEs and BFs will be set to 22,900 and 24 respectively. As for banks, the 10 largest UK banks that account for over 87% of bank lending are used. Distributionally, the incomes of the 10,000 HHs in the ABM are set to represent the UK income distribution for 2009, given in section A.1 of Appendix A. This is needed for the purpose of modelling HHs mortgage affordability used by banks as a lending criterion. Additionally, ONS data indicates that cash holdings of households represented about 14.43% of their total assets at the end of 2008.[15]

Second, each agent is given a balance sheet representing its initial conditions. The value assigned to each item in an agent's balance sheet is drawn from a distribution that replicates the empirical distribution. For example, the values of household housing wealth are set to reflect the fact that only 64% of UK households are homeowners in 2009 Q1.In the case of banks, the exact relevant items of the

[13] In 2009, there were 25.83 million households 16.9% of them were without work (i.e. with no adult working). The model assumes that only households with a working adultis eligible for obtaining mortgages to buy houses.

[14] Small and Medium Enterprise Statistics for the UK and Regions; Enterprise Directorate; The Department for Business, Innovation and Skills (BIS); Available at:http://webarchive.nationalarchives.gov.uk/20110920151722/http:/stats.bis.gov.uk/ed/sme/index.htm

[15] This is calculated by dividing the sum of households' currency and deposits (£1,172.470 billion) on the sum of households' financial liabilities and net worth at the end of 2008 (1,550.126 billion and £6,573.639 billion respectively).

balance sheets of the 10 largest UK banks in 2009 (see Appendix A.4) are used. In the third step, the behavioural rules of the agents are defined. This constitutes the main engine of the ABM. These rules describe the responses of the agents to different developments. For instance, a big firm would respond to a fall in the cost of bonds issuance by replacing part of its bank loans with bonds. Then, in the fourth step of the process, the simulation is run under three different scenarios for bank behaviour to investigate the role played by Basel capital adequacy rules. At the end of this stage, the values of bank lending aggregates to households and nonfinancial businesses are simulated for each of the 50 months. Finally, the simulated bank lending aggregates are rescaled up and compared to the actual UK bank lending aggregates for purposes of model validation.

3.2 The ACE Model

The model of this paper outlined in **Figure 2** has an the endogenous segment (the dashed area in **Error! Reference source not found.**) which is embedded within the wider economy where the relevant variables relating to the central bank , labour market, goods and services market, housing market, and capital markets are taken to be exogenous. The non-bank agents within the endogenous dashed segment are assigned to banks and they make their decisions specifically to do with their interactions with banking system whilst responding to the exogenously given data from outside the dashed segment in **Figure 2**. HHs and businesses deposit cash in their assigned banks. HHs and businesses also seek to obtain mortgages and bank loans, respectively, as conditions permit from their assigned banks. This implies that the assets and liabilities in the balance sheet of any bank are the horizontal sums of the corresponding assets and liabilities in the balance sheets of the agents who are assigned to this bank. For example, the amount of deposits on the liabilities side of a bank's balance sheet is the sum of the cash deposits of all HHs, BFs, and SMEs who are the customers of this bank.

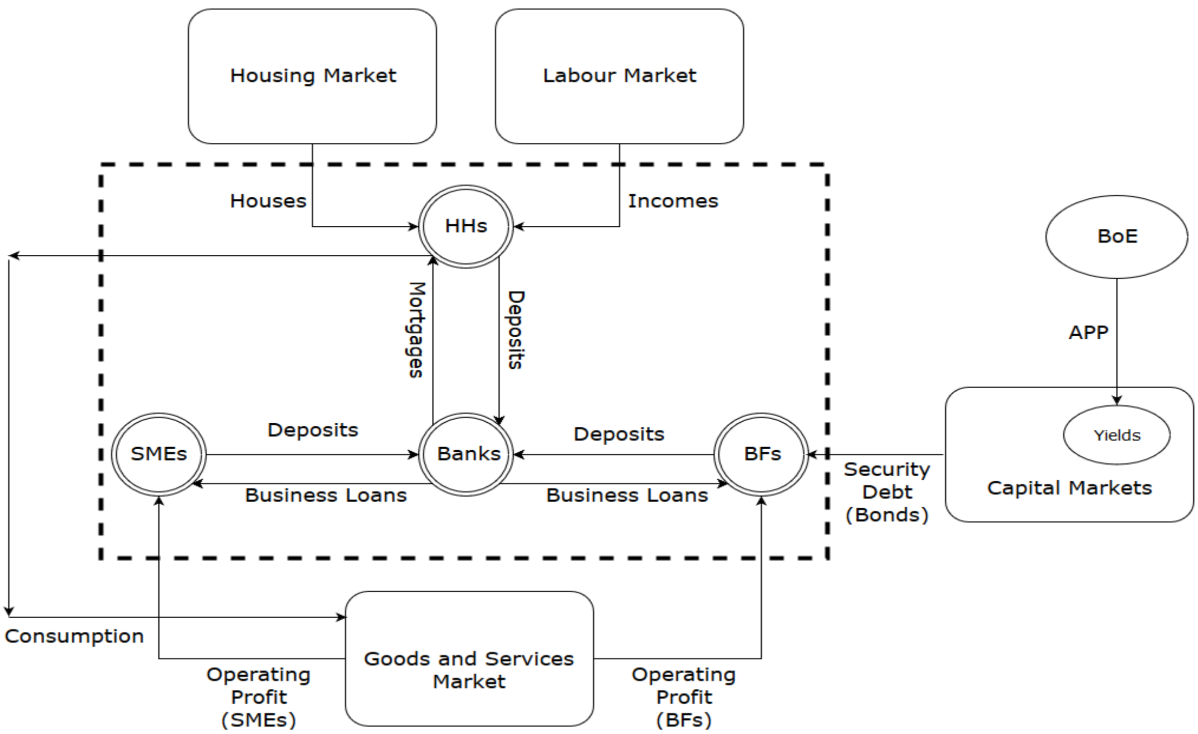
Nonfinancial firms (BFs and SMEs) employ physical capital and cash to operate and finance their operations using a mixture of debt financing and equity. The amount of physical capital (and total assets) defines the firm's size which, in turn, determines its accessibility to different debt markets. While SMEs are restricted to bank borrowing, BFs can also issue debt securities to raise debt financing. Banks hold cash (accept deposits) of HHs, BFs and SMEs, and provide loans in the form of mortgages to households and business loans to BFs and SMEs. A further description of the initial conditions of the agents and the behaviour of these agents over the simulation period will be presented in the next sections.

3.2 Agents' Behaviours

This section will set out the responses of the model agents to the developments in their surrounding environment and the subsequent interactions of one another within the endogenous segment of **Figure**

2. According to Daines, Joyce and Tong (2012), the first round of BoE purchases caused a 100 basis points fall in gilts yields. Hence, the impact of BoE's APP is introduced into the model by allowing gilts rate to decrease by 2.5 basis points each period. This fall in gilts yield accompanied by the low policy rate results in changes in the relative cost of corporate bonds and consequently has significant implications for BFs. The reaction of banks to this fall in BFs' borrowing depends on the capital adequacy regime in operation. Hence, the behaviour of banks is investigated under three scenarios that reflect three possible capital requirements regimes. The latter influence the lending behaviour of banks to households and SMEs.

Figure 2: Representation of the Agent-based Model of UK Bank Lending



Notes: The components inside the dashed area correspond to agent behaviours that are endogenous, while the data for the rest will be supplied exogenously. The latter includes asset yields, the income and consumption expenditure of households, house prices, the physical capital and operating profits of businesses. HHs: households; BFs: big nonfinancial companies; SMEs: small and medium enterprises

3.2.1 Households Behaviour

We assume each household earns an income and accumulates its wealth at each period only in the form of houses and cash deposited with its assigned bank. The demand for mortgages is governed by HH incomes. It is assumed that HHs' incomes fluctuates by 0.275% each month in line with inflation between March 2009 and March 2013 as average annual inflation rate in the UK was 3.3% during that period.

$$HHI_{i,t} = HHI_{i,t-1} \times \left(1 +/- \frac{0.033}{12}\right) \quad (1)$$

Here, $HHI_{i,t}$ is the income of household *i* in period *t*.

We assume that HHs keep constant their expenditure habits of spending between 66% -70% of income on consumption.[16]The remaining 30% of income is added to HH cash reserves which are used to pay the mortgage obligations (mortgage principal and interest) and to cover the deposit if a new mortgage is obtained. Denoting housing wealth of household *i* in period *t* as $HHH_{i,t}$, it can grow only with the allocation of a new mortgage, $NM_{i,t}$, to household *i* in period *t* with a 5% loan to value ratio in the benchmark simulation:

$$HHH_{i,t} = HHH_{i,t-1} + \frac{1}{0.95} \times NM_{i,t} \tag{2}$$

The conditions regarding whether a HH makes a mortgage application and the acceptance of the same by the bank it is assigned to is determined in part as follows. A HH who is a first time buyer is given a higher probability of making a mortgage application of 30% compared to that of a 20% probability for those who already own one. In the eligibility criteria, HH disposable income or cash at time after mortgage payments is denoted as $HHC_{i,t}$, and $MP_{i,t}$ is the payment paid by household *i* to their bank in period *t.* This is given in (3), with $PP_{i,t}$ and $IP_{i,t}$, respectively denoting principal and interest parts of the mortgage payment and given in (4) .

$$HHC_{i,t} = HHC_{i,t-1} + 0.3\, HHI_{i,t} - \frac{0.05}{0.95} NM_{i,t} - MP_{i,t} \tag{3}$$

$$MP_{i,t} = PP_{i,t} + IP_{i,t} \tag{4}$$

Here, mortgage principal repayments and interest payments are calculated as in (5) and (6).

$$PP_{i,t} = \frac{0.95}{360} \times NoM_{i,t} \times HP_{t-1} \tag{5}$$

$$IP_{i,t} = \frac{r_{HH,t-1}}{12} \times HHM_{i,t-1} \tag{6}$$

[16]This is in keeping with the UK consumption to GDP ratio. In 2009 this was around 66.134%, see https://data.worldbank.org/indicator/NE.CON.PETC.ZS?locations=GB .

Note, HP_t: house price in period *t*; $NoM_{i,t}$: the number of mortgages owed by household *i* in period *t*; $HHM_{i,t}$: the mortgage indebtedness of household *i* in period *t*; $r_{HH,t}$: interest rate on mortgages in period t.

We denote $MElg_{i,t}$ as the indicator for mortgage eligibility of household *i* to apply for a new mortgage in period *t* and $MAv_{b(i),t}$ is an indicator for new mortgages which determines whether bank assigned to household *i* is willing to lend. The value of this indicator will be derived from the bank behaviour described later. These *minimum requirements* employed by the banks are given in (7). To obtain a new mortgage, banks require the applicant HH to have a disposable income, $HHC_{i,t-1}$, that is at least twice the down payment or the deposit (5% of the house price ($0.05 \times HP_t$) and have no more than 5 mortgages. Further, mortgage payment in the coming month should be no more than 40% of HH income ,viz. $MP_{i,t+1} \leq 0.4 \times HHI_{i,t}$ in (7).

$$MElg_{i,t} = \begin{cases} 1 & if\ HHC_{i,t-1} \geq 2 \times 0.05 \times HP_t\ and\ MP_{i,t+1} \leq 0.4 \times HHI_{i,t}\ and\ NoM_{i,t-1} < 5 \\ 0 & Otherwise \end{cases} \tag{7}$$

Thus, the value of the new mortgage, $NM_{i,t}$, is given in (8) as the house price less deposit if the conditions in (7) are met under the proviso that the bank is able to do so.

$$NM_{i,t} = \begin{cases} HP_t \times (1-0.05) & if\ MAv_{b(i),t} = 1, MElg_{i,t} = 1 \\ 0 & Otherwise \end{cases} \tag{8}$$

Equation (10) gives the HH net worth or equity at time t,$HHE_{i,t}$, as its housing wealth plus cash assets less mortgage debt

$$HHM_{i,t} = HHM_{i,t-1} - PP_{i,t} + NM_{i,t} \tag{9}$$

$$HHE_{i,t} = HHH_{i,t-1} + HHC_{i,t} - HHM_{i,t} \tag{10}$$

3.2.2 Big Firms (BFs) Behaviour

As stated earlier, BoE's APP decreases the cost of corporate bonds which triggers portfolio rebalancing. This induces BFs to replace part of their bank loans with corporate bonds. The model assumes that BFs keep the size of physical capital and total debt unchanged, issue no new equity, and maintain a constant annual operating profit (i.e. profit before interest) to total assets ratio of 10%. In each period, a BF chooses the debt financing mixture to maximize its net profit ($\pi_{i,t}$) which is the difference between its operating profit ($OPP_{i,t}$) and the cost of debt financing:

$$\pi_{i,t} = BFOPP_{i,t} - r_{S,t}.BFBd_{i,t} - r_{BF,t}.BFBL_{i,t} \quad (11)$$

Here,$r_{S,t}$and $r_{BF,t}$: the interest rates on bonds and bank loans in period *t*; $BFBd_{i,t}$: the amount outstanding of BF *i*'s bonds in period *t*; $BFBL_{i,t}$: the amount of bank loans owed by big firm *i* in period *t*. The comparisons between bank borrowing and corporate bond issuance are based on the interest costs of the two sources. BFs will respond to decreases in bonds interest rate (r_S), when it becomes equal to or smaller than the interest rate on bank borrowing (r_{BF}), by issuing more bonds and using the proceeds to pay back part of their bank loans. In other words, the debt mixture of BFs is restructured towards more corporate debt and less bank loans on average.[17] Note, the exogenous components of a BF balance sheet in any period *t* to do with physical capital and gross operating profits of BFs will be anchored in empirical data. Equation (12) states that the physical capital of the BF, $BFPhC_{i,t}$, remains unchanged from one period to the next, starting with the initial distribution of

$$BFPhC_{i,t} = BFPhC_{i,t-1} \quad (12)$$

Equation (13) states the assumption that BF gross operating profits grow at empirically relevant rates in terms of its physical capital at time t:

$$BFOPP_{i,t} = 0.10\times(BFPhC_{i,t-1}) \quad (13)$$

The BF cash holdings, is net of the interest payments on its corporate bonds and bank loans:

$$BFC_{i,t} = BFC_{i,t-1} + BFOPP_{i,t} - r_{S,t}.BFBd_{i,t-1} - r_{BF(t)}.BFBL_{i,t-1} \quad (14)$$

The change in the debt composition of big firm *i* in period *t*[18],$\Delta BFDC_{i,t}$, which is key to the portfolio balancing response to the lower yield on debt as a result of APP is given as follows in (15). The status quo, with bank loans favoured over bond issuance, is maintained if, as stated in (15), the bond yield, $r_{S,t}$

[17] In a future edition of our ACE model, the extent to which funds raised by BFs from bonds are apportioned between repayment of bank loans and share repurchases will be modeled more explicitly. In view of the massive trend in the use of funds from bond issues for share repurchases, our model could overstate the switch away from bank loans by BFs. An explicit BF model that maximizes earnings per share (EPS) or net profits divided by the number of shares outstanding indicates that the return on capital, ROE, can be increased either by increasing net profits (lowering the debt cost in our analysis) or reduce the number of shares outstanding through share repurchases or buybacks.

[18]This variable is calibrated to the actual growth of BFs loans between March 2009 and April 2013.

is greater than interest on bank loans, $r_{BF,t}$. If the opposite is the case, bank loans to BFs can be decreased by upto 1.45% [19]as follows:

$$\Delta BFDC_{i,t} = \begin{Bmatrix} 0 & if\ r_{S,t} \geq r_{BF,t} \\ Random[-0.014598;\ 0.009904] & if\ r_{S,t} < r_{BF,t} \end{Bmatrix} \quad (15)$$

$$BFBL_{i,t} = BFBL_{i,t-1} + \Delta BFDC_{i,t} \quad (16)$$

$$BFBd_{i,t} = BFBd_{i,t-1} - \Delta BFDC_{i,t} \quad (17)$$

Hence, the net worth or equity of firms $BFE_{i,t}$is given as :

$$BFE_{i,t} = BFPhC_{i,t} + BFC_{i,t} - BFBL_{i,t} - BFBd_{i,t} \quad (18)$$

3.2.3 Bank Lending Behaviour

As indicated, new bank lending for mortgages and to SMEs is driven by the portfolio rebalancing implemented by BFs in response to APP induced lower bond yields. We assume that banks do not issue new externally financed equity, and do not distribute any dividends and hence avail of new equity only from retained earnings or as relevant by changing the composition of its risk weighted assets. Banks aim to smooth their total stock of lending to HHs and non-financial firms and if they suffer reduced loan demand or increased loan repayments by BFs, they will attempt to compensate this by lending to HHs for mortgages or to SMEs subject to capital constraints and perceived credit risks. To investigate the impact of regulatory capital adequacy requirements, the model implements three different scenarios: no capital requirements, a Basel I simple capital requirements where equity capital is a fixed proportion of total lending, and the more complex case where equity capital satisfies a ratio of risk weighted assets. The main behavioural difference that the introduction of Basel rules have brought about is an addition to the banks' use of credit risk estimates on an *ad hominem* basis in the pre Basel regime. This involves an institutionalized implementation of a Basel complaint cost of capital measure. In summary : To track the impact of a QE-generated fall in demand for bank loans by BFs, banks change their portfolio of loans only to optimally accommodate the slack in demand in the total lending due to big firm substitution away from bank loans.

[19]This is a historically relevant maximum fall in bank loans in a month for non-financial firms.

3.2.3.1 Scenario I: No Capital Requirements

In this scenario, banks do not have regulatory equity capital requirements. A bank grants mortgages and loans to SMEs to maximize its profit $\pi_{B,t}$, which is given by the following equation:

$$\pi_{B,t} = \sum r_{i,t}.L_{i,t} - \sum s_{i,t}.\left(L_{i,t}\right).L_{i,t} \tag{19}$$

Here i = {*BF*, *HH*, *SME*}: the agent class; $L_{i,t}$: bank lending to class *i* agents at time *t*; $r_{i,t}$: interest rate on loans class *i* agents at time *t*; $s_{i,t}(L_{i,t})$: default risk cost of class i agents at time *t* (i.e. the probability that an agent of class *i* defaults) which increases in the amount of lending to class *i* agents. We assume for simplicity that the default risk costs are quadratic , $s_{i,t}(L_{i,t})= L_{i,t}^2$. As discussed earlier, banks proxy the default risk for each class of loans in terms of the non-performing loans at each time *t* reported as write offs by UK banks for the loan class (see Appendix). The optimal amounts of mortgages and loans to SMEs in this case rely on the difference between the interest rates of the two types of loans (r_{HH} and r_{SME}), the ratio of the default risk of the other loan product to the total default risk of both loan products and the amount available for investment in the two types (i.e. the amount of total lending minus loans to BFs). Assuming that banks aim to keep the amount of total lending for these categories of loans fixed ($L_{Tot} = L_{BF,t} + L_{HH,t} + L_{SME,t}$) and aims to reallocate optimally between HHs and SMEs what remains after the wholly demand determined BF loan, we have: [20]

$$L^*_{HH,t} = \frac{\left(r_{HH,t} - r_{SME,t}\right) + 2s_{SME,t}\left(L_{Tot,t} - L_{BF,t}\right)}{2\left(s_{HH,t} + s_{SME,t}\right)} \tag{20}$$

$$L^*_{SME,t} = \frac{\left(r_{SME,t} - r_{HH,t}\right) + 2s_{HH,t}\left(L_{Tot,t} - L_{BF,t}\right)}{2\left(s_{HH,t} + s_{SME,t}\right)} \tag{21}$$

The first result here is that the banks operate without an explicit cost of capital, and even if there are larger default costs on loans to SMEs in (20), $s_{SME,t} > s_{HH,t}$, this need not imply a natural bias toward mortgage loans as r_{SME} could be greater than r_{HH}. However, equations (20) and (21) indicate that a fall in loans to BFs, viz$\Delta\ L_{BF,t} < 0$, driven by the lower bond yields, will likewise induce banks to increase their supply of mortgages to HHs to a greater extent than loans to SMEs. This is governed by the respective comparative static conditions which we denote as θ_{HH} and θ_{SME}:

---

[20] Note given the assumptions made, the optimal lending equations in (20) and (21) are obtained from the profit function given as $\pi_{B.t} = r_{BF,t}L_{BF,t} + r_{HH,t}L_{HH,t} + r_{SME,t}(L_{Tot} - L_{BF,t} - L_{HH,t}) - s_{BF,t}L^2_{BF,t} - s_{HH,t}L^2_{HH,t} - s_{SME,t}(L_{Tot,t} - L_{BF,t} - L_{HH,t})^2$.

$$\theta_{HH} = \frac{\partial L_{HH,t}}{\partial L_{BF,t}} = \frac{-s_{SME,t}}{s_{HH,t} + s_{SME,t}} < 0 \quad (22)$$

$$\theta_{SME} = \frac{\partial L_{SME,t}}{\partial L_{BF,t}} = \frac{-s_{HH,t}}{s_{HH,t} + s_{SME,t}} < 0 \quad (23)$$

Hence, each bank follows the following optimal behavioural rules when deciding the supply of new loans to be granted ($\Delta L_{HH,t}$, and $\Delta L_{SME,t}$):[21]

$$\Delta L_{HH,t} = L^*_{HH,t} - L_{HH,t-1} + \theta_{HH}\left(\Delta L_{BF,t}\right) \quad (24)$$

$$\Delta L_{SME,t} = L^*_{SME,t} - L_{SME,t-1} + \theta_{SME}\left(\Delta L_{BF,t}\right) \quad (25)$$

Equations (24)and (25)combines the optimal loan levels($L^*_{HH,t}$ & $L^*_{SME,t}$)given in Equations (20) and (21) and the impact of changes in BF demand for banks loans given in Equations (22) and (23).

3.2.3.2 Scenario II: Simple Capital Requirements with No Risk Weights

To introduce the capital adequacy requirements, which state that at least a fraction γ_{Req} of bank assets must be financed by equity, into the model, we follow Aliaga-Díaz, Olivero, and Powell (2011) who state that if a bank has insufficient capital, it is subject to a cost that increases with the distance between the required capital to asset ratio and the actual one. Hence, the profit function of a bank in this case becomes:

$$\pi_{B,t} = \sum\left(r_{i,t} - \delta\right).L_{i,t} - \sum s_{i,t}.\left(L_{i,t}\right).L_{i,t} - \left(\mu.\log\left(\frac{1}{\gamma_t} - \frac{1}{\gamma_{req}}\right)\right).L_{Tot,t} \quad (26)$$

$$\frac{1}{\gamma_t} = \frac{1}{\frac{E_{t-1}}{L_{BF,t} + L_{HH,t} + L_{SME,t}}} = \frac{L_{Tot,t}}{E_{t-1}}$$

$$\beta = \mu.\,log\left(\frac{1}{\gamma} - \frac{1}{\gamma_{req}}\right)$$

[21]If the amount in Equations (24) and/or is negative, this means that the bank will not grant any new mortgages orloans to Similarly, if the amount of in Equation (25 is negative, the bank would reduce its lending proportionally to all its SME clients. The same applies to the similar equations presented later in Scenarios II and III.

Here E: bank equity capital, $\delta = \sigma.\left(E_{t-1} / L_{Tot,t} \right)$: the cost of equity capital per £1 of total lending; σ: the cost of equity capital estimated by using the Capital Asset Pricing Model (CAPM)[22]. Note β is the cost of having insufficient equity or the cost of noncompliance with the capital rules, and we can aggregate these costs $\alpha = \delta + \beta$ as they apply to total lending . Note $1/\gamma$ is the leverage which in the case of a 8% capital ratio is 12.5. The main change in the banks' calculation of the profitability of loans in the case of a simple regulatory capital requirement is the direct cost of equity, δ, in (26) and also the penalty for deviations from the Basel approved leverage. The operational aspects of the binding capital constraints are governed by the μ which is an indicator function in Equation (26) the values for which are defined as follows:

$$\mu = \begin{Bmatrix} 1 & if\ \gamma_t < 0.08 \\ 0 & if\ 0.10 \geq \gamma_t \geq 0.08 \\ 0 & if\ \gamma_t > 0.10 \end{Bmatrix} \tag{27}$$

In addition to the required equity to assets ratio (γ_{Req}) of 8%, an optional buffer of 2% is stipulated as in Repullo and Suarez (2013). The cost of noncompliance with the capital rules is assumed to be very high and can lead to bank failure. To avoid this high cost, banks try to keep equity to asset ratio very close to 10%. In other words, each bank will change its total lending to ensure that equity to total lending ratio is between 8% and 10% (i.e. 8% $<\gamma_t<$ 10%).This means that the upper bound of the feasible amount of total lending in any period t ($\overline{L_{Tot,t}}$) which maintains the 10% equity to total lending is estimated:

$$\overline{L_{Tot,t}} = 10E_{t-1} = \sum L_{i,t}\ \text{, if } 8\% < \gamma_{t-1} < 10\% \text{ and } L_{Tot,t}^{\#} < \overline{L_{Tot,t}} \text{ if } \gamma_{t-1} < 8\%. \tag{28}$$

Thus, total lending has to be reduced from $\overline{L_{Tot,t}}$ if γ_{t-1} < 8% and we will denote this as $L_{Tot,t}^{\#}$.

Accordingly, the profit function of the bank can be rewritten as follows:

$$\pi_{B,t} = \sum \left(r_{i,t} - \delta \right).L_{i,t} - \sum s_{i,t}.\left(L_{i,t} \right).L_{i,t} - \left(\mu.\log\left(\frac{1}{\gamma_t} - \frac{1}{\gamma_{req}} \right) \right).\overline{L_{Tot,t}} \tag{29}$$

As the total capital costs $\alpha = \delta + \beta$, apply equally to every £1 lent irrespective of the category of loan, the optimal amounts of mortgages and loans to SMEs in this Scenario 2 (highlighted with a double

[22] For example, see Rizzi (2013).

asterisks **) correspond with the result in Scenario (1) with the only difference being the upper bound and (the lower bound) of the total amount of lending being given by $\overline{L_{Tot,t}}$ in (28).

$$L^{**}_{HH,t} = \frac{\left(\left(r_{HH,t}-\alpha\right)-\left(r_{SME,t}-\alpha\right)\right)+2s_{SME,t}\left(\overline{L_{Tot,t}}-L_{BF,t}\right)}{2\left(s_{HH,t}+s_{SME,t}\right)} = \frac{\left(r_{HH,t}-r_{SME,t}\right)+2s_{SME,t}\left(\overline{L_{Tot,t}}-L_{BF,t}\right)}{2\left(s_{HH,t}+s_{SME,t}\right)} \quad (31)$$

$$L^{**}_{SME,t} = \frac{\left(\left(r_{SME,t}-\alpha\right)-\left(r_{HH,t}-\alpha\right)\right)+2s_{HH,t}\left(\overline{L_{Tot,t}}-L_{BF,t}\right)}{2\left(s_{HH,t}+s_{SME,t}\right)} = \frac{\left(r_{SME,t}-r_{HH,t}\right)+2s_{HH,t}\left(\overline{L_{Tot,t}}-L_{BF,t}\right)}{2\left(s_{HH,t}+s_{SME,t}\right)} \quad (32)$$

Equations (31) & (32) indicate that a fall in loans to BFs induces banks to increase its supply of mortgages and loans to SMEs using the comparative static conditions θ_{HH} and θ_{SME} (equations 22& 23) as in Scenario I. The behavioural rules a bank follows when deciding the supply of new loans to be granted ($\Delta L_{HH,t}$, and $\Delta L_{SME,t}$) depend on the value of its equity to total lending in the previous period (γ_{t-1}). In this context, we distinguish between the three possible cases shown below.

Case A: $M = 0$ **and** $8\% < \gamma_{t-1} < 10\%$**:**

In this case a bank will maintain its total lending unchanged, and will change the size of mortgages and loans to SMEs only if there was a change in the stock of its loans to BFs:

$$\Delta L_{HH,t} = \theta_{HH} \cdot \left(\Delta L_{BF,t}\right) \quad (33)$$

$$\Delta L_{SME,t} = \theta_{SME} \cdot \left(\Delta L_{BF,t}\right) \quad (34)$$

Case B: $M = 0$ **and** $\gamma_{t-1} > 10\%$**:**

In this case, the bank has excess lending capacity that it can use to grant more mortgages and loans to SMEs. Consequently, analogous to Scenario I, the supply of new loans to be granted will be as follows:

$$\Delta L_{HH,t} = L^{**}_{HH,t} - L_{HH,t-1} + \theta_{HH}\left(\Delta L_{BF,t}\right) \quad (35)$$

$$\Delta L_{SME,t} = L^{**}_{SME,t} - L_{SME,t-1} + \theta_{SME}\left(\Delta L_{BF,t}\right) \quad (36)$$

Case C: $M = 1$ **(or** $\gamma_{t-1} < 8\%$**):**

A bank facing this situation is over-lending and will decrease its total lending to $L_{Tot,t}{}^{\#}$ as noted in (28) to decrease the cost of noncompliance with the capital adequacy rules. The behavioural rules will follow (35) and (36) with $L_{Tot,t}{}^{\#}$ replacing the capital complaint upper bound for total loans given there.

3.2.3.3 Scenario III: Complex Fractional Capital Requirements with Risk Weights

Like Scenario II, banks are required to finance a fraction of their asset using equity capital. However, the capital requirements in Scenario III assign different risk weights to different types of assets following Basel II/III and the capital requirements take the form of an *equity to risk weighted asset* ratio specified in below in (37). The profit function of a bank in this case takes the following formula:

$$\pi_{B,t} = \sum\left(r_{i,t} - \delta_i^{\#}\right).L_{i,t} - \sum s_{i,t}.\left(L_{i,t}\right).L_{i,t} - \left(\mu'.\log\left(\frac{1}{\gamma_i^{\#}} - \frac{1}{\gamma_{req}^{\#}}\right)\right).L_{Tot,t} \quad (37)$$

$$\frac{1}{\gamma^{\#}} = \frac{1}{\dfrac{E_{t-1}}{w_{BF}.L_{BF,t} + w_{HH}.L_{HH,t} + w_{SME}.L_{SME,t}}} = \frac{w_{BF}.L_{BF,t} + w_{HH}.L_{HH,t} + w_{SME}.L_{SME,t}}{E_{t-1}}$$

Here $w_{BF}<w_{HH}<w_{SME}$: risk weights for loans to BFs, mortgages, and loans to SMEs, respectively; E: bank equity capital; $\delta_i^{\#} = \sigma^{\#}.w_i.\frac{E_{t-1}}{L_{Tot,t-1}}$: the cost of equity capital per £1 of lending to class *i* agents; $\sigma^{\#}$: the cost of equity capital estimated by using the Capital Asset Pricing Model (CAPM); $\gamma_{Req}{}^{\#}$: the required equity to risk weighted assets ratio; $\gamma^{\#}$: the actual equity to risk weighted assets ratio; μ: is a positive parameter.

As in Scenario II, banks attempt to maintain equity to risk weighted assets ratio very close to 10%. Therefore, the behaviour of a bank in any period *t* depends on the value of its equity to risk weighted assets ($\gamma_t{}^{\#}$). Again, each bank will determine its total lending to ensure that 8% $<\gamma_t{}^{\#}<$ 10%, which we will denote generically as $\overline{L_{Tot,t}}^{\#}$ to cover the range of values this can take.

The first order conditions with respect to mortgages and loans to SMEs show that, in addition to the relative yields and credit risk, the amount available for investment in mortgages and loans to SMEs, the risk weights and bank equity have a significant impact on the optimal allocation between the two types of loans:

$$L_{HH,t}^{***} = \frac{\left(E_{t-1}\cdot\left(\frac{1}{\gamma_{req}^{\#}} - \left(\frac{w_{BF}.L_{BF,t-1} + w_{SME}\cdot\left(\overline{L_{Tot,t}} - L_{BF,t}\right)}{E_{t-1}}\right) + \left(\frac{\overline{L_{Tot,t}}.\mu.(w_{HH} - w_{SME})}{E_{t-1}\cdot\left(\left(r_{HH,t} - \delta_{HH,t}^{\#} - s_{HH,t}\right) - \left(r_{SME,t} - \delta_{SME,t}^{\#} - s_{SME,t}\right)\right)}\right)\right)\right)}{w_{HH} - w_{SME}} \quad (38)$$

$$L_{SME,t}^{***} = \frac{\left(E_{t-1}\cdot\left(\frac{1}{\gamma_{req}^{\#}} - \left(\frac{w_{BF}.L_{BF,t-1} + w_{HH}\cdot\left(\overline{L_{Tot,t}} - L_{BF,t}\right)}{E_{t-1}}\right) + \left(\frac{\overline{L_{Tot,t}}.\mu.(w_{SME} - w_{HH})}{E_{t-1}\cdot\left(\left(r_{SME,t} - \delta_{SME,t}^{\#} - s_{SME,t}\right) - \left(r_{HH,t} - \delta_{HH,t}^{\#} - s_{HH,t}\right)\right)}\right)\right)\right)}{w_{SME} - w_{HH}} \quad (39)$$

Equations (40)& (41) indicate that a fall in loans to BFs (L_{BF}) will induce banks to increase mortgages, and to decrease loans to SMEs as per the following comparative statics :

$$\rho_{HH}^{***} = \frac{\partial L_{HH}}{\partial L_{BF}} = -\frac{\left(w_{BF} - w_{SME}\right)}{w_{HH} - w_{SME}} < 0 \quad (40)$$

$$\rho_{SME}^{***} = \frac{\partial L_{SME}}{\partial L_{BF}} = -\frac{\left(w_{BF} - w_{HH}\right)}{w_{SME} - w_{HH}} > 0 \quad (41)$$

Thus, unlike Scenarios I and II, in Scenario III, as seen in equation (41), the slack in total bank lending that is brought about by the portfolio rebalancing by BFs away from bank loans, with $\Delta L_{BF,t} < 0$, will not lead to any increase in SME lending as the absolute differences in the administratively set risk weights that are biased against SMEs will militate against this. In fact in Case C (see Scenario II) when banks are under capitalized with ***γ_{t-1}#<8%*** , SMEs will lose loan share as follows:

$$\Delta L_{SME,t}^{***} = -\frac{1}{w_{SME}}.\left(RWA_{t-1} - \frac{1}{0.08}E_{t-1}\right) + \rho_{SME}^{***}.\left(\Delta L_{BF,t}\right) \quad (42)$$

The first term is negative, and the second term is also negative from (41) when $\Delta L_{BF,t} < 0$,

The risk weights used in the model for different loan types are taken from *BIPRU 3.4 Risk weights under the standardised approach to credit risk* available Financial Conduct Authority (FCA). The value of these risk weights are as follows:

w_{BF}	w_{HH}	w_{SME}
20%	*50%*	*100%*

Source: BIPRU 3.4 Risk weights under the standardised approach to credit risk; Financial Conduct Authority (FCA); Available at: https://www.handbook.fca.org.uk/handbook/BIPRU/3/4.html#D591

3.2.4 SMEs Behaviour

Like BFs, SMEs have a constant but lower annual operating profit to total assets ratio of 5%, and keep the size of physical capital fixed over the simulation period. The main characteristic of SMEs is that they cannot control their debt financing (like BFs) since the single source of this financing is bank loans. The latter depend solely on banks' willingness to grant loans or extend/renew current credit facilities to these firms. Additionally, the model assumes that SMEs have unlimited demand for debt financing and that they cannot raise further external equity financing during the simulation period. As shown above in Scenario III, the Basel II/III risk weight against SMEs loans imply that they cannot enjoy any increase in loans especially in the period of APP when BFs start to replace bank loans with bonds. This situation is more drastic when banks suffer capital inadequacy. Consequently, the components of a SME balance sheet in a given period t are as follows:

$$SMEPhC_{i,t} = SMEPhC_{i,t-1} \quad (43)$$

$$SMEOPP_{i,t} = 0.05 \times \left(SMEPhC_{i,t-1} + SMEC_{i,t-1}\right) \quad (44)$$

$$SMEC_{i,t} = SMEC_{i,t-1} + SMEOPP_{i,t} - r_{SME,t}.SMEBL_{i,t-1} + \Delta SMEBL_{i,t} \quad (45)$$

$$SMEBL_{i,t} = \Delta SMEBL_{i,t-1} + \Delta SMEBL_{i,t} \quad (46)$$

$$SMEE_{i,t} = SMEPhC_{i,t} + SMEC_{i,t} - SMEBL_{i,t} \quad (47)$$

Here: $SMEPhC_{i,t}$: the physical capital of SME *i* in period *t*; $SMEOPP_{i,t}$: the operating profit of SME *i* in period *t*; $SMEC_{i,t}$: the cash holdings of SME *i* in period *t*; $SMEBL$: the amount of bank loans owed by SME *i* in period *t*;$\Delta SMEBL_{i,t}$: the change in the amount outstanding of the bank loans granted to SME *i* by its bank in period *t*; $SMEE_{i,t}$: the equity of SME*i* in period *t*.

4. Initial ACE Model Conditions and Simulation Results

4.1 ACE Model Initial Conditions, Policy Rates and Risk Premia

Section 3.1 outlined the data driven agent characteristics for the UK economy and the Appendix has given additional details and the data sources for this.

Figure 3: Initial Values of Interest Rates (Annual)

Interest Rate	Initial Value
risk free rate (r_{RF})[1]	0.5%

government gilts rate (r_G)[2]	4%
interest rate on mortgages (r_{HH})	7% (r_{RF} + 6.5%)
interest rate on BFs loans (r_{BF})	5.5% (r_{RF} + 5%)
interest rate on BFs bond debt (r_S)	6% (r_G + 2%)
interest rate on SMEs loans (r_{SME})	8.5% (r_{RF} + 8%)

[1] **BoE's policy rate. (Source: Bank of England (http://www.bankofengland.co.uk))**

[2] **Median yield on 10-year gilts in 2008 Q4 (Source: DataStream®)**

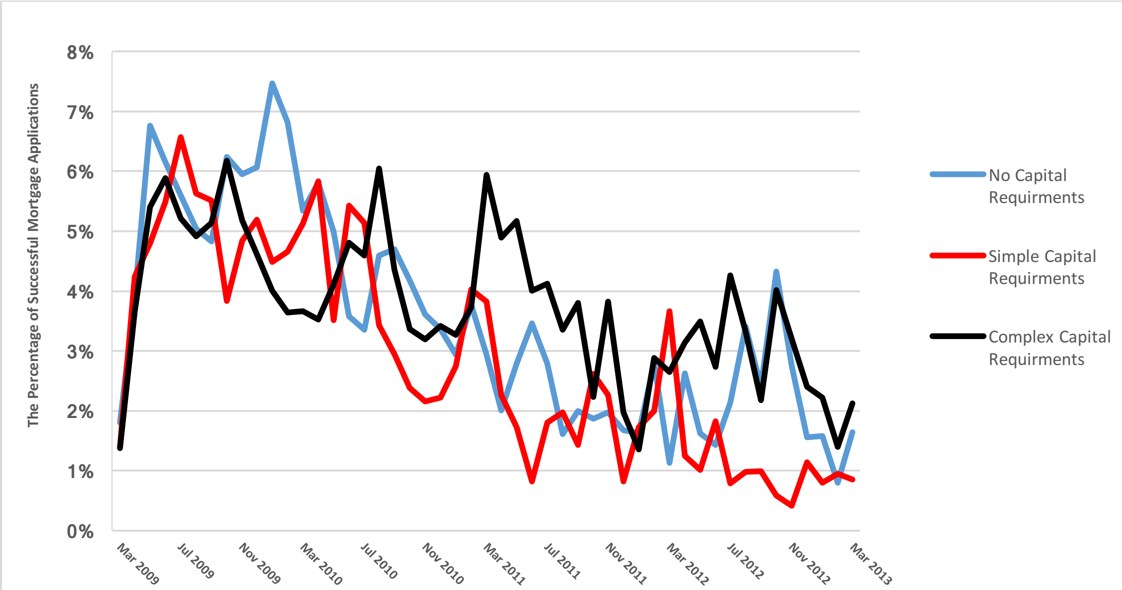
Figure A.5 in the Appendix gives the initial conditions and the balance sheet data for the agents as set out in Sections 3.2-3.4. The only remaining variables that need to be discussed are the role of the price variables. The policy rates and lowering of bond yields triggered by APP are for the most part considered to exogenous to agents' behaviour.

The model includes 6 different interest rates, the initial values for this are presented in **Figure 3** above. The initial levels of these rates are chosen in a way that reflects the actual values (where possible), especially regarding the relative riskiness of debt instruments. First, the risk-free rate (r_{RF}) and gilts rate are set to the actual levels of BoE policy rate (0.5%) and 10-year gilts rate (4%) just before the launch of APP in 2009 with the mortgage rates and the bond rates, respectively, tracking this over time. Second, premia on different types of bank loans are given to reflect the credit risk or default probability of the loans and the cost of capital for banks. In **Figure 3**, loans to SMEs are given the highest initial premia of 8%, followed by 6.5% for mortgages and 5% for loans to BFs. Lastly, in the immediate pre APP period of 2009, the fact that the corporate bonds represented only 32.7% of nonfinancial corporations' total debt in 2009 Q1 indicates that the cost of these bonds was higher than the cost of bank loans. Hence, the risk premium on BFs bonds (above gilts rate) is set at 2% initially to make the interest rate on these bonds higher than interest rate on BFs loans.

4.2 Simulation Results

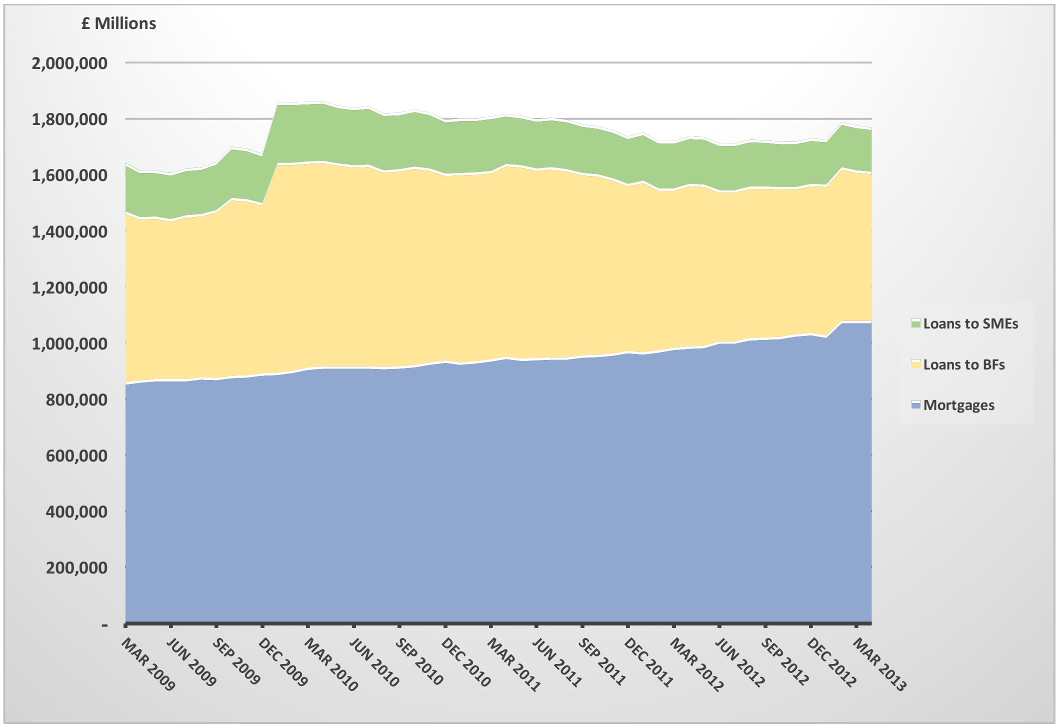
As stated earlier, the model in this paper covers a period of 50 months from the start of APP in 2009 and it involves the micro simulations of the interaction between different agents and the responses of these agents to the developments in debt markets.

Figure 4: The Proportion of Successful Mortgage Applications (Monthly) - Simulated



At any given month *t*, asset purchases under APP lead to an exogenous fall in gilts yield which is reflected in the yield of corporate bonds through the portfolio rebalancing effect. BFs start to change their debt financing structure when the cost of bonds become lower than bank loans cost. Meanwhile, each household receives its income, finances its consumption, pay its mortgage instalment, and accumulates the rest into its cash holdings. The first set of results that are pertinent are the monthly rates of mortgage approvals under the 3 bank capital regime given in **Figure 4**. These hold the key to the systematic bias in bank lending in favour of mortgages in the Basel II/III risk weighted regime. While all 3 scenarios show a downward trend in mortgage approvals, scenario 3 dominates and to a lesser extent scenario 1 shows follows driven as it is by the relative credit risks given in the estimates proxied by bank write off (see Appendix A.3 Figure).

Figure 5: Actual Lending Aggregates

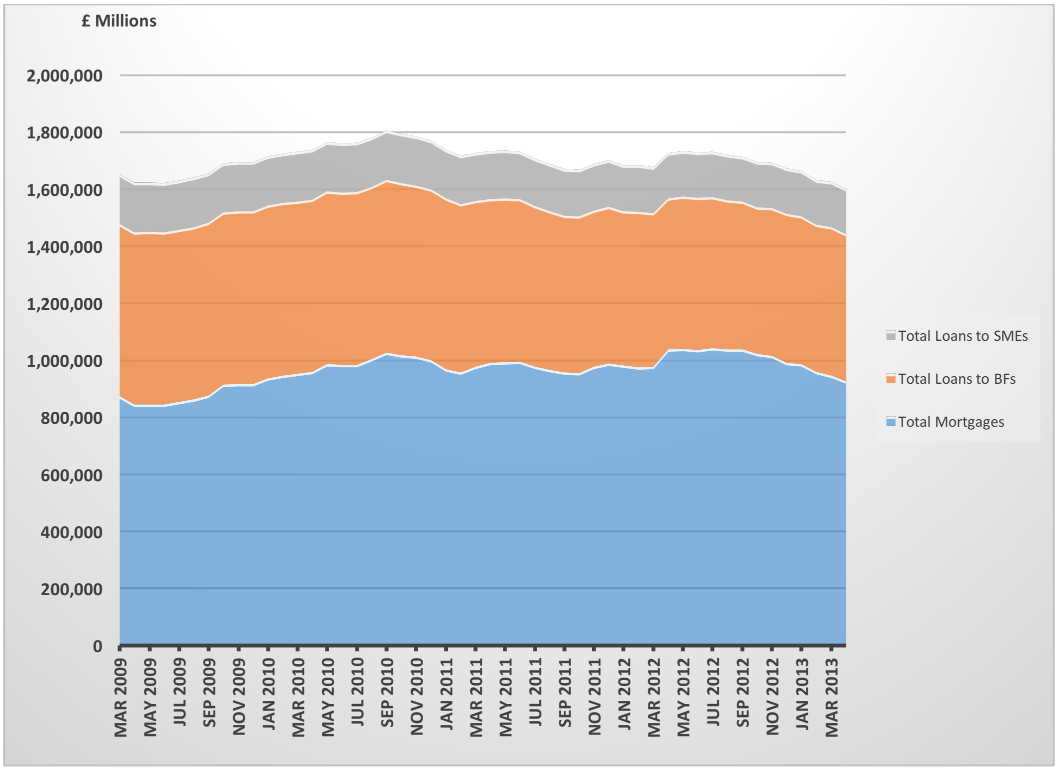


Source: Bank of England's Bankstats (http://www.bankofengland.co.uk/statistics/Pages/bankstats/default.aspx)

We will now analyse the results in terms of the aggregate lending in terms of mortgages, loans to BFs, and loans to SMEs for the 3 scenarios given in Figures 5-7, respectively . To make them comparable to actual data given in **Figure 5**, the amounts of mortgages, loans to BFs, and loans to SMEs have been rescaled up using the proportions between the actual and the hypothetical numbers of the agents. The main exogenous operative factor is that BFs do not change their debt structure during the first 20 periods till the APP impact on bond yields bite and the cost of security debt is still bigger than the cost of bank borrowing. The actual data in **Figure 5** shows how the total bank loans for the classes of loans under consideration starts at about £1.6 trillion in 2009 shows a relative peak in March 2010 at £1.81 Trillion after a severe crunch and then trends downwards to £1.75 Trillion in March 2013. The breakdown shows that only mortgages grew from £0.81 Trillion in 2009 to £0.95% in 2013, while other loans types , respectively, fell over this period from £0.62 Trillion to £0.45 Trillion for BFs and from £0.18 Trillion to £0.15 Trillion for SMEs.

Figure 6: Simulated Bank Lending Aggregates (Complex Capital Requirements; Risk Weights)

Scenario 3 (see section 3.2.4)

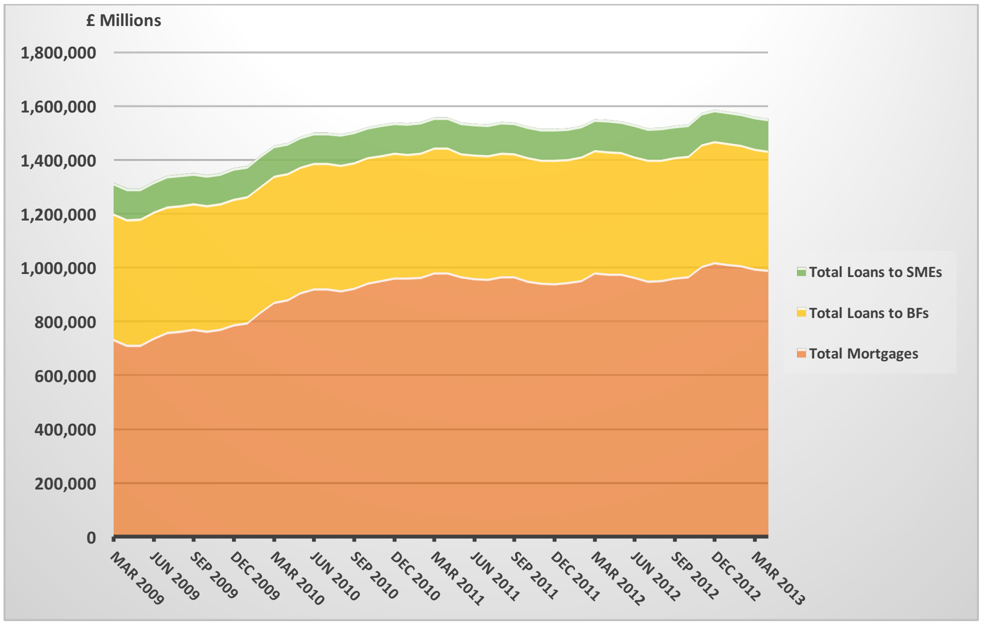


The main results here is as expected, only the extant Basel II/III scenario 3, **Figure 6**, corresponds with the actual data and produces the result that while overall lending falls, only the mortgage lending picks up somewhat while bank lending to the real economy fall. In the simulated results given in Figure 6 show a very close correspondence with the actual data though the 2013 March total lending is somewhat smaller at £1.5 Trillion. Scenario 3 simulated mortgage lending starts at about £0.9 Trillion in 2009, shows the similar peak as with the actual data in July 2010 of about £0.9 Trillion and falls to £0.8 Trillion. Lending to BFs start at £0.6 Trillion and falls to £0.53 Trillion in March 2013, while SMEs suffer a larger fall from £0.15 Trillion in 2009 to £0.08 Trillion in 2013. This is exactly as we had indicated as to how banks will respond to the conditions of APP when operating under Basel II/III risk weights.

There is a systematic bias against SME lending which operates in an iron clad way. In is important to note that while our result is not inconsistent with the studies of Thakor (1996), Hans et al. (1999), andHeid, Porath and Stolz (2004) results, in that banks suffering from capital inadequacy will look to improve their capital status by shifting out of high risk weigthed loans/assets, the ACE model here builds a more detailed conditions of APP that triggered a series of events which reduced both BF loans and loans to SMEs. SMEs suffered disproportionately only due to their unfavourable Basel risk weights. As the results from the other 2 scenarios show, there was nothing in the economic credit risk conditions surrounding SMEs that this should have been the case.

Figure 7: Simulated Bank Lending Aggregates (Simple Capital Requirements; No Risk Weights)

Scenario 2 (see section 3.2.3)

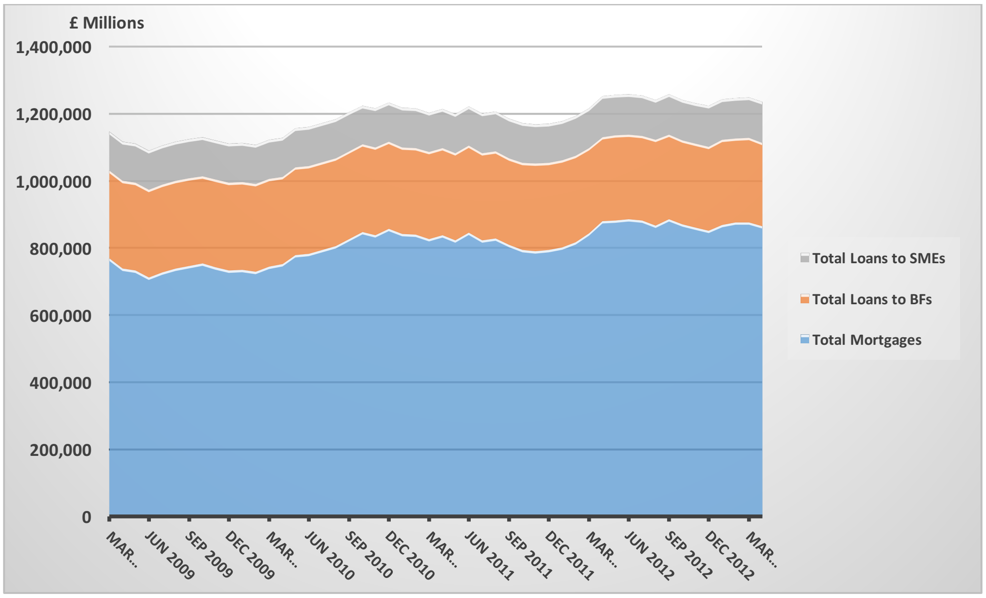


Thus, in contrast to the simulated outputs from scenario 3, the other 2 scenarios do not show a fall in lending to SMEs and BFs. In the case of scenario 2, **Figure 7**, SME's enjoy about the same level of loans around £0.1 Trillion and in fact enjoys and increase to about £0.12 Trillion in 2013 March. Likewise, lending to BFs increase from £0.42 Trillion in 2009 to £0.6 Trillion. It is expected that Basel I unweighted 8% capital implies identical leverage of 10-12.5 for all asset classes, could reduce total lending compared with scenario 3. Hence total lending in 2009 was £1.3 Trillion below the actual data of £1.6 Trillion, in March 2013, scenario 2 shows about the same level of total lending as lending as scenario 3 at £1.5 Trillion. But what is interesting is that with a lack of bias, the growth in mortgage lending is not at the expense of loans to BFs and SMEs.

Finally, the is a counterintuitive result regarding scenario 1,**Figure 8**, which shows the lowest amount of total lending at about £1.5 Trillion in 2009 - £1.2 Trillion in 2013 March. The idea that the absence of an explicit regulatory capital rule need not lead to excessive lending runs contrary to the what is often assumed. Indeed, as long as the banks are guided by the optimal rule based on the relative credit risk proxies given in section 3.2, there is clearly no threat of excessive lending. Also, the lack of bias against SME lending means that this category of lending remains stable at about £0.15 Trillion through out the conditions of APP in scenario 1.

Figure 8: Simulated Bank Lending Aggregates (No Capital Requirements)

Scenario 1 (see section 3.2.2)



4.3 Model Validation

Several validation methods have been used to validate simulated models in engineering in computer sciences. For instance, Sargent (2013) outlines 17 techniques that can be used to validate simulation models. These techniques use logical reasoning, quantitative methods, or visual representation to verify the soundness of simulated models. One of these techniques, *historical data (or empirical) validation*, is recommended by Windrum, Fagiolo and Moneta (2007) to assess models in the context of ACME. In their *history-friendly approach*, a good model is one that can generate several stylized facts observed in the actual data. To validate the model of this paper, this section examines the degree to which simulated lending aggregates represent actual lending aggregates. To do that, two sets of regressions are run. In the first set, each of the time series of simulated and actual lending aggregates is regressed on time (*t*), then the outcomes of regressions are compared between each simulated series and the corresponding actual series. The regressions in the second group investigate the correlation between simulated and actual data by regressing each actual time series on the corresponding simulated one. The summary of the regressions is presented in Figure9 and Figure10. This is done for the scenario 3 simulated results. The R^2 results, given in Figure 9 of scenario 3, which corresponds with the regime in situ clearly outperformed the regressions results of the other 2 scenarios (not reported).

Figure9: Summary of the Simulated and Actual Bank Lending Aggregates Regressions on Time

Variable	Coefficient on time	Standard Error	p value	R^2
Simulated BFs Loans	1.64×10^{10}	1.51×10^{9}	0.00	0.7059
Actual BFs Loans	1.80×10^{10}	1.68×10^{9}	0.00	0.7008

Simulated SMEs Loans	4.87×10^{9}	4.26×10^{8}	0.00	0.7269
Actual SMEs Loans	5.18×10^{9}	4.71×10^{8}	0.00	0.7122
Simulated Mortgages	2.93×10^{10}	2.17×10^{9}	0.00	0.7879
Actual Mortgages	2.91×10^{10}	2.04×10^{9}	0.00	0.8063
Simulated Total lending	5.06×10^{10}	4.11×10^{9}	0.00	0.7557
Actual Total lending	5.23×10^{10}	4.17×10^{9}	0.00	0.7574

Figure10: Summary of the Regression of Actual on Simulated Bank Lending Aggregates

Variable	Coefficient on the Simulated Variable	Standard Error	p value	R^2
Actual BFs Loans	1.100397	0.125398	0.00	0.9937
Actual SMEs Loans	1.073266	0.0112729	0.00	0.9946
Actual Mortgages	0.9807749	0.0074565	0.00	0.9972
Actual Total lending	1.03002	0.0043908	0.00	0.9991

The coefficients on the simulated variables and R^2 values in Figure10 reveal very strong (almost perfect) correlations between the actual and simulated bank lending aggregates. Similarly, the comparison between the results of the regressions of each of the actual bank lending aggregates with the corresponding results for simulated aggregates indicate that the simulated data is a very good representation of the actual data. But as discussed in the outputs from the simulations, the response of agents to a regulatory system in place is far from satisfactory as it leads to a systematic bias against loans to SMEs.

5. Conclusion

A standard textbook model of bank lending starts with the premise that banks' primary objective is to lend to non-financial firms. We set up a data driven agent based model (ABM) of the UK bank lending to households for mortgages and to big firms and SMEs that reflects the reality on the ground that this is far from the case. In the context of QE and APP launched by UK authorities in 2009, increasing bank lending is one of the main goals. Yet, ONS sectoral financial accounts data shows that although bank lending to households for mortgages has been expanding since 2009, total bank lending witnessed a noticeable drop driven by a decrease in lending to businesses, especially to SMEs. We explicitly take the reduced bond yields in the course of APP for triggering a portfolio rebalancing by big firms in the direction of bond issuance and a substitution away from bank loans as the main factor behind the demand side fall in bank loans from big non-financial firms.

In the spirit of Stiglitz (2011) and Jones (2010), we focus on the incentives and constraints posed by the Basel capital adequacy rules on the UK banking system. The ACE model was developed to investigate the conditions created by APP and QE in the UK primarily on bank supply side responses for lending to households for mortgages and to SMEs, which unlike big firms do not have access to the bond market. We have raised the important question whether regulatory capital requirements should penalize sectors like SMEs when clearly the credit risk conditions do not warrant this. Indeed, the complex Basel II/III risk weighted framework has been implicated for causing perverse incentives and destabilizing capital arbitrage using the risk weights both in the run up to 2007 GFC, Markose et. al. (2012) and in the case of the Eurozone crisis (Acharya and Steffan, 2015).

Following the recent BoE agent based model of the UK mortgage market, Battista et. al. (2017) , our data driven ACE model anchors the mortgage eligibility conditions for UK households to those based on their income distribution, extant home owner status and net worth after mortgage indebtedness. Likewise, the relevant financial balance sheet data of other agent classes are used as initial conditions. An important empirical scale factor is used to determine the proportions of the agents in the different classes to simulate the UK economy and to produce simulation outputs that are similar in value to actual macro-economic data. As we saw this has worked. Likewise, to focus on how the key bank lending decisions we recommend how ACE models should embrace the embedding of an endogenous section within a framework of the wider economic data which is fed exogenously to the agents as they make their decisions at each time step within the simulator. This is a new ingredient to ACE modelling that can produce quantitative outputs that are of similar magnitudes as actual variables and produce finely tuned institutionally rich simulations for policy analysis.

Appendix A: Empirical Evidence on the UK Economy

The UK economy data around the launch of APP in 2009 is used as empirical base for the ACE model. The Appendix includes relevant data that was used in the ACE model for the nonfinancial sectors (households and nonfinancial businesses) and banks in the UK.

A.1 Households Income Distribution

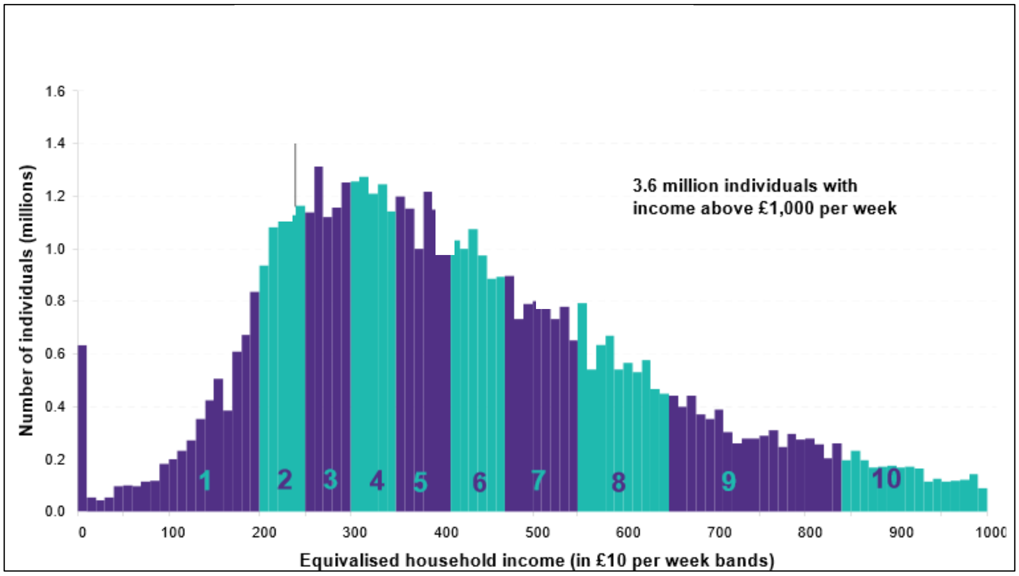
We simulate the income distribution for the 100,000 model agents from the UK income distribution given in deciles in Figure A.1. According to Institute for Fiscal Studies (IFS)[23],the average weekly income of a household in the 2008-09 financial year was £560.64 (an equivalent of £2,429.43 per month[24]) with 50% of the households making £450.52 or less a week (or £1,951.84 a month). For purpose of modelling HHs

[23] Institute for Fiscal Studies: Inequality and Poverty Spreadsheet which "provides data on British living standards, inequality and poverty" available at: http://www.ifs.org.uk/tools_and_resources/incomes_in_uk.

[24] Monthly income = Weekly Income x 52 (weeks a year) / 12 (months a year).

mortgage affordability used by banks as a lending criterion, we calculate the monthly equivalents of the weekly income data.

FigureA.1: The Probability Distribution of Household Weekly Income (2008-09)



Source: Households below average income (HBAI): 1994/95 to 2008/09; P15**;** Department for Work and Pensions; Available at: https://www.gov.uk/government/statistics/households-below-average-income-hbai-199495-to-200809

A.2 Housing and Mortgage Markets

We use the Nationwide UK house price index data[25] and ONS home ownership and renting data[26]. The latter indicates that 64% of homes in the UK are owner-occupied (the remaining 36% of homes are rented), and that about 52% of the homeowners have mortgage obligations. Some salient facts here are that the gross amount outstanding of mortgages had continuously grown from £366.764 billion in 1996 Q1 to peak at about £854.718 billion in 2008 Q2. After that, it fell by 7.1% (to £801.393 billion) during the second half of 2008, from when it started to grow again to reach £1.111 trillion in 2014 Q4.

A3. Non-Performing Loans in the UK:Used to Calibrate Default Probability

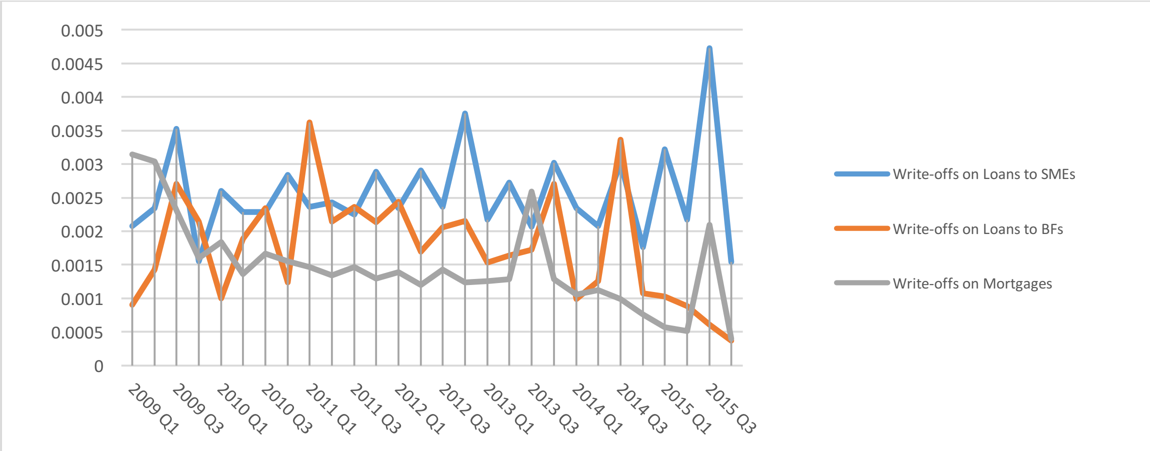
The probability of default is proxied by the ratio of loan write-offs to the total amount of loans for each loan type. The amounts of loan write-offs and total mortgages and business loans to BFs and SMEs are available from BoE.[27]

Figure A.3: Quarterly Loan Write-offs by UK Banks by Loan Type

[25] http://www.nationwide.co.uk/about/house-price-index/download-data#xtab:uk-series.

[26] http://www.ons.gov.uk/ons/rel/census/2011-census/detailed-characteristics-on-housing-for-local-authorities-in-england-and-wales/short-story-on-detailed-characteristics.html.

[27] The quarterly data on the amounts outstanding of business loans and mortgages, and the amounts of loan write-offs on the two loan types are available from BoE's Interactive Database.



Source: Bank of England (http://www.bankofengland.co.uk/boeapps/iadb/newintermed.asp)

A4. Top 10 UK Banks Equity to Total Assets Ratios

Bank	Date	Equity to Total Assets Ratio
HSBC	31/12/2008	2.05%
Barclays	31/12/2008	2.12%
Royal Bank of Scotland	31/12/2008	2.65%
Lloyds	31/12/2008	2.22%
Standard Chartered	31/12/2008	4.84%
NatWest	31/12/2008	4.19%
Santander UK	31/12/2013	4.66%
Nationwide	31/12/2008	3.36%
The Co-operative Bank	31/12/2008	5.27%
Clydesdale and Yorkshire Bank	31/12/2008	4.85%

Source: Bankscope Database available at (http://www.bvdinfo.com)

Figure A. 5: The Initial Values/Distributions of the Model's Variables

Variable	Value/Distribution						Assumptions/Empirical facts
Households							
Number of households	10,000						Scaled down from 21,464,730
Number of houses per household	Number	0	1	2	3	4	Only 64% of UK households own at least one property
	Probability	0.36	0.16	0.16	0.16	0.16	
House price	£149,400						Average house price in 2009 Q1.
Household housing wealth	Number of Houses x House price						
Household cash	Uniformly distributed between £5,000 and £50,000						
Household mortgage liability	Uniformly distributed between £0 and £70,965						- 52% of the homeowners have mortgages - HHs average mortgage liability in 2009 Q1 was £49,070
Household equity	Household housing wealth + household cash - household						

	mortgage liability	
Household income	Log-normally distributed	The distribution is estimated using the monthly equivalents of IFS's parameters of the weekly income distribution (in 2009 Q1)
Household preferred bank	Randomly selected	
Big Firms		
Number of big firms	30	Scaled down from 4,405
Big firm Physical capital	Uniformly distributed between £5 million and £300 million	
Big firm cash	(0.1283/0.8717) x physical capital	cash represented 12.83% of nonfinancial firms' total assets in 2009 Q1
Big firm debt to total assets ratio	51.66%	NFCs debt to total assets ratio in 2009 Q1 was 51.66%
Big firm loans	34.77% x (physical capital + cash)	Loans represented 67.3% of NFCs total debt in 2009 Q1. (67.3% x 51.66% = 34.77%)
Big firm bonds	16.89% x (physical capital + cash)	Bonds represented 32.7% of NFCs total debt in 2009 Q1. (32.7% x 51.66% = 16.89%)
Big firm equity	Big firm physical capital + big firm cash - big firm loans - big firms bond	
Big firm preferred bank	Randomly selected	
Small and medium enterprises		
Number of SMEs	2,290	Scaled down from 4,918,915
SME Physical capital	Uniformly distributed between £50,000 and £1 million	
SME cash	(0.1283/0.8717) x physical capital	cash represented 12.83% of nonfinancial firms' total assets in 2009 Q1
SME debt to total assets ratio	40%	SMEs are less able to use debt financing compared to BFs
SME loans	40% x (physical capital + cash)	
SME equity	SME physical capital + SME cash - SME loans	
SME preferred bank	Randomly selected	
Banks		
Number of banks	10	
Bank total mortgages	Sum of mortgages of HHs that deal with the bank	
Bank loans to big firms	Sum of loans to big firms that deal with the bank	
Bank loans to SMEs	Sum of loans to SMEs that deal with the bank	
Bank deposits	Sum of cash of households, big firms and SMEs that deal with the bank	
Bank equity	Mortgages + loans to big firms + loans to SMEs – deposits	
Interest rates		
Risk-free rate (r_{RF})	0.5%	BoE policy rate
Government gilts rate (r_G)	4%	Median yield on 10-year gilts in 2008 Q4
Interest rate on BFs bonds	6%	r_G + 2%
Interest rate on BFs loans	5.5%	r_{RF} + 5%

Interest rate on mortgages	7%	r_{RF} + 6.5%
Interest rate on SMEs loans	8.5%	r_{RF} + 8%
Risk Weights		
BFs loans risk weight	0.2	
Mortgages risk weight	0.5	
SMEs loans risk weight	1.0	

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