Monetary policy and prudential regulation in a hybrid AB-SFC model with heterogeneous expectations

Severin Reissl*

Università Cattolica del Sacro Cuore/Universität Bielefeld

September 14, 2018

Abstract

This paper explores the joint effects of prudential regulation and monetary policy in a hybrid agent-based-stock-flow-consistent model featuring an agent-based banking sector. Individual banks interact both with the aggregate portion of the model as well as with each other, for instance through their decisions on interest-rate setting and on the inter-bank market. The model features a detailed depiction of prudential regulation and an active central bank which intervenes in money markets to steer the inter-bank rate. Particular attention is paid to the modelling of both time and expectations formation. While the basic tick-length is one week, decisions are assumed to take place at various frequencies within the agent-based portion of the model whilst in the aggregate portion, variables are assumed to evolve at different speeds, incorporating differing decision-making horizons. Correspondingly, the horizons of expectations formation processes are modelled so as to match the adjustment speeds of forecasted variables. The model is calibrated to a deterministic steady state and then simulated, producing a pattern of irregular short- and longer-term fluctuations. Subsequent experiments indicate that whilst the model is generally sensitive to the specification of expectations formation processes, an implementation of the canonical form of heterogeneous expectations with heuristic switching in the banking sector has very little discernible effect since it provides only a minor improvement on standard adaptive expectations in terms of forecasting success. This suggests that in certain macro settings, simple adaptive expectations may be a fairly robust heuristic. The presence of heterogeneous expectations hence does not noticeably affect the stability properties of the model and a combination of monetary and macro-prudential policy measures are necessary to dampen macroeconomic fluctuations.

PRELIMINARY DRAFT - PLEASE DO NOT CITE

Keywords: Stock-flow consistent models, Agent-based models, Monetary policy, Prudential policy, Heterogeneous expectations

JEL-Classification: E12, E52, E58, E61, G28

*Email: severindavid.reissl@unicatt.it

1 Introduction

This document aims to provide a compact overview of a hybrid agent-based stock-flow consistent macro-model used to investigate the effects of heterogeneity in expectations formation and the joint impacts of monetary policy and prudential regulation. The hybrid model is constructed by fusing a macroeconomic stock-flow consistent model featuring households, firms, non-bank financial firms, a government and a central bank with an agent-based banking sector which interacts with the aggregate portions of the model through various channels. The banking sector features a relatively detailed prudential regulation regime modelled on the Basel III accord which makes it necessary for banks to form expectations about the dynamics of their own balance sheets in order to meet targets for prudential ratios which in turn feed back on their behaviour regarding interest rate setting, credit rationing, equity issue and dividend policy. The goal is to investigate the role of the expectations of banks and policy-makers and in particular their impact on the effects of monetary and macro-prudential policies under different assumptions about expectations formation processes.

This is very much a work in progress; the model is implemented and several simulations have been carried out but some experiments and a thorough sensitivity analysis are still ongoing and there are a few areas in which the model could be improved. Consequently there does not yet exist a full write-up of the model and the simulation results. However this document should serve to provide an overview of the model and the preliminary results sufficient for a conference discussion.

This document is structured as follows: Section 2 gives a brief motivation for the research and reviews some relevant literature. Section 3 outlines the structure of the model and the most important behavioural assumptions. Section 4 discusses preliminary simulation results and section 5 indicates planned future research and possible improvements to the model.

2 Motivation and literature review

The purpose of this project is to combine insights from various strands of the literature to advance research on agent-based stock-flow consistent (AB-SFC) models.

Over the last 10 to 15 years there have been substantial advances in the use of agent-based models in macroeconomics, leading to the emergence of a number of different frameworks, partly with different emphases, which have been applied to a variety of topics in macroeconomic research. Among others, these include the 'Macroeconomics from the Bottom Up' (MBU) model (Delli Gatti et al., 2011), the various incarnations of the Eurace model (Cincotti et al., 2010; Dawid et al., 2012), and the Keynes+Schumpeter model (Dosi et al., 2006). The basic goal of all these frameworks is to provide an alternative way to microfound macroeconomic models rooted in the complex adaptive systems paradigm, emphasising agent interactions and emergent properties. Dawid and Delli Gatti (2018) provide a comprehensive review of agent-based macroeconomics and compare the major different frameworks in detail.

A by now fairly closely related strand of the literature which emerged out of the post-Keynesian tradition in macroeconomic research is that of stock-flow consistent models (see Godley and Lavoie (2007) who develop the approach as well as Caverzasi and Godin (2015) and Nikiforos and Zezza (2017) for surveys). Stock-flow consistent models are typically aggregative (i.e. not 'micro-founded') and aim in particular at jointly modelling the dynamics of national accounts variables and flow-of-funds variables within a fully consistent accounting framework. This approach provides an important disciplining device and consistency check in writing large-scale computational models and is essential in comprehensive depictions of real-financial interactions. By now, there exists a growing literature which explicitly combines stock-flow consistent frameworks with agent-based modelling in various ways (Dawid et al., 2012; Michell, 2014; Caiani et al., 2016; Seppecher, 2016). The use of a stock-flow consistent framework may also partly help in overcoming the difficulty of communicating and comparing different agent-based models since the accounting relationships underlying any SFC model can be set out in a fairly compact fashion to give a quick overview over the institutional structure of a given model. The present project follows the trend of combining agent-based and SFC modelling techniques and in particular represents a contribution to the development of hybrid-aggregate-agent-based models in which certain parts or sectors of the economy are modelled in an aggregate/structural way or using representative agents whilst others (typically one sector) are disaggregated and modelled using ABM. Examples of this include Assenza et al. (2007); Assenza and Delli Gatti (2013) who apply this approach, using heterogeneous firms, to the Greenwald-Stiglitz financial accelerator model Greenwald and Stiglitz (1993) and Michell (2014) who uses an agent-based firm sector within an otherwise aggregate SFC framework to model the ideas of Steindl Steindl (1952) regarding monopolisation and stagnation along with Minsky's (1986) trichotomy of hedge, speculative and Ponzi finance. The advantage of such an approach is that important insights arising from agent heterogeneity and interaction can be gained from a hybrid model without the necessity of constructing a fully agent-based framework, instead focussing on those sectors for which one wishes to examine the consequences of allowing for heterogeneity.

In the context of the present project, the emphasis is on introducing heterogeneity only within the banking sector, which to the author's knowledge has not been done thus far in a hybrid AB-SFC model (indeed, even in the benchmark versions of many fully-fledged ABM frameworks (e.g. in Delli Gatti et al. (2011) and Seppecher (2012)), it is assumed for simplicity that there exists a unique/representative bank). The constructed model is then used to discuss expectations formation under bounded rationality in the context of financial regulation. The issues of bounded rationality, learning and (heterogeneous) expectations formation are relatively long-standing components of the macroeconomic literature, stemming from a dissatisfaction with the wide-ranging assumptions necessary to sustain the concepts of rational choice and rational expectations in many contexts. Bounded rationality is a broad concept, with contributions ranging from works such as that of Sargent (1993) which arguably involves only minimal departures from full rationality, via the heuristics and biases approach of (new) Behavioural Economics (Kahneman and Tversky, 2000) to the 'procedural/ecological' rationality concepts of Simon (1982) and Gigerenzer (2008) which aim to replace the traditional concept of perfect rationality altogether. Regardless of one's particular position on what (if anything) should replace the assumption of full rationality, any departure from full rationality in the traditional sense raises several thorny issues, especially how economic agents are envisioned to form expectations if the absence of full rationality does not allow for the immediate application of the rational expectations hypothesis, as will typically be the case in a computational ABM. As explained in detail by Hommes (2013) any such departure quickly leads one into the 'wilderness of bounded rationality', as there are countless different possible ways to model imperfectly rational behavior and there is often no immediately obvious criterion to prefer any one over all others. Several canonical ways of tackling this problem have been proposed. Evans and Honkapohja (2001) develop the so-called e-learning approach whereby one can derive conditions under which agents, through attempting to estimate model parameters, may be able to 'learn' the rational expectations equilibrium of a model even in the absence of full rationality and perfect information. Hommes (2013) is a book-length treatment of the idea, stemming from the seminal contribution of Brock and Hommes (1997), that agents may switch between a number of different forecasting strategies based on their relative performance, and possibly the cost of acquiring the necessary information, which may or may not lead to convergence to a rational expectations equilibrium.

While expectations formation, including under bounded rationality is thus widely discussed in the mainstream modelling literature, such considerations have had relatively less impact in AB and SFC models in which simple adaptive or naive expectations are typically assumed without much discussion. Thus for instance, Dosi et al. (2017) appears to so far be the only paper explicitly applying structural heterogeneity of expectations and e-learning in a macroeconomic ABM (although elements of the Bielefeld Eurace model in which firms attempt to estimate demand elasticities are closely related, and other approaches to modelling learning and adaptation from a major part of the agent-based literature (e.g. Salle et al., 2012; Landini et al., 2014; Seppecher et al., 2016)). Furthermore, while in most ABMs, agents are by necessity boundedly rational and endowed with imperfect information, specific modelling choices with regard to how agents form expectations or which information they have access to are seldom discussed in detail, meaning that there is much room to contribute to the existing literature.

The debates, following the global financial crisis, surrounding the appropriate conduct of prudential regulation policy and its possible interactions with monetary policy (Galati and Moessner, 2011; Barwell, 2013; Claessens et al., 2013; Freixas et al., 2015) provide a good context in which to discuss the role of expectations in agent-based macroeconomic models. As is well-known, expectations formation plays a key role in discussions of optimal policy in mainstream models and there is a well-established body of knowledge regarding optimal monetary policy (Gali, 2015) and departures from fully rational expectations are fairly well-investigated (Branch and McGough, 2009; Massaro, 2013; Benchimol and Bounader, 2018). While there is also a large and growing literature on the conduct of (macro-) prudential policy, this has not yet reached the same degree of sophistication, with debates about fundamental issues such as instruments and targets still ongoing (Schoenmaker, 2014; Banque de France, 2014; Carré et al., 2015) and comparatively few examples of macro-prudential policy in DSGE frameworks (Beau et al., 2012; Loisel, 2014; Angelini et al., 2014). Nevertheless, the typical structure of a modern DSGE model makes it obvious that also in the case of optimal prudential policy, expectations will play a crucial role. Macro-prudential policy has also begun to gain importance in the ABM literature, with several of the major frameworks being used to conduct policy experiments in financial regulation (e.g. van der Hoog, 2015; van der Hoog and Dawid, 2015; Popoyan et al., 2015; Salle and Seppecher, 2017; Krug, 2018). By contrast, there have been relatively few treatments of this topic in pure aggregative SFC models (exceptions include Burgess et al. (2016), Nikolaidi (2015) and Detzer (2016)), despite the distinct contributions of major post-Keynesian authors to the theory of financial regulation. In all cases, the conduct of prudential policy has not been linked explicitly to the treatment of boundedly rational expectations. The present project hence aims to address a perceived shortcoming in the AB(-SFC) literature regarding the treatment of expectations whilst at the same time discussing a topic with high current policy relevance.

3 Model outline

The current section provides a compact overview of the model and its main behavioural assumptions, beginning with its general sectoral stucture.

General structure

The macroeconomic sectoral structure of the model (also in terms of the different classes of assets & liabilities, as well as the transactions taking place) is summarised in figure 1.

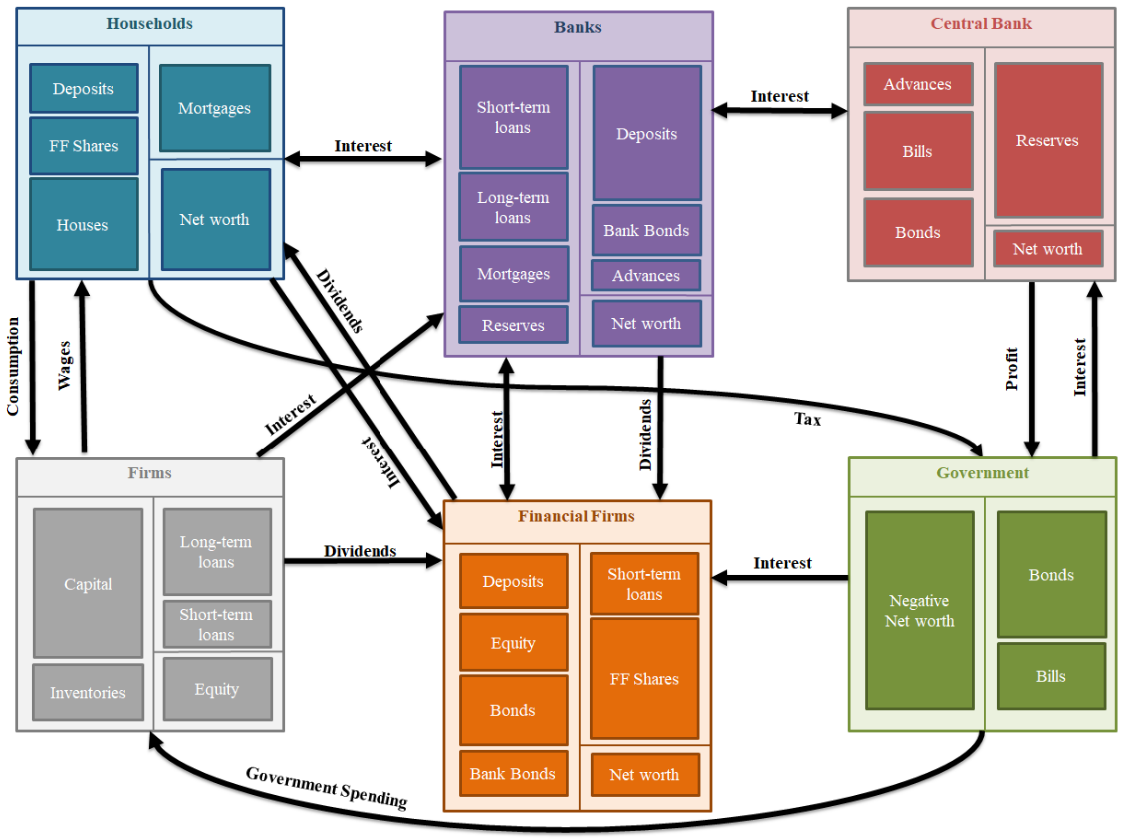

Figure 1: Model overview

The more traditional balance sheet and transactions flow matrices representing the *aggregate* structure of the model (i.e. excluding transactions occurring within the banking sector) are shown in tables 7 and 8 at the end of the document.

As can be seen, the model consists of 6 sectors, namely households, firms, non-bank financial firms, the government, the central bank and the banks. The first five sectors are modelled as aggregates without explicit micro-foundations whilst the banks are disaggregated. In the present baseline, there exists an oligopolistic banking sector consisting of 12 banks which are structurally identical (i.e. they all hold the same types of assets and liabilities) but may differ w.r.t. their decision-making and the precise composition of their balance sheets. The following sub-sections provide an overview of the behaviours of the individual sectors. The basic tick-length in simulations of this model is one week and it is assumed that while all endogenous variables are computed on a weekly basis, some variables adjust more slowly than others (with a horizon of up to one year) and expectations are formed over horizons consistent with the adjustment speed of the forecasted variable.

Households

Every week, the model computes a plan for household's desired consumption over the next month according to the Haig-Simons consumption function

$$c_d = \alpha_1 * yd^e + \alpha_2 * v_h^e, \tag{1}$$

where yd^e is expected household disposable income over the next month and v_h^e is their expected wealth (both in real terms). The motivation of this rule, which is standard in the SFC literature, bears similarity to many of the canonical ABM rules described by Dawid and Delli Gatti (2018) and is also used in the benchmark AB-SFC of Caiani et al. (2016), is that if disposable income is defined in a manner consistent with the Haig-Simons definition of income, then this rule implicitly defines a target steady/stationary state household wealth to disposable income ratio to which households adjust over time.[1]

[1] In a stationary state we must have $v_h = v_h^e$ so that we need $c_d = yd (= yd^e = c)$, meaning that we

One variation on the usual assumption of constant consumption propensities (α_1 and α_2) is that here they are assumed to depend on the (expected) real rate of return on households' financial assets according to a logistic function, meaning that the target ratio of wealth to disposable income (and hence households' saving) also becomes a function of this return rate.

$$\alpha_1 = \alpha_1^L + \frac{\alpha_1^U - \alpha_1^L}{1 + exp(\sigma_{MPC}^1 * rr_h^e - \sigma_{MPC}^2)} \tag{2}$$

Both desired consumption and the 'desired' consumption propensities are computed every period, but it is assumed, using an adaptive mechanism, that consumption adjusts more quickly towards the desired level than do the consumption propensities, incorporating the idea that some variables are more fast-moving than others.

The idea is the following: equation 1 is interpreted as giving an *aggregate level* of desired consumption of all households represented by the modelled aggregate household sector. At the same time, we assume that households on average update their consumption every month, i.e. every 4 periods. Accordingly, we assume that every period (week), 1/4 of the gap between actual and desired consumption (which may of course itself change from period to period) is closed. The same mechanism is applied to the consumption propensities, but here we assume an updating frequency of 1 year. Inspired by the idea of Calvo-pricing Calvo (1993), this principle is applied throughout the model, enabling us to introduce a notion of asynchronous adaptive decision-making at differing frequencies even in the case of sectors modelled as aggregates.

Households allocate their financial savings between bank deposits and shares in the non-bank financial firms (these might be thought of as akin to shares in an MMMF) according to a Brainard-Tobin portfolio equation (Brainard and Tobin, 1968; Kemp-Benedict and Godin, 2017), which is standard in the SFC literature (though not in ABMs). In this case,

get $\frac{v_h}{yd} = \frac{1-\alpha_1}{\alpha_2}$

deposits act as the buffer stock absorbing shocks and errors in expectations and portfolio proportions are updated on a montly basis.

The final two important behavioural assumptions regarding households are their demand for housing, and the dynamics of the wage rate. Households form a 'notional' demand for houses according to

(3)
$$H_d^n = \rho_0 + \rho_1 * V_{h,}^e + \rho_2 * LTV - \rho_3 * \overline{r_M}^e,$$

where LTV is the maximum loan-to-value ratio (which is constant in the baseline, but can be endogenised at a later point) and $\overline{r_M}$ is the average real interest rate charged on mortgages. There is hence no 'direct' speculative element in housing demand (in the sense that, for instance, (expected) house prices do not enter directly into the function), although appreciation of the housing stock obviously has a positive impact on V_h. With notional housing demand, the updating time horizon is assumed to be one quarter. Based on the notional housing demand, households formulate a demand for mortgages based on the LTV (which may or may not be fully satisfied), giving rise to an 'effective' demand for houses. The supply of houses is determined by the assumption that in each period, a constant fraction η of a constant total stock of houses in the model are up for sale. The price of houses is then determined by market clearing.

Regarding wages, it is assumed that the (desired) nominal wage rate is determined by a non-linear Phillips-curve-type equation of the form

(4)
$$W = W_{-1} * \exp(\beta_1 * (u^e - u_n^w))$$

which is supposed to mimic the aggregate outcome of a wage-bargaining process. u^e is the expected rate of capacity utilisation whilst u_n^w is an endogenous, slowly adjusting 'normal' rate of capacity utilisation perceived by workers which might be thought of as an endogenous quasi-NAIRU. A desired wage level according to the equation above is determined every period, and the actual wage level adjusts slowly (horizon one year) to this desired level.

Firms

Firms are assumed to plan their production of consumption goods weekly according to an expectation of households' consumption demand and the deviation of inventories from a target level. By contrast, demand for investment goods and government consumption are satisfied instantaneously (although we do assume that new capital goods do not come online immediately, but rather only become available to boost capacity with a lag), i.e. household consumption is the only source of inventory fluctuations. Firms use a Leontief production function the coefficients of which are fixed throughout. This production function also defines a maximum of output which can be produced given the capital stock, meaning that theoretically, there may be rationing of consumption demand in the model. Moreover, the production function together with (planned) production imply a demand for labour which is assumed to always be fully satisfied by households at the going wage rate.

The target level of inventories is computed as

$$Inv^t = \gamma_1 * u^e * y^e_{fc} \tag{5}$$

where y^e_{fc} is expected full capacity output and u^e is expected capacity utilisation, both computed over an annual horizon. Actual inventories (in the absence of fluctuations caused by errors in the prediction of consumption demand) adjust to target inventories according to

$$(6) \qquad \Delta Inv = \left(\left(\gamma_2^U - \gamma_2^L\right) * exp\left(\frac{-(Inv^t - Inv_{-1})^2}{\gamma_3}\right) + \gamma_2^L \right) * (Inv^t - Inv_{-1}).$$

This is inspired by a formulation advanced by Franke and Lux (1993) and is supposed to avoid large and sudden fluctuations in the inventory stock as a consequence of revisions of Inv^t or large expectational errors on the part of firms.

Firms set the price for their output according to a simple mark-up over unit labour cost, where the mark-up varies counter-cyclically (following Kalecki (1938)) as a function of capacity utilisation relative to its normal level. Both the mark-up and the desired price level are updated slowly with an annual horizon (just like the wage rate). In addition, the model includes a mark-up shock with positive autocorrelation which can be either switched on or off in simulations.

Firms compute desired investment in capital goods according to the investment function

$$(7) \qquad i_d = \gamma_0 + \gamma_u * (u^e - u_n) - \gamma_l * lev_f^e * \overline{r_{LL}}^e,$$

where u_n is a fixed normal rate of capacity utilisation, lev_f^e is the firms' expected leverage ratio and $\overline{r_{LL}}$ is the (weighted) average real interest rate charged on long-term loans (which are used to finance capital investment), with the time horizon being one year. This formulation for investment along with the assumption of constant productivity parameters implies that the present model does not feature persistent GDP growth but rather is a model of business-cycle-like fluctuations around a *stationary* state.

It is assumed that firms possess a fixed target for their leverage ratio. From this leverage target one can derive a target for retained earnings (which, if realised, would make leverage equal to its target) which in turn (given investment demand) determines firms' demand for long-term loans, and hence the combination of internal and external finance firms wish to use to finance their investment. Short-term loans are used to finance inventories as well as to make up for any financing shortfalls caused by errors in firms' expectations. Dividend payouts are determined by the difference between firms' profit and target retained earnings and adjust slowly, based on an annual horizon.

Non-bank financial firms

These entities may in essence be viewed as large portfolio equations. They hold government bonds, the fixed stock of firm equity as well as 'bank bonds' (see below) and bank deposits as their assets. Consequently, they receive a large share of the profit income arising in the model (prior to distributing it to households), including from banks and firms.

Financial firms' demand for government bonds and bank bonds is determined by a Tobinesque portfolio equation (see Household section) with their holdings of bank deposits acting as the buffer stock. Financial firms are financed by the shares e_{ff} they sell to households as well as, if necessary, short-term loans from banks. Given the large range of different assets they hold, they receive various flows of dividend and interest income, as shown in figure 1 and table 8. It is assumed that they distribute all profits to households (although these payments are updated slowly and hence reflect fluctuations in profits only with a lag).

Government

The government collects taxes on household income (wages, interest and profits/dividends accruing to households) at a fixed rate τ. It spends according to

$$g_d = (g_0 + \mu * (u_n - u^e)) * exp\left(1 - \frac{\overline{gby}}{gby^t}\right)^{\mu_2}. \tag{8}$$

g_d is decided upon annually and over the following year, government spending gradually adjusts to this desired value. $\overline{gby}$ is a moving average of the government debt to income ratio and gby^t is the corresponding target. Deficits are covered by issuance of government bonds on a rolling basis. Government bonds are offered in the first instance to financial firms, and the government attempts to generate sufficient demand for bonds by managing the government bond interest rate to keep it close to its market-clearing level derived from financial firms' portfolio choice.

Central Bank

Every month (again as with government spending, this is a discrete decision), the central bank sets a nominal deposit rate according to a Taylor-type pure inflation-targeting rule:

$$r_{cb,d} = r_0 + \pi^e + \phi_\pi * (\pi^e - \pi^t). \tag{9}$$

Its lending rate is given by a constant mark-up over this rate, giving rise to a corridor system. In addition, we suppose that the central bank has in mind a target interbank rate in the middle of this corridor and continuously carries out open-market operations in order to steer the level of central bank reserves to a level consistent with this target. It does so by purchasing and selling government bonds from/to the financial firms (for simplicity we assume that the financial firms are always willing to enter into such transactions). If necessary, the central bank also acts as a lender of last resort to the government. All central bank profits are transferred to the government (and all losses are reimbursed by the government).

In the present version of the model, the central bank is always able to perfectly target the correct level of reserves, meaning that banks are never 'in the Bank' to acquire advances. However there is a possibility of introducing a stochastic term (which might be thought of as representing noise in the CB's information about the required level of reserves) which induces the possibility of temporary aggregate reserve shortfalls or surpluses, which in turn also makes interactions on the interbank market more interesting.

In addition, the central bank is thought of as the macro-prudential policy-maker in the model. At present, the model includes four principal prudential policy levers, namely the capital adequacy ratio, the stable funding ratio, the liquidity coverage ratio and a maximum loan-to-value ratio on mortgages, all applying to banks. In the baseline, the targets for all these regulatory ratios are assumed constant.

The capital adequacy ratio of a bank i is given by

$$CAR^i = \frac{v_{bb}^i}{\omega_0 * IBL^i + \omega_1 * M_{ns}^i + \omega_2 * LL^i + \omega_3 * SL^i} \tag{10}$$

where IBL are inter-bank loans, M_{ns} are non-securitised mortgages, LL are long-term loans, SL are short-term loans, the ω's are risk-weights and v_{bb} is the banks' equity (different from its net worth due to the inclusion of bank bonds (see below) in $v_b b$). The stable funding ratio is given by

$$SFR^i = \frac{\omega_8 * D_h^i + \omega_9 * D_{ff}^i + v_{bb}^i}{\omega_5 * M_{ns}^i + \omega_6 * LL^i + \omega_7 * SL^i} \tag{11}$$

where D_h and D_{ff} are household and financial firm deposits respectively. Finally, the liquidity coverage ratio is in essence a minimum reserve requirement applying to 'risk-weighted' deposits and set to a target of 1 as in the Basel III framework Basel Committee on Banking Supervision (2010, 2013, 2014).

Banks

The agent-based banks possess the richest behavioural structure of all the sectors in the model; their most important behaviours are considered here in turn.

Each bank must set a total of 5 interest rates, namely the rates of interest on deposits of households and financial firms, and the rates of interest on short-term loans, long-term loans and mortgages. It is assumed that each period, a random sample of banks is drawn (such that on average, each bank is drawn once every 4 ticks) and these are allowed to adjust their interest rate in a given period (meaning that on average, each bank can adjust its interest rate once a month). The generic deposit rate offered by a bank i is given by

$$r_d^i = r_{cb,d} + \varepsilon_d + \varepsilon_{SFR}^d * (SFR^t - SFR^{e,i}) + \varepsilon_r * (\overline{r_{d,-1}} - r_{d,-1}^i), \tag{12}$$

where the ε_{SFR}^d parameter differs between the rate of interest on household and financial firm deposits (since these carry differing weights in calculating the stable funding ratio). This equation implies that banks set the deposit rate according to a fixed mark-up ε_d over the current CB deposit rate and adjust this rate according to the deviation of their (expected) SFR from the target and the deviation of their own rate from the average. Note that all parameters have identical values across banks.

The general structure of the equations determining lending rates is exemplified by the rate on mortgages:

$$r_M^i = r_{cb,l} + \varepsilon_M + \varepsilon_{SFR}^M * (SFR^t - SFR^{e,i}) + \varepsilon_{CAR}^M * (CAR^t - CAR^{e,i}) + \varepsilon_r * (\overline{r_{M,-1}} - r_{M,-1}^i). \tag{13}$$

The difference w.r.t. the deposit rate equation is that all lending rates are given by a mark-up over the CB *lending* rate. Furthermore they also all depend on the capital adequacy ratio (CAR) in addition to the SFR. In addition to varying the interest rates at which they lend, banks may also ration the amount of credit they supply, in particular with respect to mortgages and long-term loans. It is assumed that the fraction of the long-term loans demanded from a given bank which are actually granted is given by the smaller of the following to values:

$$
\xi_{LL}^{1,i} = min\left(\frac{CAR^{e,i}}{CAR^{t}} + \left(1 - \frac{CAR^{e,i}}{CAR^{t}}\right) * (1-\omega_1), 1\right) \tag{14}
$$
$$
\xi_{LL}^{2,i} = min\left(\frac{SFR^{e,i}}{SFR^{t}} + \left(1 - \frac{SFR^{e,i}}{SFR^{t}}\right) * (1-\omega_5), 1\right),
$$

where two equivalent equations exist for the rationing of mortgage loans. This means that banks ration credit if their CAR and/or SFR are below target. The ω's are the risk weights of long-term loans in calculating the CAR and SFR respectively. It is assumed that while banks adjust their interest rates only monthly (on average), they can continuously update the degree to which they ration credit.

The third central element in the modelling of the agent-based banks are the functions which distribute the demand for loans and the flows of deposits coming from the aggregate sectors between the various banks. These functions are exemplified by the one for mortgage loans, where the share of the total demand for new mortgages emanating from households which arrives at a given bank i is:

$$
share_M^i = \widehat{r_M^i}^{\iota_1} * \widehat{ration_M^i}^{\iota_2} * \widehat{share_{M,-1}^i} * Hrand^i * M_d \tag{15}
$$
$$
\widetilde{share_M^i} = \frac{share_M^i}{\sum share_M}
$$

Here, $\widehat{r_M^i}$ is the (inverse) relative mortgage interest rate charged by bank i, $\widehat{ration_M^i}$ is the (inverse) relative degree to which bank i has previously rationed credit and $\widehat{share_{M,-1}^i}$ is bank i's relative previous market share while $Hrand^i$ is a normally distributed stochastic term. The resulting shares are then normalised so that they sum to one. Multiplied by the total demand for mortgages, they give the amount of mortgages demanded from any individual bank. The functions determining the shares of deposits and other loans look very similar (with appropriate adjustments e.g. using the relative interest rate rather than its inverse for deposit distribution, and the absence of the rationing term for deposits and short-term loans).

Finally, banks can manage their capital adequacy ratio through their dividend policy and their issuance of 'bank bonds', an asset which in the model stands in for some generic form of Tier 1 bank capital. If a banks' capital adequacy ratio is equal to its target, it is assumed to distribute all of its profits so as to keep this ratio constant. It distributes more (less) than its current profit if its capital adequacy ratio is above (below) the target in order to slowly (horizon 1 year) close a part of the current gap between its actual and its target capital adequacy ratio. At the same time, a part of any gap between the actual and target captial adequacy ratio is eliminated by the continuous issuance (or repayment) of 'bank bonds'. In the model, bank bonds are an interest-paying perpetuity which banks can sell to financial firms and which enters as capital into the calculation of their capital adequacy ratio.[2] For simplicity we assume that all bank bonds are identical, i.e. there is only one market for the bonds issued by all banks, and a uniform interest rate on them which is determined by a condition, derived from the portfolio equation of financial firms, which keeps the interest rate close to its market-clearing level.

The last important element to turn to is the interbank market. Banks' final demand for reserves is determined by the target liquidity coverage ratio set by the regulator. In order to calculate their demand for/supply of funds on the interbank market, each bank calculates a clearing position netting all its in- and outflows of reserves over the present period. After adding this clearing position to their previous stock of reserves, banks end up with a 'prior' stock of reserves which is compared to their target stock, thereby determining whether they will demand or supply funds on the interbank market.

At present, the interbank market is modelled in a fairly simple fashion whereby total demand and supply are aggregated and matched, and then whichever side of the market

[2] We assume that each individual bank is privately owned through the financial firm sector to which it pays dividends. Instead of issuing shares to the public, it issues the generic interest-paying bank bonds in order to build up capital as necessary.

is short is rationed proportionately. For instance, if total demand on the interbank market is higher than total supply, each bank on the demand side receives funds according to $\frac{individual\ demand}{total\ demand} * total\ supply$. If banks are unable to obtain all the reserves they need on the interbank market, they request advances from the central bank which are always granted on demand at the central bank lending rate, which is however higher than the interbank rate, which by construction falls within the corridor and is given by

$$r_{IB} = r_{cb,d} + \frac{r_{cb,l} - r_{cb,d}}{1 + exp(-\sigma_{IB} * (R_{gap}))}, \tag{16}$$

where R_{gap} is the aggregate gap between reserves prior to the central bank's intervention and target reserves. The final set of behavioural assumptions related to banks which is worth commenting on in more detail are the dynamics of loan repayments and defaults. Whereas it is assumed that short-term loans must be continuously rolled over and that no default on them occurs, long-term loans and mortgages are multi-period and may default. Regarding repayments, it is quite simply assumed that each period, a fixed fraction $\chi_{LL/M}$ of a given banks' long-term loans and mortgages are repaid. Defaults on mortgages as well as long-term loans contain both a deterministic and a stochastic component. The deterministic component is given by

$$M^i_{np} = \zeta_M * MH * M^i_{-1} \tag{17}$$

for mortgages, and

$$LL^i_{np} = \zeta_{LL} * lev^{mean}_f * LL^i_{-1} \tag{18}$$

for long-term loans. This means that defaults on mortgages and long-term loans are increasing in a long-run moving average of the ratio of mortgages to the value of the housing stock (MH) and firms' leverage ratio respectively. In addition, each default equation also contains a normally distributed stochastic component, which is added on to the deterministic component.

At present, the model does not contain a bankruptcy mechanism for banks which for the moment does not represent a problem since no bank has so far gone bankrupt in any simulation.

Expectations

In the current baseline all expectations are modelled following an adaptive mechanism:

$$x^e = x^e_{-1} + \psi * (x_{-1} - x^e_{-1}). \tag{19}$$

While the focus of the model lies on the expectations of banks and the monetary & prudential policy-maker, expectations also enter into the behaviour of other sectors for both theoretical and computational reasons. Households forecast their disposable income, their wealth, mortgage interest rates as well as the composite rate of return on their financial assets along with its individual components. Firms forecast consumption demand, their leverage ratio, the average interest rate on long-term loans, as well as their capacity utilisation and full capacity output. Financial firms forecast the interest rates on bank bonds, bank deposits and government bonds which feed into their portfolio choice. The government forecasts capacity utilisation to determine its expenditure but it is assumed that its forecast coincides with that of firms. The central bank forecasts inflation as well as capacity utilisation (since it uses a different time horizon more appropriate to the frequency of its decision-making, the CB forecast of capacity utilisation may differ from that made by firms and the government). Finally, banks are assumed to forecast their own tier 1 capital buffer as well as the associated regulatory ratios, namely the capital adequacy ratio and the stable funding ratio. In all cases, care is taken that the horizon over which forecasts are made is consistent with the horizon over which decisions involving these expected values are made.

The first experiment, reported below, consists in replacing the adaptive expectations mechanism in the banking sector with the model of heterogeneous expectations formation and heuristic switching first proposed by Brock and Hommes (1997); more specifically we use the version presented in Anufriev and Hommes (2012) where it is assumed that agents can switch between four different specifications for expected variables given by

$$
\begin{aligned}
x^{e1} &= x^{e1}_{-1} + \psi_{ad} * (x_{-1} - x^{e1}_{-1}) \\
x^{e2} &= x_{-1} + \psi_{tf1} * (x_{-1} - x_{-2}) \\
x^{e3} &= x_{-1} + \psi_{tf2} * (x_{-1} - x_{-2}) \\
x^{e4} &= \psi_{aa} * (\overline{x_{-1}} + x_{-1}) + (x_{-1} - x_{-2}).
\end{aligned} \tag{20}
$$

The first rule is the same adaptive one used in the baseline, which is now augmented with two trend-following rules (one weak and one strong) and an ‘anchoring and adjustment’ mechanism in which the anchor is the moving average of x. Agents switch between these four mechanisms based on a fitness function calculated using the error between expected values and realisations of the forecasted variables as detailed in Anufriev and Hommes (2012).

4 Preliminary simulation results

The model is calibrated to a deterministic stationary state through imposing realistic stationary-state values for certain variables and ratios (e.g. capacity utilisation, government-debt-to-GDP, investment-to-income, government-consumption-to-income, capital-to-full-capacity-output,...), and using the SFC-structure of the model to reduce the number of degrees of freedom. This procedure greatly reduces the number of ‘free’ parameters the value of which is independent of the initial stationary state and on which the sensitivity analysis will focus. For the banking sector, which in the baseline contains 12 banks, a heterogeneous initialisation is used to begin the simulation with a size-distribution of banks similar to that found in economies with oligopolistic banking sectors such as that of the UK. The baseline simulation is conducted using 100 Monte Carlo repetitions, with stochastic elements emanating from the default process, the distribution of aggregate flows of loan demand and deposits between banks, the mark-up shock and noise in the central bank's perceived target level of reserves. After discarding a transient, the baseline simulates the behaviour of the model for 1200 periods, corresponding to 25 years (it is assumed that one year is made up of 48 weeks).

Starting from the deterministic stationary state, the random elements present in the simulation are sufficient to make the economy diverge from the stationary state and converge to an irregular cyclical movement featuring short-term fluctuations primarily driven by investment and longer cycles driven by consumption expenditure. It should be noted that the mark-up shocks are not strictly required for this outcome. Stochastic elements at the level of the individual banks alone are sufficient to induce convergence a cyclical movement at the macroeconomic level, although the presence of macro-level shocks does speed up this convergence. Figures 2 to 7 provide an overview of the aggregate results of a *representative single run* of the model. The persistent cycles are fundamentally driven by the interactions of the non-linearities present in the aggregate structure of the model, with the slow-moving consumption propensities, together with wage dynamics and the component of capital investment responding to trends in capacity utilisation giving rise to long cycles in consumption and the interaction between the central banks' interest rate policy, banks' interest rate setting and credit rationing and the influence thereof on firms' investment decision producing shorter-run fluctuations in aggregate income. The central bank appears to be relatively successful at keeping the rate of inflation close to its target, here assumed to be zero.

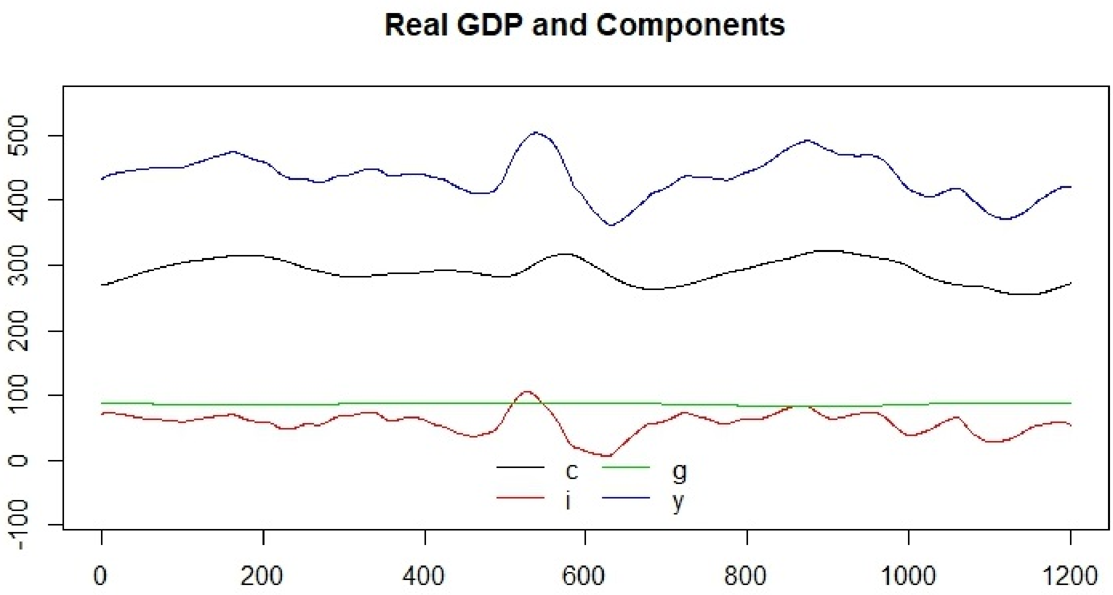

Figure 2: Real GDP and components for a single run

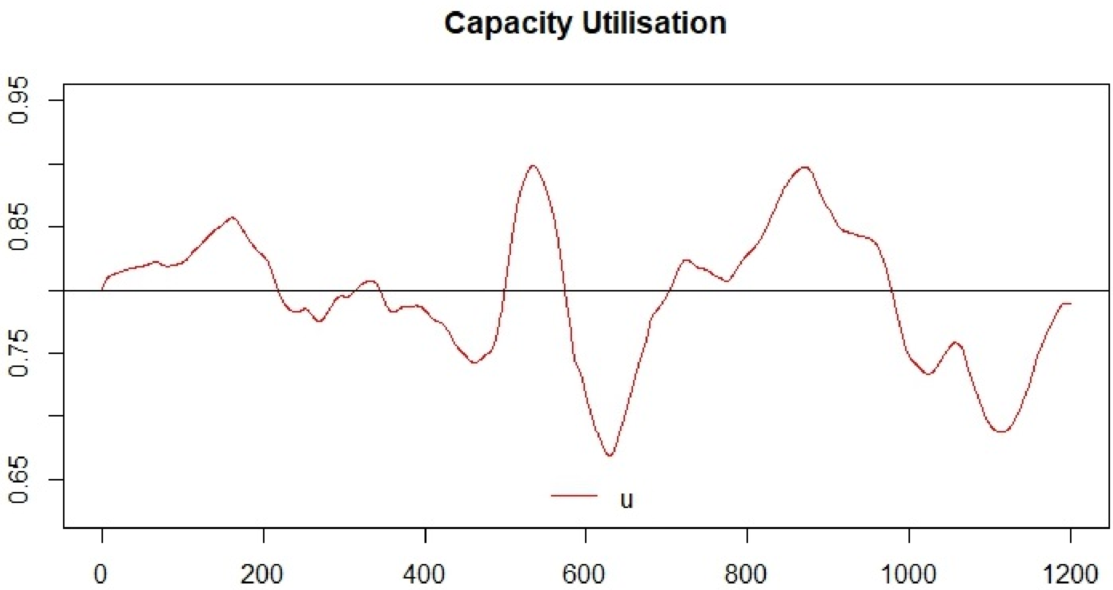

Figure 3: Capacity utilisation for a single run

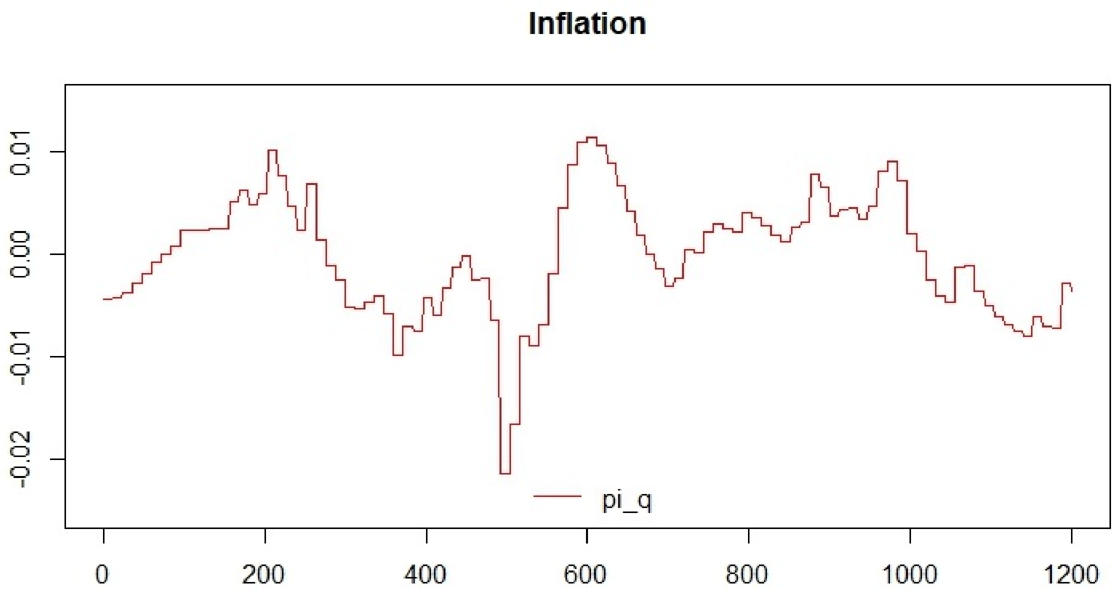

Figure 4: Quarterly inflation rate for a single run

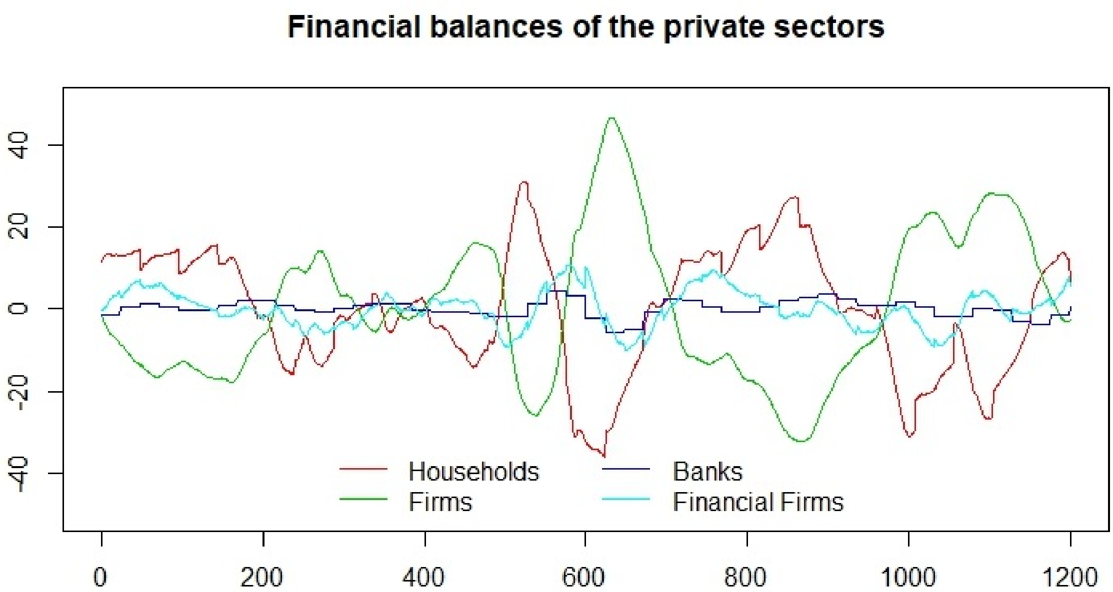

Figure 5: Sectoral financial balance of the private sectors

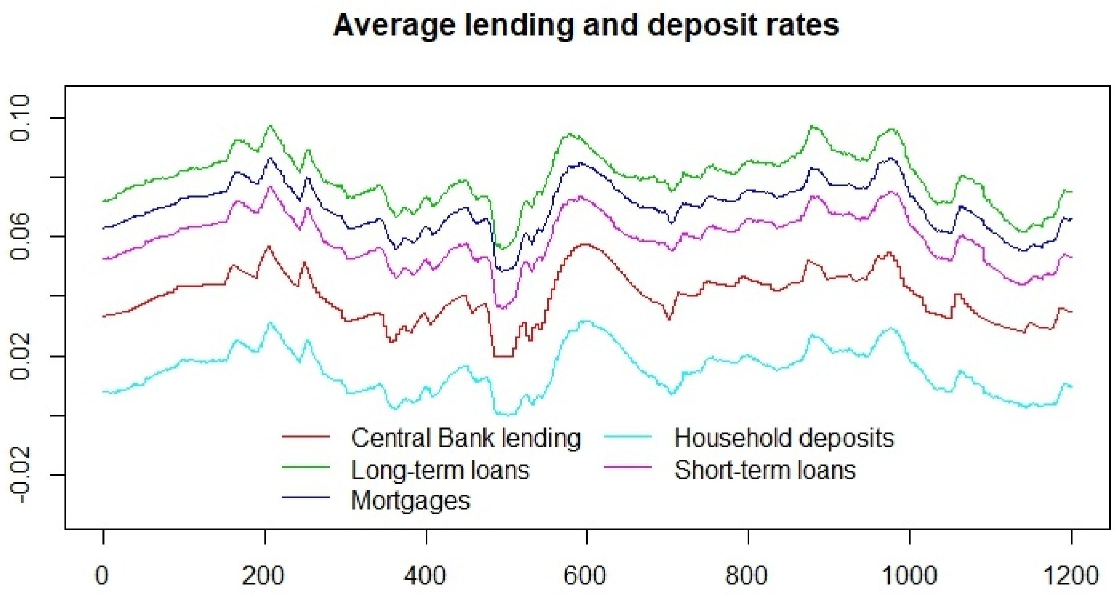

Figure 6: Lending and deposit rates

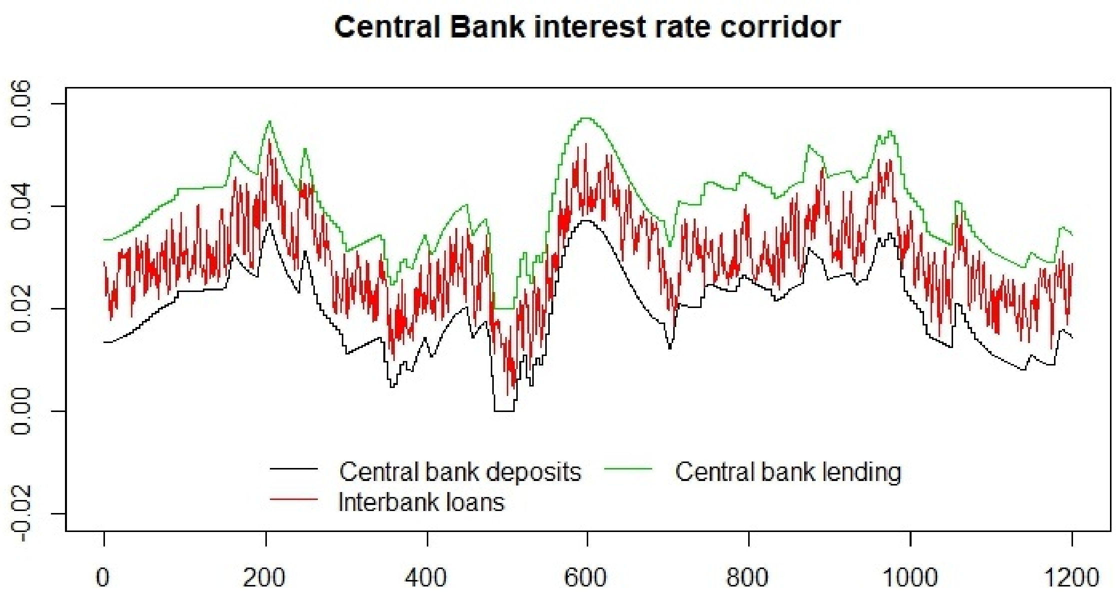

Figure 7: Central bank interest rates

While the model dynamics are qualitatively quite similar across different Monte Carlo repetitions, figure 8 shows that they almost average out when taking the mean of multiple repetitions as the peaks and troughs of cycles do not necessarily coincide across different runs. Although there appear to be common trends which do not average out, as illustrated by figure 9, which depicts the mean of real GDP across 100 Monte Carlo repetitions along with the mean standard deviation, figure 10, which compares the dynamics of real GDP for 2 different runs, shows that while the behaviour is similar qualitatively there are distinct differences in particular with regard to short-run fluctuations. These graphs make it clear that the Monte Carlo average of simulation runs is not particularly interesting as the great majority of the cyclical behaviour is averaged out. Instead, further study of the model will focus on the effects of various experiments on the variance of simulation outcomes.

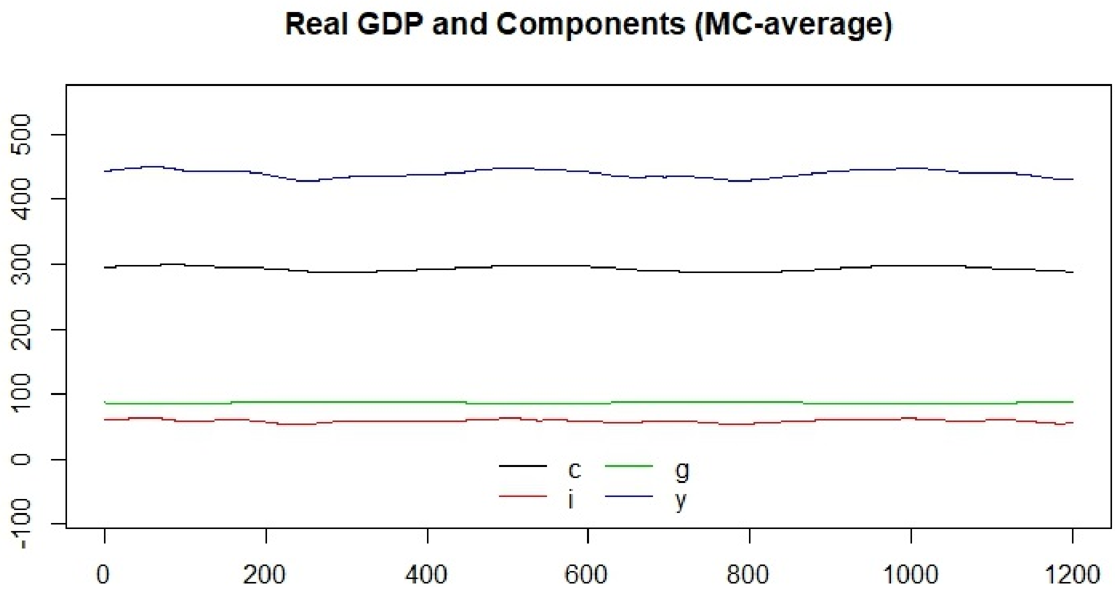

Figure 8: MC-average GDP and components

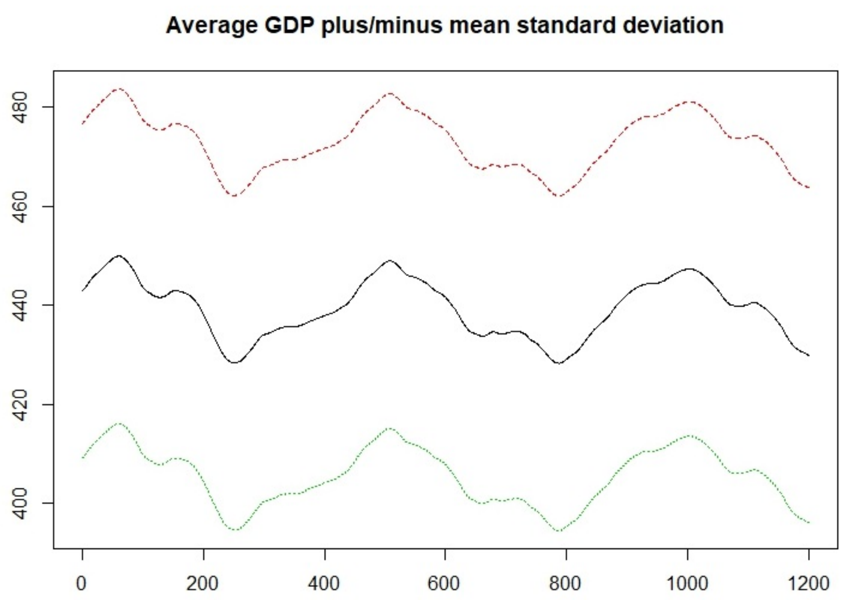

Figure 9: MC-average GDP plus/minus mean standard deviation

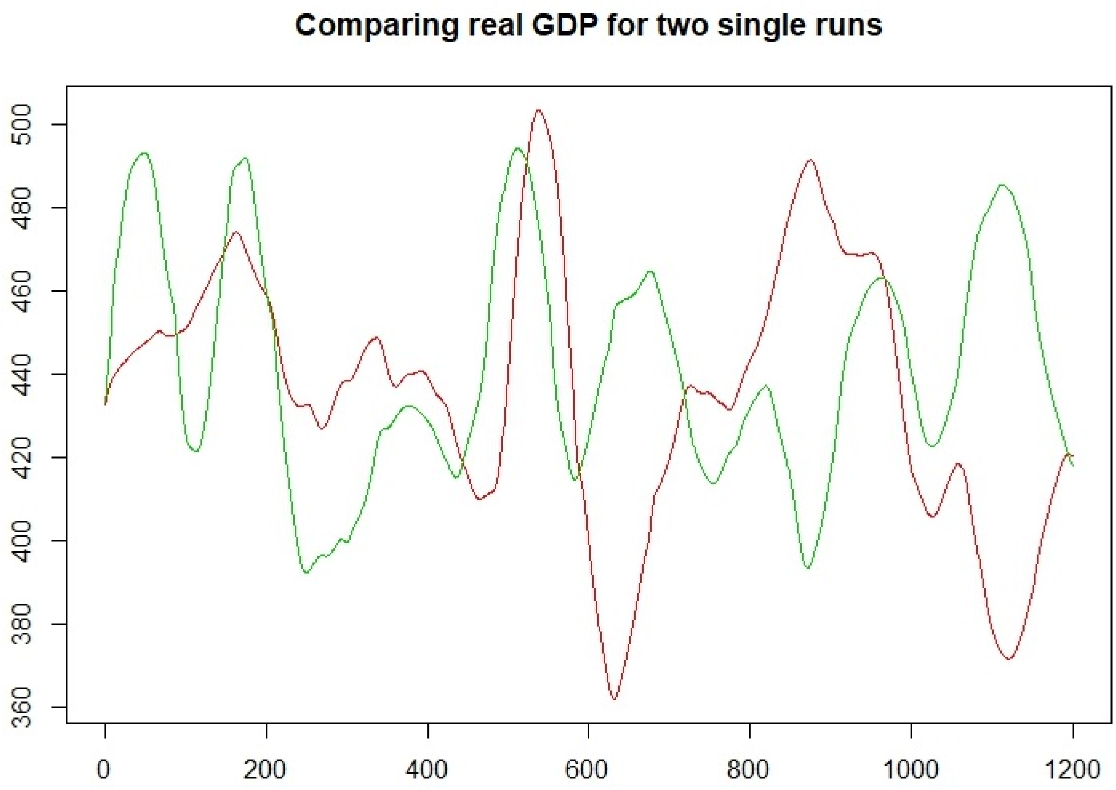

Figure 10: Comparing two single runs

Turning to the simulation results at the level of individual banks, figure 11 shows that even for individual runs the size-distribution of banks remains fairly constant, i.e. bank heterogeneity is persistent (banks do not converge to each other) and there also does not appear to be a tendency toward monopolisation. Nevertheless, the balance sheet composition of individual banks, as opposed to their total size, is variable as shown by figure 12 for the example of the distribution of mortgage loans during an individual run.

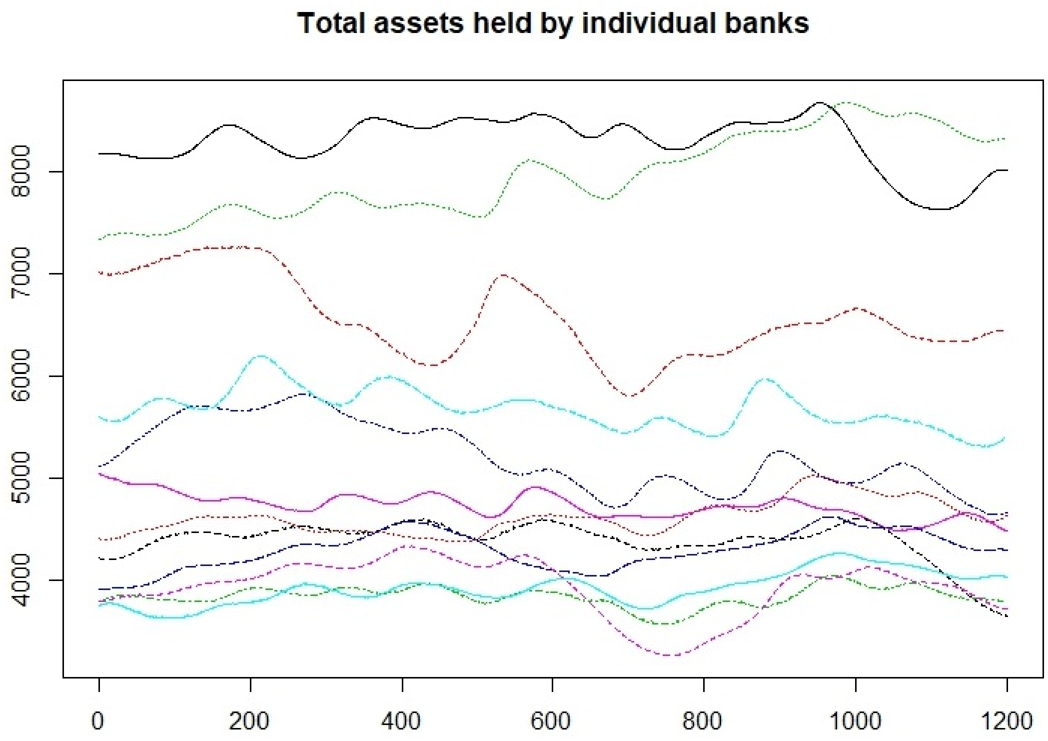

Figure 11: Total assets of individual banks

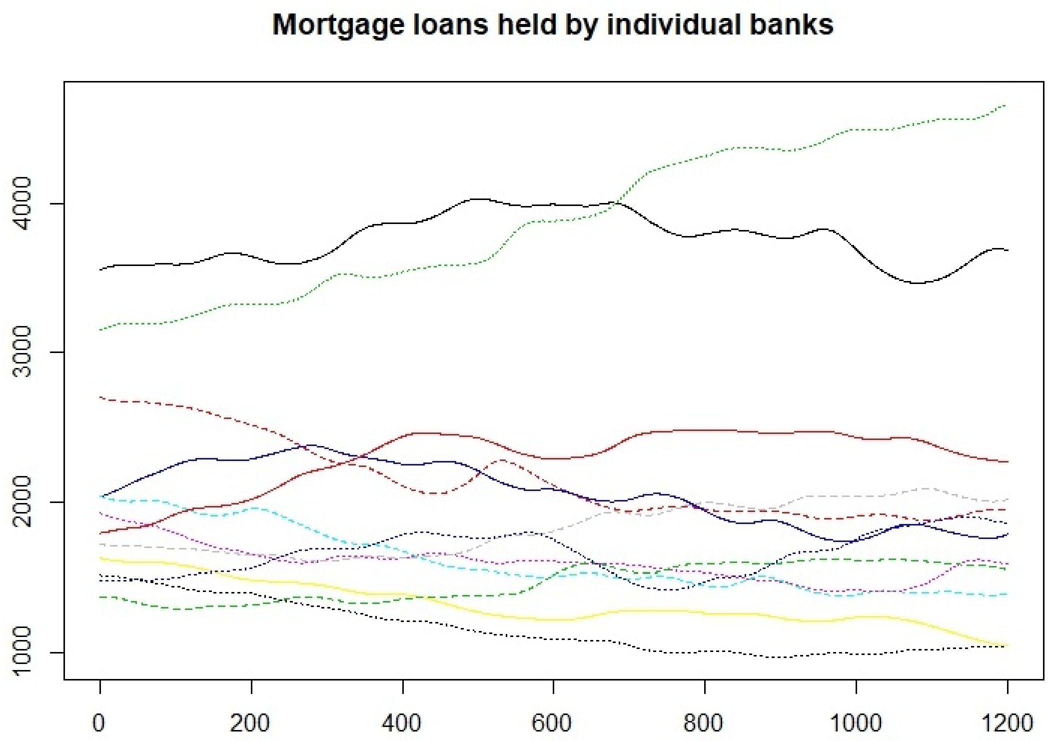

Figure 12: Mortgage loans held by individual banks

While the individual banks' regulatory ratios are fairly volatile and, in the case of the capital adequacy ratio, there is some positive correlation between them, individual banks are fairly successful at hitting their regulatory targets over time using dividend policy and bond issuance or buybacks. In addition, while average bank interest rates follow the developments of monetary policy quite closely, the rates of individual banks are influenced by their regulatory ratios and contribute to the attainment of the targets. These three elements of balance sheet management appear to be generally sufficient to eliminate large deviations in the capital adequacy and stable funding ratios relatively quickly which in turn means that taken as a whole, the banking sector never rations credit very heavily.

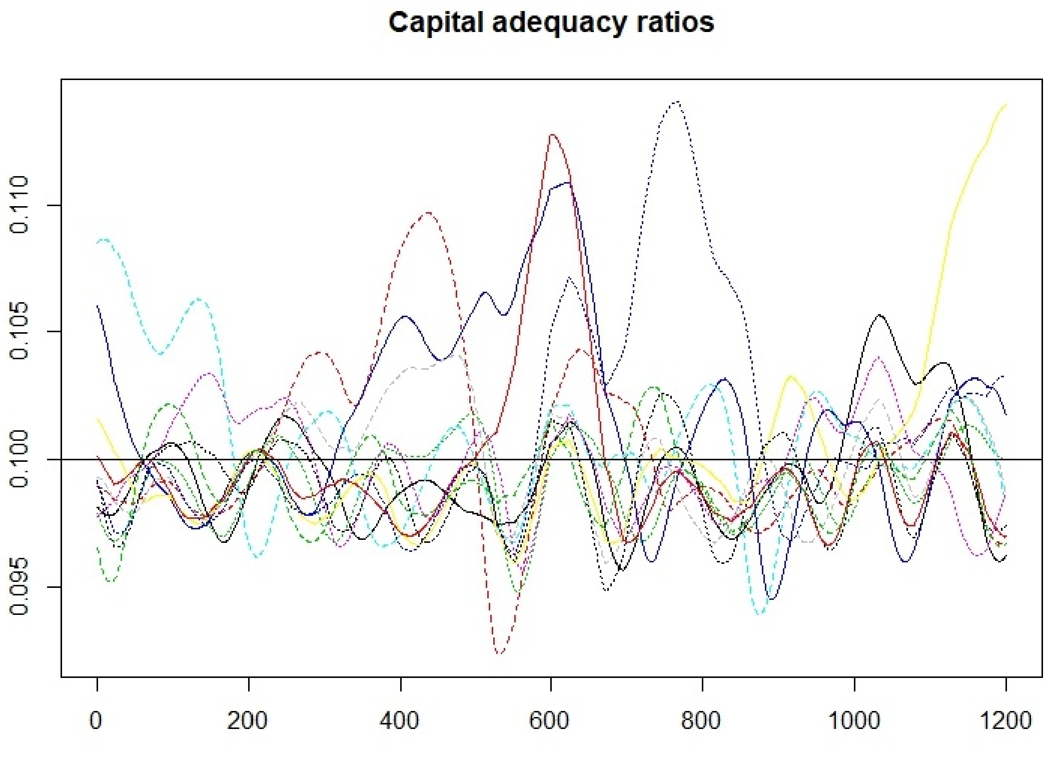

Figure 13: Capital adequacy ratios

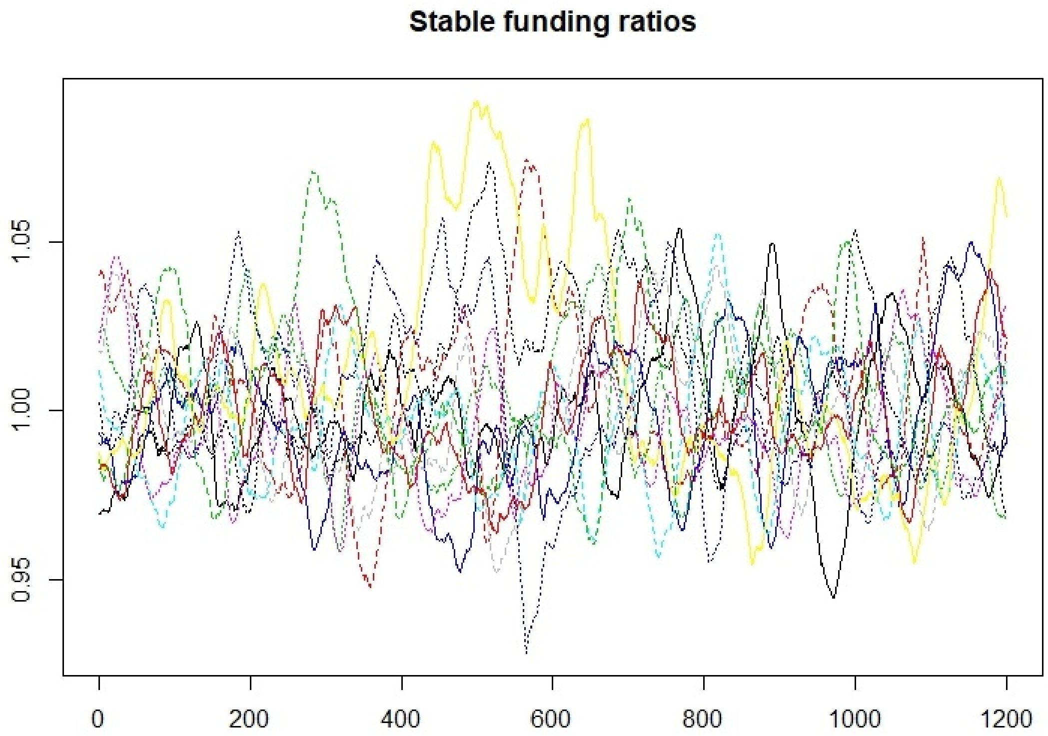

Figure 14: Stable funding ratios

To conclude the brief discussion of the baseline simulation, table 1 summarises some statistics regarding the characteristics of the cycles produced by the model.[3] These numbers suggest that the model performs reasonably well although there is certainly much room for improvement.

Table 1: Business cycle statistics for baseline simulation

	Standard deviation	Relative standard deviation	First order auto-correlation (quarterly)	Contemp. correlation w. Y
Y	0.06978393	1	0.9528563	1
C	0.06131261	0.8786065	0.9767567	0.73161
I	0.2911985	4.172859	0.9091512	0.8292683
G	0.0206177	0.2954505	0.9904009	-0.5604026
W	0.01014711	0.1454075	0.9785724	0.5036423

[3]The statistics are calculated using % deviations from the deterministic steady state.

Experiments

Given the importance of banks' balance sheet management for the observed model dynamics, a straightforward experiment to carry out is to replace banks' adaptive expectations formation process with the heterogeneous expectations and heuristic switching mechanism outlined in the previous section. As was explained in the model description, banks' expectations about their capital buffer, their capital adequacy ratio and their stable funding ratio feed into most aspects of their decision-making. Interestingly, however, an implementation of the mechanism described in Anufriev and Hommes (2012) in the present version of the model appears to have little qualitative effect on simulation results. Banks do indeed switch between different heuristics and after the transient during which frequent switching between all four heuristics occurs, the strong and weak trend-following rules become dominant. However, in the present model which is stationary and exhibits persistent cycles, simple adaptive expectations by themselves turn out to be a fairly decent forecasting heuristic upon which heterogeneous expectations provide only a slight improvement. Table 2 shows improvements in the mean forecast error for all variables forecasted by the banks, but also demonstrates that on average errors are small even under adaptive expectations. Table 3 shows perhaps more clearly that heterogeneous expectations do indeed significantly outperform simple adaptive expectations in that the former lead to far smaller standard deviations in forecast errors.

Table 2: Mean forecast errors

	CAR	**SFR**	**Capital Buffer**
Baseline	5.268677e-07	-1.790212e-06	0.002958
Het. Expectations	-1.05351e-07	-1.278779e-06	-0.000584927

Table 3: Standard deviation of forecast errors

	CAR	**SFR**	**Capital Buffer**
Baseline	0.0001514509	0.002310695	0.4227703
Het. Expectations	2.272287e-05	0.00100135	0.06806726

Yet while this improvement does affect the realisations of forecasted variables somewhat at the level of individual banks this does not alter the overall dynamics of the model and indeed the differences almost disappear when averaging across banks suggesting that there is no systematic change in the behaviour of banks as a result of this slight improvement in forecasting ability.

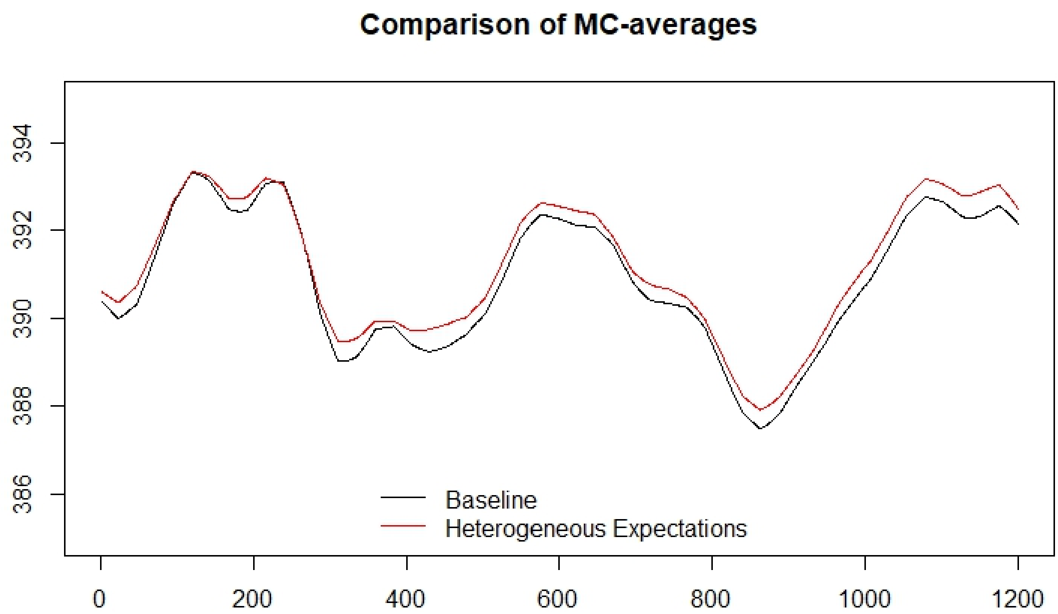

Figure 15: MC-average of banks' capital buffer under adaptive and heterogeneous expectations

Figure 16 compares the dynamics of GDP over 100 Monte-Carlo repetitions showing that the behaviour is very similar and in particular that there is practically no difference in the standard deviation.

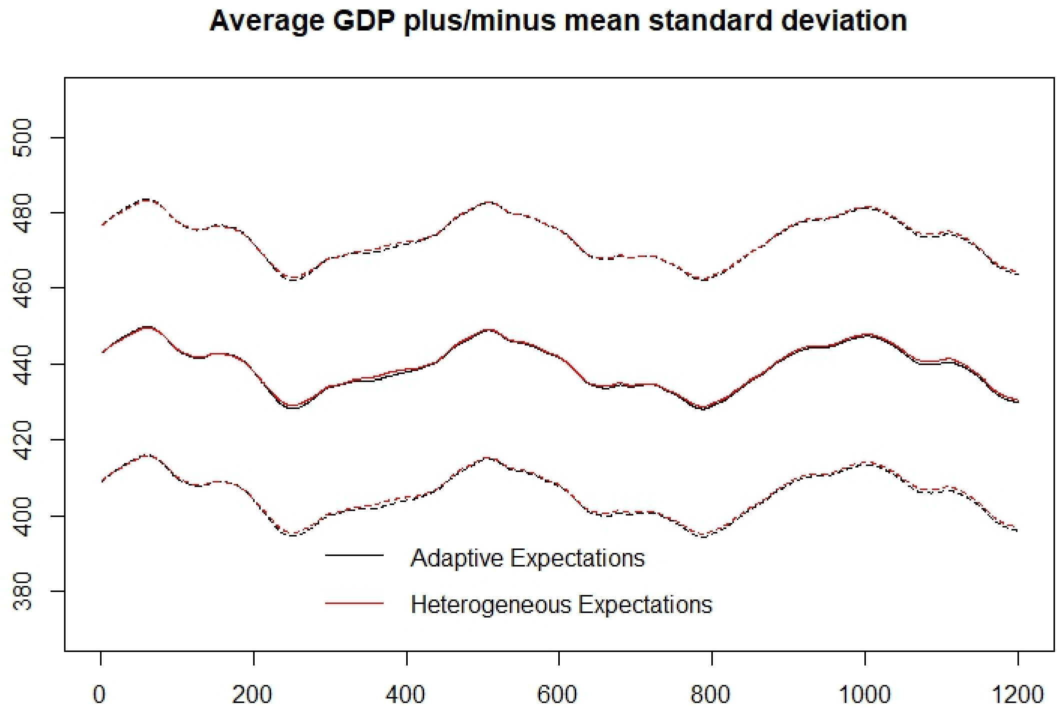

Figure 16: MC-average GDP and standard deviation for adaptive and heterogeneous expectations

While the conclusion that adaptive expectations can be a fairly successful heuristic in a relatively complex model such as this is interesting in itself, it is nevertheless curious that the presence of alternative forecasting heuristics is not sufficient to systematically alter the actual realisations of the forecasted variables or the resulting overall model dynamics, contrary to what one might have suspected. This suggests that while banks' expectations regarding the developments of their balance sheets are important in determining their reactions to, for instance, fluctuations in their capital buffer, a slightly improved ability to forecast these fluctuations is not sufficient to eliminate or even significantly abate them.[4]
To conclude our preliminary investigation of the model, we conduct three macro-prudential policy experiments. The first consists of simply augmenting the baseline version of the

[4]The assertion that banks' expectations do have an important impact on model dynamics in principle is established by a simulation in which banks are *forced* to form expectations according to the 'anchoring and adjustment' mechanism which, under heuristic switching, is almost never chosen. This leads banks to frequently make large forecast errors since their expectations adjust only very slowly to actual realisations which in turn leads to increased volatility at the aggregate level.

model with an *endogenous* target for the capital adequacy ratio, as opposed to the fixed one present in the simulations shown above. The endogenous target is given by

$$CAR^t = CAR_0^t + 0.5 * \widehat{cr}, \tag{21}$$

where $\widehat{cr}$ is the annualised growth rate of bank credit to the private non-financial sectors and CAR_0^t is an exogenous intercept equal to the fixed target in the baseline. It is assumed that the central bank revises the target CAR once a month, concurrently with its monetary policy decision, based on the average of $\widehat{cr}$ during the previous month.

The experiment is carried out using 25 MC repetitions. Comparing the MC-averages of GDP with those of the baseline model for the same number of repetitions with identical seeds it can clearly be seen that the endogenous CAR contributes to stabilising the aggregate dynamics by dampening longer-term fluctuations, albeit introducing some very minor short-term fluctuations caused by frequent adjustments of the target CAR.

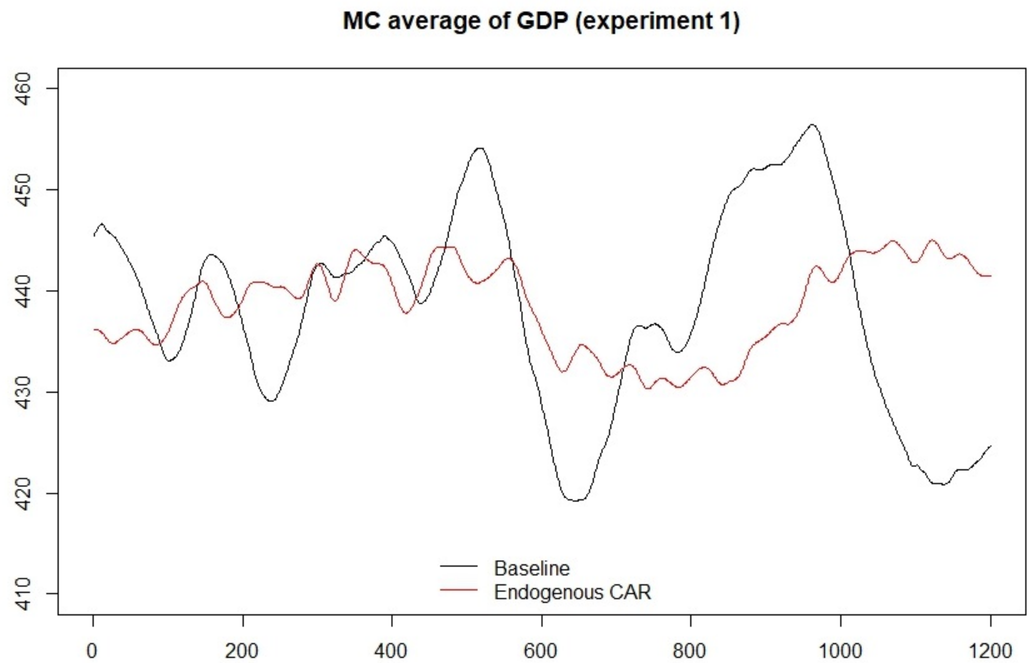

Figure 17: MC-average GDP for baseline and endogenous CAR

Table 4 shows that the endogenous CAR is able to more than halve the mean standard deviation of GDP across 25 MC repetitions while leaving its mean value across simulation periods almost unaffected. The volatility of consumption is reduced to an even greater degree than that of GDP and the central bank's ability to target inflation does not appear compromised; indeed, the decline in macroeconomic volatility also gives rise to less volatile inflation. Hence, macroeconomic fluctuations are reduced significantly at no cost in aggregate output.

Table 4: Experiment 1

	Mean GDP	Mean SD of GDP	Mean SD of inflation	Mean SD of consumption
Baseline	438.1855	29.15001	0.004945594	16.50226
Endogenous CAR	438.5558	12.001	0.003627468	5.685738

As a second experiment, we combine the endogenous CAR given above with an alternative monetary policy rule, namely one in which instead of targeting inflation directly, the central bank is purely concerned with keeping output at its 'normal' level by targeting capacity utilisation, making its interest rate rule

$$r_{cb,d} = r_0 + \pi^e + \phi_u * (u^e - u_n). \tag{22}$$

Once again, a graphical analysis shows that this policy mix improves on the baseline in terms of volatility of GDP but also that it appears superior to the use of an endogenous CAR by itself.[5]

[5]The apparent slight downward trend in MC-average GDP in the first half of the simulation reflects a prolonged transient period and disappears if the simulation time is extended.

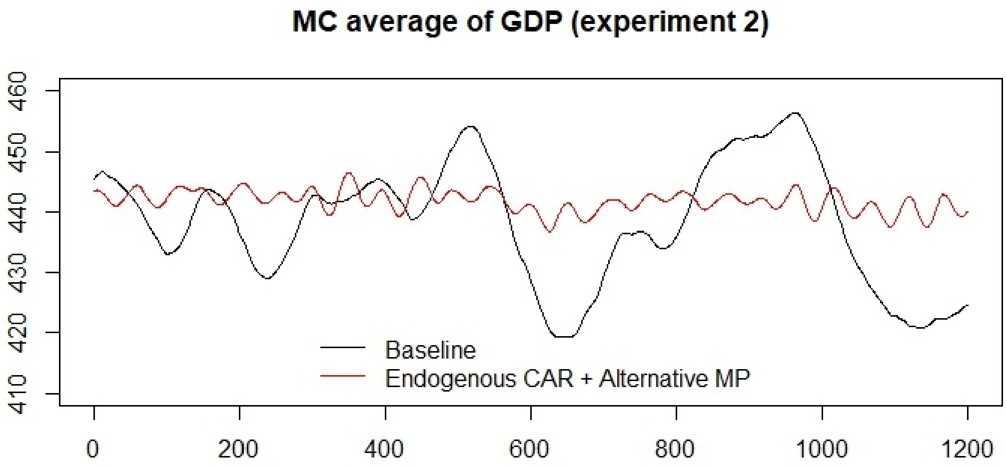

Figure 18: MC-average GDP for baseline and endogenous CAR + alternative monetary policy rule

Table 5 shows that the alternative policy mix improves significantly on both the baseline and the endogenous CAR regime in terms of macroeconomic stability and in particular that the switch from inflation to output targeting does not appear to compromise the inflation target. The volatility of consumption is more than halved even w.r.t. the endogenous CAR regime and the remaining volatility in GDP is driven almost exclusively by short-run fluctuations in investment expenditure.

Table 5: Experiment 2

	Mean GDP	Mean SD of GDP	Mean SD of inflation	Mean SD of consumption
Baseline	438.1855	29.15001	0.004945594	16.50226
Endogenous CAR	438.5558	12.001	0.003627468	5.685738
Endogenous CAR + alt. MP	441.7481	6.990253	0.003537656	2.61766

Finally, we once more investigate the potential impact of heterogeneous expectations and check the robustness of our policy results by conducting the same experiment as above, featuring both an endogenous CAR and the alternative interest rate rule but using heterogeneous expectations for the banking sector instead of simple adaptive ones.

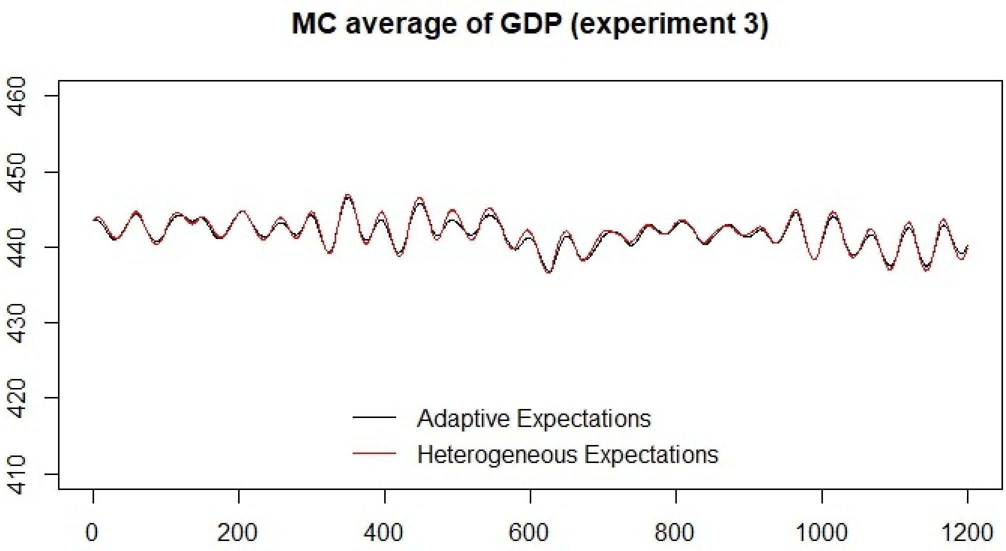

Figure 19: MC-average GDP for endogenous CAR + alternative monetary policy rule under adaptive and heterogeneous expectations

Figure 19 and table 6 show that the presence of heterogeneous expectations, as in the baseline simulation, makes almost no difference regarding the effects of the macro-prudential-monetary-policy mix. The minor remaining fluctuations in GDP are only insignificantly stronger under heterogeneous expectations and the conclusion that a mix of an endogenous CAR and an output-targeting monetary policy is strongly stabilising at no cost to average output also holds under heterogeneous expectations in the banking sector.

Table 6: Experiment 3

	Mean GDP	Mean SD of GDP	Mean SD of inflation	Mean SD of consumption
Adaptive expectations	441.7481	6.990253	0.003537656	2.61766
Heterogeneous expectations	441.9095	7.018295	0.003538496	2.50092

5 Future research

At present, a thorough sensitivity analysis of the baseline using latin hypercube sampling to sample the parameter space is still to be completed. In addition, the model still allows for a range of further policy experiments. More broadly there are several places in which the model could be improved, particularly with regard to the behaviour of the banking sector. At present banks' behaviour largely revolves around attempts to meet their various regularly constraints and there is little explicitly profit-oriented behaviour.[6] Improvements on this could be made by having banks calculating the expected revenue and cost of making a given amount of loans (including the expectation of default which at present only enters indirectly through banks' forecast of their capital buffer) and paying closer attention to their funding cost, including that emanating from the issuance of bank bonds. Furthermore, a more sophisticated modelling of the interbank market in which constant borrowers eventually become constrained could produce interesting results. Such reformulations of the banks' behaviours may in turn also affect the impact of different rules for expectations formation.

Finally, even though the model does not produce a terrible fit, more work is needed to make it reproduce more closely the empirically observed characteristics of business cycles.

[6] However this could be justified by noting that within the set-up of this model, as long as spreads between lending and deposit rates are positive, banks should always be willing to lend more when their regulatory constraints allow them to do so since there is no monotonically increasing marginal cost to granting more loans.

Bibliography

ANGELINI, P., S. NERI, AND F. PANETTA (2014): "The Interaction between Capital Requirements and Monetary Policy," *Journal of Money, Credit and Banking*, 46, 1073–1112.

ANUFRIEV, M. AND C. HOMMES (2012): "Evolutionary Selection of Individual Expectations and Aggregate Outcomes in Asset Pricing Experiments," *American Economic Journal: Microeconomics*, 4, 35–64.

ASSENZA, T. AND D. DELLI GATTI (2013): "E Pluribus Unum: Macroeconomic modelling for multi-agent economies," *Journal of Economic Dynamics & Control*, 37, 1659–1682.

ASSENZA, T., D. DELLI GATTI, AND M. GALEGATTI (2007): "Heterogeneity and Aggregation in a Financial Accelerator Model," *CeNDEF Working Papers*, No. 07-13.

BANQUE DE FRANCE (2014): "Macroprudential Policies - Implementation and Interactions," *Financial Stability Review*, 18.

BARWELL, R. (2013): *Macroprudential Policy - Taming the wild gyrations of credit flows, debt stocks and asset prices*, Basingstoke: Palgrave Macmillan.

BASEL COMMITTEE ON BANKING SUPERVISION (2010): "Basel III: A global regulatory framework for more resilient banks and banking systems," Available online: http://www.bis.org/publ/bcbs189.pdf.

——— (2013): "Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools," Available online: http://www.bis.org/publ/bcbs238.pdf.

——— (2014): "Basel III: the net stable funding ratio," Available online: http://www.bis.org/bcbs/publ/d295.pdf.

BEAU, D., L. CLERC, AND B. MOJON (2012): "Macro-Prudential Policy and the Conduct of Monetary Policy," *Banque de France Working Paper*.

BENCHIMOL, J. AND L. BOUNADER (2018): "Optimal Monetary Policy Under Bounded Rationality," *Federal Reserve Bank of Dallas Globalization and Monetary Policy Institute Working Paper*, No. 336.

BRAINARD, W. AND J. TOBIN (1968): "Pitfalls in financial model building," *American Economic Review*, 58, 99–122.

BRANCH, W. AND B. MCGOUGH (2009): "A New Keynesian model with heterogeneous expectations," *Journal of Economic Dynamics & Control*, 33, 1036–1051.

BROCK, W. AND C. HOMMES (1997): "A Rational Route to Randomness," *Econometrica*, 65, 1059–1095.

BURGESS, S., O. BURROWS, A. GODIN, S. KINSELLA, AND S. MILLARD (2016): "A dynamic model of financial balances for the United Kingdom," *Bank of England Staff Working Paper No. 614*.

Caiani, A., A. Godin, E. Caverzasi, M. Gallegati, S. Kinsella, and J. Stiglitz (2016): "Agent Based-Stock Flow Consistent Macroeconomics: Towards a Benchmark Model," *Journal of Economic Dynamics and Control*, 69, 375–408.

Calvo, G. (1993): "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12, 383–398.

Carré, E., J. Couppey-Soubeyran, and S. Dehmej (2015): "La coordination entre politique monétaire et politique macroprudentielle - Que disent les modèles DSGE?" *Revue Économique*, 66, 541–572.

Caverzasi, E. and A. Godin (2015): "Post-Keynesian stock-flow-consistent modelling: a survey," *Cambridge Journal of Economics*, 39, 157–187.

Cincotti, S., M. Raberto, and A. Teglio (2010): "Credit Money and Macroeconomic Instability in the Agent-based Model and Simulator Eurace," *Economics: The Open-Access, Open-Assessment E-Journal*, 4.

Claessens, S., K. Habermeier, E. Nier, H. Kang, T. Mancini-Griffoli, and F. Valencia (2013): "The Interaction of Monetary and Macroprudential Policies," *IMF Policy Paper, January.*

Dawid, H. and D. Delli Gatti (2018): "Agent-Based Macroeconomics," *University of Bielefeld Working Papers in Economics and Management*, No. 02-2018.

Dawid, H., S. Gemkow, P. Harting, S. van der Hoog, and M. Neugart (2012): "The Eurace@Unibi Model - An Agent-Based Macroeconomic Model for Economic Policy Analysis," *University of Bielefeld Working Papers in Economics and Management*, No. 05-2012.

Delli Gatti, D., S. Desiderio, E. Gaffeo, P. Cirillo, and M. Gallegati (2011): *Macroeconomics from the bottom up*, Springer.

Detzer, D. (2016): "Financialisation, Debt and Inequality: Export-led Mercantilist and Debt-led Private Demand Boom Economies in a Stock-flow consistent Model," *CreaM Working Paper Series Nr. 3/2016.*

Dosi, G., G. Fagiolo, and A. Roventini (2006): "An Evolutionary Model of Endogenous Business Cycles," *Computational Economics*, 27, 3–34.

Dosi, G., M. Napoletano, A. Roventini, J. Stiglitz, and T. Treibich (2017): "Rational Heuristics? Expectations and Behaviors in Evolving Economies with Heterogeneous Interacting Agents," *LEM Working Paper*, No. 2017-31.

Evans, G. and S. Honkapohja (2001): *Learning and Expectations in Macroeconomics*, Princeton NJ: Princeton University Press.

Franke, R. and T. Lux (1993): "Adaptive Expectations and Perfect Foresight in a Nonlinear Metzlerian Model of the Inventory Cycle," *The Scandinavian Journal of Economics*, 95, 355–363.

Freixas, X., L. Laeven, and J.-L. Peydró (2015): *Systemic Risk, Crises, and Macroprudential Regulation*, Cambridge MA: MIT Press.

Galati, G. and R. Moessner (2011): "Macroprudential policy-a literature review," *BIS Working Paper No. 337.*

Gali, J. (2015): *Monetary Policy, Inflation, and the Business Cycle - An Introduction to the New Keynesian Framework and its Applications*, Princeton, N.J.: Princeton University Press, 2nd ed.

Gigerenzer, G. (2008): *Rationality for Mortals - How People Cope with Uncertainty*, Oxford: Oxford University Press.

Godley, W. and M. Lavoie (2007): *Monetary Economics - An Integrated Approach to Credit, Money, Income, Production and Wealth*, Basingstoke: Palgrave Macmillan.

Greenwald, B. and J. Stiglitz (1993): "Financial Market Imperfections and Business Cycles," *The Quarterly Journal of Economics*, 108, 77–114.

Hommes, C. (2013): *Behavioral Rationality and Heterogeneous Expectations in Complex Economic Systems*, Cambridge: Cambridge University Press.

Kahneman, D. and A. Tversky, eds. (2000): *Choices, Values, and Frames*, Cambridge: Cambridge University Press.

Kalecki, M. (1938): "The Determinants of the Distribution of National Income," *Econometrica*, 6, 97–112.

Kemp-Benedict, E. and A. Godin (2017): "Introducing risk into a Tobin asset-allocation model," *PKSG Working Paper*, No. 1713.

Krug, S. (2018): "The interaction between monetary and macroprudential policy: should central banks 'lean against the wind' to foster macro-financial stability?" *Economics: The Open-Access, Open-Assessment E-Journal*, 12.

Landini, S., M. Gallegati, and J. Stiglitz (2014): "Economies with heterogeneous interacting learning agents," *Journal of Economic Interaction and Coordination*, 8, 1–28.

Loisel, O. (2014): "Discussion of "Monetary and Macroprudential Policy in an Estimated DSGE Model of the Euro Area"," *International Journal of Central Banking*, 10, 237–247.

Massaro, D. (2013): "Heterogeneous expectations in monetary DSGE models," *Journal of Economic Dynamics & Control*, 37, 680–692.

Michell, J. (2014): "A Steindlian account of the distribution of corporate profits and leverage: A stock- flow consistent macroeconomic model with agent-based microfoundations," *PKSG Working Paper No. 1412.*

Minsky, H. P. (1986): *Stabilizing an Unstable Economy*, New York, NY: McGraw Hill.

Nikiforos, M. and G. Zezza (2017): "Stock-flow Consistent Macroeconomic Models: A Survey," *Journal of Economic Surveys*, 31, 1204–1239.

Nikolaidi, M. (2015): "Securitisation, wage stagnation and financial fragility: a stock-flow consistent perspective," *Greenwich Papers in Political Economy, No. 27.*

Popoyan, L., M. Napoletano, and A. Roventini (2015): "Taming Macroeconomic Instability: Monetary and Macro Prudential Policy Interactions in an Agent-Based Model," *ISI Growth Working Paper*, No. 3/2015.

Salle, I. and P. Seppecher (2017): "Stabilizing an Unstable Complex Economy - On the limitations of simple rules," *Document de travail du CEPN*.

Salle, I., M. Zumpe, M. Yildizoglu, and M. Senegas (2012): "Modelling Social Learning in an Agent-Based New Keynesian Macroeconomic Model," *Cahiers du GREThA*, No. 2012-20.

Sargent, T. (1993): *Bounded rationality in macroeconomics*, Oxford: Oxford University Press.

Schoenmaker, D., ed. (2014): *Macroprudentialism*, London: CEPR Press.

Seppecher, P. (2012): "Flexibility of wages and macroeconomic instability in an agent-based computational model with endogenous money," *Macroeconomic Dynamics*, 16.

——— (2016): "Modèles multi-agents et stock-flux cohérents: une convergence logique et nécessaire," *Working Paper*, available online: `https://hal.archives-ouvertes.fr/hal-01309361/`.

Seppecher, P., I. Salle, and D. Lang (2016): "Is the market really a good teacher? Market selection, collective adaptation and financial instability," *GREDEG Working Paper*, No. 2016-15.

Simon, H. (1982): *Models of bounded rationality*, Cambridge MA: MIT Press.

Steindl, J. (1952): *Maturity and Stagnation in American Capitalism*, New York, NY: Monthly Review Press.

van der Hoog, S. (2015): "The Limits to Credit Growth: Mitigation Policies and Macroprudential Regulations to Foster Macrofinancial Stability and Sustainable Debt," *Bielefeld University Working Papers in Economics and Management, No. 08-2015.*

van der Hoog, S. and H. Dawid (2015): "Bubbles, Crashes and the Financial Cycle: Insights from a Stock-Flow Consistent Agent-Based Macroeconomic Model," *ISI Growth Working Paper No. 3/2015.*

Table 7: Balance Sheet Matrix

	Households	**Firms**	**Banks**	**Financial Firms**	**Government**	**Central Bank**	Σ
Bank Deposits	$+D_h$		$-D$	$+D_{ff}$			0
Reserves			$+R$			$-R$	0
CB Advances			$-A$			$+A$	0
Gov. Bonds				$+GB_{ff}$	$-GB$	$+GB_{cb}$	0
Mortgages	$-M$		$+M$				0
Long Term Loans		$-LL$	$+LL$				0
Short Term Loans		$-SL_f$	$+SL$	$-SL_{ff}$			0
Firms' Equity		$-E_f$		$+E_f$			0
Bank Bonds			$-BB$	$+BB$			0
Fund Shares	$+E_{ff}$			$-E_{ff}$			0
Fixed Capital		$+p*k$					$p*k$
Houses	$+p_h*h$						p_h*h
Inventories		$+UC*Inv$					$UC*Inv$
Σ	V_h	V_f	V_b	V_{ff}	V_g	V_{cb}	$p*k+p_h*h$ $+UC*Inv$

Table 8: Transactions Flow Matrix

	Households	**Firms**		**Banks**	**Financial Firms**	**Government**	**Central Bank**	Σ
		Current	Capital					
Consumption	$-C$	$+C$						0
Cap. Investment		$+I$	$-I$					0
Inventory Acc.		$+UC * \Delta Inv$	$-UC * \Delta Inv$					0
Gov. Spending		$+G$				$-G$		0
Taxes	$-Tax$					$+Tax$		0
Wages	$+W$	$-W$						0
Firm Dividends		$-Div_f$			$+Div_f$			0
Fin. firm Dividends	$+Div_{ff}$				$-Div_{ff}$			0
Bank Dividends				$-Div_b$	$+Div_b$			0
CB profits						$+PCB$	$-PCB$	0
Interest Mortgage	$-iM$			$+iM$				0
Interest LL		$-iLL$		$+iLL$				0
Interest SL		$-iSL_f$		$+iSL$	$-iSL_{ff}$			0
Interest Deposits	$+iD_h$			$-iD$	$+iD_{ff}$			0
Int. Bank Bonds				$-r_{bb,-1} * BB_{-1}$	$+r_{bb,-1} * BB_{-1}$			0
Int. Gov. Bonds					$+r_{gb,-1} * GB_{ff,-1}$	$-r_{gb,-1} * GB_{-1}$	$+r_{gb,-1} * GB_{cb,-1}$	0
Int. CB advances				$-r^l_{cb,-1} * A_{-1}$			$+r^l_{cb,-1} * A_{-1}$	0
Int. on reserves				$+r^d_{cb,-1} * R$			$-r^d_{cb,-1} * R_{-1}$	0
Saving	(Sav_h)	$-Sav_f$	$+Sav_f$	(Sav_b)	(Sav_{ff})	(Sav_g)	(0)	0
Δ Deposits	$-\Delta D_h$			$+\Delta D$	$-\Delta D_{ff}$			0
Δ Gov. Bonds					$-\Delta GB_{ff}$	$+\Delta GB$	$-\Delta GB_{cb}$	0
Δ CB advances				$+\Delta A$			$-\Delta A$	0
Δ Reserves				$-\Delta R$			$+\Delta R$	0
Δ Mortgages	$+\Delta M - M_{np}$			$-\Delta M - M_{np}$				0
Δ Long Term Loans			$+\Delta LL - LL_{np}$	$-\Delta LL - LL_{np}$				0
Δ Short Term Loans			$+\Delta SL_f$	$-\Delta SL$	$+\Delta SL_{ff}$			0
Δ Bank Bonds				$+\Delta BB$	$-\Delta bb$			0
Δ Fund Shares	$-\Delta E_{ff}$				$+\Delta E_{ff}$			0
Σ	0	0	0	0	0	0	0	