WORKING PAPERS

Castellón (Spain)

UNIVERSITAT JAUME I

The impact of banks' capital adequacy regulation on the economic system: an agent-based approach

Economics Department

Andrea Teglio
Marco Raberto
Silvano Cincotti

2011 / 01

The impact of banks' capital adequacy regulation on the economic system: an agent-based

Andrea Teglio
Universitat Jaume I
Department of Economics
teglio@uji.es

Marco Raberto
University of Genova
marco.raberto@unige.it

Silvano Cincotti
University of Genova
silvano.cincotti@unige.it

2011 / 01

Abstract

Since the start of the financial crisis in 2007, the debate on the proper level leverage of financial institutions has been flourishing. The paper addresses such crucial issue within the Eurace artificial economy, by considering the effects that different choices of capital adequacy ratios for banks have on main economic indicators. The study also gives us the opportunity to examine the outcomes of the Eurace model so to discuss the nature of endogenous money, giving a contribution to a debate that has grown stronger over the last two decades. A set of 40 years long simulations have been performed and examined in the short (first 5 years), medium (the following 15 years) and long (the last 20 years) run. Results point out a non-trivial dependence of real economic variables such as the Gross Domestic Product (GDP), the unemployment rate and the aggregate capital stock on banks' capital adequacy ratios; this dependence is in place due to the credit channel and varies significantly according to the chosen evaluation horizon. In general, while boosting the economy in the short run, regulations allowing for a high leverage of the banking system tend to be depressing in the medium and long run. Results also point out that the stock of money is driven by the demand for loans, therefore supporting the theory of endogenous nature of credit money.

Keywords: Agent-based models, banking regulation
JEL Classification: G2

The impact of banks' capital adequacy regulation on the economic system: an agent-based approach

Andrea Teglio * Marco Raberto † Silvano Cincotti †

April 26, 2011

Abstract

Since the start of the financial crisis in 2007, the debate on the proper level leverage of financial institutions has been flourishing. The paper addresses such crucial issue within the Eurace artificial economy, by considering the effects that different choices of capital adequacy ratios for banks have on main economic indicators. The study also gives us the opportunity to examine the outcomes of the Eurace model so to discuss the nature of endogenous money, giving a contribution to a debate that has grown stronger over the last two decades. A set of 40 years long simulations have been performed and examined in the short (first 5 years), medium (the following 15 years) and long (the last 20 years) run. Results point out a non-trivial dependence of real economic variables such as the Gross Domestic Product (GDP), the unemployment rate and the aggregate capital stock on banks' capital adequacy ratios; this dependence is in place due to the credit channel and varies significantly according to the chosen evaluation horizon. In general, while boosting the economy in the short run, regulations allowing for a high leverage of the banking system tend to be depressing in the medium and long run. Results also point out that the stock of money is driven by the demand for loans, therefore supporting the theory of endogenous nature of credit money.

Introduction

The agent-based modelling approach applied to economics allows to take into account the complex pattern of interactions among different economic agents in a realistic and complete way. The Eurace simulator is an agent-based model of the macroeconomy characterized by different kinds of agents, namely, households, firms, commercial banks, a Government and a Central Bank, and by different decentralized markets, characterized by pairwise exchange interactions, such as a labor market, a goods market, and a credit market; a financial market is also present, where firm equity shares

*Departament d'Economia, Universitat Jaume I, Castellon de la Plana 12071, Castellon, Spain
†University of Genova, Via Opera Pia 11a, 16145, Genova Italy

and government bonds are exchanged in a centralized way through a clearing house [14, 24].

This paper investigates the impact of bank lending regulation on macroeconomic activity by considering a set of economic variables as indicators. The regulatory parameter considered is the leverage ratio of commercial banks, i.e. the ratio between the value of the loan portfolio held by banks, weighted with a measure of the loan riskiness, and banks net worth or equity, along the lines of capital adequacy ratios set by the Basel II agreement [1].

The debate on implications and consequences of capital adequacy requirements for banks has been growing in the last three decades [10, 11] and has drawn particular attention after the financial crisis of 2007-2009 [19, 7]. The discussion focuses on the beneficial effects of equity requirements compared to the disadvantages in terms of economic costs and credit market effectiveness. Some of the main controversial aspects about the implications of higher equity requirements are clearly resumed in [6]. The main benefit of increased equity capital requirements is claimed to be the weakening of systemic risk, while potential drawbacks are, among others, the reduction of return on equity (ROE) for banks, the restriction of lending, and the increase of funding costs for banks. This paper focuses on the macroeconomic implications of capital adequacy regulation, studying its effect on banks' lending activity and therefore on the main economic indicators such as GDP, unemployment and inflation. In particular, three different time horizons are considered (short, medium and long run) in order to analyze the macroeconomic outcomes of the Eurace artificial economy so to take into account also the long-term effects.

The long-term macroeconomic impact of capital requirements has been intensively examined after the last financial crisis, see [5, 3, 4] and [8] for some complete and representative studies by central banks or by international institutions performing policy analysis and financial advising, like the BIS[1] or the IIF[2]. An analysis of these reports, along with a critical assessment of the used models, is beyond the scope of this paper. Let us simply summarize the main common results. Firstly, higher capital requirements reduce the probability of banking crises. Secondly, it emerges that an increase in the capital ratio causes a decline in the level of output; the magnitude of the effect depends on the specific model. Thirdly, a higher capital ratio tends to dampen output volatility, especially if counter-cyclical capital buffers schemes are adopted. These main results have been obtained using a variety of models (see [3] for a list), mainly Dynamic Stochastic General Equilibrium (DSGE) models or semi-structural models. DSGE can be considered as the standard type of model currently used in macroeconomics, even though they have been widely criticized both for their difficulties in explaining some economic phenomena (see for instance [12, 20]) and for the fact that the assumed equivalence between the micro and the macro behavior in DSGE models does not allow to take properly into account interaction and coordination among economic agents [13].

The aim of this study is to present an alternative approach based on a fully endogenous agent-based model whose dynamics does not depend on external stochastic processes but mainly on the interaction of economic agents populating the artificial

[1] The Bank for International Settlements; http://www.bis.org

[2] The Institute of International Finance, Inc.; http://www.iif.com/

economy. See [25] for a comprehensive survey on agent-based computational economics and [2] for an overview of the Eurace model.

In concrete terms, a set of computational experiments have been carried out with the objective to study the performance of the economic system according to different values of the capital ratio requirement. The outcomes of this what-if analysis show how the main macroeconomic variables characterizing the Eurace economy, i.e. both real variables (such as GDP, unemployment and capital stock), and nominal variables (such as wage and price levels) are affected by the aggregate amount of loans provided by banks, which in turn depends on banks net worth or equity and on the allowed leverage ratio.

The interpretation of results can be possibly done in accordance with the lines of the endogenous credit-money approach of the post-Keynesian tradition [17, 9, 21]. Contrary to the neoclassical synthesis, where money is an exogenous variable controlled by the central bank through its provision of required reserves, to which a deposit multiplier is applied to determine the quantity of privately-supplied bank deposits, the essence of endogenous money theory is that in modern economies money is an intrinsically worthless token of value whose stock is determined by the demand of bank credit by the production or commercial sectors and can therefore expand and contract regardless of government policy. Money is then essentially credit-money originated by loans which are created from nothing as long as the borrower is credit-worthy and some institutional constraints, such as the Basel II capital adequacy ratios, are not violated. As the demand for loans by the private sector increases, banks normally make more loans and create more banking deposits, without worrying about the quantity of reserves on hand, and the central bank usually accommodates the demand of reserves at the short term interest rate, which is the only variable that the monetary authorities can control.

The modeling architecture of the Eurace economy, which has been conceived in order to closely mimic the functioning of a modern credit-driven economy, strongly confirms the endogenous theory view. Based on this conceptual framework, we investigate the relationship between endogenous credit money and macroeconomic activity, by examining computational experiments where the institutional (e.g. Basel II) constraints on bank leverage are exogenously set.

The paper is organized as follows. In section 1 an overall description of the credit market model is given, both considering the firms and the banks sides. Section 2 presents the computational results of our study and a related discussion. Conclusions are drawn in section 3.

1 The credit market model

In the following, we outline the main features of the Eurace credit market model by describing how the demand of credit by firms arises to finance their production and liquidity needs, how the supply of credit by banks is conditioned by their capital adequacy ratio and how borrowers (firms) and lenders (banks) match their respective demand and supply schedules in the market.

1.1 Firms' side

Two types of firms are considered in the Eurace model: capital goods producers and consumption goods producers. Capital goods producers employ labor to produce on job capital goods that will be used as production factor together with labor by consumption goods producers. Given job production and only labor as production factors, capital goods producers, contrary to consumption goods producers, have not inventories as well as financing needs. In the following we will describe in more detail consumption goods producers, henceforth generally identified as firms.

Once a month, every firm computes its total liquidity needs, given by the liquidity necessary to meet its financial payments and by the expected cost of the planned production schedule. In particular, firm f at month t is subject to the following financial payments: the interest payments on its debt, henceforth R_t^f, the debt installment, henceforth I_t^f, taxes T_t^f and dividends payments D_t^f. The total liquidity needs L_t^f of firm f are therefore given by $\mathsf{L}_t^f = \mathsf{C}_t^f + \mathsf{R}_t^f + \mathsf{I}_t^f + \mathsf{T}_t^f + \mathsf{D}_t^f$, where C_t^f are the the expected costs of the planned production schedule.

Firms plan the monthly production schedule by considering the stock of inventories kept by the different malls selling their products, and by estimating the demand using a linear regression based on previous demands. Production is carried out according to a Cobb-Douglas type function, with two factors of production, i.e. labor and capital; a desired capital to labor ratio is calculated considering the marginal rate of substitution of the two factors, which depends on the given money wage and the cost of capital. Given the planned monthly production schedule and the desired capital to labor ratio, the desired capital endowment and the labor demand are determined by inverting the Cobb-Douglas production function. Demand for investments then depends on the difference between the desired and the actual capital endowment (see [15, 16] for details).

According to the pecking-order theory [22], any firm f meets its liquidity needs first by using its internal liquid resources P_t^f, i.e., the cash account deposited at a given bank; then, if $\mathsf{P}_t^f < \mathsf{L}_t^f$, the firm asks for a loan of amount $\mathsf{L}_t^f - \mathsf{P}_t^f$ to the banking system so to be able to cover entirely its foreseen payments. Credit linkages between firm f and bank b are defined by a connectivity matrix which is randomly created whenever a firm enters the credit market in search for funding. In order to take search costs as well as incomplete information into account, each firm links with a maximum of n banks of the same region, which are chosen in a random way.

Firms have to reveal to the linked banks information about their current equity and debt levels, along with the amount of the loan requested λ_t^f. Using this information, according to the decision rules outline din the next section, each contacted bank b determines the amount of money available for lending to firm f (henceforth ℓ_t^f, where $\ell_t^f \leq \lambda_t^f$), calculates the interest rate i_t^{bf} associated to the loan and communicates it to the firm. After this first consulting meeting where firm's credit worthiness has been assessed by the bank, each firm asks for credit starting with the bank with the lowest interest rate. On banks' hand, they receive demands by firms sequentially and deal with them in a "first come, first served" basis. As explained with more detail in the following section, the firm can be credit rationed. If a firm can not obtain a sufficient amount of credit from the bank that is offering the best interest rate, the firm will ask credit to the bank offering the second best interest rate, until the last connected bank of the list is reached. It is worth noting that, although the individual firm asks loans to the bank with the lowest lending rate, the total demand for loans does not depend directly on the interest rates of loans.

When firm f receives a loan, its cash account P_t^f is then increased by the amount of it. If the firm is not able to collect the needed credit amount, i.e., if P_t^f is still lower than L_t^f, the firm has still has the possibility to issue new equity shares and sell them on the stock market. If the new shares are not sold out, the firm enters a state called *financial crisis*. When a firm is in financial crisis, we mainly distinguish two cases (see [2] for further details): if the firm's available internal liquidity is still sufficient to meet its committed financial payments, i.e., taxes, the debt instalment and interests on debt, then these financial payments are executed and the dividend payout and the production schedule are rearranged to take into account the reduced available liquidity; otherwise, the firm is unable to pay it financial commitments and it goes into bankruptcy.

1.2 Banks' side

The primary purpose of banks is to channel funds received from deposits towards loans to firms. When a firm f contacts a bank b to know its credit conditions, the firm has to inform the bank about its equity level E_t^f and its total debt D_t^f, defined as the sum of the loans that the firm has received from every bank and that it has not yet payed back. Any bank meets the demand for a loan, provided that the risk-reward profile of the loan is considered acceptable by the bank. The reward is given by the interest rate which is charged and the risk is defined by the likelihood that the loan will default. Given the loan request amount λ_t^f by firm f, bank b calculates the probability that the firm will not be able to repay its debt as:

$$\pi_t^f = 1 - e^{-\left(\frac{D_t^f + \lambda_t^f}{E_t^f}\right)} . \tag{1}$$

The default probability π_t^f correctly increases with the firm's leverage and is used as a risk weight in computing the risk-weighted loan portfolio of banks, henceforth W_t^b. According to the computed credit worthiness of the firm, the bank informs it about the interest rate that would be applied to the requested loan:

$$i_t^{bf} = i_t^c + \gamma_t^b \cdot \pi_t^f , \tag{2}$$

where i_t^c is the interest rate set by the central bank and $\gamma_t^b \cdot \pi_t^f$ is the risk spread depending on the firm's credit risk. The parameter γ_t^b sets the spread sensitivity to the credit worthiness of the firm and is an evolving parameter that basically adjusts in order to reinforce the previous choices that were successful in increasing the bank's profits. The central bank acts as the "lender of last resort", providing liquidity to the banking sector at the interest rate i_t^c. Finally, it is worth noting that banks lending rate does not depend on the expected demand for loans but only on the evaluation of firm's credit risk.

Banks can then lend money, provided that firms wish to take out new loans and that their regulatory capital requirement are fulfilled. It is worth noting that granting new

Assets	**Liabilities**
M^b: liquidity deposited at the *central bank*	S^b: standing facility (debt to the *central bank*)
$\mathscr{L}^b$: bank's loan portfolio	D^b: total (households' and firms') deposits at the bank E^b: equity

Table 1: Bank's balance sheet

loans inflates the balance sheet of the banking system because it generates also new deposits[3].

The model regulatory capital requirement are inspired by Basel II accords and state that the capital ratio of banks, given by the equity E_t^b divided by the risk-weighted assets W_t^b, has to be higher than a given threshold, defined as $\frac{1}{\alpha}$, where α is the key policy parameter used in this study. Hence, if firm f asks for a loan λ_t^f, bank b supplies a credit amount ℓ_t^{bf} determined as follows:

$$\ell_t^{bf} = \begin{cases} \lambda_t^f & \text{if} \quad \alpha E_t^b \geq W_t^b + \pi_t^f \lambda_t^f \,, \\ \frac{\alpha E_t^b - W_t^b}{\pi_t^f} & \text{if} \quad W_t^b < \alpha E_t^b < W_t^b + \pi_t^f \lambda_t^f \,, \\ 0 & \text{if} \quad \alpha E_t^b \leq W_t^b \,. \end{cases} \tag{3}$$

The value of risk-weighted assets W_t^b is computed by the weighted sum of outstanding loans of bank b where the weights are given by the default probability (the default risk) of each loan defined in Eq. 1. Bank's liquidity, i.e., M^b as in Table 1, is an asset but its default risk shall be considered zero, therefore it does non enter in the computation of W_t^b.

The parameter α can be interpreted as the leverage level banks are allowed to have. Equations 3 state that bank b is available to satisfy entirely the loan demand λ_t^f if it does not push W_t^b above the Basel II threshold, set at α time the net worth (equity) of the bank, otherwise the bank can satisfy the loan demand only partially or even is not available to lend any money at all, and firm f is rationed in the credit market. Thus, it can be argued that banks are quantity takers and price setters in the loans market, with the policy constraint of a fixed capital adequacy ratio.

In order to better visualize the stock-flow accounts for banks, a typical balance sheet of a bank is reported in table 1. For any bank b, the stocks of total deposits D^b and loans $\mathscr{L}^b$ are updated daily following the changes in their stock levels, i.e., changes in the private sector (households and firms) deposits due to payments (i.e. flows of money among private sector agents) and changes in the loan portfolio due to the granting of new loans and old loan repayments. The stock of liquidity M^b of bank b is then updated accordingly following the standard accounting rule $M^b = S^b + D^b + E^b - \mathscr{L}^b$. If M^b becomes negative, S^b, i.e., the standing facility with the Central Bank, is increased to set $M^b = 0$. If M^b is positive and the bank has a debt with central bank, i.e. $S^b > 0$,

[3]When a loan is taken and spent, it creates a deposits in the bank account of the agent to whom the payment is made. In particular, firms pay wages to workers and pay new physical capital to investment firms, that are owned by households and redistribute net earnings to them.

S^b is partially or totally repaid for a maximum amount equal to M^b. Finally, at the end of the trading day, both liquidity M^b and equity E^b are updated to take into account in the same way of any money flows which regards the bank b, i.e., interest revenues and expenses, taxes and dividends. The bank can choose if to pay or not to pay dividends to shareholders and this choice is crucial for driving the equity dynamics. In particular, if a bank is subject to credit supply restriction due to a low net worth compared to the risk-weighted assets portfolio, then it stops paying dividends so to raise its equity capital and increaser the chance to match in the future the unmet credit demand. Finally, loans are extinguished in a predetermined and fixed number of constant installments.

For a more detailed explanation of the stock-flow accounts in the Eurace model and of its "balance sheet approach", see [23].

2 Results and discussion

Computational experiments have been performed considering a simulation setting characterized by 2,000 households, 20 consumption goods producers, 3 banks, 1 investment goods producer, 1 government, and 1 central bank. The experiments consist in running several simulations of the Eurace model, varying the values of the capital adequacy ratio and observing the macroeconomic implications of the different bank regulation settings. Values of α have been set in the range from 4 to 9, where $\alpha = 4$ corresponds to the case of the tightest capital requirement and $\alpha = 9$ to the most permissive case.

Figure 1 presents typical time series paths referred to the production and sales of consumption goods (top panel) and investments in capital goods (bottom panel). Considering that the Eurace model foresees a job production of investment goods, demand of capital goods always coincides with supply as evidenced by the single line in the bottom of figure 1. On the contrary, the consumption goods case in the top panel shows two lines, a black one, representing sales, and a gray one for production. The existence of inventories, not represented in the figure, explain while sometime sales may be higher than production. The Gross Domestic Production (GDP) of the Eurace economy should be then considered as the sum of the consumption goods (top panel) and capital goods (bottom panel) production.

It is worth noting that the time series showed in Figure 1 are characterized by realistic graphical patterns. First, values referred to aggregate investments are much smaller than values assumed by aggregate consumption and, nevertheless, much more volatile. Second, the time series considered in Figure 1 clearly exhibit irregular cycles which are mainly characterized by steep ascents and descents as well as periods of steady and moderate growth, with a varying periodicity whose duration could be measured in years. Third, long-run growth can be observed both in the production and sales time series as well as in the investments path. The cycles in the investments time series are clearly correlated with the ones in the two time series referred to production and sales, and can be easily interpreted as business cycles. It is also worth noting that the sources of these business cycles are endogenous, i.e., Eurace business cycles are the product of agents' behavior and interaction, as no stochastic exogenous shock is foreseen in the model setting. We argue the important role played in this respect by fluctuations in investments and disruptions in the supply chain caused by firms bankruptcies and

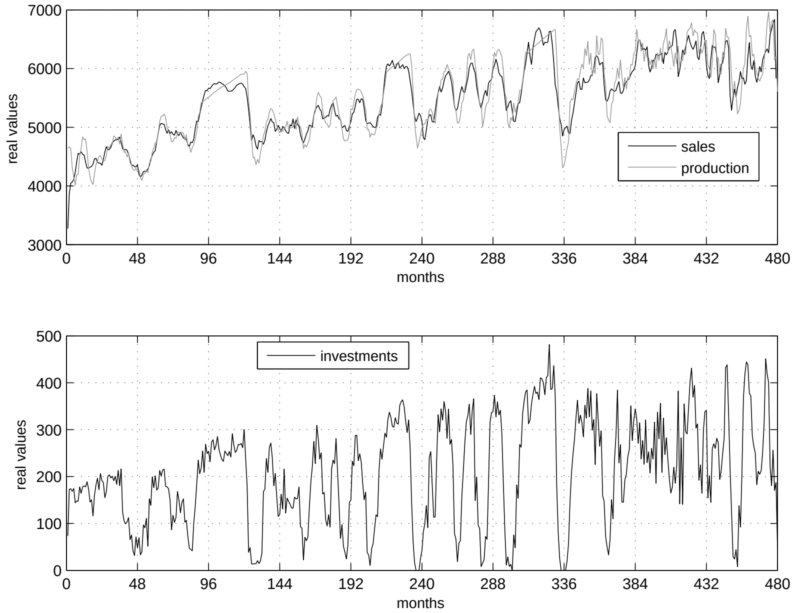

Figure 1: Top panel: aggregate production of consumption goods and sales (aggregate households' consumption). Bottom panel: investments in capital goods by the production sector. Values reported in the y-axis are real values, i.e., nominal values at current prices divided by the price index. The value of α is set to 5.

consequent inactivities. As outlined in Section 1.1, demand for investments depends, among other things, on expected aggregate demand for consumption goods; therefore an increase of unemployment reduces the aggregate demand as well as demand for investments, which in turn, like in a positive feedback mechanism, increase unemployment by reducing the employment also at investment good producers. Furthermore, in the bankruptcy[4] case, a reduction of aggregate supply also occurs due to the inactivity of the firm for a while.

Figure 2 presents the typical simulation paths of the key real economic variables, i.e., the firms' aggregate stock of physical capital (top panel), the unemployment rate (central panel) and the real GDP (bottom panel). For any of the three economic variables considered, we represent the time path related to two different values of α, i.e., $\alpha = 5$ and $\alpha = 9$. The time series have been represented *ceteris paribus*, including the same seed of the pseudo-random number generator. Consistent with the two compo-

[4]The bankruptcy for insolvency occurs when the net worth of the firm becomes lower than zero. In that case, firm' shareholders are wiped out and all workers are fired; the debt is also restructured and loans are partially written-off in the lending banks' portfolios; the firm's physical capital is frozen and the firm remains inactive as long as new financial capital is raised in the stock market.

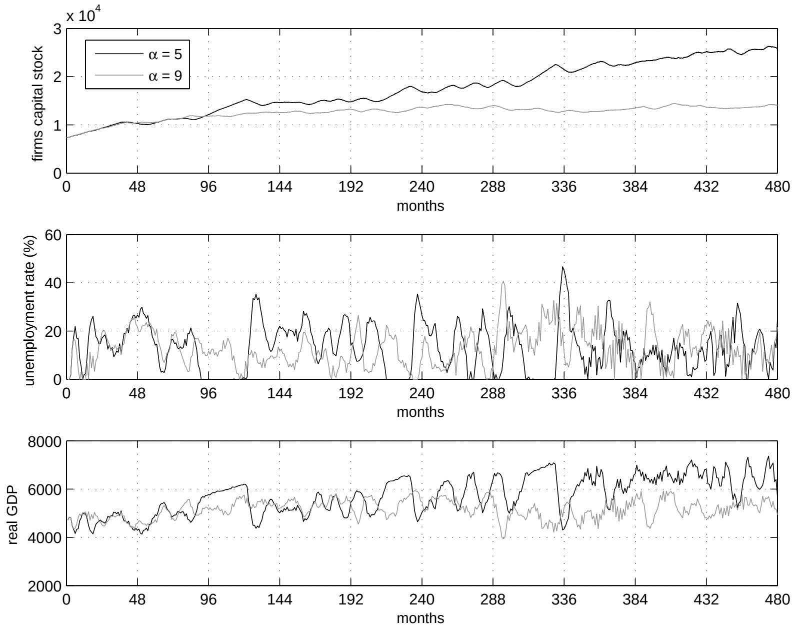

Figure 2: Firms' aggregate stock of physical capital (top panel), unemployment rate (central panel) and real GDP (bottom panel). Two different values of α have been considered for the same seed, i.e., $\alpha = 5$ (black line) and $\alpha = 9$ (gray line).

nents of GDP represented in Figure 1 for the same seed and $\alpha = 5$, i.e. production of consumption goods and investments in capital goods, the real GDP time series (bottom panel) exhibits long-run growth and irregular business cycles. The unemployment rate time series (central panel) is characterized by peaks which occur simultaneously with the bottoms of GDP cycles as well as steep drops (or increases) when the economy is booming (or in recession). Aggregate firms' physical capital (top panel) exhibits a steady growth characterized by relatively small fluctuations which, considering the capital depreciation and the fluctuations of investments, are consistent with the cycles in the bottom panel of Figure 1 and the real GDP in Figure 2.

A clear difference emerges in the long run between the paths with $\alpha = 5$ and the ones with $\alpha = 9$. In particular, the Eurace economy with $\alpha = 5$ is characterized by higher long-run growth of both production and physical capital, and consequently lower unemployment. This is actually a quite general result as shown in Tables 2 to 5, where the ensemble average over 10 random seeds has been considered and the complete set of 6 α values is shown.

Tables from 2 to 5 consider eight important economic variables, related to both the level of economic activity, such as the real GDP, the unemployment rate, and the aggregate capital stock in the economy, and to banks' balance sheets and lending ac-

α	Real GDP			Total credit		
	1 - 5	6 - 20	21 - 40	1 - 5	6 - 20	21 - 40
4	4629 (28)	5509 (45)	6239 (106)	18057 (250)	19897 (340)	18986 (729)
5	4608 (22)	5466 (31)	6064 (81)	18458 (157)	19533 (152)	17781 (609)
6	4669 (9)	5390 (40)	5859 (75)	20130 (133)	19799 (246)	16844 (447)
7	4725 (20)	5429 (33)	5918 (82)	20808 (222)	20200 (298)	16733 (933)
8	4767 (26)	5382 (33)	5715 (139)	21006 (216)	20083 (210)	16326 (927)
9	4714 (12)	5457 (36)	5920 (124)	20770 (178)	19989 (228)	16621 (780)

Table 2: Ensemble averages and standard errors (in brackets) of real GDP and total credit for different values of α. Statistics are computed over 10 seeds of the random number generator.

α	Banks' equity			Credit rationing (%)		
	1 - 5	6 - 20	21 - 40	1 - 5	6 - 20	21 - 40
4	4048 (64)	4610 (103)	2560 (203)	12.2 (0.1)	0.2 (0.1)	10.5 (0.2)
5	3664 (79)	3851 (242)	1954 (433)	4.3 (0.1)	0.0 (0.0)	13.8 (1.7)
6	3588 (87)	3699 (232)	1621 (423)	0.5 (0.0)	0.0 (0.0)	8.3 (1.1)
7	3279 (94)	3032 (248)	1436 (622)	0.0 (0.0)	0.9 (0.7)	15.1 (3.3)
8	3072 (31)	2941 (162)	1319 (510)	0.0 (0.0)	0.0 (0.0)	14.1 (3.1)
9	2957 (46)	2902 (258)	1192 (334)	0.0 (0.0)	0.1 (0.1)	13.5 (2.8)

Table 3: Ensemble averages and standard errors (in brackets) of banks' aggregate equity and credit rationing (%) for different values of α. Statistics are computed over 10 seeds of the random number generator.

tivity, such as the equity stock, the total credit supplied and the percentage of credit rationing suffered by firms. Tables include also two main nominal variables, namely the price and the wage levels. With regard to prices, it should be noticed that in a non money-neutral economy prices depend both on real and monetary variables and that the monetary aggregate in the Eurace model is endogenous, because it depends on the total credit supply. Three different periods have been considered, i.e., the first 5 years of the simulation (the short run), the central part of the simulation (the medium term) and the last 20 years (the long run). The time averages of the variables have been considered in any period and, in order to increase the robustness of results, the values in the tables report the ensemble averages of the time averages. The ensemble averages have been computed over 10 different seeds of the pseudo-random number generator. Standard errors are shown in brackets.

The tables show how the ensemble average values of the economic variables change with respect to the different values of the allowed leverage level α. Furthermore, the three reference periods permit to interpret the macroeconomic implications of the different strategies of leverage regulation, according to the considered time span. In particular, a major difference is evident comparing the short run (the first 5 years) and the long run (the last 20 years). The results observed in the first 5 years can be interpreted considering that the risk weighted assets of each of the three banks have been initial-

α	Firms' capital stock			Unemployment (%)		
	1 - 5	6 - 20	21 - 40	1 - 5	6 - 20	21 - 40
4	9307 (20)	14881 (354)	20916 (880)	15.6 (0.6)	12.7 (0.4)	12.5 (0.3)
5	9446 (33)	14128 (282)	19959 (677)	16.9 (0.5)	11.7 (0.5)	13.9 (0.5)
6	9495 (12)	13690 (356)	17983 (638)	15.3 (0.2)	11.8 (0.5)	13.6 (0.6)
7	9573 (23)	13802 (276)	18302 (577)	14.2 (0.4)	11.6 (0.3)	13.2 (0.5)
8	9634 (26)	13414 (357)	16737 (1036)	13.5 (0.6)	11.5 (0.4)	13.1 (0.7)
9	9575 (19)	13946 (325)	18489 (1000)	14.5 (0.3)	11.5 (0.3)	13.4 (0.5)

Table 4: Ensemble averages and standard errors (in brackets) of firms' aggregate capital stock and unemployment rate (%) for different values of α. Statistics are computed over 10 seeds of the random number generator.

α	Price index			Wage level		
	1 - 5	6 - 20	21 - 40	1 - 5	6 - 20	21 - 40
4	0.76 (0.00)	0.87 (0.02)	1.07 (0.03)	1.53 (0.02)	2.0 (0.05)	2.82 (0.11)
5	0.76 (0.00)	0.84 (0.01)	1.05 (0.03)	1.53 (0.02)	1.88 (0.05)	2.74 (0.10)
6	0.77 (0.00)	0.82 (0.01)	0.97 (0.02)	1.53 (0.01)	1.81 (0.04)	2.43 (0.09)
7	0.78 (0.00)	0.83 (0.01)	0.98 (0.02)	1.54 (0.00)	1.83 (0.04)	2.47 (0.08)
8	0.78 (0.00)	0.81 (0.02)	0.92 (0.04)	1.54 (0.00)	1.77 (0.06)	2.25 (0.14)
9	0.78 (0.00)	0.83 (0.02)	0.98 (0.04)	1.55 (0.00)	1.86 (0.05)	2.51 (0.15)

Table 5: Ensemble averages and standard errors (in brackets) of aggregate price and wage levels for different values of α. Statistics are computed over 10 seeds of the random number generator.

ized to be five times the initial level of equity. This implies that for values of α lower or equal to 5, the constraint on bank leverage is binding and it is not possible for banks in the short run to increase the supply of credit in order to match the demand by firms. The limitation of banks' loans explains the high percentage values we observe for credit rationing in the first 5 years for $\alpha = 5$ and in particular for $\alpha = 4$, see Table 3, and the consequent lower level of credit-money in the economy as observed in Table 2. The lower level of credit supply reduces the opportunities for firms to invest, to increase production and to hire new workers, and this is clearly evident in the short-run values of GDP, employment and firms' capital stock which are the lowest for the values of α less or equal to 5 and increase more or less monotonically as α increases, see Tables 2 and 4. On the contrary, the aggregate equity level of banks is monotonically decreasing with the leverage level α in the short run. In fact, in the case banks face a credit demand higher than their supply constraints, as fixed by the institutional arrangements (α) and their equity level, they stop the payment of dividends to raise their net worth and to become able to meet the demand of credit in excess of supply.

The short run macroeconomic implications of the different values of α fade if the medium term time span is considered (years between 6 and 20) and disappear in the long run. Indeed, it emerges that the short run implications are somehow reversed in the second half of the simulation, where we observe a better economic welfare on average for the highest capital requirements (low values of α), and in particular for $\alpha = 4$. The values of real GDP in table 2 actually show that lower capital requirements do not allow for economic expansion in the long run. We state that banks' equity plays again a crucial role in determining these findings. In fact, firms' failures occurring in the course of the simulation and the consequent debt write-offs reduce considerably the equity of banks, see Table 3. Furthermore, the consequences of firms' failure are more severe when the value of α is high. The reasons is twofold: first in the case of low capital requirements (high α), banks do not stop dividends' payments, due to the absence of credit rationing in the short run; therefore, they keep their net worth at the initial relatively low levels; second, debt write-off are higher for more indebted firms, and firms' indebtedness is higher for high α, due to the easier access to credit in the short run. In fact, as it is clearly evident in Table 3, banks' equity levels in case of lower capital requirements are small in the first part of the simulation and are also subject to the biggest reduction.

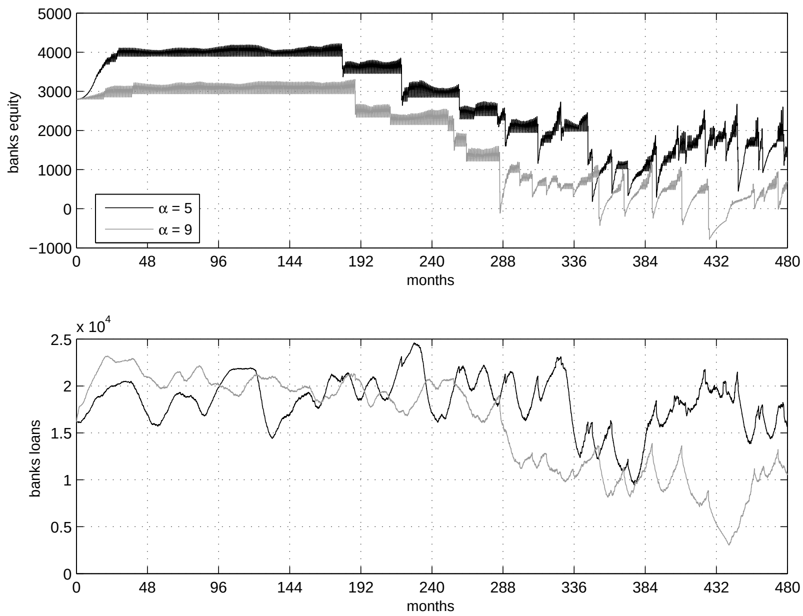

Figure 3: Banks' aggregate equity level (top panel) and aggregate amount of outstanding loans (bottom panel). Two different values of α have been considered for the same seed, i.e., $\alpha = 5$ (black line) and $\alpha = 9$ (gray line).

Figure 3 shows the dynamics of the aggregate equity of banks (top panel) and the total level of loans supplied by banks to firms (bottom panel). It is worth reminding that the dynamics of the equity of any bank depends on dividends' payments and on the eventuality of debt write-offs, due to firms' bankruptcy. In normal conditions, banks usually pay out all their profits as dividends to shareholders; however, in the case the Basel II-like institutional constraint set by α is binding, i.e., the demand for credit at a bank is higher than the allowed supply at the present equity level, then the bank stops dividends payments in order to increase its equity and thus being able to satisfy the entire loan demand in the future. This behavioral feature explains the increase in the aggregate level of equity that is occurring in the case of low αs. In particular, it is worth noting the rise in the aggregate equity level that can be observed in the figure (top panel) at the beginning of the simulation for $\alpha = 5$, i.e., when the constraint is more binding and therefore credit rationing is expected to occur. This effect can be examined also by looking at banks' equity values of the first 5 years in table 3, considering that bank's equity is always initialized at a value close to 3000 (as shown also by figure 3). The subsequent large drops of equity in figure 3 are therefore explained by firms' bankruptcy and consequent debt write-offs.

The dynamics of the aggregate amount of loans (bottom panel) is consistent with the equity paths represented in the top panel, in particular whenever the demand for loans is rationed by insufficient levels of equity on the side of banks. In fact, at the beginning of the simulation the aggregate amount of outstanding loans in the $\alpha = 5$ case is lower than the amount in the $\alpha = 9$ case, consistently with the aggregate equity increase occurring for $\alpha = 5$ which indicates credit rationing. Furthermore, in the second part of the simulation, the higher amount of outstanding loans for $\alpha = 5$ can be explained by the lower severity of credit rationing in that case, as the higher equity level for $\alpha = 5$ should clearly indicate.

Figure 4 shows the dynamics of two key nominal variables of the economy, i.e., the price (top panel) and the wage level (bottom panel). The paths of the two variables exhibit a general upward trend with some volatility, in particular for prices. It is worth noting that the steepness of the upward trend depends on α and on the period considered. In particular, in the short run the price and wage values are generally higher for $\alpha = 9$, while in the long run the upward trend of prices and wages is clearly steeper for $\alpha = 5$. This result is consistent with the figures showed in the tables and with economic intuition, i.e., the dynamics of prices and wages positively depends on the one of monetary aggregates and on the conditions of the real side of the economy.

Figure 5 shows in the top panel the dynamics of the monetary aggregate, i.e. the aggregate amount of liquid monetary resources in the Eurace economy, and presents in the bottom panel the sum of the aggregate amount of outstanding loans and of central bank liabilities. The monetary aggregate is defined at any time as the sum of all private (i.e., held by households and firms) and public (i.e., held by the Government and the Central Bank) deposits plus banks' equity. The initial value of the aggregate amount of outstanding loans is given by the sum of the debt of any firm, where firms' debt has been uniformly initialized so to have a leverage, i.e., a debt to book value of equity ratio, equal to 2, considering also the assigned book value of assets. In real economies the amount of outstanding banknotes is part of the central bank liabilities. In Eurace, the initial value of central bank liabilities is defined as residual, i.e., as the difference between the initial value of the previously defined monetary aggregate and the initial aggregate amount of outstanding loans. The high-powered money provided by the central bank is therefore the part of the monetary aggregate not explained by banks' loans. In absence of a quantitative easing policy performed by the central bank, i.e., if the cen-

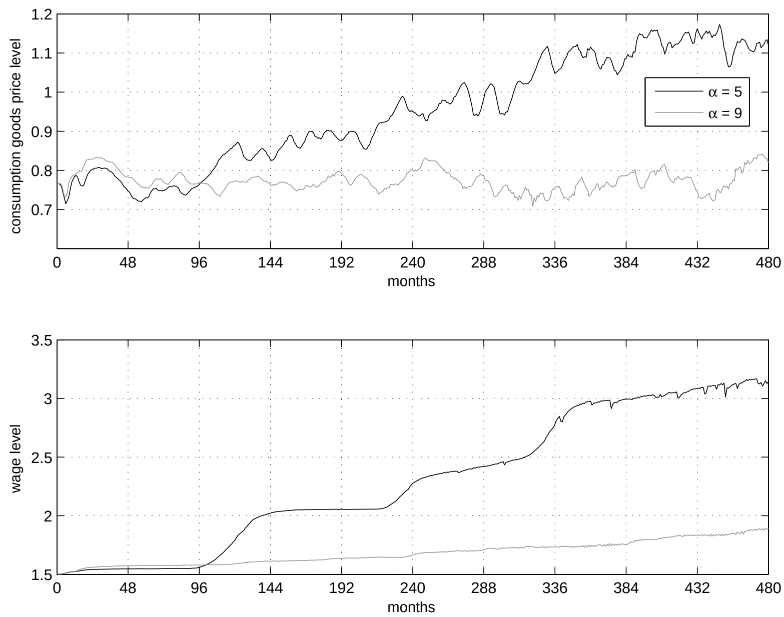

Figure 4: Price level (top panel) ana wage level (bottom panel). Two different values of α have been considered for the same seed, i.e., $\alpha = 5$ (black line) and $\alpha = 9$ (gray line).

tral bank does not inflate its balance sheet by purchasing government bonds, as it is the case for the results presented in this study[5], central bank liabilities has to be considered constant, and the variation of the monetary aggregate should be eventually explained only by the dynamics of the aggregate amount of outstanding loans. Figure 5 confirms the above argument, as the time value of the monetary aggregate (top panel) is identical to the time series presented in the bottom panel, i.e., to the value of outstanding loans plus central bank liabilities, the latter to be considered constant in the simulations. This result further corroborates the rationale behind the theory of endogenous money. The different behavior observed with respect to the two values of α is consistent with the figures presented in the tables and with previous considerations. In particular, the values of the monetary aggregate and its counterpart, i.e. the aggregate outstanding loans plus the central bank liabilities, are characterized by higher values in the short run for $\alpha = 9$, while in the long run the situation is reversed and the time series referred to $\alpha = 5$ dominate.

The clear evidence of results presented in this study is that the monetary aggregate plays a key role in determining the real variables of the economy. Furthermore, the

[5]A study about the effects of quantitative easing in the Eurace economy can be found in Cincotti et al. 2010 [14].

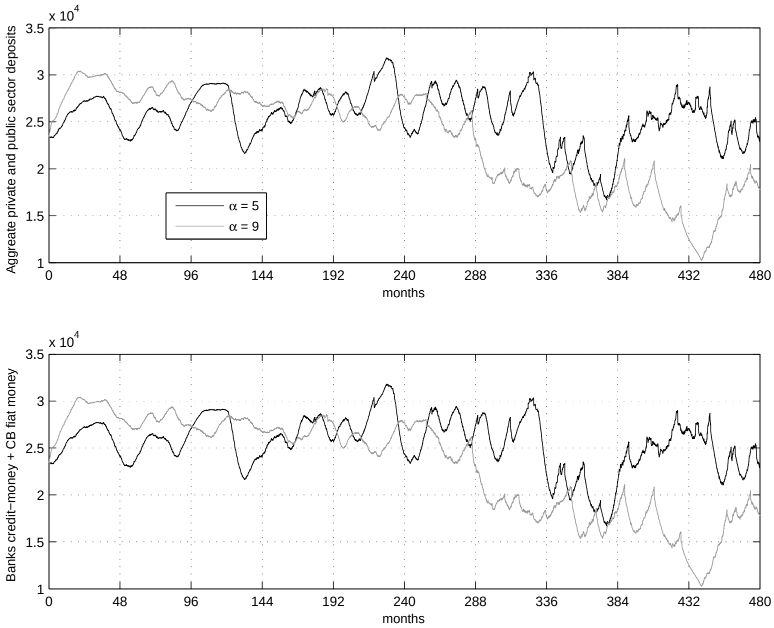

Figure 5: Aggregate amount of liquid monetary resources (top panel) and aggregate amount of outstanding loans plus central bank liabilities (bottom panel). Two different values of α have been considered for the same seed, i.e., $\alpha = 5$ and $\alpha = 9$.

monetary aggregate is made by two components, an endogenous one, or endogenous money, which is given by the aggregate outstanding loans created by the banking sector, and an exogenous one which is set by the monetary authorities, i.e., by the central bank. The first component should be considered as endogenous because is determined by the self-interested interaction of private agents, i.e., banks and firms, while the second component can be considered as exogenous because may depend on discretionary unconventional monetary policies, like quantitative easing. The rate of growth and long-run dynamics of endogenous money, however, depends also on parameters or institutional constraints, like α, which can be considered as exogenous because set by the regulatory authorities. Actually, the main result of the paper regards the role of a policy setting, like banks' capital adequacy ratio, on the dynamics of endogenous money and therefore on the growth of the economy.

Investigating the role played by the monetary aggregate in the real economy has been the subject of research in economics for many years and is still the topic of a wide debate, as testified by the controversy between endogenous and exogenous money theorist [9, 17, 18]. In this paper, we limit to point out an interesting similarity between Eurozone economic data and Eurace data concerning the cross-correlation between the percentage variations of GDP and percentage variations of M3, as shown in figure 6.

The left panel shows the cross-correlation diagram between the percentage variations of real GDP, shown in Figure 2 (bottom panel), and the monetary aggregate, shown in Figure 5 (top panel), both for $\alpha = 5$. The right panel presents again the cross-correlation diagram computed now considering the percentage variations of Eurozone real GDP and the percentage variation of a broad measure of the monetary base, the so-called M3. Eurozone cross-correlation diagram has been computed on a quarterly base, contrary to the Eurace case, where data are all macroeconomic data are conventionally generated on a monthly time scale. In fact, Eurone GDP are provided on a quarterly base, therefore also M3 data, which are recorded on a monthly base, has been transformed to a quarterly time series, by considering the quarterly average. Eurozone GDP data are working day and seasonally adjusted as well as chain-linked to adjust for inflation with the 2000 as reference year. Eurozone GDP data refers to the period I quarter 1995 - IV quarter 2010, while M3 data to the period January 1995 - December 2010. All data are available on Internet at the European Central Bank statistical data warehouse[6].

It is worth noting that, apart the different time scales involved, the two cross-correlation diagrams are characterized by a similar pattern, as in both cases the percentage variations of real GDP lead the percentage variations of the monetary aggregate. This finding further confirm the rationale behind the theory of endogenous money, stating that the stock of money is determined by the demand for bank credit, which is in turn induced by the economic variables that affect the GDP.

3 Conclusions

After start of the global financial crisis in 2007, an increasing attention has been devoted to the design of proper regulation systems of the banking sector. A great effort has been done in order to understand and foresee the consequences of different regulation strategies on the stability of the financial system, on growth, and on the main macroeconomic variables. As pointed out in the introduction, many reports on this topic are available, mainly produced by central banks research centers or by international organizations. One of the central themes is the assessment of the long-term impact of different capital requirements for banks. The methodology is typically based on a set of economic models that originate in the DSGE class, which are estimated or calibrated according to data sets belonging to specific countries or areas.

The aim of this paper is to tackle the same topic using an agent-based approach. The Eurace model provides with a complex economic environment where to run computer simulations and to perform what-if analysis related to policy issues. The model has been calibrated by using realistic empirical values both for the parameters of the model and for the state variables initialization.

Capital adequacy ratio, i.e., the ratio between banks' equity capital and risk-weighted assets, has been chosen as the key varying parameter that assumes six different values. For each value a set of ten simulations with different random seeds has been run, and the results have been reported and analyzed.

[6] `http://sdw.ecb.europa.eu`

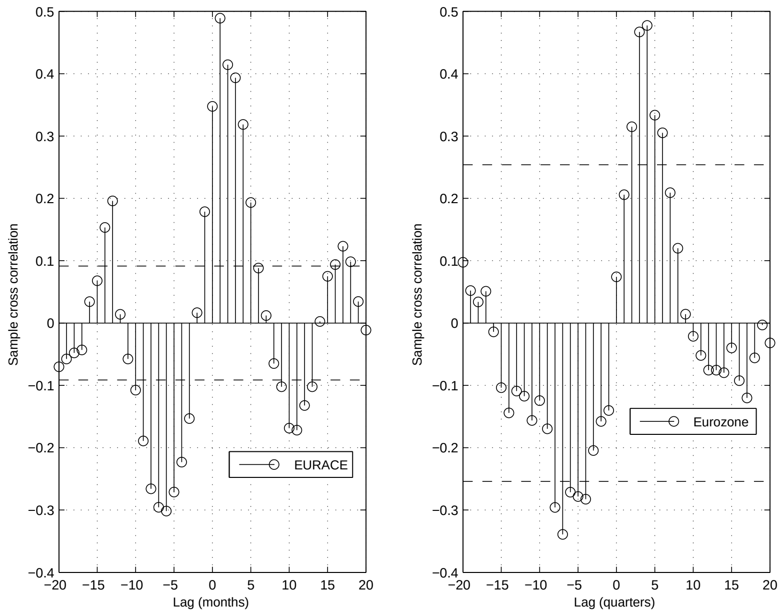

Figure 6: Cross-correlation diagram between Eurace real GDP and monetary aggregate data (left panel) and between Eurozone real GDP and M3 data. The dashed symmetric bounds refers to the 95 % confidence level interval for the sample cross-correlation under the null hypothesis of zero theoretical cross-correlation. The bounds values are given by $\pm\frac{2}{\sqrt{N}}$, where N is the sample size. This explains the difference between the left panel bounds, where we have 480 monthly data, i.e., 40 years of simulation, and the Eurozone case (right panel) characterized by only 64 quarterly data, i.e., the 16 years from 1995 to 2010.

The outcomes of the models consist of time series that are characterized by quite realistic graphical patterns. In particular long-run growth and endogenous business cycles are observed. The capital adequacy ratio proved to have significant macroeconomic implications that depend critically on the considered time horizon.

In the short run (up to five years) a lower leverage policy, restricting the credit supply, has negative macroeconomic consequences, reducing growth, investments and employment. Actually, the limited credit supply determines firms' rationing, whereas a higher leverage allows firms to get loans without incurring in credit rationing. However, the higher debt load that firms acquired in the short run in the case of less restrictive policies, i.e., low capital adequacy ratio, turns out to have significative implications if considered along with the lower equity capital of banks. Indeed, in the case of low capital adequacy ratio, firms financial fragility becomes higher and consequently firms bankruptcies are more frequent. These bankruptcies undermine the equity capital of banks, that in the case of high leverage has not been sufficiently raised by banks, determining a severe reduction of the lending capacity of the banking sector in the long run. On the other hand, if capital adequacy ratio is higher, firms experience less opportunities to increase production and hire new workers in the short run, but later, due to the higher equity of banks, that needs to raise it by retaining dividends in order to face the credit demand, the banking system proves to be more stable, with lower values of credit rationing and a higher level of total loans.

According to the outcomes of the Eurace model, the credit dynamics markedly influences the macroeconomic activity. The banking system is therefore crucial, and an appropriate set of regulations seem to have great potential benefits for growth and economic stability. The model we presented reproduces in detail the interaction among economic agents, and shows that it can already be effectively used as an environment where performing economic analysis and forecast, and where testing policy strategies.

Acknowledgement

This work was carried out in conjunction with the Eurace project (EU IST FP6 STREP grant: 035086) which is a collaboration lead by S. Cincotti (Università di Genova), H Dawid (Universitaet Bielefeld), C. Deissenberg (Université de la Méditerranée), K. Erkan (TUBITAK-UEKAE National Research Institute of Electronics and Cryptology), M. Gallegati (Università Politecnica delle Marche), M. Holcombe (University of Sheffield), M. Marchesi (Università di Cagliari), C. Greenough (Science and Technology Facilities Council Rutherford Appleton Laboratory).

References

[1] Basel ii: International convergence of capital measurement and capital standards: A revised framework - comprehensive version. Technical report, BIS, Basel Committee on Banking Supervision, 2006.

[2] Eurace Final Activity Report. Technical report, Eurace Project, 2009.

[3] An assessment of the long-term economic impact of stronger capital and liquidity requirements. Technical report, BIS, Basel Committee on Banking Supervision, 2010.

[4] Interim report on the cumulative impact on the global economy of proposed changes in the banking regulatory framework. Technical report, Institute of International Finance, 2010.

[5] Strengthening international capital and liquidity standards: A macroeconomic impact assessment for canada. Technical report, Bank of Canada, 2010.

[6] Anat R. Admati, Peter M. DeMarzo, Martin F. Hellwig, and Paul Pfleiderer. Fallacies, irrelevant facts, and myths in the discussion of capital regulation: Why

bank equity is not expensive. Working Paper Series of the Max Planck Institute for Research on Collective Goods 2010-42, Max Planck Institute for Research on Collective Goods, September 2010.

[7] Tobias Adrian and Hyun Song Shin. Liquidity and leverage. *Journal of Financial Intermediation*, 19(3):418–437, July 2010.

[8] Paolo Angelini, Laurent Clerc, Vasco Curdia, Leonardo Gambacorta, Andrea Gerali, Alberto Locarno, Roberto Motto, Werner Roeger, Skander Van den Heuvel, and Jan Vlcek. Basel iii: Long-term impact on economic performance and fluctuations. Questioni di economia e finanza, Banca d'Italia, 2011.

[9] Philip Arestis and Malcolm Sawyer. The nature and role of monetary policy when money is endogenous. *Cambridge Journal of Economics*, 30(6):847–860, November 2006.

[10] Allen N. Berger, Richard J. Herring, and Giorgio P. Szego. The role of capital in financial institutions. *Journal of Banking & Finance*, 19(3-4):393–430, June 1995.

[11] Jurg Blum and Martin Hellwig. The macroeconomic implications of capital adequacy requirements for banks. *European Economic Review*, 39(3-4):739–749, April 1995.

[12] Ricardo J Caballero. A fallacy of composition. *American Economic Review*, 82(5):1279–92, December 1992.

[13] Ricardo J. Caballero. Macroeconomics after the crisis: Time to deal with the pretense-of-knowledge syndrome. *Journal of Economic Perspectives*, 24(4):85–102, Fall 2010.

[14] Silvano Cincotti, Marco Raberto, and Andrea Teglio. Credit money and macroeconomic instability in the agent-based model and simulator Eurace. *Economics: The Open-Access, Open-Assessment E-Journal*, 4(26), 2010. http://dx.doi.org/10.5018/economics-ejournal.ja.2010-26.

[15] H. Dawid, S. Gemkow, P. Harting, and M. Neugart. Spatial skill heterogeneity and growth: an agent-based policy ananlysis. *Journal of Artificial Societies and Social Simulation*, 12(4), 2009.

[16] Herbert Dawid, Michael Neugart, Klaus Wersching, Kordian Kabus, Philipp Harting, and Simon Gemkow. Eurace Working Paper 7.1: Capital, Consumption Goods and Labor Markets in Eurace. Technical report, Bielefeld University, april 2007.

[17] G. Fontana. Post keynesian approaches to endogenous money: a time framework explanation. *Review of Political Economy*, 15:291–314, 2003.

[18] W. Godley and M. Lavoie. *Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth*. Palgrave Macmillan, 2007.

[19] Martin Hellwig. Capital regulation after the crisis: Business as usual? Working paper series of the max planck institute for research on collective goods, Max Planck Institute for Research on Collective Goods, July 2010.

[20] Katarina Juselius and Massimo Franchi. Taking a dsge model to the data meaningfully. *Economics: The Open-Access, Open-Assessment E-Journal*, 1(2007-4), 2007.

[21] Peter Kriesler and Marc Lavoie. The new consensus on monetary policy and its post-keynesian critique. *Review of Political Economy*, 19(3):387–404, 2007.

[22] S. Myers and N.S. Majluf. Corporate financing and investment decisions when firms have information that investors do not have. *Journal of Financial Economics*, 13(2):187–221, June 1984.

[23] A. Teglio, M. Raberto, and S. Cincotti. *Balance sheet approach to agent-based computational economics: the EURACE project*, volume 77 of *Advances in Intelligent and Soft Computing*, pages 603–610. Springer Verlag, 2010.

[24] A. Teglio, M. Raberto, and S. Cincotti. *Endogeneous credit dynamics as source of business cycles in the Eurace model*, volume 645 of *Lecture Notes in Economics and Mathematical Systems*, pages 203–214. Springer Verlag, 2010.

[25] L. Tesfatsion and K. Judd. *Agent-Based Computational Economics*, volume 2 of *Handbook of Computational Economics*. North Holland, 2006.