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From financial instability to green finance: the role of banking and monetary policies in the Eurace model

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Abstract

We investigate appropriate banking and monetary policies aimed to pressure the banking and financial sector to shift from speculative lending, cause of asset bubbles and economic crises, to green investments lending, in order to foster the transition to a more energy efficient production technology. For this purpose, we consider an enriched Eurace model, which include new features such as a residential housing market, mortgage lending and heterogenous capital goods allowing for different degrees of energy efficiency in the production technology. Credit money in Eurace is endogenous and limited by Basel capital adequacy regulation on the supply side, while on the demand side it is determined by firms' investments and households' house purchasing. We introduce a differentiation of capital requirements according to the destination of lending, demanding higher banks' capital in the case of speculative lending, thus encouraging banks to finance firms investments. As up-to-date capital goods have better energy efficiency in the model design, a higher pace of investments implies also a positive environmental effect. Results suggest that the proposed regulation is able to foster investments and capital accumulation in the short term, improving the energy efficiency of firms. However, reducing mortgages with a restrictive regulation has a negative impact on total private credit, and thus on endogenous money supply, weakening consumption and aggregated demand. In the long term, the contraction of total credit becomes stronger, and the negative outcomes on aggregated demand also affect investments. Therefore, in the long run, the positive effects on capital and energy efficiency become negligible, while the main economic indicators deteriorate.

Keywords: Green finance, Capital requirements, Energy efficiency, Agent-based modelling

JEL classification: E51, Q58, C63

From financial instability to green finance: the role of banking and monetary policies in the Eurace model

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Abstract

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1. Introduction

Achieving the goal to limit global temperature increases below 2 deg C with respect to preindustrial levels, as agreed by 195 countries at the United Nations climate change conference, known as COP21, held in Paris in December 2015, will require enormous investments in the green sectors of the economy. Strongest efforts shall be devoted in particular to fostering the transition of energy production from fossil fuels to renewable sources and to the improvement of energy efficiency in buildings, industries and in the transportation sector.
Year 2015 hit a new record high for global investment in renewable energy projects that, excluding large hydro-electric projects, amounted to $ 285.9 billions, whose more than half have been made in the developing world including China, India and Brazil, see UNEP (2016). However, different studies have pointed out that the size of investment required each year in low carbon sectors to limit the temperature increase to the target should be much higher, i.e. in a range from $ 650 billions to $ 1 trillion, see e.g. IEA (2012); WEF (2013). Therefore, there is a relevant so-called green investment gap that need to be covered. This however looks a particular challenging task in the present economic environment characterized by low growth in advanced economies and increasing risks in developing ones. Furthermore, green investments are usually characterized by high political uncertainty regarding the real long-term commitment of public policies of support, by long-term time horizon and very high initial capital costs (Nelson and Shrimali (2014)). These features make low-carbon investments unattractive to private investors in absence of a strong and sizeable long-term commitment by the government to some form of public support.
The most well-known and discussed solution to the low-carbon investment challenge has been the introduction of a price on carbon (Nordhaus (2013); WB (2015)), either through a carbon tax, i.e. a tax on the carbon content of goods and services, or through a cap-and-trade system of emissions allowances, with the aim to address the market failure related to the exclusion of environmental costs from the market pricing system. The rationale is that a carbon price would push private agents to correctly internalize environmental costs and therefore to perform the appropriate green investments aimed to reduce them. However, carbon price mechanisms still have strong political opposition[1] on the grounds that they are harmful for business and can damp economic growth.
Beside carbon pricing, a new idea that is gaining attention concerns the design of appropriate banking regulation and monetary policies aimed to push banks to lend to low-carbon activities so to easy the green investment gap, see e.g. Rozenberg et al. (2013); Ferron and Morel (2014); Aglietta et al. (2015); Campiglio (2016). In particular, proposals have been discussed aimed at differentiating reserve ratio requirements or capital requirements in favor of green

[1] See e.g. the repeal of the carbon tax by the new Australian government in 2014 or the debate in the US 2016 presidential race

investments. A similar proposal concerns setting undifferentiated capital requirements but reducing the risk weights of loans directed to the green sector so to easy the fulfillment of the minimum capital requirement provisions for banks supporting green investments. A banking regulatory framework, where banks that lend to firms undertaking green investments are required to respect looser requirements, could indeed manage to direct credit towards the green sector and therefore reduce the green investment gap.
In this paper, we investigate the banking regulatory provision that differentiates the capital adequacy ratio according to the type of lending. In particular, we employ an agent-based macro-economic model and simulator to study the effectiveness and the long-run impact on the economy of this type of regulatory provision. A number of agent-based macro models[2] have been proposed in recent years to address the known limitations of the traditional DSGE modelling approach in macroeconomics, see Fagiolo and Roventini (2016) for a comprehensive review and comparison of the two approaches. Furthermore, agent-based macro-models has going to be applied also to study climate change economics and investigate related policies, see e.g. Farmer et al. (2015); Gerst et al. (2013); Monasterolo and Raberto (2016); Tonelli et al. (2016). We claim that the agent-based modelling approach is particularly suited to encompass the relevant features needed to address our research question, such as the endogenous nature of money created by the banking system in modern economies, see e.g. McLeay et al. (2014); Werner (2014), and the non-equilibrium evolutionary dynamics of the economy (Kaldor (1972); Arthur (2006)).
Our regulation design follows an idea of Campiglio (2016), suggesting to impose different capital adequacy ratios according to the type of lending that banking institutes provide. Accordingly, we have designed a set of computational experiments characterized by capital requirements for mortgages that can be higher or lower than a reference value, i.e. 10 %, which is the basic capital requirement value adopted for firms' loans. The rationale behind this choice is the assumption that house purchases are made mostly for speculative purposes and may produce asset bubbles with destabilizing effects, while loans to business firms are aimed to increase and renew their capital endowment with positive effects for the productive capacity of the economy and for environmental sustainability, as in our model design, investments in capital goods provide also an environmental benefit as the new vintages are characterized by higher energy efficiency[3].

The paper is structured as follows: Section 2 outlines the agent-based macroeconomic model we have employed and Section 3 presents the computational

[2] A non exhaustive list could include the K+S model, see Dosi et al. (2010, 2013, 2015), the so-called `modellaccio" (Caiani et al. (2015) and other models by the Ancona research group (Riccetti et al. (2015); Russo et al. (2016)), the CC-MABM (Assenza et al. (2015)), the Mark I CRISIS model (Klimek et al. (2015); Gualdi et al. (2015)), Iceace (Erlingsson et al. (2014)), Eurace (Cincotti et al. (2012a)) and Eurace@UNIBI (Dawid et al. (2016))

[3] It is worth noting that a 20 % increase in energy efficiency by 2020 with respect to 1990 is among the three well know 20-20-20 targets set by the European Union in 2009, see: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009D0406

experiments performed and discusses the relevant results. Concluding remarks are drawn in section 4.

2. The enriched Eurace model

2.1. Model overview

Eurace is an agent-based macroeconomic model and simulator that has bee developed in the last ten years within two EU-funded projects[4], see Cincotti et al. (2010, 2012a,b); Raberto et al. (2012); Teglio et al. (2012); Raberto et al. (2014); Teglio et al. (2015). The baseline Eurace model includes different types of agents: households (HHs), which act as workers, consumers and financial investors; consumption goods producers (CGPs), henceforth firms, producing a homogenous consumption goods; a capital goods producer (KGP); commercial banks (Bs) and two policy makers agents, namely a government (G) and a central bank (CB), which are in charge of fiscal and monetary policy, respectively. Agents' behavior is modelled as myopic and characterized by limited information, scarce computational capabilities and adaptive expectations. The details about agents' decision making in the baseline Eurace model are described in Teglio et al. (2015). Agents interact through different markets where consumption and capital goods, labor and credit are exchanged in a decentralized setting with disperse prices set by suppliers and based on costs.

In order to investigate the appropriate banking and monetary policies aimed to force the banking and financial sector to move away from speculative lending, cause of asset bubbles and economic crises, to the financing of the green sector, an enriched Eurace model has been designed. The new model includes a residential housing market and a related mortgage lending device. It also includes an energy sector, where electricity production is based on fossil fuels. In particular, electricity is an additional production factor used by consumption goods producers, which use heterogeneous capital goods characterized by endogenous electricity efficiency. Finally, we designed banks' capital requirements which can vary according to the type of lending, i.e. loans to business firms or mortgages to households.

The housing market is characterized by households that sell or buy homogeneous houses units subject to budget constraints. If a prospective buyer needs a mortgage, she/he can send a request to a bank, which provides the mortgage only if the expected future income of the potential buyer is deemed sufficient to face scheduled mortgage payments and the bank itself satisfies Basel capital requirements conditions. Households buying and selling decisions in the market are set by an exogenous probability, unless in the case of an household who is in troubled financial conditions (because mortgages payments have exceeded a given threshold fraction of income) and is forced to fire sale her/his housing units at a discounted price to reduce mortgage payments and the debt burden. Trading in the housing market is decentralized, prices are posted by sellers while

[4]FP6 European Project EURACE and EU-FP7 project SYMPHONY

prospective buyers are randomly queued to choose the available housing unit at the lowest price.
Consumption goods producers (CGPs) need electricity, in addition of labor and capital, as a production input. The electricity efficiency of the production process is not constant but depends on the composition of the capital goods vintages in the capital endowment of every firm (CGP). The lower the average age of capital goods of a firm, the higher the energy efficiency of production, or equivalently, the lower the energy intensity of production, i.e. the amount of electricty/energy[5] required per unit of output.
Banks' capital adequacy ratios have been differentiated with respect to the type of lending, i.e. loans to business firms, aimed to increase both the productive basis of the economy and the energy efficiency of the production process, and mortgages to households for house purchases, that in the model have a mere speculative/trading purpose.

The full details about the housing market in Eurace as well as the different conditions for mortgages lending and their effects on the housing price and the economy can be found in Ozel et al. (2016).
The following two paragraphs will provide the modelling details about the use of energy sector and the energy efficiency of the production sector as well as about the differentiation of banks' capital requirements.

2.2. The energy sector and energy efficiency

We assume that to produce the amount q_{C_f} of consumption goods, firm f needs an appropriate number of employees and an appropriate capital endowment, as fixed by the Cobb-Douglas technology, see (Teglio et al., 2015, Appendix, Eq. 8). In this new setting the firms also needs an amount of energy, say q_E, determined by the equation:

$$q_E = \epsilon_f \, q_{C_f} \, ,$$

where ϵ_f is a firm-specific energy intensity variable that gives the energy amount required per unit of output. We assume no substitutability between energy and the other two inputs, i.e. labor and capital. CGPs are never rationed in their energy demand which is immediately delivered by the power producer agent[6] on request at a price p_E which is determined by a mark-up on the price of fossil fuels, p_O. The price of fossil fuels is exogenously given and constant.
Energy costs $P_E q_E$ are a variable cost that is taken into account by the firm in

[5]In the paper, we will use the terms electricity and energy interchangeably, with no distinction.

[6]The power producer (PP) agent is a very stylized agent that imports fossil fuels from the foreign sector and produces electricity on request with no labor force needed. PP profits depends on the difference between p_E and p_O and are paid out to shareholders (households) in the Eurace economy.

addition to labor costs, interest rates and capital depreciation in the determination of unit costs of output, see (Teglio et al., 2015, Appendix, Eq. 10). Thus energy costs have also an impact on consumption goods prices.

Energy intensity ϵ_f is determined by the different vintages of capital goods owned by firm f. We assume that each unit of capital goods, when employed in the production process by the firm, requires an amount of energy per unit of output, i.e. an energy intensity ϵ_K, that depends on the time the capital goods has been manufactured by the capital goods producer (KGP) and delivered to the firm (CGP). In particular, we assume that, due to technological progress, the capital goods producer is able to manufacture capital goods characterized by an energy intensity ϵ_K which decreases over time at the monthly rate ξ_K. The energy intensity of each firm then decreases over time according to the size and timing of its investment decisions. When a firm f makes an investment ΔK_f, its energy intensity decreases according to the weighted average:

$$\epsilon_f = \frac{\widehat{\epsilon}_f \, K_f + \epsilon_K \, \Delta K_f}{K_f + \Delta K_f} \,, \tag{1}$$

where $\widehat{\epsilon}_f$ was the electricity intensity characterizing the production process of the firm before the investment, while ϵ_K is the electricity intensity of the new vintages of capital goods ΔK_f.

As ϵ_K is supposed to decrease over time according to an exogenously given technological progress, firm specific electricity intensity ϵ^f improves over time due to new investments; therefore, investment decision making, based on net present value calculations, needs to take into account not only the additional positive cash flows from sales due to the higher productive capacity, as stated in (Teglio et al., 2015, Appendix, Eq. 3), but also the negative cash flow related to the energy expenses due to the additional output, as well as the positive cash flows given by the savings of energy expenses per unit of output because of the lower average ϵ^f. In particular, firm f chooses the investment ΔK_f that maximizes a net present value NPV given by three terms as follows:

$$NPV = NPV^{old} + PV^{(1)} + PV^{(2)} \,, \tag{2}$$

where NPV^{old} takes into account the present value additional future revenues, due to the expanded production capacity, net of the present cost of capital, as showed in (Teglio et al., 2015, Appendix, Eq. 3), while $PV^{(1)}$ and $PV^{(2)}$ are given by the following equations:

$$PV^{(1)} = -\sum_m \frac{p_E \, \epsilon_f \, \Delta_m q_{C_f}}{\left(1 + \frac{r_{K_f}}{12}\right)^m} \tag{3}$$

$$PV^{(2)} = +\sum_m \frac{p_E \, \Delta\epsilon_f \, q_{C_f}}{\left(1 + \frac{r_{K_f}}{12}\right)^m} \tag{4}$$

where r_{K_f} is the yearly weighted average cost of capital for firm f, $\Delta_m q_{C_f}$ is the additional output[7] at future month m given by the planned investment, $\Delta\epsilon_f$ is the decrease in energy intensity due to investments and q_{C_f} is the previous production level. Therefore, $PV^{(1)}$ measures the present value of higher energy expenses due to the output increase, while $PV^{(2)}$ assesses the savings in energy expenses due to the better ϵ_f applied to the previous output level.

2.3. Differentiation of banks' capital requirements

Following the provisions of the Basel capital regulations, bank agents in Eurace are characterized by minimum capital requirements, i.e. by a minimum ratio between equity (net worth) and risk weighted assets that each bank must satisfy. The rationale for capital requirements is to provide a minimum capital buffer that should be employed to cushion loans or mortgages write-offs and consequent equity losses so to reduce the likelihood of incurring in negative equity and insolvent banks. In particular, in the Eurace model, we state that a bank b, when receiving a new loan request $\widehat{\ell}_f$ from a firm or a new mortgage request from a household, it is allowed to fulfill the request only if its equity base E_b is higher than a fraction Ψ of its risk-weighted portfolio of loans and mortgages, including the new prospective loan or mortgage, i.e. only if following condition holds:

$$E_b \geq \Psi\Big(\sum_i \omega_i a_i + \omega_{a^*} a^*\Big), \tag{5}$$

where Ψ is the capital adequacy ratio, i.e. a policy parameter ranging from 0 to 1, set by the regulatory authority, ω_i is the risk weight of any existing asset a_i (loan or mortgage) of the bank, and a^* is the new prospective asset (loan or mortgage) with its risk weight ω_{a^*} if the credit request will be agreed.

A lower capital adequacy ratio Ψ implies a looser credit regulation policy and a higher the likelihood of boom and bust credit cycles with direct effects in the economy. The role of capital requirements for the determination of credit supply and the boom and bust cycles in the Eurace model has been thoughtfully explored, see Cincotti et al. (2012b); Raberto et al. (2012); Teglio et al. (2012). In particular, we performed different computational experiments by varying the leverage α of the banking system, defined as the inverse of the capital adequacy ratio, i.e. $\alpha = \ /\Psi$, in a setting where credit is characterized by loans to firms only. Our experiments showed that, while loose capital requirements (relatively low ψ, i.e. high α) may induce a credit-driven boom in the short run, the over-levered firms may face at some point[8] in the future the impossibility to sustain the increasing interest payments with consequent default cascades which are furtherly amplified by the ensuing rationing of bank credit, see Raberto et al. (2012); Teglio et al. (2012). Furthermore, we also explored Cincotti et al. (2012b) the potential benefits of a macroprudential approach to banks' capital regulation that would allow varying capital requirements depending on some

[7]it is worth noting that the additional output is assumed to be a decreasing function of m to take into account the investments depreciation, see (Teglio et al., 2015, Appendix, Eq. 5).

[8]This could be considered what is usually known as Minsky moment, see Minsky (1986).

measures of the business cycle, such as the unemployment, the credit to GDP ratio or the credit growth rate.

In the present study, we differentiate the capital adequacy ratio according to the type of credit provided, i.e. loan or mortgage. In particular, if the request received by bank b is for a new loan $\widehat{\ell}_f$ by firm f, we stipulate that the bank is allowed to grant the loan only if the following relation holds:

$$E_b \geq \Psi_L \Big(\sum_i \omega_i a_i + \omega_{\widehat{\ell}_f} \widehat{\ell}_f \Big) , \tag{6}$$

while in the case there is request for a mortgage $\widehat{\mu}_h$ made by household h, then the mortgage is granted only if

$$E_b \geq \Psi_M \Big(\sum_i \omega_i a_i + \omega_{\widehat{\mu}_h} \widehat{\mu}_h \Big) , \tag{7}$$

where $\sum_i \omega_i a_i$ in both Eq. 6 and 7 is the usual risk weighted portfolio of existing loans and mortgages of the bank and in principle $\Psi_L \neq \Psi_M$.
In Eq. 6 and 7 we propose a banking regulation that works with two thresholds, depending on the nature of the loan. If Ψ_M is higher than Ψ_L, mortgage loans will require a higher capital adequacy ratio than to loans to firms (and *vice versa*). Therefore, a bank could be in the situation of fulfilling the capital requirements for firms loans but not for mortgages. In particular, when the amount of risky assets of a bank becomes high, thus raising banks leverage, loans are preferred to mortgages and the proposed banking regulation becomes effective.

3. Computational experiments

A number of computational experiments have been performed in a simulation setting characterized by 3,000 households, 50 consumption goods producers, 3 banks, 1 capital goods producer, 1power producer, 1 government, and 1 central bank. The aim of computational experiments is to assess the impact of differentiating banks' capital requirements based on the type of credit provided, i.e. between mortgages to households for house purchase and loans to firms for productive investments. The rationale behind this choice is the assumption that house purchases are made mostly for speculative purposes and may produce asset bubbles with destabilizing effects, while loans to business firms are aimed to increase their capital endowment with long-run positive effects for the productive capacity of the economy. Banking regulation should then favour lending to business firms with respect to lending for house purchases, e.g. through setting lower capital requirement in the former case. A similar proposal has been set out by Campiglio (2016) to spur green investments, at the expenses of speculative ones, as an alternative to carbon taxation.
To investigate the issue, we have designed a set of computational experiments characterized by capital requirements for mortgages that can be higher or lower than a reference value, i.e. 10 %, which is the basic capital requirement value

adopted for business loans. In our model design, investments in capital goods provide also an environmental benefit as the new vintages are characterized by higher energy efficiency.

In the following, we use the maximum leverage allowed to banks, henceforth α, i.e. the inverse of the capital requirement ratio, to parameterize the computational experiments, as it is more intuitive. In particular, the value of α is set to 10 (the inverse of 10 %) for all types of loans during the first year of any simulation, while since the second year α it is differentiated into a α_L for business loans and a α_M for mortgages. The maximum allowed leverage α_L is then kept at 10 for loans to firms, while in the case of mortgages α_M is changed to a lower or higher value in the range from 0 to 20 and the new value is maintained for the rest of the simulation. The values assumed by α_M are $(0, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 17, 20)$. It is worth noting that the grid for α_M is not equally spaced from 0 to 20 but is more dense around $\alpha_M = 8$, where indeed we observe the most interesting behavior of the observed economic variables. Furthermore, it should be considered that zero is quite an extreme value that α_M can assume, as it means that no more mortgages are granted.
For any value of α_M considered, 50 different simulations have been performed depending on the seed of the pseudorandom number generator. Figures from 1 to 10 show the distribution of some relevant economic variables for any value of α_M considered. In particular, the distributions are represented as boxes which include all the values from the 25th to the 75th percentile and with horizontal segments and diamond markers which represent the median and the mean of the distribution, respectively. Box-plots also include whiskers extending to the most extreme data points not considered outliers, while outliers which are plotted individually.

For every seed (simulation), we consider the time average over two given time periods in order to differentiate a short run and a long run. In this respect, the box-plot figures can be organized into two different groups, where the first group, from Fig. 1 to Fig. 5, reports the time averages from year 2 to year 6 included, i.e. the first 5 years after the differentiation of capital requirements, while the second group, from Fig. 6 to Fig. 10, presents the time averages over the following ten years, i.e. from year 7 to year 16. The first simulation year has not been considered in the computation of the time averages because in this period α_M is not yet differentiated but set to 10 in all cases. To conclude, results have been divided into two periods that can be considered as a short/medium run period for the first 5 years and a long-run period for the following 10 years.

The first time window has been set to five years because this is the time span where the effects of the change of α_M are observed to be more relevant and statistically significant on productive investments. In particular, in the panel (a) of Figure 1 we can observe that both the average and the median values of the loans distribution have clearly higher values when α_M is lower than 8. We employ the Wilcoxon rank sum test to verify the null hypothesis that the data reported for different values of α_M are taken from distributions with equal medians. If we assume the null hypothesis that the distributions of loans for $\alpha_M = (0, 3, 4)$ have the same medians of the distributions for $\alpha_M \geq 6$, this is rejected at the significance level of 5 %. Therefore a regulatory action that decreases substantially the maximum allowed leverage (or, equivalently, increases the capital requirements) for speculative investments, here proxied by mortgage debt for house purchase, is effective in diverting credit from speculative to productive investments, at least in the short run (first 5 years). This is also evident when we observe investments and the aggregate capital stock of the economy, panel (b) and (d) of Figure 1, as well as the average energy intensity ϵ, i.e., the amount of required energy for unit of output, panel (c) of the same Figure. The higher pace of investments for low α_M, because of more credit available, implies newer vintages for firms' capital goods and therefore lower energy intensity on average for the aggregate capital endowment. Panel (b) of Figure 1 shows that the medians of the distribution of the aggregate capital stock in the economy are clearly higher for values of α_M lower than 9. In particular, we observe a downward transition of the accumulated capital stock from $\alpha_M = 4$ to $\alpha_M = 9$. According to the Wilcoxon rank sum test, the difference is statistically significant at the significance level of 1 %. Consistently, we get a lower average energy intensity for lower α_M, see panel (c) of Figure 1. Also in this case, the difference is statistically significant. It is worth noting that the differences in the main variables of figure 1 are statistically significant in the range of α_M from 4 to 9 , confirming that this is a quite critical transition interval.

Figure 2 presents the main results related to the housing market. In particular, we can observe that, as expected, the aggregate amount of mortgages (panel a) is very sensitive to the value of α_M as well as the average housing price (panel b). The looser the banking regulation for mortgages the higher is the average housing price, therefore increasing the likelihood of credit-driven housing market bubbles and raising the instability of the housing market. In particular, the increase in the average numbers of fire sales in the housing market, as pointed out by panel c of Fig. 2, is due to the growing difficulty faced by some households to make mortgage payments. This increases the probability of housing bubble bursts, with possible destabilizing effects on the real economy though the lending channel. Ozel et al. (2016) present a detailed discussion about the effects of credit regulation on the housing market dynamics in Eurace and the possible destabilizing effects of housing bubble busts on the real economy.

Figure 3 presents the effects of the differentiated loan *versus* mortgage requirements on the real economy. While the medians of the distribution of unemployment rates (panel b) do not exhibit both graphically and statistically significant differences for different values of α_M, we can clearly observe from panel c that GDP growth rates are significantly higher for $\alpha_M \geq 8$. For lower values of α_M, we have observed already higher investment rates, as pointed out by higher levels of loans and capital accumulation showed by panel a and b of Fig. 1, respectively. The difference in GDP growth rates can be only explained by a even higher difference in the consumption growth rates that should offset the contribution to GDP by higher investment rate at low α_M. This is actually what we observe in panel (d) of figure 3. Therefore, the increase of investments rates is realized at the expense of consumption growth rates; but while on the one hand the combined effect looks neutral for unemployment, on the other hand it is not neutral for GDP growth rates, pointing out an important drawback of increasing capital requirements for mortgages. We argue that the explanation of this finding is twofold and concerns both supply and demand side aspects. On the supply side, we understand that fostering investments requires additional labor force employed at the capital goods producer; however, due the internal dynamics of the economy, the overall net result is not a reduction of unemployment but a sort of crowding out effect that diverts the labor force from the consumption goods sector to the capital goods one, see in particular panel (a) and (b) of Fig. 5. On the demand side, we observe that the reduction of mortgages at low α_M is not fully compensated by the increase of loans, as the total aggregate credit in the economy, i.e. the sum of mortgages and loans, reported by panel a of Fig. 3, exhibits a strong increase for high values of α_M similar to the one of mortgages. Our previous work Raberto et al. (2012); Teglio et al. (2012); Cincotti et al. (2012b) has shown how the level of credit in the economy, i.e. the level of credit money endogenously generated by the banking system, positively affects economic growth, at least in the short term. This happens through the supply side channel, i.e. the availability of resources to firms for investments, as well as through the demand channel, via the higher capital income of households, as shareholders of highly profitable banks, and via the higher general money supply which automatically translates to higher nominal demand. Furthermore, both our recent work (Ozel et al. (2016)) and empirical evidence ((ECB, 2013, pag. 21, Chart D)) point out that mortgages seem positively cross-correlated with economic activity and, differently from loans, seem to lead the business cycle.

Figure 4 shows the effects of the policy on prices, i.e., the consumption and the capital goods price level, the nominal wage and the central bank policy rate. The main result is that, while the distribution of capital goods prices is both graphically and statistically independent on the value α_M, see panel b, both consumption goods prices (panel a) and nominal wages (panel c) depend on it, yet in an opposite way. The level of nominal wages in Eurace depends on the labor market status; in particular, when unemployment is low, firms may face labor shortage and then compete to attract workers by rising their wage offer, see Dawid et al. (2014); Teglio et al. (2015) for more details on the Eurace labor market. The distribution of unemployment rates looks scarcely dependent on α_M, see panel a of Fig. 3; however, the median values of nominal wage does depend on on α_M, see panel c of Fig. . This evidence can be explained considering that the higher α_M, the tighter is the labor market competition among CGPs, as shown by the employement rate in the consumption good sector, see panel a of Fig. 5; on the other hand, at low α_M the competitive effort to attract workers mainly regards the capital good sector, which is characterized by just one single player, differently from the consumption goods sector, where many agents operate.

Interestingly, higher labor costs do not translate into higher consumption goods prices. Indeed, CGPs apply mark-up pricing where unit costs are given by labor costs, energy cost and debt service cost, where the first two costs are variable costs and the latter one is a fixed cost, see Teglio et al. (2015) for more details on the Eurace mark-up pricing. Therefore, higher consumption goods prices are clearly explained by the interests cost of the higher debt burden which CGPs are subject to at lower α_M (see panel a of figure 1). Higher consumption goods prices combined with lower nominal wages have of course a depressing effect on real wages, as also reported on panel c of Fig. 5, thus pointing out another negative consequence of a policy aimed at increasing capital requirements limited to mortgages.

To summarize our findings so far, the strategy of increasing capital requirements for mortgages has proven to be successful in fostering investments and capital accumulation in the short term (five years), and consequently in improving energy efficiency (reducing energy for unit of output) of firms because of the newer vintages of capital goods available. However, these results are achieved at some welfare costs for households which can be summarized in lower consumption growth rates and purchasing power.

The next part of the paper examines if these results are confirmed also in the long run, i.e., in the following 10 years. Figures 6-10, present the distributions as box-plots of the same economic variables presented in figures 1-5, yet in a different time period, i.e. from year 7 to year 16, instead of from year 2 to year 6. Figure 6 shows that while the distribution of energy intensity (panel a) still exhibits both a graphically and statistically significant pattern for different values of α_M, the distribution of loans, capital stock and investments, are less affected in the long run than in the short run. This means that, during the last 10 years, some counterbalancing force in the economic system is seriously weakening the effects of a regulation which is *de facto* reducing total mortgage loans (as shown in figure 7). We think that this counterbalancing effect is mainly due to the lower amount of total credit in the economy which in turn reduces the level of endogenous money. In the long run, when α_M is decreased in order to limit mortgages, the economy suffers from the demand side. Consumption growth is critically reduced and consumption goods producers have therefore to scale down production and employment. We see that the unemployment rate is increasing in the long run from an average of 2% to an average close to 8% when mortgages are hindered. In the first five years, the aggregate credit for low α_M values is reduced by a 30% with respect to high α_M values, while in the next ten years the difference grows to 66%, showing that the loss in mortgages and endogenous money accumulates during the years undermining aggregated demand (see Ozel et al. (2016) for further details). Actually, consumption growth rates suffer a 50% loss in the long run when α_M is low, against a 33% loss in the short run. It is also worth noting that investment decision-making by firms is based on net present value calculations, where expected demand play a crucial role (see Teglio et al. (2015) for further details). This explains to some extent why total loans depend on consumption, and why we do not observe a significant increase of loans when a mortgage-restricting policy is adopted.

Thus, our simulations show that in the long run the effects of a mortgage-restricting policy are mainly negative. For very low values of α_M the policy is basically freezing the housing market (see the patterns related to the level of mortgages and the housing markets in Fig. 7) with negative outcomes for the real economy, as shown in Fig. 8. For higher values of α_M the mortgage markets re-activates, showing of course more instability, characterized by increasing fire sales. In the long term the advantage for lower leverages in term of capital stock accumulation during the short term is no more valid. It still exists an advantage in term of energy efficiency, with an environmental benefit related to energy consumption, however at the price of an increasing welfare costs, which in the long term does not concern only purchasing power and consumption rates but also unemployment rates.

4. Concluding remarks

Inspired by some recent proposals, aiming at promoting green investments at the expenses of speculative ones, we designed a set of computational experiments within the agent-based model Eurace. We devised a simple regulation for banks in order to incentive loan to firms for productive investments instead of real estate mortgage lending. The regulation consists in demanding higher capital requirements for banks in the case of mortgage loans, thus encouraging banks to give loans to firms. As up-to-date capital goods have better energy efficiency in the model design, a higher pace of investments implies also a positive environmental externality. Simulations outcomes suggest that the regulation is successful in promoting investments and capital accumulation in the short term, and consequently in improving energy efficiency of firms. However, these results are achieved at some welfare costs for households which can be summarized in lower consumption growth rates and purchasing power. The reason is that reducing mortgages with a restrictive regulation has a negative impact on the total private credit in the economy, and therefore on the endogenous money supply. This, in turn, reduces consumption and aggregated demand.

In the long term, the contraction of total credit increases, and the negative outcomes on aggregated demand become more serious, reducing also firms investments. Therefore, in the long run, the positive effects on capital and energy efficiency become negligible, while the main economic indicators show a period of recession.

Finally, in line with previous experiments, our model shows the important role of endogenous money in the economy. Mortgages loans represent the crucial way to channel money to households, and if they are hindered all the economy suffers, reaching higher unemployment rates. Besides, the model has also shown that a loose regulation of mortgages can lead to instability in the housing market with negative repercussion on the real economy. This means that a fine tuned regulation, that keeps into account the business cycle dynamics is probably needed. Our next step will be to implement this fine tuning, considering macro-prudential rules, or more sophisticated regulations with the goal to foster green investments on the one hand, and to provide enough credit to sustain the performance of the economy on the other hand.

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Appendix

This appendix provides a compact description of the model according to the "stock-flow consistent" approach along the lines introduced by Godley and Lavoie (2012). This approach allows to check the consistency between stocks and flows in the model, both at the level of the single agent and at the aggregate one, in line also with post-Keynesian stock-flow-consistent modelling approach, see also Caverzasi and Godin (2015).
A detailed description of the behavioral rules characterizing each agent is reported in Teglio et al. (2015), whereas the details of the housing market mechanism are illustrated in Ozel et al. (2016).

Here, we present three matrices that show:

- Agent class balance sheets
- Sectorial balance sheet
- Stock and monetary flows among sectors.

In particular, Table 1 reports the balance sheets of each agent class that populates the Eurace economy. Table 2 shows all assets and liabilities for each sector (here a sector is the aggregate set of agents belonging to the same class). Finally, Table 3, called transaction flow matrix, shows all the stock and monetary flows among sectors.

Agent class balance sheets

The balance sheets of any class of agents populating the Eurace economy is shown in Table 1. Each agent is characterized by liquidity M in the assets side and by equity E in the liabilities side. Households are also characterized by a portfolio of stock shares and government bonds and by housing units in the assets side and by mortgages in the liabilities side. Capital goods and inventories, in the assets side, and debt, in the liabilities side, characterize also the consumption goods producer class. The assets side of the bank agent is also defined by loans and mortgages whereas the liabilities side by deposits and debt. Bonds are also presents in the liabilities side of the government. Finally, the Central Bank is also characterized by loans and government bonds in the assets side and deposits and fiat money in the liabilities side.

Sectorial Balance sheets

Table 2 shows, in a compact way, the relation among sectors. In details, a plus (minus) sign corresponds to agents' assets (liabilities) and each column can be read as the aggregated balance sheet of a specific agent. Rows show liabilities and the corresponding claims (assets) among sectors, thus generally adding up to zero. Exceptions are capital and inventories, accumulated by CGPs, housing units belonging to households and households' equity shares, which are issued

Table 1: Agent class balance sheets

Agent class	**Assets**	**Liabilities**
Household *abbrev.*: HH *index*: $h = 1, \ldots, N_{Hous}$	Liquidity: M_h Stock portfolio: $\Sigma_b n_{E_{h,b}} p_{E_b} +$ $\Sigma_f n_{E_{h,f}} p_{E_f} +$ $n_{E_{h,K}} p_{E_K}$ $n_{E_{h,PP}} p_{E_{PP}}$ Gov Bonds: $n_{h,G}\ p_G$ Housing units: X_h	Mortgages: U_h Equity: E_h
Consumption Goods Producer *abbrev.*: CGP *index*: $f = 1, \ldots, N_{Firm}$	Liquidity: M_f Capital goods: K_f Inventories: I_f	Debt: $D_f = \sum_b \ell_{f,b}$ Equity: E_f
Capital Goods Producer *abbrev.*: KGP	Liquidity: M_K	Equity: E_K
Power Producer *abbrev.*: PP	Liquidity: M_{PP}	Equity: E_{PP}
Bank *abbrev.*: B *index*: $b = 1, \ldots, N_{Bank}$	Liquidity: M_b Loans: $\mathcal{L}_b = \sum_f D_f$ Mortgages: $U_b = \sum_h U_{b,h}$	Deposits : $\mathcal{D}_b = \sum_h M_{b,h} + \sum_f M_{b,f} + M_{b,K}$ Standing facility with the central bank: $D_b = \ell_{b,CB}$ Equity: E_b
Government *abbrev.*: G	Liquidity: M_G	Outstanding government bonds value : $D_G = n_G\ p_G$ Equity: E_G
Central Bank *abbrev.*: CB	Liquidity: M_{CB} Loans to banks: $\mathcal{L}_{CB} = \sum_b D_{CB,b}$ Gov Bonds: $n_{CB,G}\ p_G$	Outstanding fiat money: Fiat_{CB} Deposits: $\mathcal{D}_{CB} = \sum_b M_{CB,b} + M_{CB,G}$ Equity: E_{CB}

Table 1. Balance sheets of any class of agents populating the Eurace economy. Balance sheet entries in the table have a subscript character, that is the index of the agent to which the variable refers. In some cases, we can find two subscript characters, where the second one refers to the index of the agents representing the balance sheets counterparts. For instance, D_f refers to the total loans of firm f, i.e. a liability, and $\mathcal{L}_b$ refers to the total loans of bank b, i.e. an asset. $\ell_{f,b}$ (or $\ell_{b,f}$) refer to the loans issued by banks b to firms f. Of course $\sum_b \mathcal{L}_b = \sum_f D_f$ represents a balance sheet identity, that is verified along the entire simulation. $n_{E_{h,x}}$ represent the number of outstanding equity shares of agents x held by households h. The market price of the equity shares is given by p_{E_x}. The stock portfolio's value of household h is then computed as: $\sum_x n_{E_{h,x}} p_{E_x}$. Government bonds' number and market price are given by n_G and p_G, respectively.

by CGPs, KGP, power producer and banks and do not add up to zero because of the difference between market price and book value.

	Sectors							
	Non-Financial Private Agents (NFPAs)					Policy Makers		Σ
	HHs	**CGPs**	**KGP**	**PP**	**Bs**	**G**	**CB**	
Tangible Capital Inventories	$+X_H\ p_X$	$+K_F\ p_K$ $+I_F\ p_C$						$+X_h\ p_X\ +K_F\ p_K$ $+I_F\ p_C$
Debt(-) / Credit(+)	–Mortgages	–Loans			+Loans +Mortgages –Loans$_{CB}$		+Loans$_{CB}$	0
Liquidity: NFPA Banks/Gov Central Bank	$+M_H$	$+M_F$	$+M_K$	$+M_{PP}$	-D_B $+M_B$	$+M_G$	- D_{CB} +M$_{CB}$ –Fiat$_{CB}$	0 0 +M$_{CB,0}$
Gov Bonds	$+n_G^H\ p_G$					$-n_G\ p_G$	$+n_G^{CB}\ p_G$	0
Equity Shares (+) / Net worth (-)	$+\Sigma_f n_{E_f} p_{E_f}$ $+n_{E_k} p_{E_k}$ $+n_{E_{PP}} p_{E_{PP}}$ $+\Sigma_b n_{E_b} p_{E_b}$ $-E_H$	$-E_F$	$-E_K$	$-E_{PP}$	$-E_B$	$-E_G$	$-E_CB$	$+\Sigma_f n_{E_f} p_{E_f} - E_F$ $+n_{E_k} p_{E_k} - E_K$ $+n_{E_{PP}} p_{E_{PP}} - E_{PP}$ $+\Sigma_b n_{E_b} p_{E_b} - E_B$ $-E_H - E_G - E_{CB}$
Σ	0	0	0	0	0	0	0	0

Table 2: Sectorial balance sheet matrix. Subscripts represent the index of the agent to which the stock refers. Uppercase indexes are used when the stock refers to the whole sector, e.g. F refers to the sectors of all CGPs, whereas lowercase subscripts are used when it refers to the single agent (for instance in the case of sums). Finally, superscript characters are introduced in the case of government bonds units n_G, i.e. n_G^H and n_G^{CB}, because the balance sheet counterpart (in the asset side) is hold by two sectors, i.e. households and central bank.

Finally, it is worth noting that in table 2, the difference between fiat money (on the liability side) and central bank liquidity (on the asset side) is always constant (and equal to the initial central bank liquidity $M_{CB,0}$. Fiat money is the money created by the central bank to provide loans to commercial banks, when they are in liquidity shortage, or to buy government bonds in the secondary market, through quantitative easing operations. Households, that sell government bonds to the central bank, deposit the sale proceeds at their own banks, while the money lend to banks by the central bank is lent to households of firms, then in turn deposited again in the banking sector. Therefore, in both cases, the liquidity of the banking sector is increased by an amount equal to the new Fiat money created and this additional liquidity is deposited by banks at the central bank, then increasing central bank liquidity by an amount always equal to the Fiat money originally created. It is worth noting however that the money supply in the economy can variate independently from the fiat money created by the central bank, because it endogenously raises every time a bank grants a new loan or mortgage and it decreases when the loan or mortgage is paid back.

Stock and monetary flows among sectors

All the stock and monetary flows among agents are described in the transaction flow matrix (table 3), where the current account describes the flows of revenues (plus sign) and payments (minus sign) that agents get and make. Rows show the monetary flows among agents. The result of agents' transactions is the net cash flow.

The capital account section of Table 3 describes the balance sheet changes related to each sector.

		HHs	CGPs	KGP	PP	Bs	G	CB	Σ
Current Account	Consumption	$-$	$+$						0
	Electricity		$-$		$+$				0
	Wages	$+$	$-$	$-$	$-$				0
	Transfers	$+$					$-$		0
	Investment		$-$	$+$	$+$				0
	Taxes	$-$	$-$	$-$	$-$	$-$	$+$		0
	Dividends	$+$	$-$	$-$	$-$	$-$			0
	Coupons	$+$					$-$	$+$	0
	CB coupons payback						$+$	$-$	0
	Banks loan interests		$-$			$+$			0
	Banks mortgage interests	$-$				$+$			0
	Banks mortgage principal payments	$-$				$+$			0
	CB loans interests					$-$		$+$	0
	CB interests payback					$+$		$-$	0
		=	=	=	=	=	=	=	
	Net cash flow	Savings	Profits	Profits	Profits	Profits	Surplus	Seignoirage	0
Capital Account	Net cash flow	+Savings	+Profits	+Profits	+Profits	+Profits	+Surplus	+Seignoirage	0
	Δ Capital		$+\Sigma_f \Delta K_f p_K$	$-\Delta K_K p_K$	$-\Delta K_{PP} p_{PP}$				0
	Δ Loans	$+\Delta$ Mortgages	$+\Delta$ Loans			$-\Delta$ Mortgages $-\Delta$ Loans $+\Delta$ Loans$_{CB}$		$-\Delta$ Loans$_{CB}$	0
	Δ Issue of new shares / bonds	$-\Sigma_f p_{E_f} \Delta n_{E_f}$ $-p_{E_G} \Delta n_{E_G}$	$+\Sigma_f p_{E_f} \Delta n_{E_f}$				$+p_{E_G} \Delta n_{E_G}$		0
	Δ Quantitative easing	$+p_{E_G} \Delta n^{QE}_{E_G}$						$-p_{E_G} \Delta n^{QE}_{E_G}$	0
	Δ Private Liquidity & Δ Banks' deposits	$-\Delta\ M_H$	$-\Delta\ M_F$	$-\Delta\ M_K$	$-\Delta\ M_{PP}$	$+\Delta\ D_B$			0
	Δ Banks / Public Liquidity & Δ Central bank deposits					$-\Delta\ M_B$	$-\Delta\ M_G$	$+\Delta\ D_{CB}$	0
	Δ CB Liquidity / Δ Fiat Money							$+\Delta\ M_{CB}$ $-\Delta$ Fiat$_{CB}$	0
	Σ	0	0	0	0	0	0	0	

Table 3: **Sectorial transaction flow matrix of agents populating the EURACE economy**. Note that HH stands fo Households, CGP stands for Consumption Goods Producer, KGP stands for Capital Goods Producer, PP stands for Power Producer, Gov stands for Government and CB stands for Central Bank.

References

Aglietta, M., Espagne, E., Perrissin-Fabert, B., 2015. A proposal to finance low carbon investment in europe. France Stratégie: Paris.

Arthur, W. B., 2006. Out-of-equilibrium economics and agent-based modeling. Handbook of computational economics 2, 1551–1564.

Assenza, T., Delli Gatti, D., Grazzini, J., 2015. Emergent dynamics of a macroeconomic agent based model with capital and credit. Journal of Economic Dynamics and Control 50, 5 – 28.

Caiani, A., Godin, A., Caverzasi, E., Gallegati, M., Kinsella, S., Stiglitz, J. E., 2015. Agent based-stock flow consistent macroeconomics: Towards a benchmark model. Available at SSRN.
URL `http://dx.doi.org/10.2139/ssrn.2664125`

Campiglio, E., 2016. Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy. Ecological Economics 121, 220–230.

Caverzasi, E., Godin, A., 2015. Post-keynesian stock-flow-consistent modelling: a survey. Cambridge Journal of Economics 39 (1), 157–187.

Cincotti, S., Raberto, M., Teglio, A., 2010. Credit money and macroeconomic instability in the agent-based model and simulator eurace. Economics: The Open-Access, Open-Assessment E-Journal 4 (2010-26).

Cincotti, S., Raberto, M., Teglio, A., 2012a. The Eurace macroeconomic model and simulator. In: Agent-based Dynamics, Norms, and Corporate Governance. The proceedings of the 16-th World Congress of the International Economic Association. Vol. II. Palgrave.

Cincotti, S., Raberto, M., Teglio, A., 2012b. Macroprudential policies in an agent-based artificial economy. Agent-based Models and Economy Policy, 205–234.

Dawid, H., Gemkow, S., Harting, P., Van der Hoog, S., Neugart, M., 2016. Agent-based macroeconomic modeling and policy analysis: The eurace@unibi model. In: Chen, S.-H., Kaboudan, M. (Eds.), Handbook of Computational Economics and Finance. Oxford University Press, Oxford.

Dawid, H., Harting, P., Neugart, M., 2014. Economic convergence: Policy implications from a heterogeneous agent model. Journal of Economic Dynamics and Control 44, 54 – 80.

Dosi, G., Fagiolo, G., Napoletano, M., Roventini, A., 2013. Income distribution, credit and fiscal policies in an agent-based Keynesian model. Journal of Economic Dynamics & Control 37 (8), 1598–1625.

Dosi, G., Fagiolo, G., Napoletano, M., Roventini, A., Treibich, T., 2015. Fiscal and monetary policies in complex evolving economies. Journal of Economic Dynamics and Control 52, 166 – 189.

Dosi, G., Fagiolo, G., Roventini, A., September 2010. Schumpeter meeting keynes: A policy-friendly model of endogenous growth and business cycles. Journal of Economic Dynamics and Control 34 (9), 1748–1767.

ECB, 2013. Monthly Bulletin October.
URL `https://www.ecb.europa.eu/pub/pdf/mobu/mb201310en.pdf`

Erlingsson, E., Teglio, A., Cincotti, S., Stefansson, H., Sturluson, J., Raberto, M., 2014. Housing market bubbles and business cycles in an agent-based credit economy. Economics: The Open-Access, Open-Assessment E-Journal 8 (2014-8).

Fagiolo, G., Roventini, A., 2016. Macroeconomic policy in dsge and agent-based models redux: New developments and challenges ahead. Available at SSRN.
URL `http://dx.doi.org/10.2139/ssrn.2763735`

Farmer, J. D., Hepburn, C., Mealy, P., Teytelboym, A., 2015. A third wave in the economics of climate change. Environmental and Resource Economics 62 (2), 329–357.

Ferron, C., Morel, R., 2014. Smart unconventional monetary (sumo) policies: Giving impetus to green investment. Climate Report 46.

Gerst, M. D., Wang, P., Roventini, A., Fagiolo, G., Dosi, G., Howarth, R. B., Borsuk, M. E., 2013. Agent-based modeling of climate policy: An introduction to the engage multi-level model framework. Environmental modelling & software 44, 62–75.

Godley, W., Lavoie, M., 2012. Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth, 2nd Edition. Palgrave Macmillan.

Gualdi, S., Tarzia, M., Zamponi, F., Bouchaud, J., 2015. Tipping points in macroeconomic agent-based models. Journal of Economic Dynamics and Control 50, 29 – 61.

IEA, 2012. Energy technology perspectives 2012: pathways to a clean energy system. OECD/IEA.

Kaldor, N., 1972. The irrelevance of equilibrium economics. The Economic Journal 82, 1237–1255.

Klimek, P., Poledna, S., Farmer, D., Thurner, S., 2015. To bail-out or to bail-in? answers from an agent-based model. Journal of Economic Dynamics and Control 50, 144 – 154.

McLeay, M., Radia, A., Thomas, R., 2014. Money creation in the modern economy. Bank of England Quarterly Bulletin 54 (1), 14–27.

Minsky, H., 1986. Stabilizing an Unstable Economy. Yale University Press.

Monasterolo, I., Raberto, M., 2016. A hybrid system dynamics–agent based model to assess the role of green fiscal and monetary policies. Available at SSRN.
URL http://dx.doi.org/10.2139/ssrn.2748266

Nelson, D., Shrimali, G., 2014. Finance mechanisms for lowering the cost of renewable energy in rapidly developing countries. Climate Policy Initiative.

Nordhaus, W. D., 2013. The climate casino: Risk, uncertainty, and economics for a warming world. Yale University Press.

Ozel, B., Nathanael, R. C., Raberto, M., Teglio, A., Cincotti, S., 2016. Macroeconomic implications of mortgage loans requirements: an agent based approach. Working Papers 2016/05, Economics Department, Universitat Jaume I, Castelln (Spain).

Raberto, M., Cincotti, S., Teglio, A., 2014. Economic Policy and the Financial Crisis. Routledge Frontiers of Political Economy. Taylor & Francis, Ch. 9.

Raberto, M., Teglio, A., Cincotti, S., 2012. Debt deleveraging and business cycles. an agent-based persperctive. The Open-Access, Open-Assessment E-Journal 6, 2012–27.

Riccetti, L., Russo, A., Gallegati, M., 2015. An agent based decentralized matching macroeconomic model. Journal of Economic Interaction and Coordination 10 (2), 305–332.

Rozenberg, J., Hallegatte, S., Perrissin-Fabert, B., Hourcade, J.-C., 2013. Funding low-carbon investments in the absence of a carbon tax. Climate Policy 13 (1), 134–141.

Russo, A., Riccetti, L., Gallegati, M., 2016. Increasing inequality, consumer credit and financial fragility in an agent based macroeconomic model. Journal of Evolutionary Economics 26 (1), 25–47.

Teglio, A., Mazzocchetti, A., Ponta, L., Raberto, M., Cincotti, S., 2015. Budgetary rigour with stimulus in lean times: Policy advices from an agent-based model. Working Papers 2015/04, Economics Department, Universitat Jaume I, Castelln (Spain).
URL https://ideas.repec.org/p/jau/wpaper/2015-07.html

Teglio, A., Raberto, M., Cincotti, S., 2012. The impact of banks' capital adequacy regulation on the economic system: An agent-based approach. Advances in Complex Systems 15 (supp02), 1250040.

Tonelli, F., Fadiran, G., Raberto, M., Cincotti, S., 2016. Approaching industrial sustainability investments in resource efficiency through agent-based simulation. In: Borangiu, T., Trentesaux, D., Thomas, A., McFarlane, D. (Eds.), Service Orientation in Holonic and Multi-Agent Manufacturing. Springer, pp. 145–155.

UNEP, 2016. Global trends in renewable energy investment 2016. UNEP Report.

WB, 2015. State and trends of carbon pricing 2015. World Bank Publications.

WEF, 2013. The green investment report: The ways and means to unlock private finance for green growth,(geneva, switzerland: World economic forum).

Werner, R. A., 2014. Can banks individually create money out of nothing?the theories and the empirical evidence. International Review of Financial Analysis 36, 1–19.

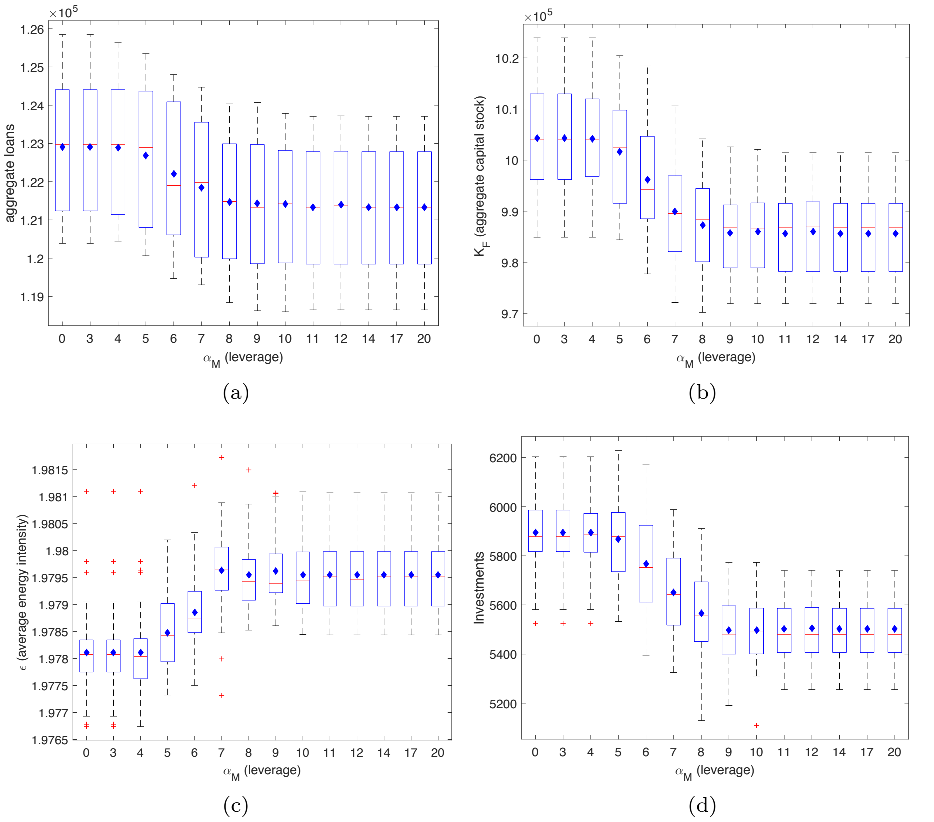
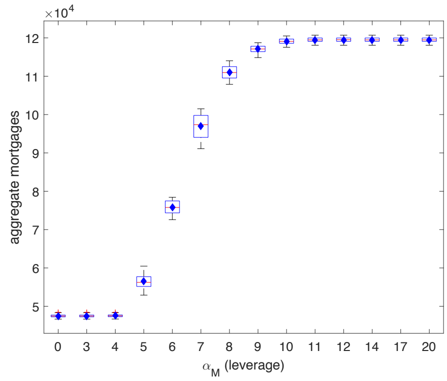
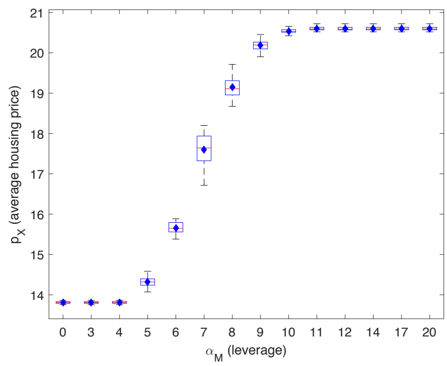


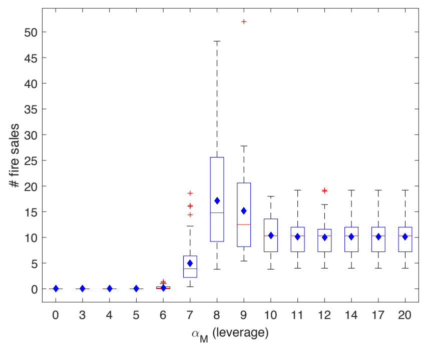
Figure 1: The four panels represent aggregate loans (a), aggregate capital stock (b), average energy intensity (c) and aggregate investments (d), respectively. The boxplots report for each value of α_M considered the time averages from year 2 to year 6 for any of the 50 seeds (simulations). As for energy intensity and capital stock, we report the value at year 6 instead of the time average along the five years period.



(a)

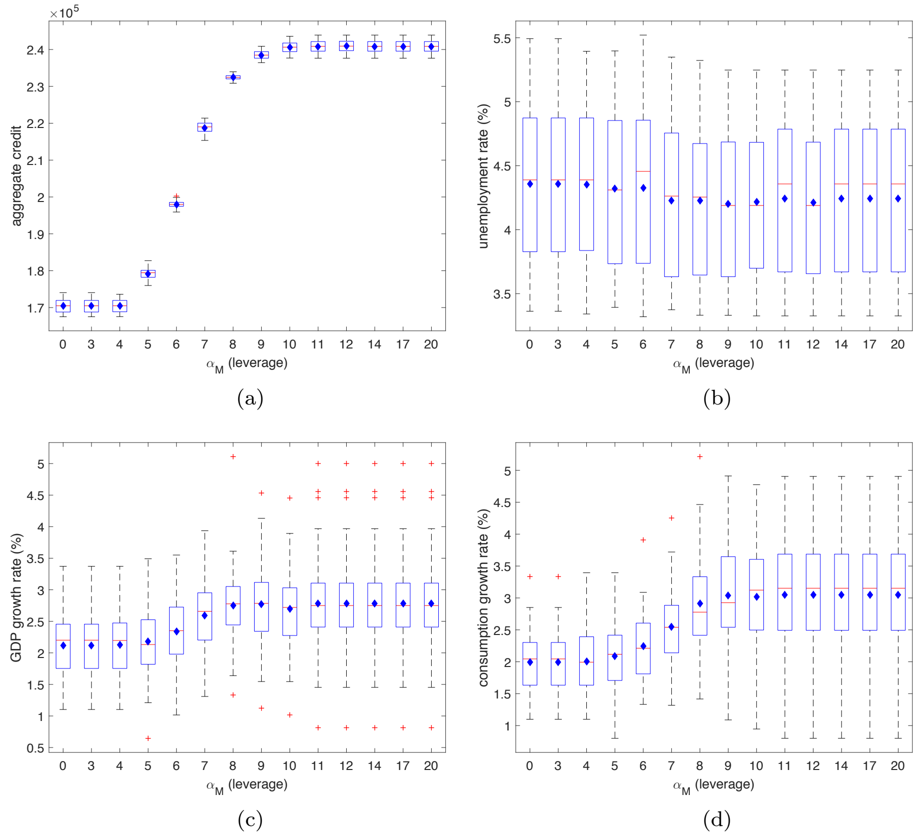


(b)



(c)

Figure 2: The three panels represent aggregate aggregate mortgages (a), average housing price (b), and the number of average fire sales (c), respectively. The boxplots report for each value of α_M considered the time averages from year 2 to year 6 for any of the 50 seeds (simulations).



(a) (b) (c) (d)

Figure 3: The four panels represent total credit (loans + mortgages) (a), the unemployment rate (b), the real GDP growth rate (c) and the real consumption growth rate (d), respectively. The boxplots report for each value of α_M considered the time averages from year 2 to year 6 for any of the 50 seeds (simulations).

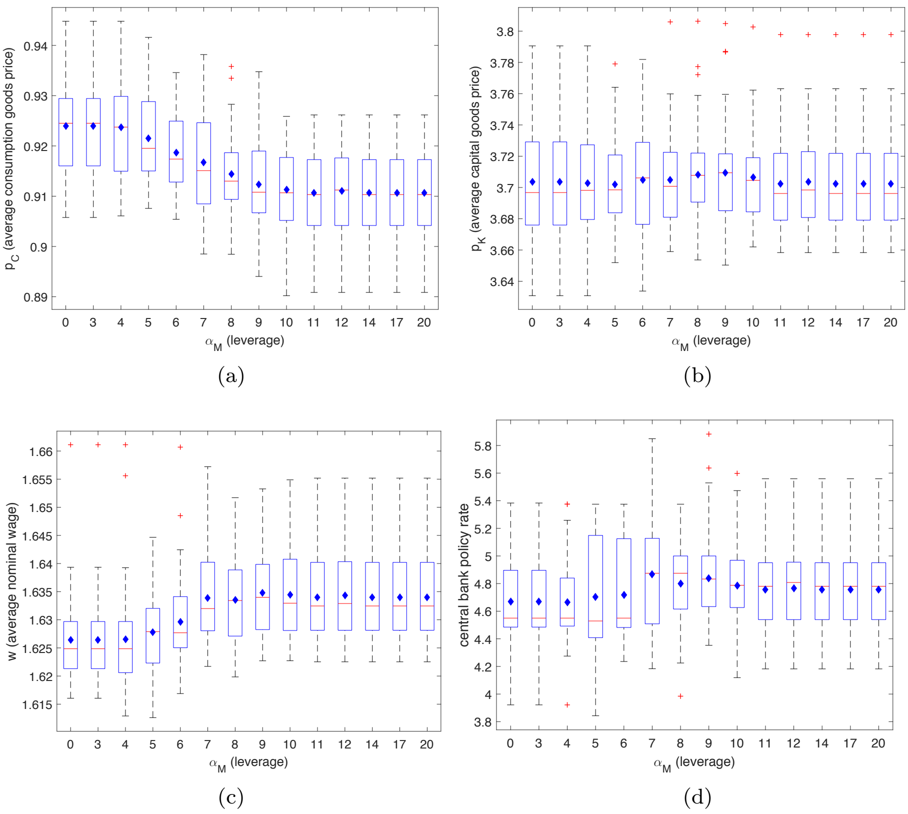
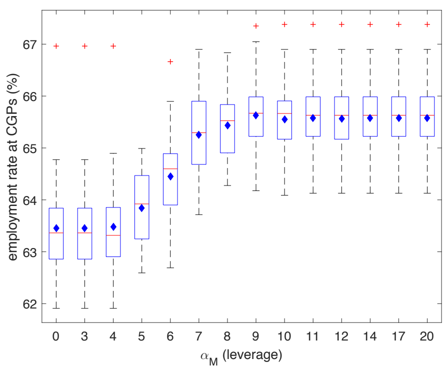
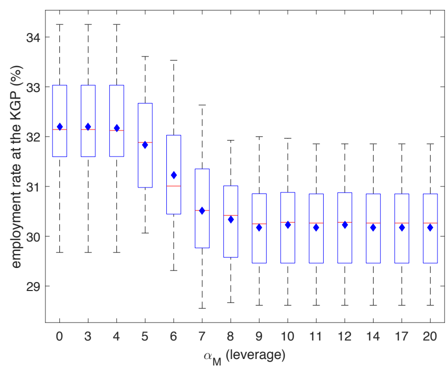


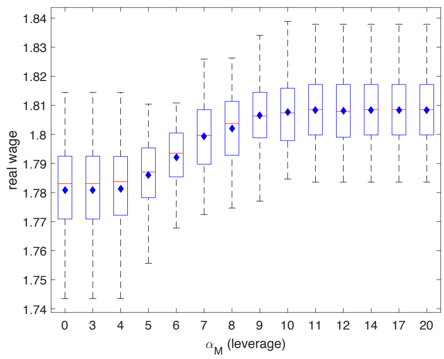
Figure 4: The four panels represent consumption goods price level (a), capital goods price level (b), nominal wage level (c) and central bank interest rate (d), respectively. The boxplots report for each value of α_M considered the time averages from year 2 to year 6 for any of the 50 seeds (simulations).



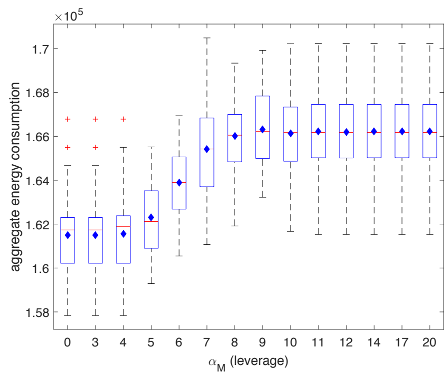
(a)



(b)



(c)



(d)

Figure 5: The four panels represent the employment rate in the consumption goods sector (a), the employment rate in the capital goods sector (b), the real wage level (c) and the aggregate energy consumption (d), respectively. The boxplots report for each value of α_M considered the time averages from year 2 to year 6 for any of the 50 seeds (simulations).

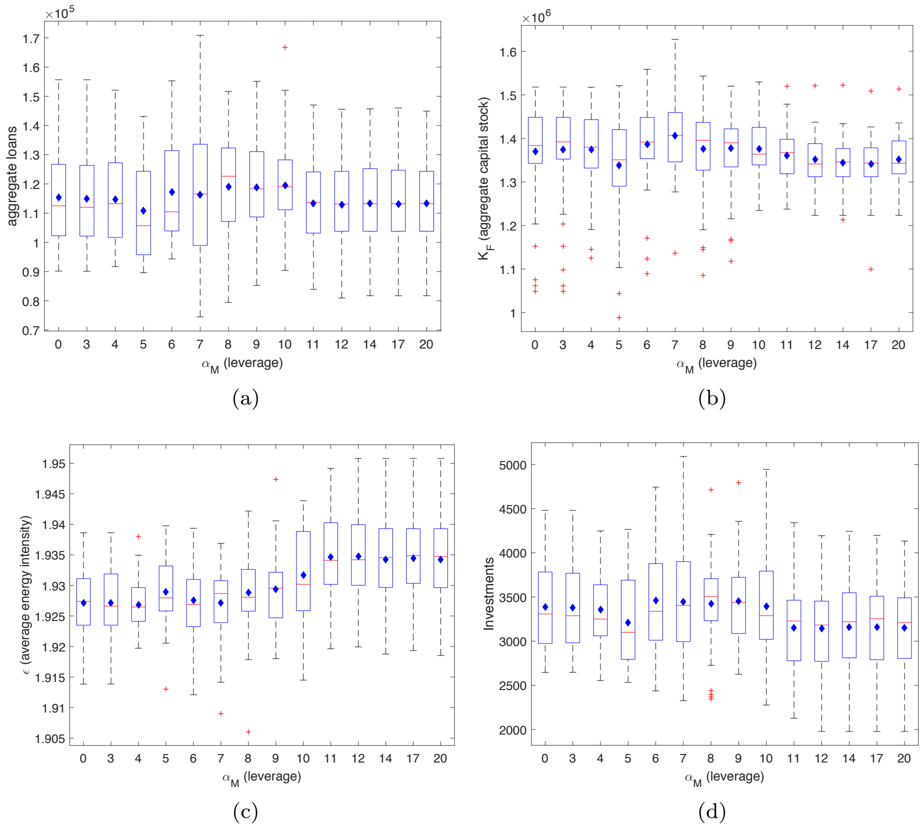


Figure 6: The four panels represent aggregate loans (a), aggregate capital stock (b), average energy intensity (c) and aggregate investments (d), respectively. The boxplots report for each value of α_M considered the time averages from year 7 to year 16 for any of the 50 seeds (simulations). As for energy intensity and capital stock, we report the value at year 16 instead of the time average along the ten years period.

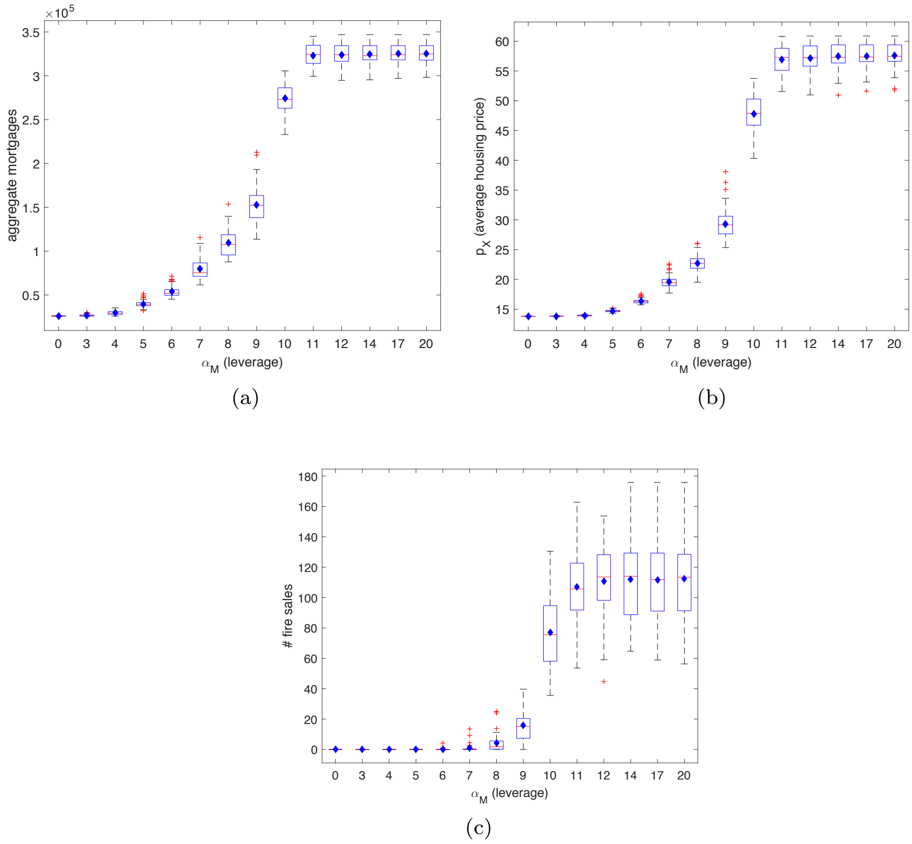


Figure 7: The three panels represent aggregate aggregate mortgages (a), average housing price (b), and the number of average fire sales (c), respectively. The boxplots report for each value of α_M considered the time averages from year 7 to year 16 for any of the 50 seeds (simulations).

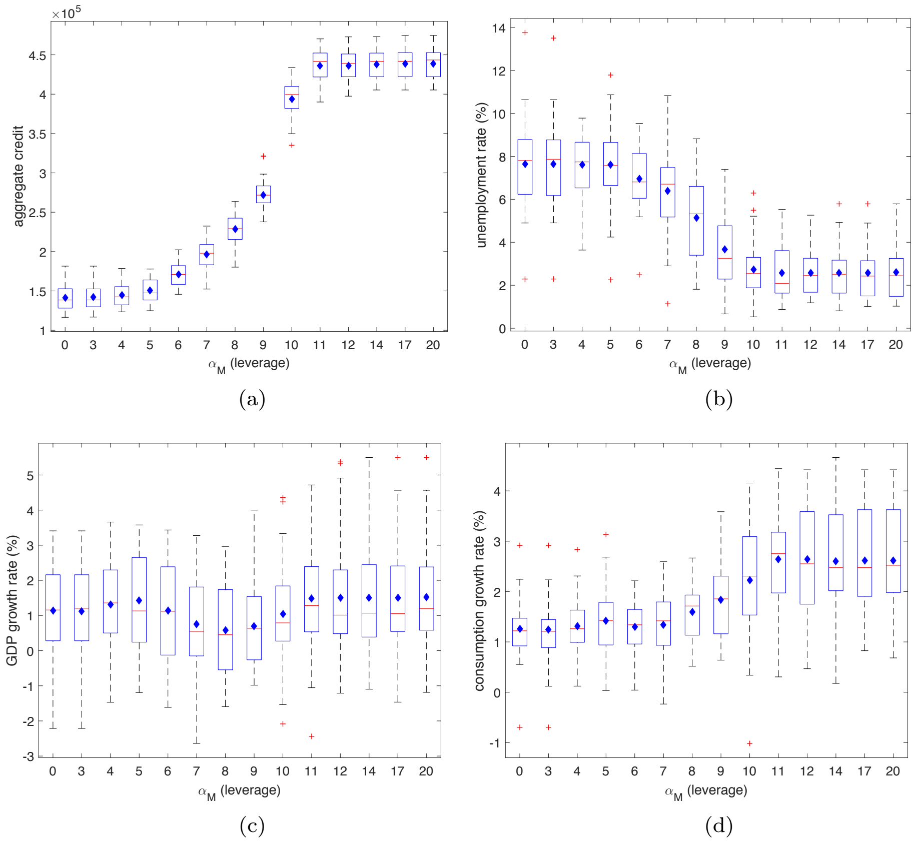


Figure 8: The four panels represent total credit (loans + mortgages) (a), the unemployment rate (b), the real GDP growth rate (c) and the real consumption growth rate (d), respectively. The boxplots report for each value of α_M considered the time averages from year 7 to year 16 for any of the 50 seeds (simulations).

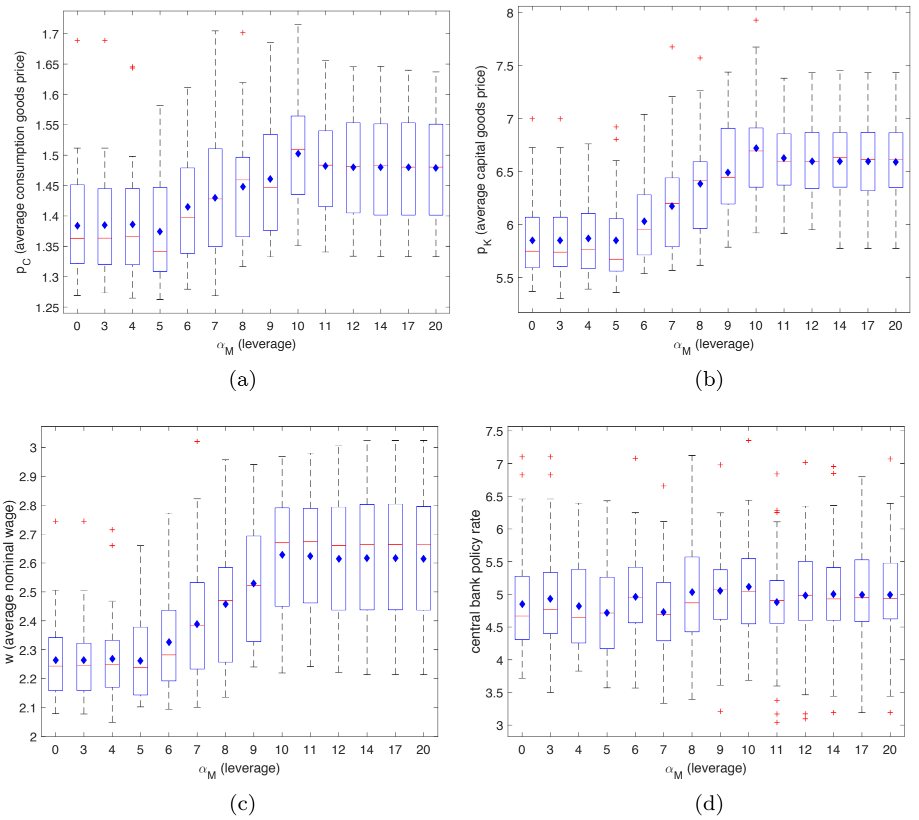


Figure 9: The four panels represent consumption goods price level (a), capital goods price level (b), nominal wage level (c) and central bank interest rate (d), respectively. The boxplots report for each value of α_M considered the time averages from year 7 to year 16 for any of the 50 seeds (simulations).

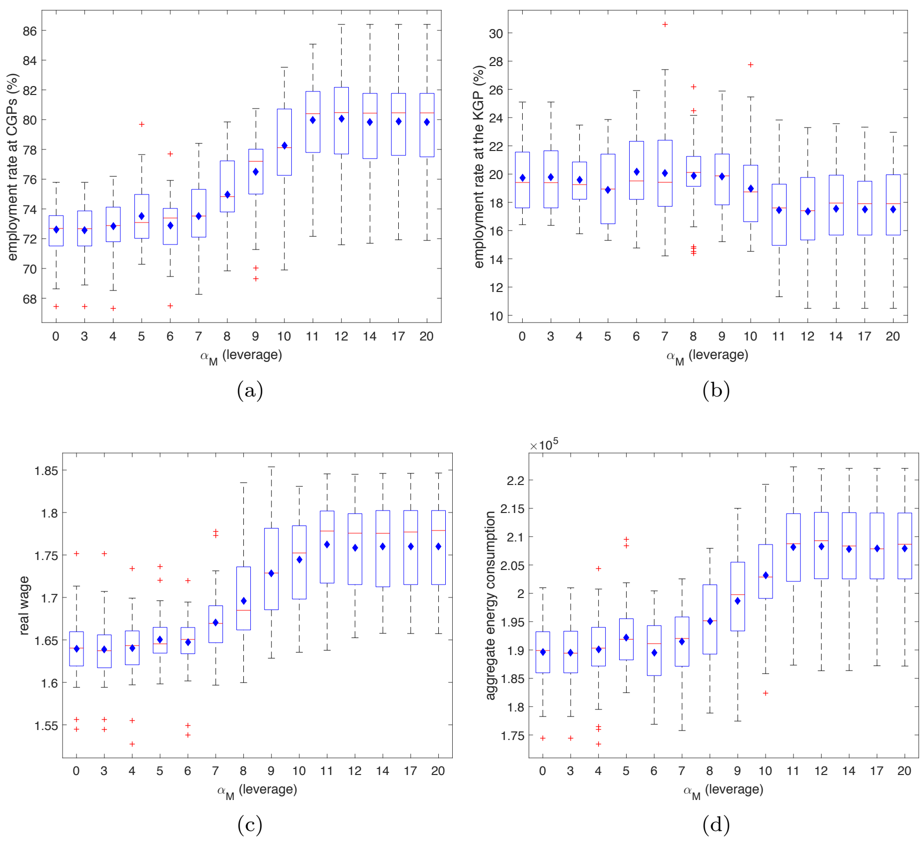


Figure 10: The four panels represent the employment rate in the consumption goods sector (a), the employment rate in the capital goods sector (b), the real wage level (c) and the aggregate energy consumption (d), respectively. The boxplots report for each value of α_M considered the time averages from year 7 to year 16 for any of the 50 seeds (simulations).