Credit-driven busiuess cycles in the Eurace agent-based macro model

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Abstract

This paper presents the design of an housing market and a related mortgage market for the Eurace macroeconomic model and simulator. Eurace is a fully-specified agent-based model of a complete economy that includes different types of agents and integrates different types of markets. Agents include households which act as consumers, workers and financial investors, consumption goods producers as well as capital goods producers, banks, a government and a central bank. Agents interact in different types of markets, namely markets for consumption goods and capital goods, a housing market, a labor market, a credit market and a financial market for stocks and government bonds. Except for the financial market, all markets are characterized by decentralized exchange with price setting behavior on the supply side. Agentss decision processes are characterized by bounded rationality and limited information gathering and computational capabilities; thus, agentss behavior follows adaptive rules derived from the management literature about firms and banks, and from experimental and behavioral economics of consumers and financial investors.

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the banking system, which is constrained by Basel capital adequacy regulatory provisions, while on the demand side depends on firms financing production activity and households indebtedness for housing needs and speculation.
The aim of this study is twofold, from the one hand we want to understand the economic role of the housing market in the model, and from the other hand we want to understand the effect of mortgage regulation. In this respect, we clearly observe that the main impact of the housing market is given by the endogenous money creation mechanism, due to the new mortgage loans that banks grant to households. These loans increase households bank deposits and, in turn, stimulates the aggregate demand of goods. Our computational experiment shows that the inflow of endogenous money affects both the financial variables of the economy and, to a minor extent, the real ones, including real GDP and unemployment rate. Finally, we observe that the looser the housing market regulation is, the more relevant is the endogenous money creation and consequently the higher the impact on both the nominal and the real variables of the economy.
Keywords: housing market, agent-based modelling, endogenous credit money

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JEL classification:

C63 Computational Techniques, Simulation Modeling

E32 Business Fluctuations, Cycles

E51 Money Supply, Credit, Money Multipliers

1. Introduction

The study addresses the crucial issue of the interplay between credit and business cycles in an economy by means of the agent-based Eurace (European agent based computational economic) model and simulator. Eurace is a fully-specified agent-based model of a complete economy that includes different types of agents and integrates different types of markets (Cincotti et al., 2010; Raberto et al., 2012; Teglio et al., 2012). Agents include households which act as consumers, workers and financial investors, consumption goods producers as well as capital goods producers, banks, a government and a central bank. Agents interact in different types of markets, namely markets for consumption goods and capital goods, a housing market, a labor market, a credit market and a financial market for stocks and government bonds. Except for the financial market, all markets are characterized by decentralized exchange with price setting behavior on the supply side. Agents' decision processes are characterized by bounded rationality and limited information gathering and computational capabilities (Tesfatsion, 2003; Tesfatsion and Judd, 2006); thus, agents's behavior follows adaptive rules derived from the management literature about firms and banks, and from experimental and behavioral economics of consumers and financial investors.

The dynamics of credit money is endogenous and depends on the supply side by the banking system, which is constrained by Basel capital adequacy regulatory provisions (Blum and Hellwig, 1995; Santos, 2001), while on the demand side depends on firms financing production activity and households indebtedness for housing needs and speculation. In particular, in this work we primarily address the housing market role in the economy (Muellbauer and Murphy, 2008) and we extend the Eurace model by accommodating a housing market and a mortgaging mechanism. We observe the impact of mortgages on business cycles in the extended artificial economy (Catte et al., 2005). In this new context, in addition to banks' leverage, their financial links to the other banks and firms, also, their mortgage loans are considered among the list of factors at observing reaction of banking sector to real economy (Gallegati et al., 2008). Empirical studies on how to measure risk implications of mortgage loans are lacking. Nevertheless, there have been critics against widely employed risk measurement approaches, where in general households' total mortgage debt, a 'stock' entry on their balance sheet, to households' disposable income, a 'flow' entry on their monthly income statement, e.g., see Skingsley (2007). In that line, the impact of households' housing wealth on their general consumption behavior has been a focus of recent studies following the financial crises triggered by housing bubbles (Carroll et al., 2011). Some of these studies point the necessity to consider the portion of mortgages within the households total wealth (Calomiris et al., 2013). These studies have lead new discussions at identifying relevant measures in order to evaluate the risk of individual household's mortgage debts (Svensson, 2014).

The remainder or the paper is organized as follows. Section 2 gives an overview of the agent-based model of the housing market within the Eurace model, in Section 3 we present the computational results, while in Section 4 we give some conclusions based on the empirical results.

2. The agent-based model

We employ the large-scale agent-based model and simulator Eurace, which represents a fully integrated macro-economy consisting of the real sector, the credit sector, the financial sector and the public sector.

The original Eurace model includes different types of agents (namely, households, consumption as well as capital goods producers, banks, a government and the central bank) and related markets, i.e. consumption and capital goods markets, a labor market, a credit market, and stock and government bond markets. In the Appendix, we describe in details agents' decision making and interactions through different market settings in the original Eurace model (Cincotti et al., 2010; Raberto et al., 2012; Teglio et al., 2012).

In this study, we enrich the original Eurace model by introducing homogeneous housing assets, mortgage lending and a housing market into the artificial economy. Households are endowed with homogeneous housing units that they can trade in the housing market. Households can also take mortgages from banks to buy housing units from other households. The new modelling features introduced in this study are described in the following section. Agents' balance sheet entries are described in Table 2.

2.1. The housing market

The housing market is active the first day of every calendar month. Households may be active in the market with an exogenously probability Φ_H and assume randomly the role of buyer or seller with equal likelihood. Decision making in the housing market has been modelled as mainly random because we are more interested on the credit aspects of housing markets bubbles and bursts, and on their impact on the economy as a whole, than on the functioning and the microstructure of the market and the related behavioral aspects. However, we allow also for a special case, called fire sale case, where households enter the housing market because financially distressed and are forced to sell their houses at a discounted price with respect to the last average market price p_H.

The market is a posted price market with decentralized exchange and households can sell or buy one housing unit at a time. If a household h is randomly selected to enter the housing market with a seller role, she/he posts one of her/his housing unit for sale at price p_{H_h} given by:

$$p_{H_h} = p_H(1 + \xi\, \psi_H)\,, \tag{1}$$

Agent	**Assets**	**Liabilities**
Household *abbrev.*: Hous *index*: $h = 1, \ldots, N_{Hous}$	Liquidity: M_h Stock portfolio: $\Sigma_b n_{E_{h,b}} p_{E_b} +$ $\Sigma_f n_{E_{h,f}} p_{E_f} +$ $n_{E_{h,K}} p_{E_K}$ Gov Bonds: $n_{h,G}\ p_G$ Housing units: X_h	Mortgages: U_h Equity: E_h
Consumption Goods Producers *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 Producers *abbrev.*: KGP *index*: k	Liquidity: M_k	Equity: E_k
Bank *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.*: Gov *index*: g	Liquidity: M_g	Outstanding government bonds value : $D_g = n_G\ p_G$ Equity: E_g
Central Bank *abbrev.*: CB *index*: 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: M_{cb} Deposits: $\mathcal{D}_{cb} = \sum_b M_{cb,b} + M_{cb,g}$ Equity: E_{cb}

Table 2. Balance sheets 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 $\sum_b \mathcal{L}_b$ and $\sum_f D_f$ represent 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.

where ξ is a random draw from uniform distribution between 0 and 1 and ψ_H is the maximum percentage price increase of housing price with respect to the previous month market price. Conversely if a household h is financially distressed[1], she/he posts one of her/his housing unit for sale at price p_{H_h} given by:

$$p_{H_h} = p_H(1 - \xi\,\psi_S)\,, \tag{2}$$

where ξ is a random draw from uniform distribution between 0 and 1 and ψ_S is the maximum fire sale price reduction. The rationale behind Eq. 1 is that financially distressed households post their housing units for sale at a discounted price to increase the likelihood of a transaction and then to be able to reduce their indebtedness and future mortgage payments. Conversely, we stipulate that households that are randomly selected for the seller role have not any particular necessity to liquidate their housing units and therefore are willing to sell only if they can realize a small random gain with respect to the last housing market price p_H. Households with the buyer role are randomly queued and each buyer in the queue in turn selects the cheapest available housing unit to buy and a transaction takes place at the posted sale price if the buyer has the necessary financial resources or is able to get a mortgage from a bank. The housing market closes when all buyers have had their turn or there are no more houses for sale. A new housing price p_H is then computed as the average of realized transaction prices.

[1] A household is financially distressed if the ratio between quarterly mortgage payments and quarterly net labor and capital income is higher than a given threshold Ψ_S. If ratio is higher than Ψ_S, where $\Psi_W > \Psi_S$, the household undergoes a mortgage restrucring with a consequent loss on the equity of the credit bank.

Table 1: Housing Market Parameters

Symbol	**Description**	**Value**
Φ_H	Housing market entrance exogenous probability	0.5
φ_H	Maximum selling price increase	0.025
φ_S	Maximum fire sale price reduction	0.05
$DSTI$	Debt Service To Income (DSTI)	0.0 to 0.6
Ψ_S	DSTI threshold for fire sale triggering	0.6
Ψ_W	DSTI threshold for mortgage write-off triggering	0.7
T_H	Mortgage duration in years	30

2.2. Mortgage lending

We consider variable rate mortgages where the annualized rate r_H is determined at the beginning of each month as the central bank interest rate, r_{CB}, see the Appendix, plus a fixed spread. Mortgage payments are monthly are spread over T_M years. Monthly mortgage payments R_n of each mortgage n include both interests and the principal installment, where the latter is fixed and determined by the ratio between the initial mortgage amount and mortgage duration in months, while monthly interest payments are computed on the outstanding mortgage principal according to r_M which follow the central bank interest rate. Buyers may use their cash to buy housing units or, if they do not have enough liquidity, they apply for mortgages to banks which evaluate their capability to face mortgage repayments before granting the mortgage. In particular, banks compare household's net income[2] (both labor and capital) earned in the last quarter with household's expected quarterly mortgage payments, including both

[2]Eq. .13 in the Appendix reports household's monthly income

old outstanding mortgages and the new requested mortgage. Banks grant the requested mortgage only if the ratio between expected quarterly mortgage payments of the household and her/his net quartely income is lower or equal than a pre-determined threshold, which is called debt service to income (DTSI) (Svensson, 2014).

3. Computational Results

The artificial economy is populated by 3000 households, 50 consumption goods producers, 1 investment good producer, 1 government, 3 banks, and 1 central bank. For each combination of parameters that are under investigation the economy is simulated for 30 years. Each of such different initialization is run with 20 different seeds of random number generator. Due to necessity of high computational power, the experiments are performed on a 64 node linux cluster.

We divide these results section into two parts, according to the two main research questions of the paper. The first part, in section 3.1, investigates the macroeconomic effects of introducing an housing market and a related mortgage market into the Eurace model. The second part, in section 3.2, investigates how regulation (or deregulation) of banks mortgages can influence both the housing market and the main economic indicators.

3.1. The housing market role in the economy

In the baseline version of the model, households are endowed with a fixed number of housing units but they have no possibility to buy new housing units or to sell them. This baseline version of the model corresponds to a required debt service to-income ratio (DSTI) equal to zero; in this case households are never eligible for a mortgage and are therefore unable to enter the housing market. For values of the required DSTI higher than zero, households are able to obtain mortgages from banks, according to their expectation to be able to pay it back. Higher DSTI requirements mean a looser banking regulation and an easiest access to bank credit.

Figures from 7 to 14 summarize in boxplots the effect of different DSTI requirements on the main economic indicators in the economy. In this first section we should focus on the first two values of DSTI$=0$ and DSTI$=0.1$ which highlight the transition from an economy without housing (and mortgage) market to an economy with housing (and mortgage) market. The economic impact of different regulation strategies, i.e., higher or lower DSTIs, will be discussed later, in the next section.

In order to understand the housing market role in the economy we show also some sample trajectories of several aggregated variables like loans, consumption and unemployment. Figures from 2 to 6 show these trajectories for three selected values of DSTI. Again, we will focus for the moment on the difference between an economy with or without housing market, i.e., DSTI equal to zero or different from zero. The time series of these plots correspond of course to a specific random seed, whereas the aforementioned box-plots represent all the set of used seeds.

By visually analyzing the sample time series, it clearly emerges that the introduction of a mortgage market increases the money supply. Figure 3 shows that for positive DSTIs banks start to grant mortgages and the total amount of credit in the economy raises. This higher credit amount affects on one side the money supply (bank deposits on figure 4) and on the other side the housing price (figure 5).

These results are still valid if we observe the whole set of simulations. Figures

11 show that the mortgage level becomes positive when DSTI departs from zero (compare for instance DSTI = 0 and = 0.1). In general, all features observed in the time series plot for one seed are confirmed in the box-plots for all seeds.

3.1.1. The mortgage-driven endogenous monetary expansion

The mortgages granted by banks directly affect households deposits. As it is well known [3], whenever a bank makes a mortgage, it simultaneously creates a matching deposit in the borrowers bank account, thereby creating new money. This endogenous money creation affects households aggregated demand, supporting consumption. From figure 10 we see that both mean and median consumption level (and growth rate) are significantly higher when the endogenous creation of money is reinforced by the existence of banks mortgages.

Let us point out that households consumption is not directly affected by a wealth effect mechanism; meaning that the individual desired level of consumption does not depend explicitly on households total assets. However, the higher liquidity in households deposits makes less probable a rationing in the goods market, supporting consumption both in boom and recession periods. This effect can be observed by comparing the much higher stability of consumption across different simulation seeds in figure 10. The huge reduction in dispersion between DSTI= 0 and DSTI= 0.1 shows the role of endogenous money in stabilizing consumption, apart from increasing its average level.

Supporting aggregated demand makes of course improves firms sales, and put them in a better position to invest. Looking at the box-plots for real investments and firms loans between DSTI= 0 and DSTI= 0.1, it emerges that higher consumption (i.e., higher sales) affects firms investment decision and, consequently,

[3] See for instance the Bank of England Quarterly Bulletin 2014 Q1

the level of loans requested by firms and granted by banks.

Therefore, real GDP is positively affected by plugging the housing market into the Eurace economic model, both in terms of total production and of economic stability, measured by the dispersion level around the median. Observing the unemployment rate we draw similar conclusion. The average rate of unemployment (the blue diamond in figure 7) is clearly decreasing from DSTI= 0 to DSTI= 0.1, while the median seems not significantly affected. This, again, suggests that the additional amount of endogenous money created by mortgages tends to stabilize the main economic indicators, including employment.

3.1.2. Stylized Facts on Credit and GDP

In a few words, we have shown that mortgages affect consumption and sales, that in turn stimulate investments and firms loans demand. This economic propagation mechanism is actually confirmed by empirical evidence. In the past three decades within the Euro zone, growth rates of loans to firms revealed a relatively stable relationships with the business cycle ECB Bulletin (2013). Growth in loans to non-financial corporations tend to lag real GDP fluctuations. On the other side, loans to households tend to lead GDP growth slightly or occasionally they are observed to follow a coincident pattern relative to GDP growths[4]. Our computational results show similar patterns.

Figure 1 demonstrates the dynamic relationship between loans, mortgages and the business cycle in the model. It clearly shows that empirically observed stylized facts are also observed in the model.

The upper plot in Figure 1 suggests that loans to the private sector lags GDP growth. The phase difference is observed to be around 2 quarters. This phase

[4]For a recent overview, see the "Stylized Facts of Money" in ECB Bulletin (2013)

difference we observe in the Eurace model is somewhat shorter than the differences that have been observed in empirical data, where it can go up to one year. This difference may be explained by the modeling simplifications where firm agents' responses to aggregate demand variation are shorter. The lower panel in the same figure displays a clear lead of mortgages to business cycles. This lead of mortgages can partly be explained by the already mentioned mechanism where any housing transaction causes injection of money in the economy whose size is proportional to the nominal value of the housing unit.

The lagging pattern of loans to firms over the business cycle may suggest that during recoveries firms can first finance investment expenditure using their internal funds, as cash flows improve during a recovery, and only later they seek for external financing (as suggested by ECB Bulletin (2013)). On the other way around, it may also indicate that during recessions the reduction of banks equity capital caused by firms defaults prevents further loan issuing, due to Basel II restrictions.

The lead of mortgages confirms that mortgages produce an injection of liquidity to households and hence an increase in demand, production, and GDP growth. This, in return, increases demand for investment at producers' side, which leads them to request more loans from the banking sector. Overall, what we observe is a pattern of systematic responses, where money creation via mortgages is responded by a growth in GDP and later an increase in loan requests for further investment in productions. A comparison of upper and lower panels in Figure 1 clearly reveals this dynamicity.

3.2. Mortgage lending regulation

In the previous sections the impact of the housing market in the Eurace model has been explained, showing the central role of endogenous money creation triggered by the mortgage market activation. However, a legitimate question is: to what extent an increasingly unregulated mortgage market, allowing for easier access to credit, could help improving the economic performance and stabilizing the economy? In order to answer this question, in first place we introduced the possibility to get mortgages to buy housing units (going from DSTI= 0 to DSTI= 0.1), and then we gradually relaxed the financial constraints of mortgage lending regulation, allowing households with higher debt-to-income ratios to receive credit from banks. This relaxation of credit constraints is associated with the increase of the DSTI threshold, i.e, when DSTI is high enough also citizen with low income with respect to debt service are eligible for a mortgage loan. A high value of DSTI could be also labeled as sub-prime lending, recalling the recent housing market crisis in the U.S.

Looking to the box-plots figures, resuming results for all seeds, we can try to give an answer to the question. Figure 11 shows that the total amount of mortgages in the economy is sharply raising up to a certain level of DSTI (around 0.4), but it tends to stabilize or to even decline later. The same can be noticed about bank deposits in figure 4, therefore showing that the endogenous money creation channel is somehow sterilized when regulation becomes too loose. On the other hand, the smoothness and stability of the housing market is seriously undermined by a loose regulation, as shown in 13 and 12. When credit is given to fragile, or sub-prime borrowers, the number of housing units fire-sales increases, driving down the housing price and triggering many debt write-off, that in turn damage banks equity capital.

This propagation mechanisms can be observed both in the box-plots and in the time trajectories. Looking at the loosest regulation case (DSTI = 0.6), a clear time structure can be observed, where fire sales tend to increase in the last part of a boom, causing a crash of the housing price and, afterwards, a strong reduction in banks equity and therefore in banks financial stability. Through the channel of the reduced lending capacity of banks, also real economy can be affected, as the two crisis around year 21 and year 29 clearly show.

So, we can summarize that the benefit of additional endogenous money creation is no more relevant after a certain DSTI threshold, i.e., bank deposits grow quickly up to DSTI = 0.3, and then stabilize. On the other hand for higher DSTI, the economy becomes more unstable; the average number of total firms defaults in figure 14 has a clear parabolic shape with a minimum value around DSTI = 0.4. In particular, the considerable difference between mean and median for high DSTI values suggests the presence of simulation seeds with disastrous outcomes in terms of firms defaults chains.

Looking at real GDP in figures 8 and 9, the difference is not so striking but a decreasing trend can be observed from DSTI = 0.3, both concerning GDP levels and growth. A similar pattern is followed by the unemployment rate and by the GDP components, i.e., consumption and investments (figures 6, 2). In particular, the box amplitude shows how dispersion in investments is much higher than dispersion in consumption, indicating a higher volatility across the different seeds.

Therefore, our results suggest that the positive effects related to the introduction of an housing market mechanism in the economy becomes weaker when the regulation of mortgage loans becomes too loose.

4. Conclusions

This paper presents the design of an housing market and a related mortgage market for the Eurace macroeconomic model and simulator. The aim is twofold, from the one hand we want to understand the economic role of the housing market in the model, and from the other hand we want to understand the effect of mortgage regulation.

We clearly observe that the main impact of the housing market is given by the endogenous money creation mechanism, due to the new mortgage loans that banks grant to households. These loans increase households bank deposits and, in turn, stimulates the aggregate demand of goods. Our computational experiment shows that the inflow of endogenous money affects both the financial variables of the economy and, to a minor extent, the real ones, including real GDP and unemployment rate.

The second part of the experiment studies how the artificial economy reacts when increasing the debt-service to income (DSTI) ratio thresholds in order to obtain a mortgage from a bank. DSTI measures the rigor of banking regulation, and our study shows that increasing DSTI has non linear effects on the economy. Endogenous money and economic performance raise quickly and significantly for low values of DSTI (until 0.3 - 0.4), then becomes stable, and finally, after a threshold (around DSTI = 0.5), the economic performance deteriorates. This worsening is due to a higher instability of the economy when sub-prime borrowers have access to credit, increasing the number of housing units fire sales, bank write off and, finally, firms bankruptcies.

Therefore, our study indicates from the one hand the importance of the housing market in the economy for its role of regulating aggregate demand through endogenous money creation. From the other hand our results warn against too loose regulations of the mortgage market, that can lead to economic instability, paving the way for economic crises.

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[5] www.projectsymphony.eu

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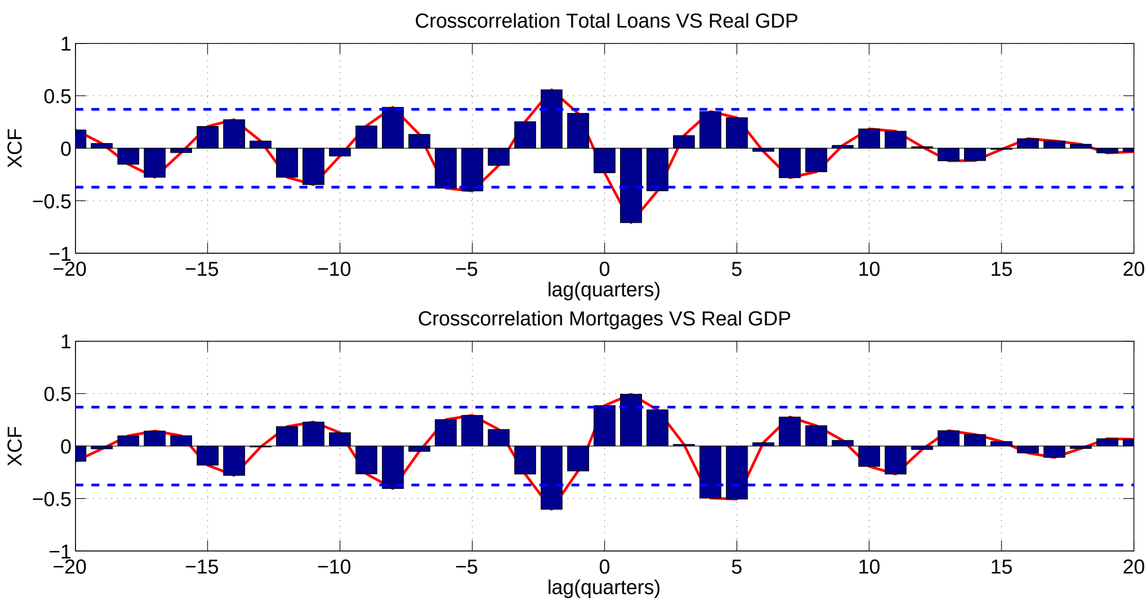

Figure 1: Cross Correlation between Total Loan and Real GDP. Cross Correlation between Mortgages and Real GDP. Note that GDP growth leads when lags have − signs and it lags when they have + signs.

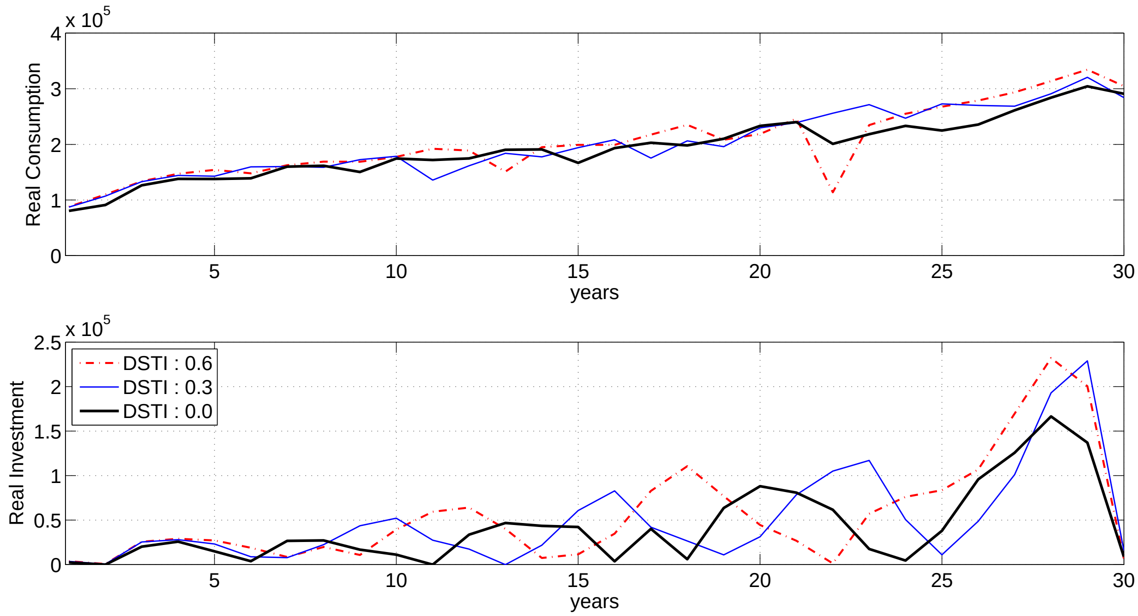

Figure 2: Real Consumption and Real Investment over different DSTI.

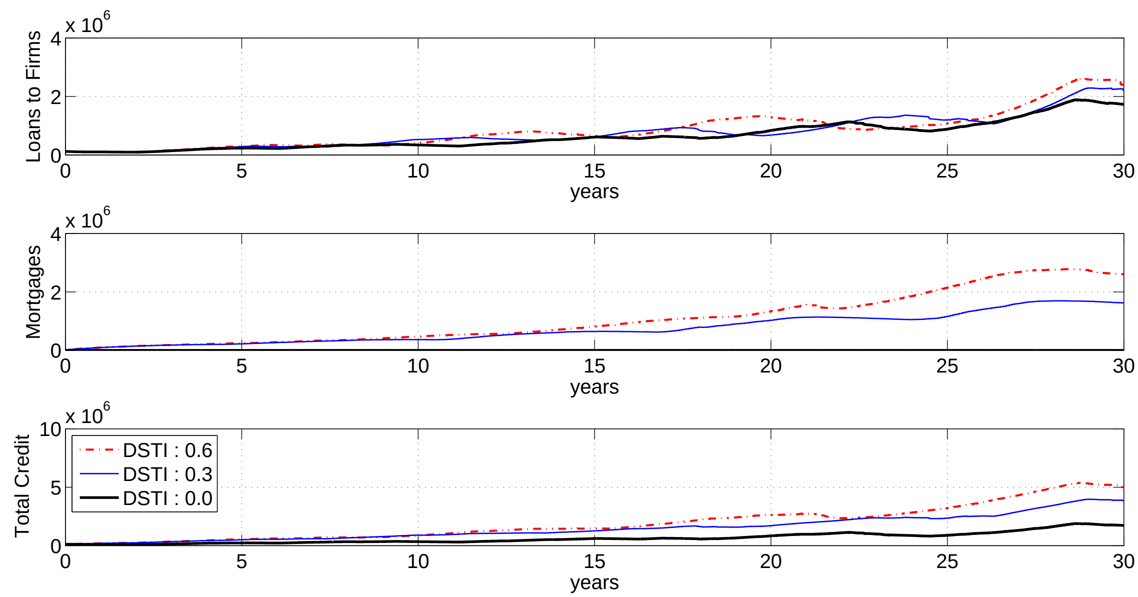

Figure 3: Firms Loans, Mortgages, and Total Credit over different DSTI.

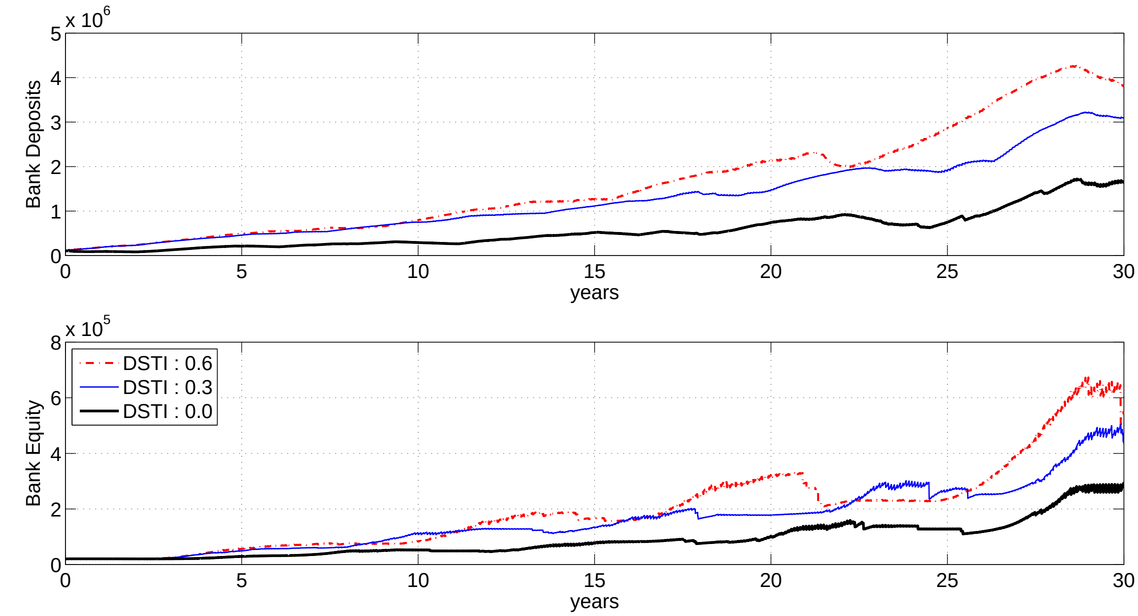

Figure 4: Bank Deposit and Bank Equity over different DSTI.

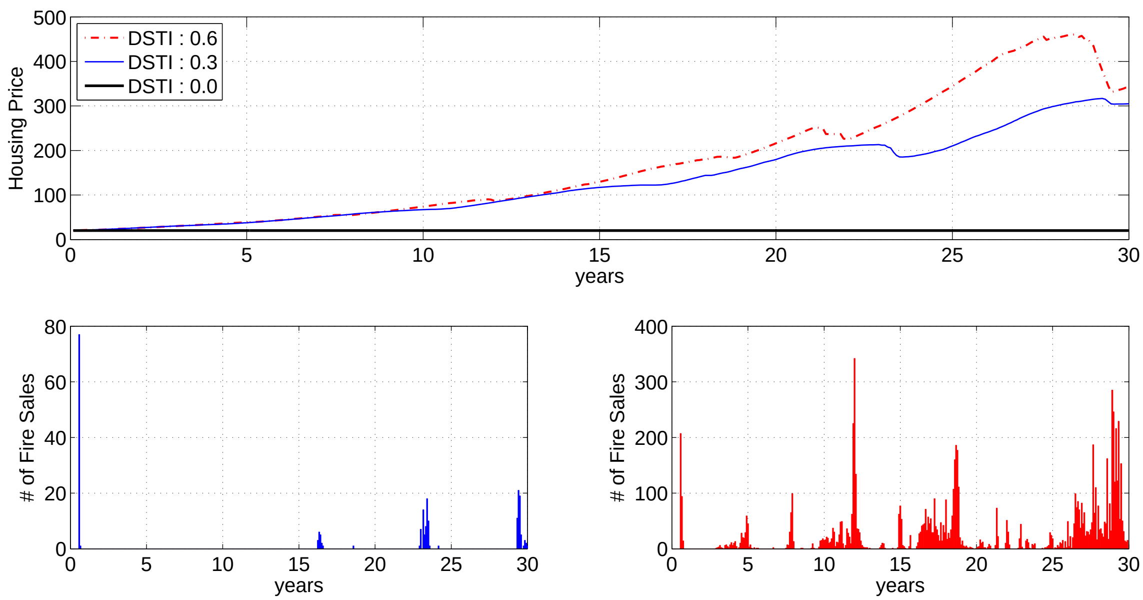

Figure 5: House Price and Fire Sale over different DSTI.

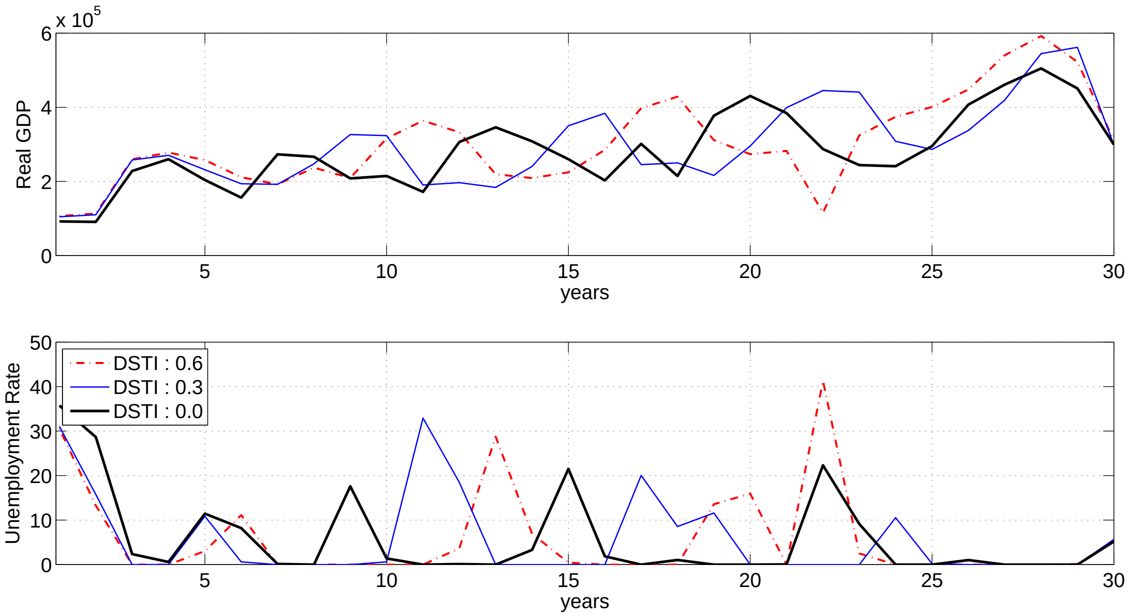

Figure 6: Real GDP and Unemployment Rate over different DSTI.

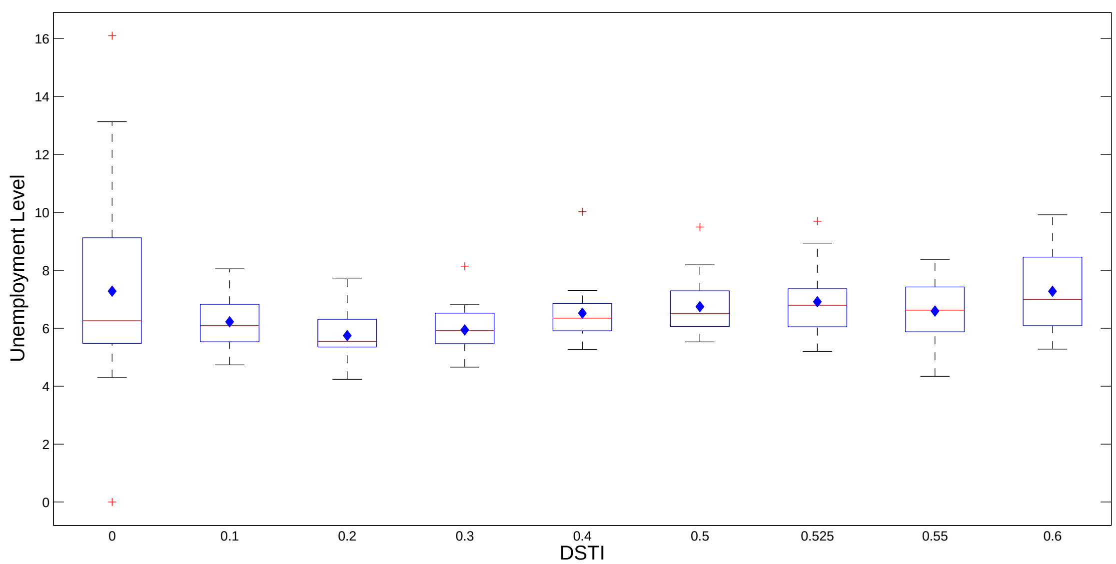

Figure 7: Unemployment Level over different DSTI.

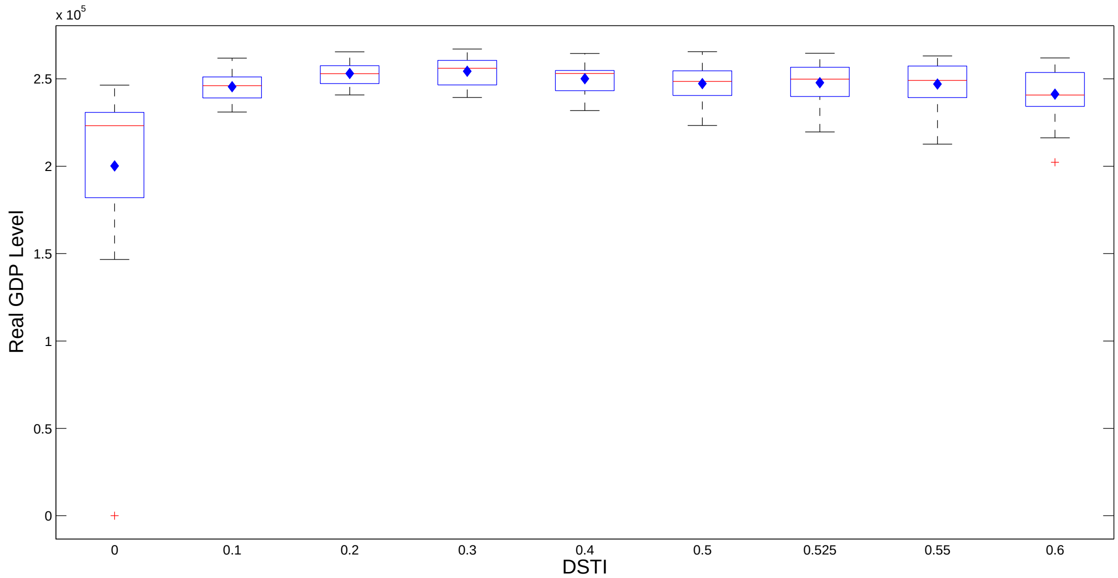

Figure 8: Real GDP Level over different DSTI.

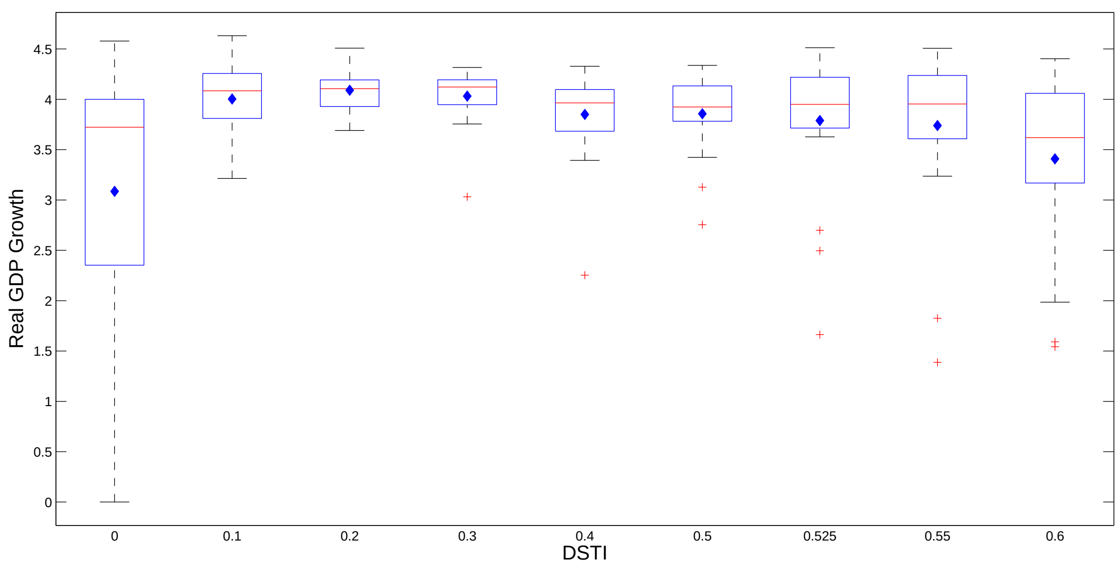

Figure 9: Real GDP Growth over different DSTI.

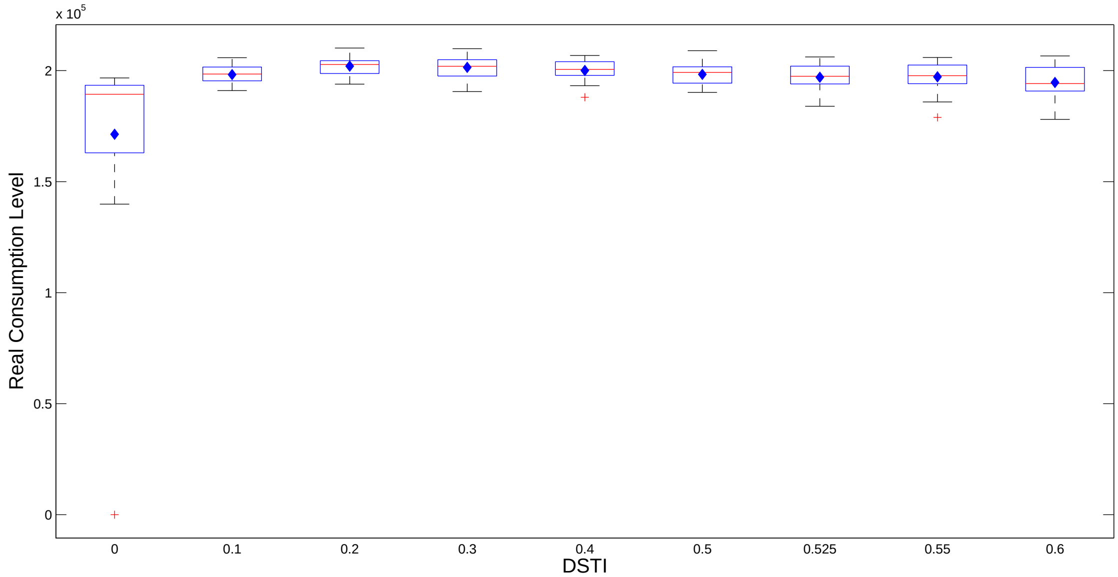

Figure 10: Real Consumption Level over different DSTI.

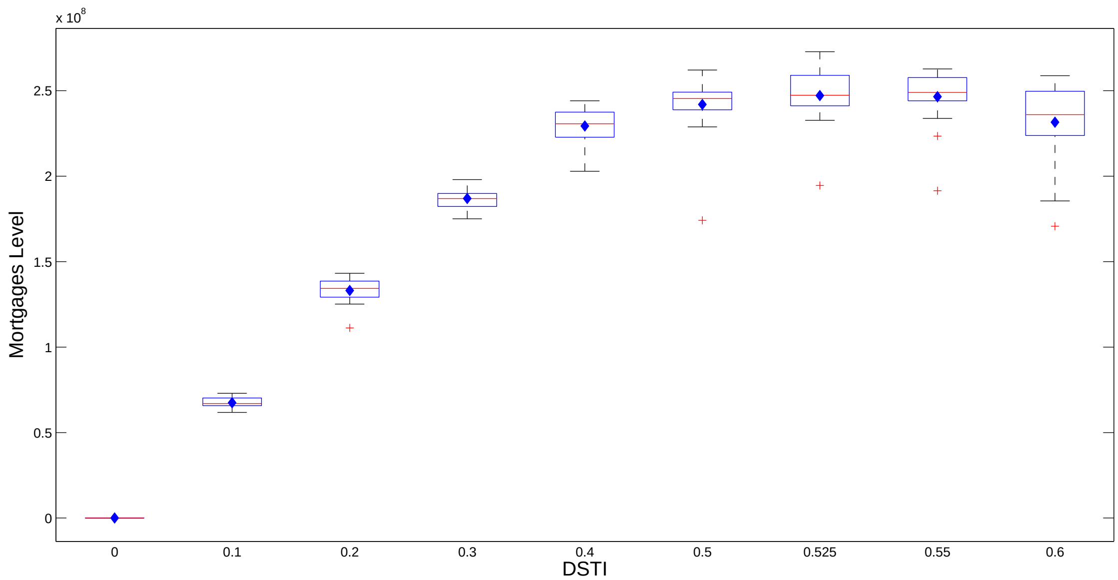

Figure 11: Mortgages Level over different DSTI.

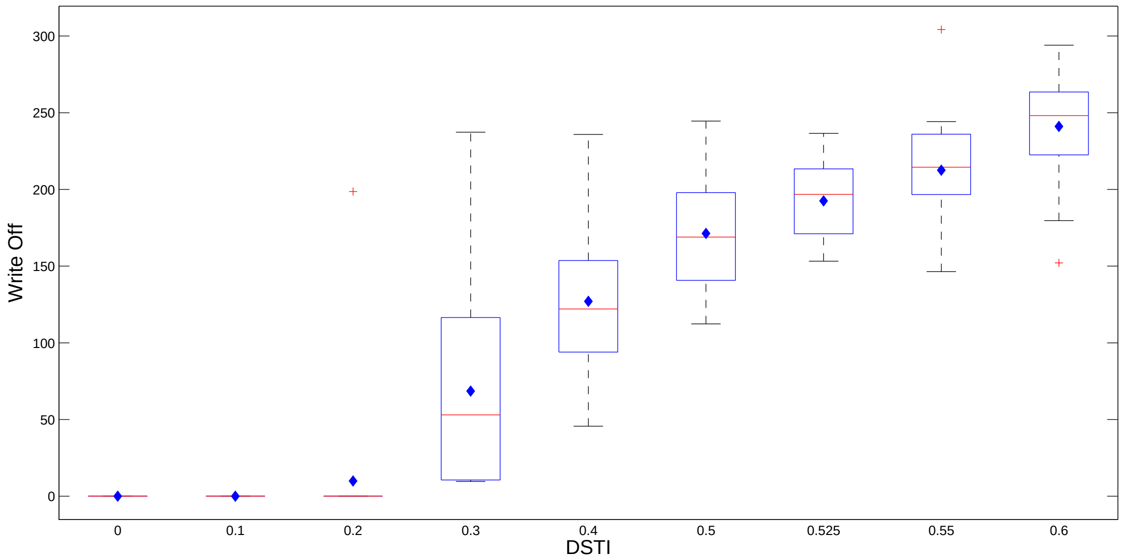

Figure 12: Write Off over different DSTI.

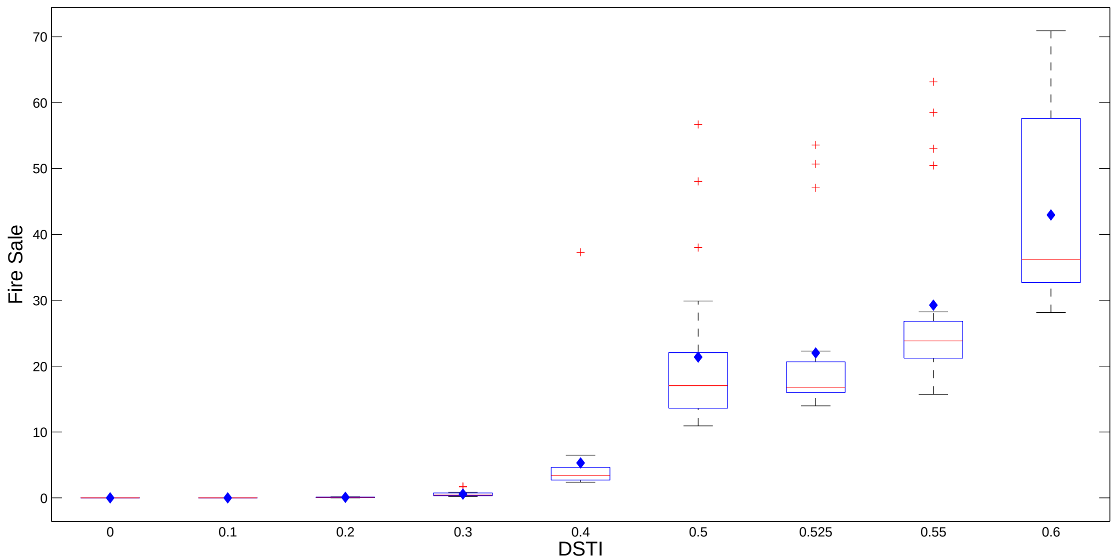

Figure 13: Fire Sale over different DSTI.

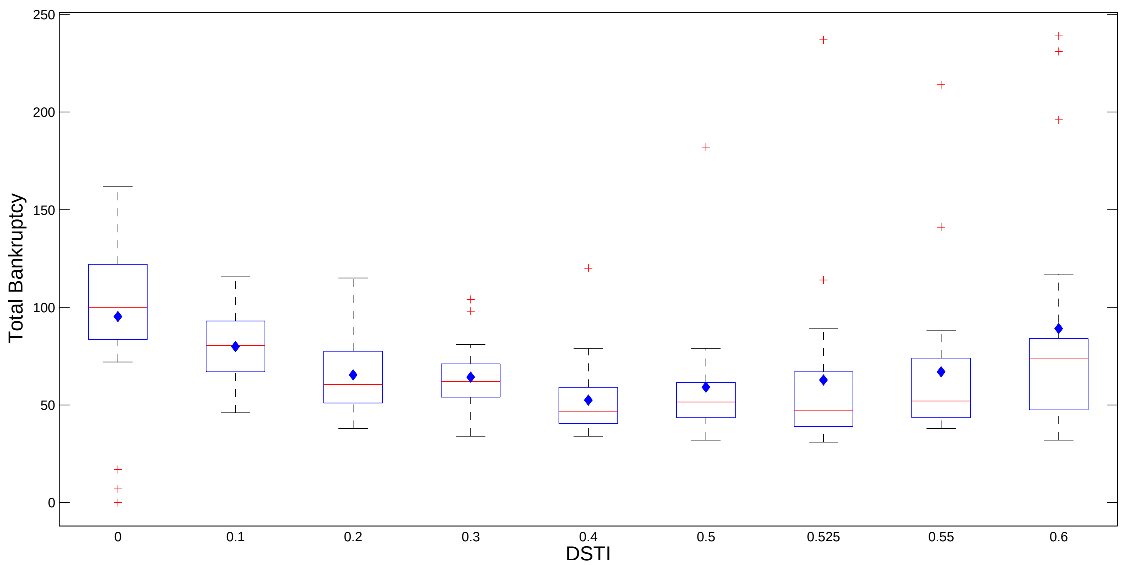

Figure 14: Total Bankruptcy over different DSTI.

Appendix

Eurace agents

In the following, we report the equations characterizing agents' behaviour and decision making. Agents' formation of expected values, wishes or plans about key economic variables are also reported and denoted with the superscript e, while wishes or plan are marked by an hat on the variable symbol. Tables .2, .3, .4, .5 and .6 include agents' parameters set for the simulations' initialization, used to produce the presented results.

Appendix .1. Schedulling

The elementary simulation time step can be considered a calendar day; however, most agents' decisions and economic events occur at a weekly, monthly, or even yearly periodicity, and are asynchronous. For instance, trading of stocks and government bonds is active every day; consumption budget decisions are made monthly by households but purchases are made on weekly basis; firms' decision about production planning, new hirings, pricing, investments and financing are characterized by a monthly periodicity but are asynchronous, i.e., each firm makes its monthly production/investments decisions at a particular day, henceforth activation day, of the calendar month.[6]

Finally, decisions by policy makers can be taken on a monthly or yearly basis. In particular, the policy rate is set by the central bank at the beginning of each calendar month, at the same time the government sets the amount of bonds to issue during the month to address its liquidity needs; tax rates instead are usually adjusted on a yearly basis according to the predefined fiscal policy.

[6]A calendar month is defined as a set of 20 days

Consumption goods producers (firms)

We provide below a sequential list of the key decision variables each consumption goods producer, henceforth firm f, plans or decides once a month, at its particular activation day:

- the expected demand of consumption goods $q^e_{C_f}$ it will face, based on a linear interpolation of past T_C monthly sales;
- the desired level of inventories $\widehat{I}_f$ to meet expected demand $q^e_{C_f}$;
- the production needs $\bar{q}_{C_f}$ necessary to accumulate the desired level of inventories $\widehat{I}_f$, i.e., $\bar{q}_{C_f} = \max[0, \widehat{I}_f - I_f]$;
- the production plan $\widehat{q}_{C_f}$ as a linear combination[7] of production needs $\bar{q}_{C_f}$ and previous month production q_{C_f}, i.e., $\widehat{q}_{C_f} = (1-\lambda)\bar{q}_{C_f} + \lambda q_{C_f}$;
- the labor force $\widehat{N}_f$ needed and the amount of physical capital $\widehat{K}_f$ needed to meet the desired production plan, given the present endowment of capital goods K_f, the present number of employees N_f, and the Cobb-Douglas production technology, as follows:

$$\widehat{N}_f = \left(\frac{\widehat{q}_{C_f}}{\gamma\,(K_f)^\beta}\right)^{\frac{1}{\alpha}}; \tag{.1}$$

$$\widehat{K}_f = \left(\frac{\widehat{q}_{C_f}}{\gamma\,(N_f)^\alpha}\right)^{\frac{1}{\beta}}; \tag{.2}$$

  where γ is the total factor productivity, while α and β are the output elasticities of labor and capital, respectively;
- the labor demand N^d_f given by the difference, if not negative, between the needed labor force $\widehat{N}_f$ and the present number of employees N_f;

[7] This provision is aimed to smooth the production plan over time and then reduce oscillations in input demand.

- the planned investment in new capital goods $\widehat{\Delta K}_f$, which is bounded by the difference $\widehat{K}_f - K_f$ and maximizes the present value of the foreseen additional revenues $p^e_{C_m}\Delta_m q_{C_f}$, originated by the investment at any next month m, after deducting the investment costs at the capital goods price p_K, as follows:

$$\widehat{\Delta K}_f = \underset{\widehat{\Delta K}_f \leq (\widehat{K}_f - K_f)}{\arg\max} \left(- p_K \widehat{\Delta K}_f + \sum_m \frac{p^e_{C_m}\Delta_m q_{C_f}}{(1+\tau_C)\left(1+\frac{r_{K_f}}{12}\right)^m} \right); \quad (.3)$$

where τ_C is the value added tax on consumption, $p^e_{C_m}$ is the expected price level at any future month m and $\Delta_m q_{C_f}$ is the additional output given by the planned investment. The latter two quantities are estimated as follows:

$$p^e_{C_m} = p_C\left(1+\frac{\pi^e_C}{12}\right)^m; \quad (.4)$$

$$\Delta_m q_{C_f} = \gamma N_f^\alpha \left(K_f + (1-\xi_K)^m \widehat{\Delta K}_f\right)^\beta - \gamma N_f^\alpha K_f^\beta; \quad (.5)$$

where π^e_C is the expected yearly inflation rate[8] and ξ_K is the capital goods constant monthly depreciation rate[9]. Finally, r_{K_f} is the yearly average cost of capital of firm f; for the sake of simplicity, this cost is estimated by averaging the cost of different loans.

- the total liquidity needs $\widehat{M}_f$ given by the foreseen cost of planned capital goods investments $p_K\widehat{\Delta K}_f$, planned labor costs $w_f\widehat{N}_f$, debt interests $\mathcal{I}_f$

[8]Expected inflation π^e_C is estimated as a weighted average between the declared central bank inflation target $\widehat{\pi}_{CB}$ and the present yearly realized inflation rate π_C, i.e., $\pi^e = \omega_\pi \widehat{\pi}_{CB} + (1-\omega_\pi)\pi_C$, where the weight parameter ω_π can be considered as a sort of trust of private agents on the central bank policy action.

[9]Due to capital depreciation, the cash flows given by the additional revenues of investments decrease exponentially over time and therefore the sum of Eq. .3 is truncated when the addend is lower than a positive very small threshold.

and the installment $\delta_D D_f$ of debt repayment, taxes[10] $\mathcal{T}_f$ and the foreseen dividend payout $n_{E_f} d_f$, i.e.,

$$\widehat{M}_f = p_K \widehat{\Delta K}_f + w \widehat{N}_f + \mathcal{I}_f + \delta_\ell D_f + \mathcal{T}_f + n_{E_f} d_f\,; \tag{.6}$$

where δ_ℓ is the monthly fraction of debt repayment[11] and, considering the yearly interest rate r_{f,b_i} paid by firm f on its i-th debt of amount D_{f,b_i} to bank b, monthly debt interests payments are given by:
$\mathcal{I}_f = \sum_{b,i} \frac{r_{f,b_i}}{12} D_{f,b_i}$;

- the amount of new loan $\widehat{\ell}_f$ requested to the banking system, given by the difference, if not negative, between $\widehat{M_f}$ and present liquidity M_f;

- if rationed in the credit market, i.e., the new loan ℓ_f received is lower than $\widehat{\ell}_f$, the amount of new shares Δn_{E_f} to issue in the stock market, given by:

$$\Delta n_{E_f} = \frac{\widehat{M_f} - \ell_f - M_f}{p_{E_f}}\,; \tag{.7}$$

where p_{E_f} is the present stock price;

- if rationed also in the stock market, the reduction of the costs under its control, in order to make the total financial needs consistent with the available liquidity. First, the total dividend payout is reduced up to zero, then, if still not sufficient, the investment plan is sized down and, eventually, the production plan as well.[12]

[10] $\mathcal{T}_f$ include taxes on corporate earnings and the value added tax (VAT) paid by consumers. VAT is collected by firms and transferred by them to the government.

[11] See table .3

[12] If the available liquidity is not even sufficient to meet compulsory payments, i.e. debt service and taxes, then the firm enters a process called illiquidity bankruptcy, where it fires all its employees and stay inactive till it is able to raise the necessary funds in the stock market. It is worth remembering that the model foresees also a more severe case called insolvency bankruptcy, which is triggered whenever the equity of the firm becomes negative and therefore involves also a debt restructuring process with a consequent loan and equity

As soon as the decisions above are taken, the firm pays its financial commitments, namely, debt interests and debt installments, taxes on corporate earnings, the value added tax and dividends to shareholders. Then, in the same activation day, the firm enters factors (labor and capital goods) markets to fulfill its production and investment plans, also considering possible revisions downward due to rationing in the credit and stock markets. In particular, if the number of employees is higher than needed, the firm fires workers in excess, otherwise it starts the first labor market session to hire new additional employees. If the firm is unable to hire all the needed new employees, it increases its wage offer by a fixed percentage ξ_w and starts a second market session. If rationed again, it increases again its wage offer but exits the labor market ending up with a number of employees N_f lower than the planned one. Monthly wages are paid in advance at the end of the labor market sessions.[13] Then, the firm purchases the amount of new capital goods according to fulfill its investment plan. New capital goods are immediately delivered and summed up to the existing capital endowment. We assume that firms are never rationed in the capital goods market. Finally, firms execute the production process that, following the Cobb-Douglas technology, delivers immediately an amount of new consumption goods q_{C_f} given by the new levels of labor N_f and capital K_f, as follows:

$$q_{C_f} = \gamma N_f^{\alpha} K_f^{\beta} \, . \tag{.8}$$

The new produced goods are summed to present inventories and made available for sale to households during the 20 business days following firms' activation days. Finally, the new sale price p_{C_f} is set based on a fixed mark-up μ_C on the

write-off for lending banks.

[13]Further details about the Eurace labor market are provided in Dawid et al. (2014).

overall unit costs c_{u_f}, i.e.,

$$p_{C_f} = (1 + \mu_C) c_{u_f} \, ; \tag{.9}$$

where overall unit costs are a weighted average of inventories' unit costs $c_{u_f}^{(I)}$ and new produced goods unit costs $c_{u_f}^{(q)}$, given by labor costs and the the interest bill, as follows:

$$c_{u_f} = \frac{I_f \, c_{u_f}^{(I)} + q_{C_f} \, c_{u_f}^{(q)}}{I_f + q_{C_f}} \qquad c_{u_f}^{(q)} = \frac{w_f \, N_f + \mathcal{I}_f}{q_{C_f}} \, . \tag{.10}$$

After twenty days, the day before a new activation day occurs, each firm calculates its monthly income statement along with monthly interests, taxes and net earnings; then computes the share of dividend payout as a fraction ξ_d of net earnings, if positive, and updates its balance sheet.[14]

Firm Parameters		
Symbol	**Name**	**Value**
λ	previous month production weight	0.5
γ	total factor productivity	1.5
α	output elasticities of labor	0.662
β	output elasticities of capital	0.338
ξ_K	capital goods constant monthly depreciation rate	0.005
ξ_w	monthly wage percentage increase	0.01

Continued on next page

[14]In particular, each firm updates the value of its net worth or equity. If the equity becomes negative the firm is declared insolvent and enters a special process termed insolvency bankruptcy, where the its fires all its employees, undergoes a restructuring of its debt with a related loan write-off and a corresponding equity loss on creditor banks' balance sheets, and stays inactive for a period of time after which it enters again the market with a healthy balance sheet. Physical capital of insolvent firms is therefore not lost but remains inactive for a while.

Table .2 – *Continued from previous page*

Symbol	Name	Value
μ_C	fixed mark up	0.1
ξ_d	fraction of net earnings paid as dividends	0.75
ω_π	central bank inflation target weight	0.5

Capital goods producer

There is just one type of technology for capital goods. Capital goods are produced on request and therefore do not generate inventories. Energy and raw materials are the only factor of production and are assumed to be imported from abroad. The price of capital goods is set according to a mark-up on input prices, which are exogenously given. Profits of investment good producers are distributed in equal shares among all households. Thus, the amount paid by consumption goods producers for investment goods is partially (the part related to mark-up) channelled back into the economy. In the experiments performed in this study, however, in order to separate the effects of the different fiscal policies from the exogenous dynamics of raw materials and energy, the price of these commodities has been conventionally set to zero, and the price of capital goods is set to a constant value. The model can therefore be considered as a closed economy where the revenues of the capital goods producer coincide with its profits and are fully channelled back into Eurace economy through dividends and tax payments.

Banks

Banks are always active on a daily basis being ready to receive loans requests from firms. As outlined in the previous paragraph, each firm sends a loan request at its activation day and firms' activation days are uniformly distributed over the calendar month. Whenever a bank receive a loan request $\widehat{\ell}_f$ by a firm f, the request is evaluated and a loan eventually offered according to the following steps:

- the bank assesses the risk of the new loan; first, it estimates the default probability π_{D_f} of the prospective borrower, based on its leverage, along the lines of the Moodys KMV model (Saunders and Allen, 2010); then, it assesses the risk weight $\omega_{\widehat{\ell}_f}$ of the new loan through an ad-hoc cubic function approximating[15] the so-called Basel II internal ratings approach, i.e.,

$$\pi_{D_f} = \frac{D_f + \widehat{\ell}_f}{D_f + \widehat{\ell}_f + E_f} \qquad \omega_{\widehat{\ell}_f} = 2.5\big(\pi_{D_f}\big)^3 . \tag{.11}$$

  The rationale is that the lower the capital base of the borrower with respect to its debt, the higher the likelihood of default is, and then the loan's risk, because of possible equity losses due to negative earnings;

- the bank b checks if its risk-weighted loan portfolio including the new prospective loan, weighted by its risk, still fulfils regulatory capital requirements, i.e. if the following condition holds:

$$E_b \geq \Psi\Big(\sum_i \omega_{\ell_i}\,\ell_i + \omega_{\widehat{\ell}_f}\,\widehat{\ell}_f\Big) ; \tag{.12}$$

  where Ψ is the so called capital adequacy ratio, i.e. a policy parameter, ranging from 0 to 1, set by the regulatory provisions for the banking system;

- the bank b rejects the loan requests or otherwise it offers to firm f a loan amount $\ell_{b,f} \leq \widehat{\ell}_f$ to the extent the capital requirement condition of Eq. .12 is satisfied; the new loan is offered for a duration of T_ℓ months at a yearly interest rate $r_{b,f}$ given by central bank rate plus a stochastic

[15] According to the graphical representation reported in Yeh et al. (2005).

mark-up depending of the loan risk ω_{ℓ_f}.

The borrowing firm ranks the loan offers received according to their interest rates and accepts the loan offers with the lowest rates up to the amount of money requested.

At the end of any calendar month, each bank computes its income statement along with income taxes and net earnings, then decides the dividends payout, to be paid each first day of the calendar month, then updates its balance sheet. All net earnings, if positive, are paid out as dividends, unless the bank had to decline loan requests because of the capital adequacy ratio constraint. In this case, the bank retains all net earnings to increase its equity base.

Bank Parameters		
Symbol	**Name**	**Value**
ψ	capital adequacy ratio	0.10
T_ℓ	loan duration (months)	24
δ_ℓ	monthly fraction of debt repayment	$1/T_\ell$

Households

Households are always ready on a daily basis to make a financial trade and to look for a new job, if unemployed. In particular, at any daily simulation step, each household has a given exogenously probability π_H to change the allocation of its financial portfolio. In this case, the household forms beliefs about the expected returns of all financial assets (firms' shares and government bonds) according to a weighted average of fundamentalist, random and chartist prototype expected returns, then she/he computes the new "optimal" asset allocation according to a preference structure based on the myopic loss aversion hypothesis of prospect theory (Kahneman and Tversky, 1979; Benartzi and Thaler, 1995);

finally, the household issues buy and sell orders to get the desired optimal allocation. Full details about households' financial beliefs and preference and the working of the financial market are provided in Raberto et al. (2008); Teglio et al. (2009).

After financial market transactions are over, unemployed households enter the labor market to evaluate pending job offers. Here, households are randomly queued to apply to the set of available jobs characterized by the highest wages, provided that they are higher than their reservation wage.[16]. If a household is not successful in getting a new job, her/his reservation wage is decreased by a constant rate δ_w and the household re-evaluates again pending job offers. If the job search is again unsuccessful, household's reservation wage is again decreased by the same rate δ_w and she/he leaves the labor market till next daily simulation step. Further details about the Eurace labor market are provided in Dawid et al. (2014).

Employed households receive their salary from their employers (the firms) on a monthly basis but at different days which coincide with firms' activation days, i.e. the dates when they have been hired. Salaries w_f are identical among the employees of the same firm f but differ across firms, according to the labor market outcome, because firms raise their wage offer whenever they are unable to find the needed employees. Households employed in the public sector receive from the government a public wage w_g, which is set equal to the average wage in the private sector in the last 12 months. Unemployed households receive on a monthly basis an unemployment benefit[17] from the government; the benefit is paid the same day of the month the household is fired. The day of the

[16]The reservation wage is set equal to the last received wage and is therefore heterogeneous among households

[17]The unemployment benefit is set at a fraction δ_U of the last salary received by the households

month a households receive the salary or the unemployment benefit, it gets also a transfer payment[18] y_{T_h} from the government and computes and pays taxes on both the labor income y_{L_h} (the salary or the unemployment benefit) and the capital income, given by the stocks' dividends y_{E_h} and bonds' coupons y_{B_h} received during the previous 20 days. The same day the household receives its labor/unemployment benefit income, it also determines its monthly consumption budget $\mathcal{C}_h$, which is modelled according to the theory of buffer-stock saving behavior (Carroll, 2001; Deaton, 1992), stating that households consume more or less than their net income with the aim to get a target ratio λ_C of liquid wealth[19] W_h to total net income $y_{h,\text{net}}$. In particular, being the total net income $y_{h,\text{net}}$ given by:

$$y_{h,\text{net}} = (1 - \tau_N)\, y_{L_h} + (1 - \tau_K)\big(y_{E_h} + y_{B_h}\big)\,, \tag{.13}$$

where τ_N and τ_K are the tax rates on labor and capital income, respectively, the monthly consumption budget $\mathcal{C}_h$ is determined by:

$$\mathcal{C}_h = y_{h,\text{net}} + \xi_C \Big(W_f - \lambda_C\, y_{h,\text{net}}\Big)\,, \tag{.14}$$

where ξ_C gives the speed of adjustment of consumption to meet the desired wealth to income target ratio. Therefore, households consume more (less) than their net income if their liquid wealth if higher (lower) than a multiple λ_C of their net income.

[18] The transfer payment is set to a fraction δ_T of the average wage paid by firms

[19] The liquid wealth is given by liquidity plus the market value of the stocks and government bonds portfolio.

Household Parameters		
Symbol	**Name**	**Value**
ξ_C	adjustment speed of consumption	0.01
λ_C	target ratio of liquid wealth to net income	70
π_H	probability of financial asset portfolio allocation	0.1
δ_w	constant rate of reservation wage decrease	0.01

Central Bank

The central bank is in charge of monetary policy, which consists of two main tasks: to provide liquidity in infinite supply to banks, whenever they need it, and to set the monthly policy rate r_{CB}, which is the cost banks pay when borrowing liquidity. In particular, at the beginning of each month, the central bank collects the information about the latest values of inflation and unemployment in the Eurace economy and sets the policy rate r_{CB} for the incoming month as follows:

$$r_{CB} = \pi_C + r^* + \omega_\pi \left(\pi_C - \widehat{\pi}_C\right) + \omega_\upsilon \left(\widehat{\upsilon}_N - \upsilon_N\right), \tag{.15}$$

where π_C is the last realized value of the inflation rate, measured in a yearly moving window, r^* is the assumed real interest rate, $\widehat{\pi}_C$ is the inflation target, $\widehat{\upsilon}_N$ is the unemployment target, and υ_N is the previous month unemployment rate.

It is worth noting that Eq. .15 resembles the well known Taylor rule (Taylor, 1993), but departs from the standard one for including a sort of unemployment gap, i.e., $\left(\widehat{\upsilon}_N - \upsilon_N\right)$, instead of the usual output gap. The reason of this choice is practical as it is not obvious, in particular in an agent-based model, how the output gap could be measured. However, the two measures are clearly strongly interconnected and the unemployment gap used in Eq. .15 is certainly a satisfactory indicator of economic recession.

Central Bank Parameters		
Symbol	**Name**	**Value**
r^*	assumed real interest rate	0.02
$\widehat{\pi}_C$	inflation target	0.02
$\widehat{\upsilon}_N$	unemployment target	0.0
ω_π	inflation weight	0.2
ω_υ	unemployment weight	0.2

Government

The government is in charge of both fiscal and welfare policies. The revenues of the government come from taxes that are applied to four sources: corporate earnings, consumption, capital income (dividends and bond coupons) and labour income (wages and unemployment benefits). Taxes are collected on a monthly basis, while the four related tax rates are usually revised yearly, depending on the particular fiscal policy adopted, as outline in section **??**.

Governments expenditures include the labor cost of public sector employees[20], unemployment benefits, transfers and government bond coupons.

On a monthly basis, if in short of liquidity, the government decides to issues new bonds, which are directly sold in the bond market at a discounted price with respect to the market price p_G, and then purchased by households.

Government bonds are perpetuities that pay a monthly fixed coupon that depends on the bond nominal value $\widehat{p}_G$ and the fixed nominal yearly interest rate r_G. Government bond market price depends on households' trading behavior,

[20] The number of public employees is set at a fixed percentage δ_G of the total household population.

which, like in the stock market case, is characterized by a mix of chartists, random and fundamentalist typical patterns. In particular, in the case of bonds, the fundamental price is determined by discounting the supposedly risk-free future bond coupons with the central bank policy rate.

Government Parameters		
Symbol	**Name**	**Value**
r_G	fixed nominal yearly rate on bonds	0.02
δ_U	fraction of last wage setting the unemployment benefit	0.7
δ_T	fraction of the average wage level setting the transfer payment	0.5
δ_G	fraction of public employees among household population	0.2