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# Housing Market Bubbles and Business Cycles in an Agent-Based Credit Economy

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**Abstract**
In this paper the authors present an agent-based model of a credit network economy. The artificial economy includes different economic agents that interact using simple behavioral rules through various markets, i.e., the consumption goods market, the labor market, the credit market and the housing market. A set of computational experiments, based on numerical simulations of the model, have been carried out in order to explore the effects of different households' creditworthiness conditions required by the banking system to grant a mortgage. The authors find that easier access to credit inflates housing prices, triggering a short run output expansion, mainly due to the wealth effect. Also, with a more permissive policy towards household mortgages, and thus higher levels of credit, the artificial economy becomes more unstable and prone to recessions usually caused by falling housing prices. Often the authors find that an initial crisis can leave firms in a fragile state. If the situation is not cured, a subsequent crisis can lead to mass bankruptcies of firms with catastrophic effects on the credit sector and on the real economy. With stricter conditions on household mortgages the economy is more stable and does not fall into serious recessions, although a too severe regulation can slow down economic growth.

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**Keywords** Credit cycles; housing market; agent-based model; subprime lending

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## 1 Introduction

The most widely used modeling approach in macroeconomics is based on the general equilibrium framework, and a class of models, known as dynamic stochastic general equilibrium (DSGE) models (see e.g. Smets et al. (2002)), are the workhorses in the field. The shortcomings of the general equilibrium framework and its variations have been known for a long time (Kirman (1989)) and recently have been subject to severe scrutiny due to lack of consideration of financial factors and their inability to foresee the great recession[1]. Recently, it has been also emphasized that agent-based models can be used as an alternative tool for economic modeling and policy making[2], see e.g. Farmer and Foley (2009). Agent-based models have shown promise of being able to take into account the complex interactions of different economic agents (see e.g. Tesfatsion and Judd (2006) for a review), the interplay between credit supply and the real economy (see e.g. Delli Gatti (2010), Raberto et al. (2012) and Teglio et al. (2012)) and reproducing multiple stylized facts of the economy (see e.g. Dosi et al. (2010) and Dosi et al. (2013)). Unlike DSGE models, agent-based models rule out the representative-agent paradigm, shown by Kirman (1992) to be flawed in many respects. Furthermore, agent-based models do not assume that the economy will end up in an equilibrium state subject to exogenous shocks, but allow shocks to be endogenously generated due to interactions between economic agents or sectors, i.e., firms and banks, borrowers and lenders, that interact in decentralized markets with limited information and foresight.

We present here an agent-based model of the economy, henceforth Iceace model, where different economic agents interact using simple behavioral rules through various markets, i.e., the consumption goods market, the labor market, the credit market and the housing market. The modeling approach followed in developing the Iceace model is largely based on the EURACE model and simulator (see e.g. Cincotti et al. (2012) and Raberto et al. (2012)), in particular for what concerns the stock-flow consistency modeling approach and the careful balance-sheet accounting both at the single agent and at the aggregate level. A simulator has been developed from the Iceace[3] model in order to be able to perform computational experiments and test the effects of different policy settings on the workings of the artificial economy.

[1] "The state of economics. The other-worldly philosophers". The Economist. July 16th 2009, print edition.
[2] "Economics after the crisis. New model army". The Economist, January 19th 2013, print edition.
[3] The name Iceace should be read as "Ice" and the acronym 'ACE' and means agent-based computational economics for Iceland, as the model is under development within a project funded by the Icelandic Center for Research (Rannis), see `http://iceace.github.io/home/`

The work presented in this paper centers around the issue of how changes in asset prices, housing prices in our case, affects household consumption and thus the real economy. It is well documented in the literature that changes in the wealth of households affect their consumption (see e.g. Case et al. (2005) and Carroll et al. (2011)). This transmission channel, between the wealth of households and their consumption, is one reason why we have introduced a housing market into the Iceace model. Another is because of the way the housing market can play a role in business cycles of the real economy through mortgage defaults. As in reality, the households of our model generally require mortgages to buy housing. If, for some reason, the debt burden of households becomes unsustainable, banks assets will inevitably be impaired. If the shock to the asset side of the banking system is large enough, the credit market can freeze with catastrophic effects for the real economy (Meh and Moran (2010)).

The housing market part of our model will not focus on the geographical aspect of the market, like e.g. Diappi and Bolchi (2008) and Gilbert et al. (2009). Our modeling perspective is more in line with Geanakoplos et al. (2012), looking to the financial aspects of the market, such as housing prices, mortgage payments, household debt, the fragility of the banking sector, and the effect of the housing market dynamics on the real economy.

The rest of the paper is organized as follows. In section 2 we present a broad overview of our model and the timing of events. We then and describe the most important features of the model in detail in sections 2.1-2.6. Finally we present our results in section 3 and then give some concluding remarks in section 4.

## 2 The model

The economy is populated by households, firms, construction firms, banks, an equity fund, the government, and a central bank. Households provide a homogeneous labor force to firms and constructions firms. They buy homogeneous consumption goods (CGOODS in table 2) from firms according to their consumption budget. They also invest in new housing units built by construction firms; moreover, they can buy or sell housing units in the housing market.

Firms employ labor, using the labor market to hire and fire workers as needed, and capital goods to produce the homogeneous consumption good according to their production plan; construction firms employ labor as well, through the labor market, and capital goods to produce new housing units. Banks supply loans to firms and construction firms, and provide mortgages to households; banks also collect private sector deposits (i.e., from households, firms and constructions firms) and may borrow from the central bank if in shortage of liquidity. The government collects taxes on both labor and capital income and it pays unemployment benefits

| Agent | Assets | Liabilities |
|---|---|---|
| Household<br>*abbrev.*: Hous<br>*index*: $h = 1,\ldots,N_{Hous}$ | housing $X^h$<br>liquidity, $M^h$<br>equity fund shares, $V_d^h$ | mortgages, $U^h$<br>*equity*, $E^h$ |
| Firm<br>*index*: $f = 1,\ldots,N_{Firm}$ | capital goods, $K^f$<br>inventories, $I^f$<br>liquidity, $M^f$ | debt (loans from banks), $D^f$<br>*equity*, $E^f$ |
| Construction firm<br>*abbrev.*: TFirm<br>*index*: $s = 1,\ldots,N_{TFirm}$ | capital goods, $K^s$<br>inventories, $I^s$<br>liquidity, $M^s$ | debt (loans from banks), $D^s$<br>*equity*, $E^s$ |
| Bank<br>*index*: $b = 1,\ldots,N_{Bank}$ | loans, $\sum_b \mathscr{L}^b = \sum_{f,s} D^{f,s}$<br>mortgages, $\sum_b U^b = \sum_h U^h$<br>liquidity, $M^b$ | private sector[4] deposits, $\sum_b \mathscr{D}^b = \sum_{h,f,s} M^{h,f,s}$<br>debt with the central bank, $D^b$<br>*equity*, $E^b$ |
| Equity Fund<br>*abbrev.*: Fund<br>*index*: $e$ | liquidity, $M^e$<br>firms' shares, $V_f^e$<br>construction firms' shares, $V_s^e$<br>banks' shares, $V_b^e$ | *equity*, $E^e$ |
| Government<br>*abbrev.*: Gov<br>*index*: $g$ | liquidity $M^g$ | debt to the central bank, $D^g$<br>*equity*, $E^g$ |
| Central Bank<br>*abbrev.*: CB<br>*index*: $c$ | liquidity, $M^c$<br>loans to banks, $\mathscr{L}_b^c = \sum_b D^b$<br>loans to the government, $\mathscr{L}_g^c = D^g$ | outstanding fiat money<br>banks liquidity, $\sum_b M^b$<br>government liquidity, $M^g$<br>fund liquidity, $M^e$<br>*equity*, $E^c$ |

**Table 1:** Balance sheets of agents populating the Iceace economy.

and transfers to households. The central bank sets the policy rate, providing a standing facility to banks and loans to the government if needed. The equity fund owns all the equity shares of firms, constructions firms and banks. It collects their dividends, redistributing it to households. The shares of the equity fund are equally distributed among households, giving households an equal share in the dividend payment of the equity fund. The equity fund may retain part of the dividends received to provide financing to firms and construction firms, if, firstly, they are in need of financing and, secondly, have been rationed in the credit market.

Table 1 presents the balance sheets of the agents while table 2 shows the exchange of real assets, financial assets and their related monetary flows among agents, occurring respectively in the consumption goods market, the labor market and the credit market. Monetary transactions related to the exchange of real goods are not reported in table 2. Table 3 shows the cash flow of agents. The cash flow of each agent is grouped by whether it occurs weekly, monthly or quarterly.

The elementary time step of the model is conventionally set equal to a day; however, most of events occur on a weekly, monthly or quarterly base, as can be seen by the timing of cash flows in table 3, and are synchronous. In particular, at the first day of every month, firms and construction firms make their pricing and production plans, the labor market opens and closes, households decide wether to enter or not the housing market. At the first day of any quarter, after the monthly

| | Hous | Firm | TFirm | Bank | Fund | Gov | CB |
|---|---|---|---|---|---|---|---|
| Hous | HOUSING | CGOODS | HOUSING | **deposits** | **equity** *dividends* | *transfers* | |
| Firm | LABOR | | | **deposits** | | | |
| TFirm | LABOR | | | **deposits** | | | |
| Bank | **mortgage** *interests* *principal* | **loans** *interests* | **loans** *interests* | | | | **deposits** |
| Fund | | **equity** *dividends* | **equity** *dividends* | **equity** *dividends* | | | **deposits** |
| Gov | *taxes* | | | | | | **deposits** *seigniorage* |
| CB | | | | **loans** *interests* | | | |

**Table 2:** Interactions matrix. The matrix should be read as follows: row agents are the ones demanding or receiving real assets (in small caps), financial claims (in bold face) with related future monetary flows (in italics); column agents are the ones supplying the corresponding real assets, financial claims and monetary flows.

time step, the income statements of the economic agents in the model are calculated and balancing of agents' accounts takes place.

In what follows, sections 2.1-2.6, we discuss in detail the agents that populate the economy and the markets where they interact.

## 2.1 Production and pricing

### Firms

Firms are characterized by a Leontief production technology with two inputs: labor units $L$ and capital goods $K$, i.e.,

$$q^f = \min(\gamma_L L^f, \gamma_K K^f), \tag{1}$$

where $\gamma_L$ and $\gamma_K$ are the productivity of labor and capital, respectively; $f$ is the index of the firm. Neither depreciation nor investments are considered in this model setting, therefore capital shall be considered as a constant. Furthermore, in the simulation presented here, we conventionally set $\gamma_K = +\infty$ for any firms; therefore, the amount of physical capital is not binding for production as it would be due to the Leontief technology. It is worth noting, however, that the endowment of physical capital is initialized to a specific amount and its value, given by the fixed capital price $P_K$, impacts the assets side of the balance sheet and therefore the financial position of the firm.

Production takes place the last day of any month and is available for sale since the first day of the following month; the production amount depends on the number

| Agent | Timing | Cash flow |
|---|---|---|
| Household | weekly | - consumption, $\hat{C}^h_B$ |
| *abbrev.*: Hous | monthly | + labor income, $Z^h_\ell$ |
| *index*: $h = 1, \ldots, N_{Hous}$ | | - taxes on labor income, $Z^h_\ell \, t_\ell$ |
| | | +/- net housing investment, $\Delta X^h \, P_H$ |
| | | +/- net change in mortgages, $\Delta U^h$ |
| | | + general transfer benefits, $\xi_g W$ |
| | | + unemployment benefits, $\xi_u W$ |
| | quarterly | + dividends from Fund, $Z^h_e$ |
| | | - taxes on capital, $Z^h_e \, t_e$ |
| | | - mortgage payments, $R^h$ |
| Firm | weekly | + sales, $q^f \, P_C$ |
| *index*: $f = 1, \ldots, N_{Firm}$ | monthly | - labor cost, $L^f \, W^f$ |
| | quarterly | + new loans, $\Delta D^f$ |
| | | - interest payments on loans, $r_L \, D^f$ |
| | | + investment from Fund, $\mathscr{E}^f$ |
| | | - dividends, $div^f$ |
| Construction firm | monthly | + sales, $q^s \, P_H$ |
| *abbrev.*: TFirm | | - labor cost, $L^s \, W^s$ |
| *index*: $s = 1, \ldots, N_{TFirm}$ | quarterly | + new loans, $\Delta D^s$ |
| | | - interest payments on loans, $r_L \, D^s$ |
| | | + investment from Fund, $\mathscr{E}^s$ |
| | | - dividends to Fund, $div^s$ |
| Bank | monthly | +/- net change in mortgages, $\Delta U^b$ |
| *index*: $b = 1, \ldots, N_{Bank}$ | quarterly | + interests on loans, $\sum_{f,s} D^{(f,s)} \, r_L$ |
| | | - new loans, $\Delta \mathscr{L}^b$ |
| | | + mortgage payments, $\sum_h R^h$ |
| | | - dividends to Fund, $div^b$ |
| | | +/- net change in loans with CB, $\Delta \mathscr{L}^c_b$ |
| Equity Fund | quarterly | + dividends from Firm, TFirm, Bank, $\sum div^{(f,s,b)}$ |
| *abbrev.*: Fund | | - dividends to Hous, $\sum Z^h_e$ |
| *index*: $e$ | | - investments in Firm, TFirm, $\sum \mathscr{E}^{(f,s)}$ |
| Government | monthly | + taxes on labor income, $\sum Z^h_\ell \, t_\ell$ |
| *abbrev.*: Gov | | - unemployment benefits, $\sum Z^h_u$ |
| *index*: $g$ | | - general benefits, $\sum Z^h_g$ |
| | quarterly | + taxes on capital, $\sum Z^h_e \, t_e$ |
| Central Bank | quarterly | +/- net change in loans to Banks, $\Delta \mathscr{L}^c_b$ |
| *abbrev.*: CB | | |
| *index*: $c$ | | |

**Table 3:** Timing of cash flow of agents populating the Iceace economy.

of employees $L^f$ available to firm $f$ and on labor productivity $\gamma_L$ which is taken constant over time and equal across firms.

Firms are price makers and set prices equal to the average unit production costs plus a fixed mark-up, $\mu$, which is fixed over time and across firms. Total production costs related to the last month period are composed by two parts: a variable part related to labor costs $w^f L^f$, where $w^f$ is the monthly nominal wage paid by firm $f$ to its employees, and a second part which does not depend on the amount of production and is given by the cost for the service of debt, i.e., $r_L D^f$, where $r_L$ is the nominal loan rate[5] paid by firms to the banking system, and $D^f$ is the amount of debt owed by the firm to banks. Unit production costs $c^f$ related to the last month period are therefore given by:

$$c^f = \frac{w^f L^f + r_L D^f}{q^f}; \tag{2}$$

$c^f$ is then averaged with the average production costs $\bar{c}_I^f$ of firm' inventories $I^f$ in order to compute the new average production costs $\bar{c}^f$ as follows:

$$\bar{c}^f = \frac{\bar{c}_I^f I^f + c^f q^f}{I^f + q^f}. \tag{3}$$

The new monthly price $p^f$ applied by firm $f$ to goods for sale (both inventories and newly produced goods) is then given by:

$$p^f = (1+\mu)\bar{c}^f. \tag{4}$$

At the beginning of the month, firms make also their production plans $\tilde{q}^f$ for the present month. Based on their production plans, firms will form their labor demand. Production, as previously stated, will take place at the end of the month and will be available for sale in the following month. Firms first form an expectation on their expected sales both during the present and the next month. We stipulate that sales expectations, denoted as $\hat{q}^f$, are identical in the two months and depend on previous month sales. In particular, expected sales are generally set equal to previous month sales unless in the previous month all the inventories were sold out. In this latter case, expected sales are set equal to an amount 10% higher than sales in the previous month. Accordingly, the best production plan is given by $\hat{q}^f - \max(I^f - \hat{q}^f, 0)$, where the rationale is to produce the expected sale foreseen next month, as production will be only available after one month,

[5] The nominal loan rate, $r_L$, is calculated as a 1% spread on the Central Bank rate, $r_{CB}$, and is invariant between firms . For more information on how the Central Bank rate is formed see section 2.6

minus the possible remaining inventories unsold in the present month. Finally, the production plan by firm $f$ in the present month is indeed set to:

$$\tilde{q}^f = \eta\, q^f + (1-\eta)\big(\hat{q}^f - \max(I^f - \hat{q}^f, 0)\big)\,. \tag{5}$$

Therefore the actual plan takes into account a weighted average between previous production $q^f$ and the supposed optimal plan, $\eta \in (0, 1)$, to avoid possible unrealistic and too wide oscillations of output.

Given $\tilde{q}^f$, based on eq. 5, firms compute the labor demand $L_d^f$ needed to fulfill their plans as:

$$L_d^f = \frac{\tilde{q}^f}{\gamma_L}\,. \tag{6}$$

The difference between $L_d^f$ and the present labor endowment $L^f$ determines new hiring (if positive) or layoffs (if negative) for the firms.

### Construction firms

In the artificial economy, construction firms, indexed by $s$, produce housing units, according to a Leontief production technology, and sell them on the housing market (see section 2.3). Two inputs are needed to produce housing, labor units $L$ and capital goods $K$, described by eq. 7. Construction firms start with an initial endowment of physical capital, $K^s(0)$. Their production capacity is limited by this physical capital and they cannot invest in new physical capital. In that way we have a constant upper limit to the growth of the housing stock in the model.

$$q^s = \min(\psi_L L^s, \psi_K K^s)\,, \tag{7}$$

The production of each housing unit takes twelve months. Each housing unit can only be advanced by one month at a time. The construction firm can be forced to halt a particular housing construction project. This can happen for two reasons. Firstly, if the construction firm is rationed in the labor market or, secondly, if the construction firm is rationed in the credit market and is unable to get funding from the Equity Fund[6]. When a particular housing unit has been worked on for twelve months the housing unit is complete and is then counted as inventory of the construction firm.

When deciding the amount of housing to produce, the planned production $\tilde{q}^s$, in the following month the construction firms look to the evolution of housing prices. Here we define $\Delta P_H$ as the change in housing price, as well as the current number of projects under construction, $\alpha^s$. If the price of housing is increasing, $\Delta P_H > 0$, the

[6] see section 2.4 for further details

construction firms will randomly choose an integer amount to produce, uniformly distributed in the interval $[\alpha^s, \psi_K K^s]$, where $\psi_K K^s$ is the maximum production capacity of construction firm $s$. When the price of housing is decreasing, the construction firms want to decrease their production and randomly choose an integer amount to produce, again uniformly distributed, in the interval $[1, \alpha^s]$.

As a consequence, that when housing price is increasing, on average, the construction firms tries to produce more housing units, while if the housing price is decreasing, production tends to be lower. Based on the production plan, the construction firm will form its demand for labor, $L_d^s$, according to equation 8 and try to fill vacant positions in the labor market (see section 2.2), or fire workers if the construction firm is currently employing more workers than needed to fill the production plan.

$$L_d^s = \frac{\tilde{q}^s}{\psi_L}. \tag{8}$$

Construction firms will post their finished housing units, inventory, for sale on the housing market, where they compete with used housing units offered for sale by the households themselves. Section 2.3 explains how construction firms set prices in the housing market.

### 2.2 Labor market

The labor market is decentralized and is active the first day of any month after the production planning. Production plans by firms and construction firms set their need for employees according to eqs. 6 and 8. The difference between the need for employees and their present labor endowment set the labor demand of any producer and its behavior in the labor market.

The labor market is then characterized by four phases: wage adjustment, firing, turnover and new hirings. First, producers with a positive labor demand raise their wage offer $w^{(f,s)}$ by a fixed percentage $\gamma_w$ to keep their present workers as well as to attract new ones, and post open job positions. Conversely, producers with a negative labor demand fire workers that are in excess of their need. The selection of fired workers is deterministic and households with the lowest skills are selected for firing. In the turnover phase, a set of employee is randomly selected, with a selection probability $\varsigma$ for anyone, to look for new and better paid positions at different employers. These employees are queued in descending order according to their skills and in turn decide to fill a new position if it is paid better than the present one. Finally, it is the turn of unemployed households, again queued in the market in descending order according to their skills, to look for the remaining, if any, open positions and to fill them.

### 2.3 Housing market

The housing market is decentralized and is active the first day of any month. The housing market is mostly based on the model described in Erlingsson et al. (2013). With respect to this previous model, the supply side of the market is enriched by new housing units produced by constructions firms. We stipulate that households can buy or sell only one housing unit at any market round (month). Housing units are homogeneous. The bulk of demand and supply of housing is made by households who are selected with a probability $\rho_H$ to enter the market as buyers or sellers with equal likelihood. This modeling choice aims to address the trading activities driven not by speculative reasons but by different reasons, like family needs, migration[7], etc... However, we stipulated that, if households are in financial distress, they are forced to enter the market to liquidate one housing unit, repay mortgages and thus to reduce their debt (mortgage) burden. We call this behavior fire sale of housing. Households are considered to be in financial distress if their past quarterly mortgage costs (interest + principal payments) $R^h$ are higher than a given fraction $\theta$ of their total past quarterly net income, given by both labor income $Z^h_\ell$ and capital income $Z^h_e$. The fire sale condition is then given by:

$$R^h > \theta\left(Z^h_\ell + Z^h_e\right), \tag{9}$$

where $\theta$ is a parameter defined in the interval $(0,1)$. The market is a posted-price market where sellers post prices and buyers search for the cheapest housing units. Posted prices are based on the last market round (last month) average transaction price $P_H$. In particular, households selected to be random sellers and construction firms post selling prices $p^i_H$ given by:

$$p^i_H = P_H\left(1+\varepsilon^i\right) \quad i \in \{\text{random sellers (Hous) and construction firms}\} \tag{10}$$

where $\varepsilon^i$ is a random draw by seller $i$ from a uniform distribution defined in the interval between 0 and $\lambda^{\text{rnd}}_H$. The rationale of Eq. 10 is that if sellers are not subject to particular financial needs, as the households selected at random to sell or construction firms, then they are willing to sell their housing units only if they make a gain with respect to the reference price, $P_H$. Conversely, in the fire sale case, we stipulate that sellers can accept a selling price lower than the latest market price to facilitate the liquidation of the housing unit and then the easing of their financial distress. If the fire sale condition holds, households post selling prices $p^h_H$ given by

$$p^j_H = P_H\left(1-\hat{\varepsilon}^j\right) \quad j \in \{\text{households in financial distress}\} \tag{11}$$

[7] It is worth noting however that no geographical features are considered in this model

where $\hat{\varepsilon}^h$ is a random draw by household $h$ from a uniform distribution defined in the interval between 0 and $\lambda_H^{\text{firesale}}$.

Buyers, i.e. households selected to buy, are randomly queued so that each one, when getting its turn, will select the cheapest available housing unit to buy and a transaction occurs provided that the household has the necessary financial resources or is able to get a mortgage. The market closes when all buyers have had their turn on the market or the supply of housing is depleted. A new housing price $P_H$ is then calculated as the average of realized transaction prices.

### 2.4 Credit market

Banks provide loans to producers, both consumption goods producers and construction firms, to finance their operations, and mortgages to households to finance their purchase of housing units. In both cases, lending activity by banks is constrained by a minimum capital requirement which states that the equity base $E^b$ of bank $b$ must be equal or higher than a fraction $\chi$ of the sum of its risky assets, i.e., the sum of loans to firms and mortgages to households. A second constraint holds concerning the equity of the borrower, i.e., producers must have a positive equity to receive a loan, while households must fulfill a minimum equity ratio requirement, i.e. their net wealth $E^h$ must be equal or higher than a fraction $\phi$ of their total wealth $P_H X^h + M^h + P_F V^h$, given by the sum of housing wealth $P_H X^h$, liquid wealth $M^h$, and equity fund shares wealth $P_F V^h$. See Table 1 for details about the used symbols.

#### Loans

The market for loans to firms and construction firms opens each quarter and is active the first day of the period. Demand for loans $\mathscr{L}_d^{(f,s)}$ by firms and constructions firms, collectively called producers, is set by their liquidity needs to pay dividends to the Equity Fund and interests to banks, i.e.,

$$\mathscr{L}_d^{(f,s)} = max\big(r_L D^{(f,s)} + \text{div}^{(f,s)} - M^{(f,s)}, 0\big) \tag{12}$$

Producers apply for credit first to their preferred bank randomly set at the beginning of the simulation, then if rationed make a second application to another randomly selected bank. For the sake of simplicity, we stipulate that loans are infinitely lived and are never paid back.

If the producers are rationed by both their preferred bank and by a second bank, they will be forced to cut their dividend payment. If this still is not enough to cover the interest payment on loans, $r_L D^{(f,s)}$, the producers will look to the Equity Fund for additional equity to continue their operations. In order to be accepted by the Equity Fund the producers must have a minimum equity ratio of 5%.

If producers are rejected by the Equity Fund, having an equity ratio of less than 5% and not being able to pay the interest on their loans, they will be considered bankrupt and will go through what is defined as an illiquidity bankruptcy. The illiquidity bankruptcy entails that the debt of the producer is restructured, with a corresponding loss for the banking system, so that the payment of interest is equal to the earnings before interest and taxes (EBIT). In the case of negative EBIT the debt of the producer will be set to zero. After receiving this debt relief the producer will continue normal operations.

A more severe bankruptcy will occur if the producer has negative equity. In this case the producer exits the economy. The producers debt is written off, causing a loss for the banking system, and its employees are laid off. A new producer is started with one employee and with new initial equity, physical capital and inventories. The new firm will set its price to the mean price of the market while keeping its wage level. The initial physical capital endowment of the newly founded producer, $(f,s)$, is inherited from the failed firm, $(j,i)$, so that $K^{(f,s)} = K^{(j,i)}$. Inventories of the new firm are set to a level representing one workers output over one month, $I^f = \gamma_{Lf}$ for consumption goods producers or $I^s = 0$ for construction firms, and liquidity of the producer is set to the same level as in the start of the simulation, $U^{(f,s)} = 0$. When the asset side has been initialized the producer is given a loan from the banking system consistent with the leverage given to producers at the start of the simulation, $D^f = (P_K K^f + P_C I^f + U^f)/(1+\nu^f)$ for consumption goods producers and $D^s = (P_K K^s + P_H I^s + U^s)/(1+\nu^s)$ for construction firms. The residual is then the equity of the producer, $E^f = P_K K^f + P_H I^f + U^f - D^f$ for consumption goods producers and $E^s = P_K K^s + P_H I^s + U^s - D^s$ for construction firms.

Note that this mechanism for both illiquidity and insolvency bankruptcy of producers within the artificial economy entails that the number of producers is constant over time.

### Mortgages

Mortgages are the financial instruments that households use to borrow from banks for buying housing units. We consider a well-known type of mortgage, the adjustable-rate mortgage (ARM)[8] with a life span of 40 years. The ARM takes into account the change of the financing conditions within the economy through the change of the annual mortgage rate $r_M$. The mortgage rate changes on a quarterly base following the monetary policy decision by the central bank and is calculated at the beginning of each quarter as the central bank interest rate, $r_{CB}$, plus a fixed

[8] In Iceland a special type of inflation-indexed mortgage is also widely used. This special type of mortgage alongside the fixed rate mortgage will be considered in future enhancements of the Iceace model.

2% spread. No cap on the interest rate or payment variation between quarters is considered. Given the annual mortgage rate $r_M$, the annuity factor, $A^m$, can be computed for each mortgage $m$ considering its remaining life as follows:

$$A^m = \frac{1}{\frac{1}{4}r_M} - \frac{1}{\frac{1}{4}r_M\left(1+\frac{1}{4}r_M\right)^n}, \tag{13}$$

where $n$ is the number of quarters remaining in the mortgages's life. The annuity factor allows to easily compute the quarterly mortgage costs $R^m$ related to mortgage $m$ repayment, which should include both interests, $R^m_r$, and a fraction of the principal, $R^m_U$. Let us denote as $U^m$ the principal amount remaining to repay for mortgage $m$, the related mortgage repayment costs (principal and interests) are then given by the annuity factor as follows:

$$R^m = \frac{U^m}{A^m}. \tag{14}$$

The quarterly interest payment $R^m_r$ is straightforward to calculate as $R^m_r = U^m \frac{1}{4} r_M$. Finally, the part of the principal which is repaid, $R^m_U$, is simply given by the difference between the total payment $R^m$ and the interest payment $R^m_r$, i.e., $R^m_U = R^m - R^m_r$.

Households ask for a mortgage for the purchase of new housing units if they are not endowed with enough liquidity. Beside the equity ratio, households must satisfy an additional requirement to get a mortgage, i.e., households need to show to be able to pay the costs (interests and principal repayment) of all their mortgages, including the new one, given their present income and the present mortgage rate. In particular, for any household asking for a new mortgage $m*$, the total quarterly costs of present mortgages $\sum_m R^m$ plus the additional quarterly costs related to the new requested mortgage, i.e., $R^{m^*}$, must not be higher than a fraction $\beta$ of the total quarterly net income, including both labor $Z_\ell$ and capital income $Z_e$. The condition that needs to be fulfilled by a household to get a mortgage is then:

$$\sum_m R^m + R^{m^*} \leq \beta\left(Z_\ell + Z_e\right). \tag{15}$$

Like for producers, any household has its preferred bank to whom asking for a mortgage. Unlike producers, it does not turn to a different bank if rationed by its preferred one.

When a household sells a unit of housing it uses the amount received to pay back the entire mortgage. If the amount received is more than the mortgage owed the difference will be kept as liquidity.

If it happens that a household is spending a very large part of its disposable income on mortgage payments, such that $R^h > \theta_{\text{high}}\left(Z^h_\ell + Z^h_e\right)$, the household will get a debt write-off, since reasonably it is unable to service the debt. The write-off will lower the debt service to a sustainable level, $R^h = \theta_{\text{low}}\left(Z^h_\ell + Z^h_e\right)$, and the total mortgage of the household will be: $U^h = R^h \,/\, r_M$. This will, of course, be reflected by the asset side of banks' balance sheets, creating a loss equal to the total debt write-off.

### 2.5 Households' consumption and the wealth effect

At the beginning of each month, households set their consumption budget, i.e., the amount of money to spend on the consumption market during the month. The consumption budget $C^h_B$ of any household $h$ depends on the labor $Z^h_\ell$ and capital $Z^h_e$ income realized in the last quarter[9] and on its quarterly mortgage expenses $R^h = \sum_m R^{m,h}$. Any households then determines its monthly disposable income $\Upsilon^h$ as:

$$\Upsilon^h = \frac{1}{3}\left(Z^h_\ell + Z^h_e - R^h\right). \tag{16}$$

which is the amount that could be reasonably spent for consumption. Consumption decisions then is mainly modeled according the theory of buffer-stock saving behavior (Carroll, 2001; Deaton, 1992), which states that households consumption depends on a precautionary saving motive, determined by a target level of liquid wealth $M^h$ to income ratio. Let's denote $\rho_C$ as the target ratio between the stock of liquid wealth, $M^h$, and the monthly disposable income, $\Upsilon^h$; according to the buffer-stock theory of saving, the monthly consumption budget would be then given by $\Upsilon^h + \alpha_C(M^h - \rho_C\Upsilon^h)$. According to this rule, consumption is set at a value lower (higher) than the disposable income if the actual ratio $M^h/\Upsilon^h$ is lower (higher) than the target $\rho_C$. The rationale is then to adjust the consumption budget every month so to adaptively meet the pre-determined liquid wealth to disposable income target ratio by consuming less (more) than the disposable income if $M^h < \rho_c\Upsilon^h$ ($M^h > \rho_c\Upsilon^h$), so to increase (decrease) $M^h$. The parameter $\alpha_C$ sets the speed of adjustment. Furthermore, we take also into account the wealth effect on consumption given directly by the quarterly variation of households' equity or net wealth $E^h$, which is mainly given by the rising or falling housing prices. Indeed, according to Carroll et al. (2011) the wealth effect of an increase in housing prices is much higher than the wealth effect observed from rising stock prices. According to Calomiris et al. (2012), the wealth effect ranges from 5% to 8%. Mixing together the buffer-stock theory of saving and the wealth effect, the monthly consumption budget $C_B$ is then given by:

$$C^h_B = \Upsilon^h + \alpha_C(M^h - \rho_C\Upsilon^h) + \omega E^h\,, \tag{17}$$

[9] It is worth remembering here that the labor income changes on a monthly basis, while capital income and mortgage payments are computed and accounted quarterly. The labor income in then the sum of three months, or one quarter, worth of labor income.

where the parameter $\omega$ sets the size of the wealth effect on consumption. It is worth noting that the wealth effect is a shock transmission mechanism from the housing market to the real economy, since an increase (decrease) in housing wealth, due to an increase (decrease) in the price of housing, will result in increased (decreased) households' net wealth and then consumption. This will result in more (less) production by firms and therefore in an increase (decrease) of the employment level.

The consumption market opens at the beginning day of every week and all households are randomly queued and willing to spend a fraction[10] of their part of the monthly consumption budget not yet spent in the previous weeks. The household selects a firm to buy consumption goods from at random, though giving more weight to the probability of selecting firms that offer the lower prices. In particular, the probability is inversely proportional to prices, e.g. a firm offering double the minimum price has half the probability of being selected by a household as a firm offering the minimum price.

The consumption goods market closes either when there are no goods for sale or when all households have spent their entire weekly consumption budget.

### 2.6 Policy makers: Central Bank and the Government

The Central Bank has two main functions in the model. Firstly, the Central Bank is responsible for the monetary policy and sets the interest rate, $r_{CB}$, on a monthly basis according to a Taylor rule. The Taylor rule takes into account both the unemployment rate, $\mathscr{U}$, and the rate of inflation, $\mathscr{I}$, and sets the interest rate according to eq. 18.

$$r_{CB} = \mathscr{I} + \frac{1}{2}(\mathscr{I} - \mathscr{I}_{CB}) - \frac{1}{2}\mathscr{U}\,, \tag{18}$$

where $\mathscr{I}_{CB}$ is the inflation target of the Central Bank. The minimum interest rate is set to 0.5%. Secondly, the Central Bank acts as a liquidity provider for the banking sector. If the banks of the artificial economy require liquidity they can draw upon the Central Bank credit line at any time and without limit.

The government, being responsible for the fiscal policy in the economy, has two main functions. Firstly, it collects taxes on revenues, both labor tax, $t_\ell$, and capital income tax, $t_e$. The second function is to distribute this income among households, both as general transfer benefits, $\xi_g W$, distributed equally among all households and unemployment benefits, $\xi_u W$, given to unemployed households. The government will always aim at having zero deficit, thus raising (lowering) taxes and lowering (raising) benefits if the balance is negative (positive). The

[10] The value of the fraction depends on the number of weeks remaining in the month, i.e. it can range from 1/4 for the first week of the month to 1 for the last week

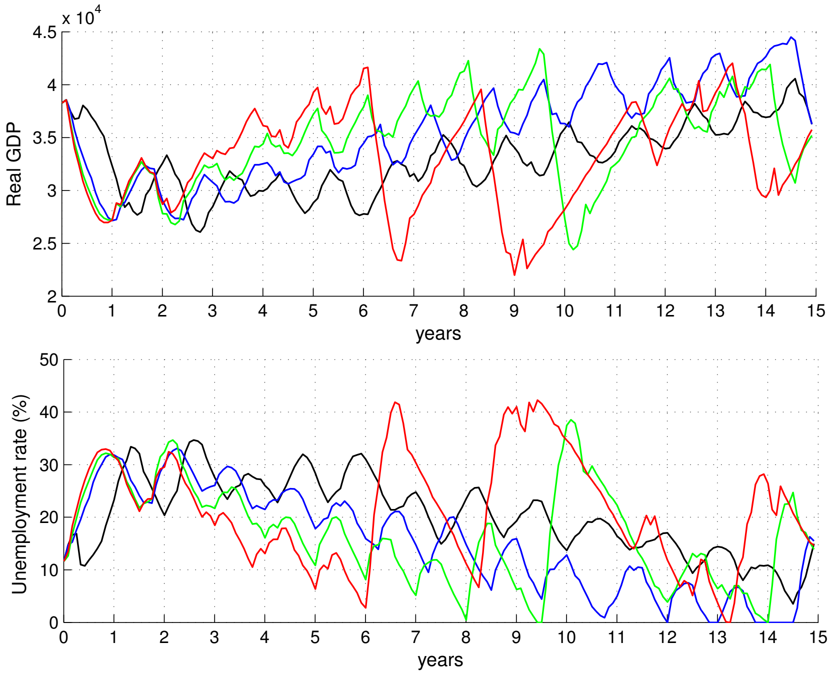


**Figure 1:** Simulation paths for GDP and unemployment rate. Four values of $\beta$ are considered, i.e., $\beta = 0.2$ (black line), $\beta = 0.25$ (blue line), $\beta = 0.3$ (green line) and $\beta = 0.4$ (red line).

parameter, $\Gamma$ defined in the interval (0, 1), decides the ratio between using taxes and benefits to balance the budget of the government. A higher $\Gamma$ means that taxes are used more than benefits to balance the budget when there is a deficit, but benefits are raised more when there is a surplus. In a way a higher $\Gamma$ can be interpreted as a more social type of government, where both taxes and benefits are higher than when $\Gamma$ is low. Taxes, both on labor and capital income, cannot be raised above 50% and the maximum transfer benefits are 40% of average wages. The minimum tax is 10% while benefits can go to 0% of average wages. The unemployment benefits are fixed at 50% of the average wage.

## 3 Results

A set of computational experiments, based on numerical simulations of the agent-based model, has been carried out and is presented in this section. The main objective of computational experiments is to study the effect on the economy of banks' different standpoints, represented in the model by parameter $\beta$, towards the creditworthiness of the borrowers defining households financial robustness (see section 2.4 for details). Parameter $\beta$ sets banks' attitude when evaluating the eligibility of an household for a mortgage loan (see eq. 15). A higher $\beta$ means looser creditworthiness conditions required by the bank to grant a mortgage. The setting for the simulations is the following: 8000 households, 125 firms, 25 construction

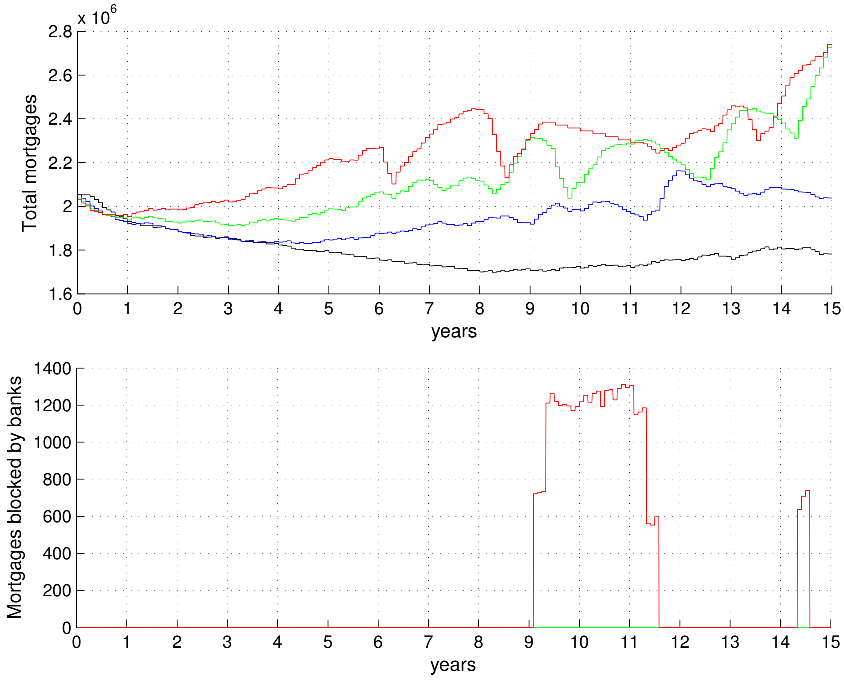


**Figure 2:** Simulation paths for mortgages. Four values of $\beta$ are considered, i.e., $\beta = 0.2$ (black line), $\beta = 0.25$ (blue line), $\beta = 0.3$ (green line) and $\beta = 0.4$ (red line).

firms, 2 banks, 1 government and 1 central bank. For each configuration of the parameters, several random seeds that generate different stochastic processes have been used in order to improve the reliability of the outcomes.

For the sake of a clear presentation of results, this section is divided into three parts. In the first part, there is a short discussion regarding the initialization of the model and how some parameters are derived from empirical data. In the second part, a single simulation (that can be considered as a specific realization of the agent-based economic model) is presented, and a qualitative analysis of economic interactions is performed. Finally, the third part, where the results of all simulations, corresponding to fifty different seeds, are statistically aggregated and analyzed as a whole. In this way, we can first describe in detail the economic mechanisms of interaction and propagation emerging from a representative simulation, and then show that these mechanisms hold for every simulation, irrespective of the random seed used.

### 3.1 Initialization of the simulation settings

We initialize the balance sheet of economic agents both by looking into empirical evidence from the Icelandic economy[11] and by setting the initial values of the

[11] Empirical data retrieved from Statistics Iceland (statice.is)

variables from a limited set of assumptions. In this way we aim to restrict the degrees of freedom of the model.

We set the number of firms in the model, $N_{Firm} + N_{TFirm}$, to 150. According to Statistics Iceland data about one in every six firms in Iceland are is the construction industry. Therefore the number of construction firms in our model is: $N_{TFirm} = 25$, which leaves us with $N_{Firm} = 125$ consumption goods producers. Also, the labor force share of construction firms ($\delta^s$) according to Statistics Iceland is about 7.5% of the total labor force. From the data we also find the maximum yearly growth of the housing stock, $\rho^s = 0.015$.

We also limit the degrees of freedom by deriving the initial state of many variables from just a few assumptions. We start with setting the gross money wage, $W(0) = 5$, for producers and the initial unemployment level, $\mathscr{U}(0) = 10\%$, which gives us the initial number of employees for each producer, $L^{f,s}$. The total number of employees working in the construction firms is set according to $\delta^s$, so that $\sum_s L^s = \delta^s (1 - \mathscr{U}) N_{Hous}$. Consequently, $\sum_f L^f = (1 - \delta^s)(1 - \mathscr{U}) N_{Hous}$. Now we can set the initial debt of producers so that the service of the debt is 20% of the labor cost: $D^{f,s} = 0.2 \left( \frac{W(0) L^{f,s}}{r_L} \right)$, where $r_L$ is the initial loan rate, given by $r_{CB} + 1\%$, where the initial central bank policy rate is set to 2%. Then the Equity of firms is set using the initial leverage of firms and construction firms, $E^{f,s} = \frac{D^{f,s}}{\nu^{f,s}}$. Given the liabilities side of the balance sheet of producers, we set their liquidity, $M^{f,s}$, to 0 and their inventories to a month's worth of production, given a single employee, $I^f = \gamma_L L^f$ for consumption goods producers, and $I^s = 0$ for construction firms. Physical capital is then used to balance the assets and liabilities of producers. Using a similar approach we construct the initial balance sheet of households by assuming that each household starts with 5 housing units, $X^h(0) = 5$, each worth, $P_H(0) = 20W(0)$, and a liquidity equal to three months' wages, $M^h(0) = 3W(0)$. Consequently we can decide the initial mortgages of households, $U^h$, and equity, $E^h$, using the starting leverage, $\nu^h$. After initializing the balance sheet of producers and households we can start constructing the balance sheet of banks. Firstly we assume that deposits of banks are given by the sum of producers' and households' liquidity: $\mathscr{D} = \sum_{h,f,s} M^{h,f,s}$. Banks assets are composed by producers' debt, $\mathscr{L}^b$, households mortgages, $U^b$, and finally the banks own liquidity, $M^b$, which is initially set to a ratio of total assets. Then equity can be set using the initial capital adequacy ratio, $\chi(0)$. Banks' debt to the central bank is set to balance assets and liabilities of the bank.

Some parameters, like the mortgage duration $T_M$, and the capital adequacy ratio of banks $\chi$, are derived from common knowledge while other parameter values, like the size of the wealth effect of housing, $\omega$, come from the literature (see e.g. Carroll et al. (2011) and Case et al. (2005)). Finally some parameter values are based on best-guess estimates and conventions when working with agent-based

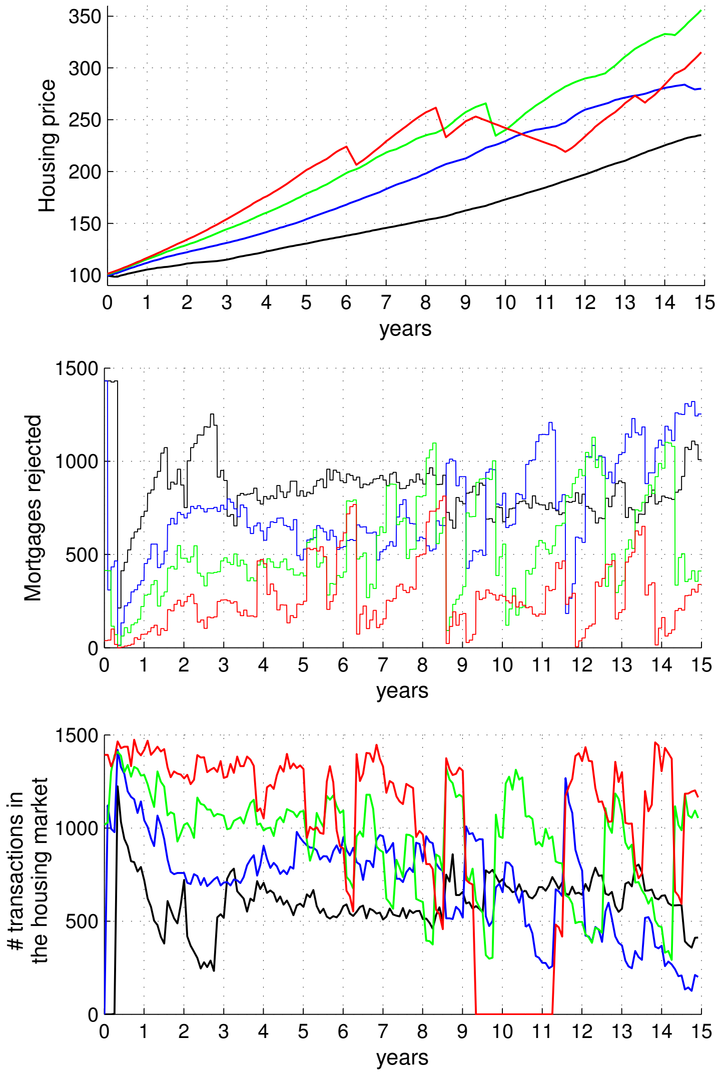


**Figure 3:** Simulation paths for housing market variables. Four values of $\beta$ are considered, i.e., $\beta = 0.2$ (black line), $\beta = 0.25$ (blue line), $\beta = 0.3$ (green line) and $\beta = 0.4$ (red line).

models. Tables 7 and 8 in the appendices summarize the values given to relevant parameters and initial values of the main endogenous variables of the model.

### 3.2 Analysis of economic interactions

Figures 1 to 6 show the time series from a single simulation run. The main features of this particular simulation are shared by the whole set of simulations composing our computational experiment, as shown in section 3.3.

The monthly GDP, calculated as the sum of real production of consumption goods producers and construction firms, levels associated with different $\beta$s are plotted in figure 1. The black line corresponds to the most restrictive attitude

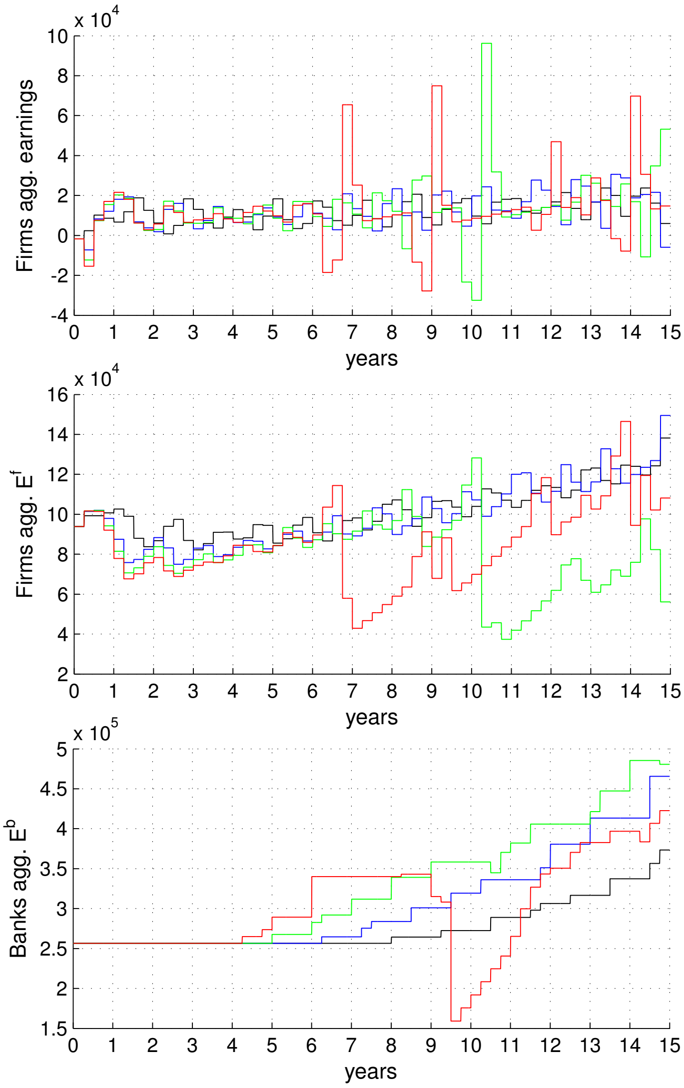


**Figure 4:** Simulation paths for equity capital and earnings. Four values of $\beta$ are considered, i.e., $\beta = 0.2$ (black line), $\beta = 0.25$ (blue line), $\beta = 0.3$ (green line) and $\beta = 0.4$ (red line).

towards borrowers ($\beta = 0.20$), meaning that a high income to housing expenditure ratio is requested to get a loan, whereas the red line corresponds to the most permissive case ($\beta = 0.40$), that we could homologate to subprime lending. The blue ($\beta = 0.25$), and green ($\beta = 0.30$) lines represent two intermediate cases.

In figure 2 the direct impact of such different lending strategies on the total mortgages amount is clearly visible. When financial requirements are low, a higher amount of mortgages is granted and the housing market is more active, with a much higher level of transactions, at least in the first 6 years of simulation. Going back to figure 1, we can appreciate the economic implications of the different borrowing requirements. If only the first 6 years were considered, the result would be very clear: the more you lend, the more you grow. In other words, more permissive

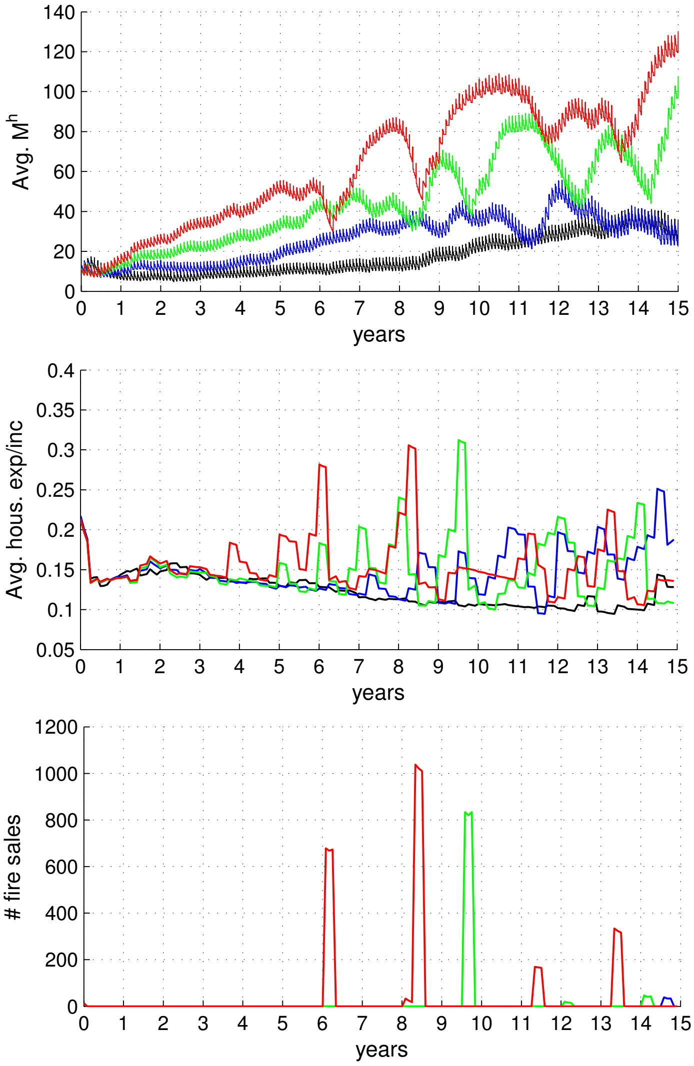


**Figure 5:** Simulation paths for GDP and unemployment rate. Four values of $\beta$ are considered, i.e., $\beta = 0.2$ (black line), $\beta = 0.25$ (blue line), $\beta = 0.3$ (green line) and $\beta = 0.4$ (red line).

household's financial requirements entail higher GDP growth rates. However, the second part of the simulation tells another story. The red GDP trajectory shows two deep recessions, the first starting at year 6, the second starting after year 8. The green line also shows a deep recession after year 9. What is visible to the naked eye, looking at these plots, and confirmed by the statistical aggregation of all the simulations in table 4, is that the volatility of GDP increases when a higher amount of credit money is allowed to enter the economic system. At a first glance, the blue line, corresponding to the intermediate value of ($\beta = 0.25$), seems to be the best compromise between the slow growth of the black line ($\beta = 0.20$) and the instable behavior of the two other cases with higher $\beta$'s.

It can be relevant to analyze how the economic system runs into a crisis when the value of $\beta$ is high enough, examining the crucial events that involve different economic agents, and observing the main economic interactions.

From the households (borrowers) perspective, as it has been shown, a more permissive policy leads to an increase in mortgages, and, consequently, in the aggregate liquid wealth of the household, i.e. $\sum_h M^h$, (see figure 5). The new available mortgage loans obviously push the housing price up (figure 3), raising the nominal wealth of households. In turn, the greater liquidity, combined with the wealth effect, entails an increasing goods' demand that leads to higher consumption, and thus production. On the other hand, a more permissive loans policy increases households' housing expenditures, due to the raise of the mortgage interest payments with respect to their income, as reported in figure 5. We can notice that in both the red and the green cases, the housing expenditure starts to raise quite early (around year 4). At year 6, the year of the first crisis for $\beta = 0.40$, the average housing expenditure is slightly less than 30%, which is a very high value compared to the cases of lower $\beta$'s. Furthermore, this 30% percentage is an average value, meaning that, in some cases, the interest payment associated to households debt load is simply not bearable. As a consequence, some households are forced to sell their house in order to get sufficient liquidity to pay back the mortgage. These fire sales, also shown in figure 5, start immediately after the peak of the housing expenditure versus income ratio, causing a decrease in the housing price (figure 7). We argue that these price dynamics can be described as a bubble determined by an excess of credit money.

When the housing price has decreased enough, around the second quarter of year 6, the housing markets starts up again and the number of transactions rises sharply, as figure 2 shows. It is worth noting that this "market efficient" reactivation of the housing transactions is a main distinguishing factor between the first crisis of year 6 and the second crisis starting in the second quarter of year 8, as we will explain later.

Before going on and describing the second crisis, it is useful to analyze what happens from firms and banks side. Figure 4 shows several time series related to firms. It is important to underline that the first crisis does not trigger any firms' bankruptcy in the model. It is basically a demand crisis due to the excessive burden of interest payments for the households, with a consequent reduction of consumption. The fall of the housing prices exacerbates this reduction through the wealth effect. In turn, firms have to reduce production with obvious effects on firms aggregate revenues and equity.

After almost one year of crisis, as we have seen, households' demand starts to raise again and the economy slowly recovers. At year 8, the GDP red line ($\beta = 0.40$) reaches again a comparable level with respect to the other $\beta$ values. However, figure 4 shows that firm's equity still remains at a significantly lower

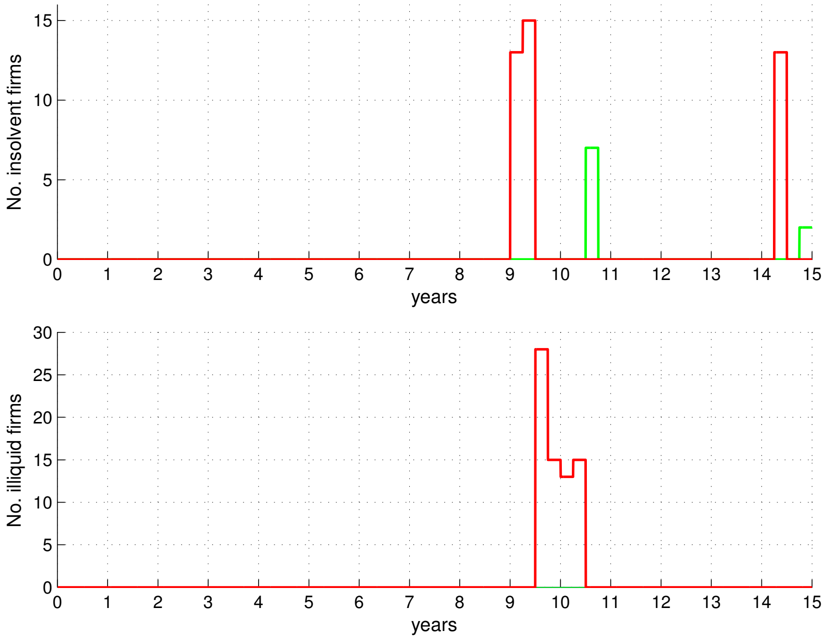


**Figure 6:** Simulation paths for firms bankruptcies. Four values of $\beta$ are considered, i.e., $\beta = 0.2$ (black line), $\beta = 0.25$ (blue line), $\beta = 0.3$ (green line) and $\beta = 0.4$ (red line).

level, meaning that the first crisis left firms in a more fragile financial condition, undermining the solidity of the whole economics system. In fact leading after half a year to a serious bankruptcy chain that triggers a second crisis, which can be described as a sort of double dip recession (figure 1). During this second crisis, the bankruptcy of many firms results in a further reduction in banks' equity that, in turn, are unable to meet the Basel II adequacy ratio, setting a minimum equity capital requirement with respect to the weighted total assets owned by the bank. As a consequence, banks are no more able to lend money, as far as they have not cured their balance sheets, and the housing market freezes, as shown in figure 2.

It could be interesting to resume here the mechanism of interaction between housing market and firms' activity emerging from the model in the case of a permissive financial requirements policy for households' mortgages ($\beta = 0.40$). In a first crisis, triggered by the housing price bubble and by the consequent incapability for households of paying back their mortgages, firms' profit and equity capital is seriously reduced. Later, after a 2 year slow recovery of the economy, a second crisis is triggered again by an excessive amount of households' debt burden. This time many firms are financially fragile, due to the previous crisis, and go into bankruptcy, triggering loan write-offs that reduce banks' equity capital, preventing banks from granting new mortgages due to the Basel II regulation, completely freezing the housing market.

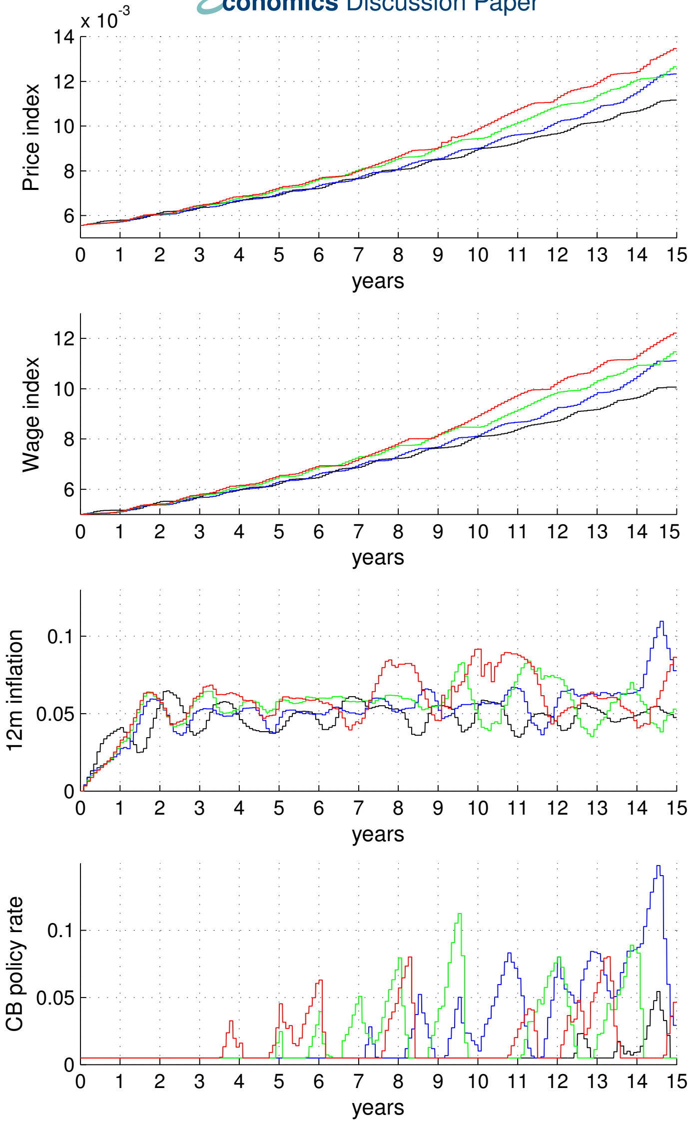


**Figure 7:** Simulation paths for prices. Four values of $\beta$ are considered, i.e., $\beta = 0.2$ (black line), $\beta = 0.25$ (blue line), $\beta = 0.3$ (green line) and $\beta = 0.4$ (red line).

On the other hand, looking at the time series of the various economic variables represented in figures 1 to 6, for lower values of $\beta$, it clearly emerges a much more stable context. There are, of course, fluctuations in the GDP, but they do not seem to be rising in amplitude and there is no trace of the violent crisis that characterize higher $\beta$ cases. As a last comment, it is worth noting that the economic performance with the lowest $\beta = 0.2$ value is significantly lower than the performance with $\beta = 0.25$.

The conclusion of this qualitative analysis is therefore quite evident. High values of $\beta$ (corresponding to a loose regulation) cause a higher economic instability with a higher chance for deep and violent recessions. On the other hand, too strict regulations (as for $\beta = 0.2$) can be an obstacle to growth and limit the economic

| | period (years) | $\beta = 0.2$ | $\beta = 0.25$ | $\beta = 0.3$ | $\beta = 0.4$ |
|---|---|---|---|---|---|
| Real GDP | 1-15 | 33,127 | 35,033 | 35,530 | 33,460 |
| | | (1712) | (2358) | (2307) | (1694) |
| | 1-6 | 31,596 | 31,228 | 32,578 | 33,693 |
| | | (409) | (624) | (862) | (956) |
| | 7-15 | 34,147 | 37,570 | 37,498 | 33,304 |
| | | (1330) | (1644) | (1464) | (979) |
| Yearly real GDP growth (%) | 1-15 | 0.07 | 1.36 | 1.32 | 0.92 |
| | | (0.77) | (0.58) | (0.57) | (0.67) |
| | 1-6 | -3.30 | 0.08 | 2.32 | 2.88 |
| | | (1.21) | (0.98) | (0.95) | (0.92) |
| | 7-15 | 1.77 | 1.73 | 0.52 | 0.60 |
| | | (0.14) | (0.15) | (0.22) | (0.36) |
| GDP volatility | 1-15 | 29,936 | 45,110 | 45,030 | 51,945 |
| | | (393) | (777) | (856) | (3639) |
| | 1-6 | 33,688 | 23,213 | 30,202 | 35,017 |
| | | (189) | (453) | (415) | (604) |
| | 7-15 | 20,549 | 24,347 | 34,448 | 58,408 |
| | | (602) | (763) | (1793) | (5059) |
| Unemployment (%) | 1-15 | 20.5 | 16.5 | 15.7 | 21.2 |
| | | (0.8) | (1.2) | (1.0) | (0.7) |
| | 1-6 | 24.4 | 25.2 | 22.2 | 20.0 |
| | | (0.79) | (0.75) | (0.95) | (1.01) |
| | 7-15 | 17.9 | 10.7 | 11.3 | 22.0 |
| | | (0.52) | (0.50) | (0.18) | (0.47) |
| Housing stock | 1-15 | 43,315 | 43,372 | 43,370 | 43,089 |
| | | (292) | (289) | (283) | (237) |
| | 1-6 | 41,173 | 41,250 | 41,291 | 41,295 |
| | | (114) | (115) | (115) | (115) |
| | 7-15 | 44,744 | 44,787 | 44,756 | 44,285 |
| | | (177) | (172) | (167) | (115) |

**Table 4:** Real values of the Iceace economy for three different periods of the simulations and four different values of $\beta$. Standard error shown in parenthesis.

activity. There seems to exist a trade-off between growth and stability, and policy makers should be careful in setting a balanced regulation according to their goals and to the economic conditions.

### 3.3 Analysis of aggregated outcomes

The average values (and standard errors) of several economic variables have been computed considering 50 different random simulation seeds, and are collected in tables 4 to 6. The idea is to show that the economic reasoning presented in section 3.2 is not just related to a specific simulation outcome but characterizes the whole set of runs in the computational experiment. In order to better explain how different regulation rules affect the macro economy in the short and in the long run, the economic variables are presented for three different time spans. The first one represents the whole period considered. The second one includes the first 6 years, that we could consider as a short-medium run, while the last time span considers the long run, from year 7 to year 15. In general, the specific analysis

| | period (years) | $\beta = 0.2$ | $\beta = 0.25$ | $\beta = 0.3$ | $\beta = 0.4$ |
|---|---|---|---|---|---|
| Price level | 1-15 | 0.0079 | 0.0082 | 0.0084 | 0.0086 |
| | | (0.0002) | (0.0003) | (0.0003) | (0.0003) |
| | 1-6 | 0.0063 | 0.0064 | 0.0064 | 0.0065 |
| | | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| | 7-15 | 0.0090 | 0.0095 | 0.0098 | 0.0100 |
| | | (0.0002) | (0.0002) | (0.0002) | (0.0002) |
| Wage level | 1-15 | 7.12 | 7.40 | 7.60 | 7.73 |
| | | (0.20) | (0.24) | (0.27) | (0.27) |
| | 1-6 | 5.67 | 5.70 | 5.75 | 5.79 |
| | | (0.06) | (0.07) | (0.08) | (0.80) |
| | 7-15 | 8.10 | 8.54 | 8.83 | 9.01 |
| | | (0.15) | (0.17) | (0.19) | (0.19) |
| Housing price | 1-15 | 153.7 | 195.5 | 220.6 | 222.2 |
| | | (5.4) | (8.8) | (10.2) | (8.6) |
| | 1-6 | 116.7 | 132.0 | 145.0 | 156.2 |
| | | (1.5) | (2.7) | (3.9) | (5.0) |
| | 7-15 | 178.4 | 237.8 | 271.0 | 266.2 |
| | | (4.0) | (5.8) | (6.0) | (2.9) |
| Central bank interest rate (%) | 1-15 | 0.65 | 1.91 | 2.37 | 1.62 |
| | | (0.05) | (0.24) | (0.23) | (0.11) |
| | 1-6 | 0.50 | 0.50 | 0.59 | 1.03 |
| | | (0.00) | (0.00) | (0.03) | (0.11) |
| | 7-15 | 0.75 | 2.86 | 3.56 | 2.01 |
| | | (0.06) | (0.22) | (0.12) | (0.06) |
| No. Firm Bankruptcies | 1-15 | 0.0 | 0.0 | 0.2 | 8.7 |
| | | (0.0) | (0.0) | (0.1) | (1.5) |
| | 1-6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | (0.0) | (0.0) | (0.0) | (0.0) |
| | 7-15 | 0.0 | 0.0 | 0.3 | 14.4 |
| | | (0.0) | (0.0) | (0.1) | (1.4) |

**Table 5:** Nominal values of the Iceace economy for three different periods of the simulations and four different values of $\beta$. Standard error shown in parenthesis.

presented in section 3.2 is confirmed by the data presented in tables 4 to 6. The main macroeconomic effect of decreasing the limitation on households mortgage borrowing (increasing $\beta$), raises dramatically the volatility of real GDP growth, as already commented in the previous section and corroborated by table 4. We used the standard deviation of the GDP growth as a straightforward measure of the economic volatility.

Looking at table 4, one can appreciate the short and long term effects of the computational experiment. In the case of a very permissive requirements policy, i.e., $\beta = 0.40$, the mean real GDP level and the mean yearly GDP growth are the highest in the first six years, and the lowest in the last nine years, with respect to all $\beta$ values. The opposite obviously happens to the unemployment rate, which is the lowest in the first six years and the highest in the last nine. This facts show that, apart from a huge rise in volatility, also the overall performance of the economic system is seriously compromised in the long run. The narrative of section 3.2 is again confirmed by looking at table 5. In the case of subprime lending ($\beta = 0.40$) the rate of banks' mortgage rejections in the first period is very low, allowing

| | period (years) | $\beta = 0.2$ | $\beta = 0.25$ | $\beta = 0.3$ | $\beta = 0.4$ |
|---|---|---|---|---|---|
| Household total debt | 1-15 | 1,794,667 | 1,977,154 | 2,147,666 | 2,272,147 |
| | | (11676) | (16899) | (27978) | (26677) |
| | 1-6 | 1,873,190 | 1,883,715 | 1,955,635 | 2,063,031 |
| | | (10468) | (7682) | (4953) | (12781) |
| | 7-15 | 1,742,318 | 2,039,447 | 2,275,686 | 2,411,557 |
| | | (4128) | (15580) | (21590) | (10065) |
| Household leverage | 1-15 | 0.43 | 0.37 | 0.34 | 0.35 |
| | | (0.03) | (0.03) | (0.03) | (0.02) |
| | 1-6 | 0.66 | 0.56 | 0.52 | 0.51 |
| | | (0.02) | (0.03) | (0.03) | (0.03) |
| | 7-15 | 0.29 | 0.24 | 0.23 | 0.25 |
| | | (0.01) | (0.01) | (0.01) | (0.00) |
| Household exp/income | 1-15 | 1.016 | 1.026 | 1.044 | 1.075 |
| | | (0.006) | (0.006) | (0.007) | (0.010) |
| | 1-6 | 0.998 | 1.029 | 1.065 | 1.093 |
| | | (0.009) | (0.008) | (0.007) | (0.011) |
| | 7-15 | 1.028 | 1.022 | 1.029 | 1.062 |
| | | (0.002) | (0.004) | (0.006) | (0.010) |
| Firm total debt | 1-15 | 247,814 | 259,345 | 271,813 | 258,296 |
| | | (336) | (890) | (2026) | (2700) |
| | 1-6 | 245,537 | 254,046 | 259,054 | 262,019 |
| | | (206) | (459) | (590) | (703) |
| | 7-15 | 249,333 | 262,877 | 280,319 | 255,814 |
| | | (209) | (746) | (1723) | (3413) |
| Firm leverage | 1-15 | 2.44 | 2.73 | 3.25 | 3.17 |
| | | (0.03) | (0.04) | (0.04) | (0.10) |
| | 1-6 | 2.63 | 2.99 | 3.18 | 3.25 |
| | | (0.02) | (0.04) | (0.05) | (0.06) |
| | 7-15 | 2.32 | 2.56 | 3.29 | 3.11 |
| | | (0.03) | (0.02) | (0.04) | (0.12) |

**Table 6:** Financial values of the Iceace economy for three different periods of the simulations and four different values of $\beta$. Standard error shown in parenthesis. Leverage is defined as $debt/equity$.

households' total debt to grow much faster. Households ratio between expenditure and income is higher, due to a higher interest bill generated by mortgage loans, making their financial condition more fragile. However, the main indicator of financial fragility, the debt-equity ratio, is lower for high $\beta$s; at a first glance this could seem inconsistent with our narrative, but it actually reveals a subtler aspect. The growth of households' debt (increasing $\beta$) is in fact compensated by a growth of households' assets value, resulting from higher asset prices, since the housing stock is barely variable among different $\beta$'s. Therefore, what enlarges equity in households balance sheet is the boost of the housing price. The point that is not fully captured in the tables, which only presents ensemble averages over a given time period, is that the apparent financial stability of households, due to the equity increased by the housing price bubble, collapses when the house price index falls, deflating households balance sheet. Looking at figures 4 and 3, one can observe this phenomenon, particularly highlighted by fire sales which entail that households, despite their apparent financial robustness, are forced to sell their houses in order to avoid bankruptcy. A little lesson we can learn from this, is that we should focus on various stability indicators, looking both at stocks (e.g. leverage) and flows (e.g. expenditure income ratio) in order to have a more complete picture.

The ratio between total expenditure and total income, reported in table 6 is an interesting indicator. It is below 1 in the first six years only in the case of $\beta = 0.20$, and it is rapidly increasing with $\beta$. This is more evidence that, for high $\beta$s, households are on average financing the excess spending with new credit.

Looking at firms' data, the scenario emerged in section 3.2 is again confirmed. Raising $\beta$ fosters an accumulation of firms' debt and an erosion of firms' equity in the first six years, jeopardizing firms' financial stability, as also pointed out by the value of firms' leverage, i.e., debt-equity ratio, that is much higher in the case of high $\beta$s. The consequences of all this are visible in the average number of bankruptcies affecting the economic system, dramatically raising for $\beta = 0.40$.

# 4 Concluding remarks

The paper investigates the macroeconomic implications of an easy access to mortgage loans. The adopted methodology belongs to the agent-based modeling approach. We built a model of a credit network economy, including a consumption market and a housing market, following a rigorous balance sheets approach in order to ensure the stock-flow consistency of the model. We designed a computational experiment varying the conditions that needs to be fulfilled by a household to get a mortgage. For each set of parameters 50 simulation runs with different random seeds have been performed in order to improve the statistical relevance of the experiment.

Results tell us that an easy access to mortgage loans causes a higher economic instability with a higher chance for deep and violent recessions. On the other hand, too strict regulations can be an obstacle to growth and limit the economic activity. The main propagation mechanism emerged from the study passes trough the growth of a price bubble in the housing market and trough the consequent loans write-off, affecting banks' equity capital, when the bubble bursts. The richness of the model permits to follow the economic dynamics with a high level of detail, following the evolution of every economic agent in the system.

We claim that this approach is able to present an useful picture of our complex economic system, pointing out dynamics and interactions that are not usually taken into account in aggregated models. The message for policy makers emerging from our study is the existence of a trade-off between growth and stability. Therefore, a strong and balanced regulation of the credit market, according the economic conditions, is required to prevent economic crises.

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# Appendix 1

| Parameter | Description | Value |
|---|---|---|
| **Time constants** | | |
| $T_D$ | Loan duration | $+\infty$ |
| $T_M$ | Mortgage duration in years | 40 |
| $T_H$ | Housing construction time in months | 12 |
| **Housing market** | | |
| $\phi$ | Minimum equity ratio of mortgage borrowers | $-\infty$ |
| $\lambda_H^{rnd}$ | Seller price interval for housing | 0.025 |
| $\lambda_H^{firesale}$ | Fire sale price reduction interval | 0.05 |
| **Households** | | |
| $\omega$ | Households wealth effect | 0.07 |
| $\varsigma$ | Households labor turnover probability | 0.1 |
| $\nu^h$ | Households starting leverage | 1 |
| $\zeta_{min}$ | Minimum amount of housing units | 1 |
| $\theta$ | Household budget threshold for fire sale | 0.6 |
| $\theta_{\text{high}}$ | Household budget threshold for mortgage write-off | 0.7 |
| $\theta_{\text{low}}$ | Household budget ratio for mortgage write-off | 0.5 |
| $\alpha_C$ | Speed of adjustment of household savings | 0.1 |
| $\rho_C$ | Household target ratio of liquid wealth over disposable income | 1 |
| **Firms and construction firms** | | |
| $\nu^f$ | Firms starting leverage | 4 |
| $\mu$ | Firms markup on consumption goods | 1.1 |
| $\gamma_L$ | Firms labor productivity | 1000 |
| $\gamma_K$ | Physical capital utilization of firms | $+\infty$ |
| $\nu^s$ | Construction firms starting leverage | 1 |
| $\psi_L$ | Construction firms labor productivity | 0.8 |
| $\psi_K$ | Physical capital utilization of construction firms | 0.7 |
| $\delta^s$ | Labor force share of construction firms | 0.075 |
| $\rho^s$ | Maximum yearly growth rate of housing stock | 0.015 |
| **Banks** | | |
| $\chi_{\text{min}}$ | Minimum capital adequacy ratio of banks | 0.085 |
| **Government and Central bank** | | |
| $\Gamma$ | Tax and benefit ratio policy parameter | 0.9 |
| $\mathscr{I}_{CB}$ | Central bank inflation target | 0.02 |

**Table 7:** Table of general parameters in the Iceace economy.

# Appendix 2

| Variable | Description | Value |
|---|---|---|
| **Price and interest rates** | | |
| $P_H(0)$ | Initial price of a housing unit | $20W(0)$ |
| $P_C(0)$ | Initial price of consumption goods | 0.0056 |
| $P_K(0)$ | Initial price of capital goods | $100 * P_C$ |
| $r_{CB}(0)$ | Initial Central Bank interest rate | 0.02 |
| $r_L(0)$ | Initial bank loans interest rate | $r_{CB} + 0.01$ |
| $r_M(0)$ | Initial bank Mortgage interest rate | $r_{CB} + 0.02$ |
| **Firms and Construction firms** | | |
| $W^{f,s}(0)$ | Initial wage of firms and construction firms | 5 |
| **Households** | | |
| $X^h(0)$ | Households initial amount of housing units | 5 |
| $M^h(0)$ | Households initial liquidity | $3W(0)$ |
| **Banks** | | |
| $\chi(0)$ | Initial capital adequacy ratio of banks | 0.1 |
| $M^b(0)/(M^b(0) + U^b(0) + \mathscr{L}^b(0))$ | Initial liquidity ratio of banks | 0.091 |
| **Government and Central bank** | | |
| $t_\ell(0)$ | Initial income tax | 0.2 |
| $t_e(0)$ | Initial capital income tax | 0.2 |
| $\xi_U(0)$ | Initial unemployment benefit ratio | 0.5 |
| $\xi_T(0)$ | Initial general transfer benefit ratio | 0.3 |
| $\mathscr{U}(0)$ | Initial unemployment level | 0.1 |

**Table 8:** Table of initial values for some of the variables of the artificial economy.