A model of an artificial financial economy as a framework for policy design

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Abstract This study addresses the problem of monetary and fiscal policy design within an agent-based model of a financial economy under a general equilibrium perspective. We present a model of an artificial economy that involves different agents typologies, i.e., households, firms, a commercial bank, a central bank, and a government. Agents take endogenous financial decisions which include consumption and portfolio investments for households, capital structure and dividends policy for firms, lending and borrowing rates for the commercial bank, standing facilities for the central bank, and taxation strategies for the government. Economic policies are set by a government which collects taxes and issues government bonds, and by a central bank which fixes the base interest rate. A particular attention has been dedicated to the modelling of households beliefs formation, that depends on the observation of both the financial market and the real economy, and of households preference structure, that incorporates some psychological features derived by the Prospect Theory. We propose a fiscal policy experiment where the

government decides to increase the unemployment benefits, and we analyze the effects of this fiscal measure on the financial market. The higher expenditures level is financed by new bonds emission by the government, causing a reduction in bonds prices. On the other hand, a higher purchasing power of households pushes consumption and prices, thus raising the equity of the firms and their stocks price levels. Therefore, from our study it can be argued that the adopted fiscal measure has significant effects on the financial market.

1 Introduction

This paper presents an agent-based model of a financial economy populated by different types of agents, i.e., households, firms, a commercial bank, a central bank and a government, which interact through a closed structure of financial flows and through a multi-asset financial market.

The agent-based framework provides an useful computational facility for economics, where performing experiments on policy design issues in a realistic environment, characterized by non-clearing markets and bounded rational agents (see [11] for a recent survey). Under this respect, this study addresses both the issue of monetary policy design by the central bank, that operates by means of the interest rate setting, and the issue of fiscal policy design by the government, that decides among different taxation strategies.

A distinctive feature of our study is the endogenous modelling of agents financial decisions, e.g., portfolio allocation for households or dividend payment for

firms, who make choices which are subject to the policy strategies by the Government and the Central Bank about taxation and interest rates.

A particular attention is devoted to the balance sheets, considering the dynamics of the financial flows among agents. Firms and bank's equity are divided into shares among households and traded in the financial market. Firms also recur to debt financing, asking for bank loans. The bank collects households deposit and accesses to the standing facilities of the central bank, that sets the interest rate. The government collect taxes and pays bonds coupons to bondholders.

Another important feature of the model concerns households beliefs formation mechanism and households financial preferences. The belief formation process on asset returns takes into account expected cash flows, establishing an endogenous integration between the financial side and the real side of the economy. The model of financial preferences applies some general concepts from *Prospect Theory* [1, 2], such as the endowment effect (i.e., agents derive utility not from wealth, but from gains and losses defined to some reference level), and loss aversion (i.e., a loss hurts more than an equally large gain produces joy).

Barberis et al. [3] recently proposed a model of agents financial decision making, according to *Prospect Theory's* psychological assumptions, following the standard consumption-based equilibrium asset pricing framework. In this respect, our approach is different and consists into the integration of a preference structure based on *Prospect Theory* in an agent-based model of a financial economy, in the lines of recent studies in the field, see e.g. [4]. In particular, our work is based on the concepts of myopic loss aversion and mental accounting [5].

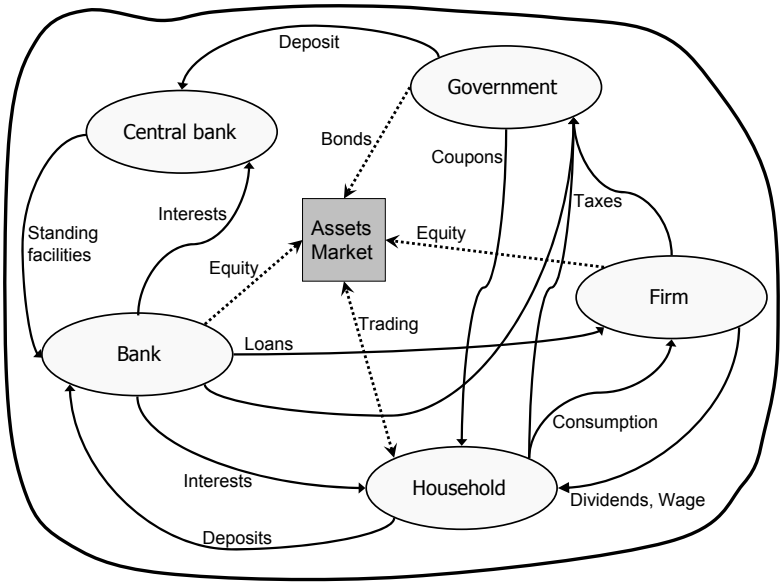

Fig. 1 General scheme of the main interactions in the model. Financial flows between agents are represented, along with their interaction with the multi-asset financial market.

The monetary policy of the central bank is based on an inflation targeting rule, and uses the interest rate as an operational instrument. On the other hand, firms take their dividends pay-out policy and investment decisions on the base of the central bank interest rate. The main idea is that firms will compare the debt cost with the equity capital cost, and will consequently decide their financing strategies, i.e., asking for bank credit or resorting to internal resources, if available.

The paper is organized as follows. The model is outlined in Section 2. Computational experiments and results are discussed in Section 3. Section 4 provides some concluding remarks.

2 The model

The general pattern of the model is outlined in Figure 1, where the main interactions among agents are represented. It is worth noting that, with respect to the financial flows, the model is closed. Figure 1 shows that all the flows between agents are contained in the model: there are neither exogenous input flows nor output flows. All the decision making of the agents is also endogenous and depends on behavioral rules that will be explained in the sections of agents description with more detail. Lacking a labor market in the model, the wage level is determined exogenously by means of a stochastic process.

The time structure of the model is the following: two nested time units are considered, let say the day and the month. The month is indexed by τ; firms, the commercial bank, the Government and the central bank make decisions on a monthly basis. Conversely, the financial market operates daily and the day, indexed by t, is the time unit considered by households for their financial investments. Each month is supposed to be subdivided into a given number of days.

2.1 Firms

Each firm j is characterized by a variable endowment of physical capital A^j_τ, and earns monthly revenues R^j_τ that depend on the amount of consumption goods firm j produced in the previous period. Physical capital is acquired by means of both equity capital E^j and debt financing D^j; A^j is measured in terms of the same monetary numeraire of E^j and D^j, and its initial amount A^j_0 is determined by the

initial level of equity and debt, i.e., $A_0^j = E_0^j + D_0^j$. The equity is divided into shares among households and traded in the financial market, the debt is a loan provided by the commercial bank. The quantity of consumption goods produced by firm j at month τ is modeled according to a linear production function that depends on physical capital, i.e., the quantity of goods $Q_\tau^j = a^j A_\tau^j \kappa_\tau^j$. The factor κ_τ^j represents exogenous productivity shocks that modeled according to a lognormal distribution with mean 1 and variance σ_τ^j. Firm j net earnings π^j are given by

$$\pi_\tau^j = R_\tau^j - N_\tau^j w_\tau - r_{\tau-1}^L D_{\tau-1}^j - T_\tau^j \tag{1}$$

where T_τ^j are taxes paid to the Government on gross earnings, after deducing interest payment, and r^L is the commercial bank lending rate. N_τ^j is the number of households working for firm j at month τ, determined in proportion to its physical capital, while w_τ is the wage level. Net earnings can be paid to shareholders by means of dividends d_τ^j or partially retained to finance new investments in physical capital I_τ^j. New investments can be financed also by bank loans and the issue of new shares; investments in physical capital are made considering the difference between the productivity of firm j χ^j and the average cost of capital in the financial market. Generally speaking, firms' financial decision making follows empirically observed managerial behavioral rules, see e.g. [7]. Firms are never rationed in the credit market.

Let us note retained earnings with $\widehat{\pi}^j$, i.e., $\widehat{\pi}_\tau^j = \pi_\tau^j - \mathscr{N}_\tau^j d_\tau^j$, where $\mathscr{N}_\tau^j$ is the number of aggregate outstanding shares and d_τ^j is the per share dividend. The dynamics

of firms assets and liabilities is thus given by:

$$\begin{cases} A_\tau^j = A_{\tau-1}^j + I_\tau^j \\ D_\tau^j = D_{\tau-1}^j + I_\tau^j - \widehat{\pi}_\tau^j \\ E_\tau^j = A_\tau^j - D_\tau^j . \end{cases} \tag{2}$$

In order to decide its dividends pay-out policy, firm j compares its return on equity $ROE_\tau^j = \pi_\tau^j / (\mathscr{N}_\tau^j P_\tau^j)$ with the debt cost, given by r_τ^L, that is the lending rate to firms r^L calculated on a monthly basis, according to the following strategy:

$$\begin{cases} \theta_\tau^j = \theta_{\tau-1}^j + \theta_{step} \quad \text{if} \quad (ROE_\tau^j - r_\tau^L) \; > \; \theta_{var}^j, , \\ \theta_\tau^j = \theta_{\tau-1}^j + \theta_{step} \quad \text{if} \quad (ROE_\tau^j - r_\tau^L) \; < -\theta_{var}^j, , \end{cases} \tag{3}$$

where θ_τ^j is the percentage of net earnings distributed to shareholders in the form of dividends, θ_{step} is the adjusting step, while θ_{var} is a sensitivity factor relative to firm j.

2.2 Households

Households are simultaneously taking the roles of workers, consumers and market traders. They receive a labor income from the firm at a common wage, if employed, and an unemployment subsidy from the government, if unemployed.

An essential aspect of the model is defining agents' behavior while facing their savings-consumption decision, that have been modeled within the framework of the buffer-stock theory of consumption [9,8]. The dynamics of cash on hand X_τ^i is given by:

$$X_{\tau+1}^i = R_\tau^i \left(X_\tau^i - C_\tau^i \right) + \varsigma_{\tau+1}^i w_{\tau+1} , \tag{4}$$

where R^i represents the gross total return of savings at time t, thus incorporating price returns, assets' cash flows and interests on the saving account. The term $\varsigma^i_{\tau+1} w_{\tau+1}$ refers to labor income at time $\tau+1$, which will be equal to zero if the household is unemployed, i.e., $\varsigma^i_{\tau+1} = 0$. Let us consider the ratio x^i_τ between cash on hand and permanent labor income, i.e.,

$$x^i_\tau = X^i_\tau / w_\tau \quad \forall t. \tag{5}$$

The main attractive feature of the buffer-stock theory of saving is that optimal consumption behavior can be articulated in very simple and intuitive terms. Consumers have a target level of cash on hand to income ratio $\bar{x}^i$, i.e., a target buffer stock of liquid assets with respect to permanent income, that they use to smooth consumption in the face of an uncertain income stream. If their buffer stock falls below target, their consumption level C^i_τ will be lower than their expected income and liquid assets will rise, while if they have assets in excess of their target they will spend freely and assets will fall.

Households can either invest their savings in the asset market, by trading stocks or bonds, or can put them in a saving account that pays a fixed, risk-free interest rate. They form beliefs about assets future returns considering a common forward horizon of three months. The implied idea is that households are able to foresee assets trends only for short periods of time, also if they plan to hold their assets for a longer period of time. Besides, each household i is characterized by an evaluation period ε_i which is a multiple of the forward horizon and is used to compute preferences and evaluate investments [5]. Beliefs are formed according to three stylized behavior, i.e., random, chartist and fundamental. In particular, expected

asset returns for each asset j, issued by the j-th firm, are given by a linear combination of three terms: a scalar random component $\rho^r_{j,i}$, a set of past returns $\rho^c_{j,i}$ computed in a backward time window, and a fundamentalist scalar term $\rho^f_{j,i}$. In order to compute the fundamental return, each household estimates a fundamental price

$$p_{j,i} = (E^j_\tau + \widehat{\pi}^j)/\mathscr{N}^j \tag{6}$$

taking into account the equity capital of firm j and the expected retained earnings in the forward horizon. Given the fundamental price and considering the last market price, the household derives the expected fundamental return $\rho^f_{j,i}$. Composing the three terms and adding expected cash flow yields $y^e_{j,i}$ (i.e., dividends for stocks and coupons for bonds), households determines a set of total expected returns $\rho_{j,i}$ as

$$\rho_{j,i} = \alpha^r_i \rho^r_{j,i} + \alpha^c_i \rho^c_{j,i} + \alpha^f_i \rho^f_{j,i} + y^e_{j,i} \tag{7}$$

where α^r_i, α^c_i and α^f_i are household's weights that sum to one. Then households build a normalized histogram $H[\rho_{j,i}]$ where the set of total expected returns is grouped in M_i bins. It is worth noting that a large number of bins M_i means that the household is more careful when examining the asset's past performance, taking into account more elements (it uses a higher resolution to build the histogram).

The histogram $H[\rho_{j,i}]$ can be seen as a prospect $\mathscr{P} = [\rho^H_{j,i}, p^H_{j,i}]$ where $\rho^H_{j,i}$ are the bins center values of the expected total returns histogram and $p^H_{j,i}$ are the associated probabilities, i.e., the level of the normalized histogram. If the evaluation period of the household is longer than the forward horizon used in the beliefs formation, it means that the prospect should be iterated accordingly. To this aim, we mod-

elled how the structure of a prospect varies when the evaluation period changes. Following the concepts of myopic loss aversion, we introduce a new prospect $\mathscr{P}^n$ that represents the mental accounting (see [5]) of the agent when considering the risky investment, that means an n times iteration of prospect $\mathscr{P}$. Accordingly, the number of elements of the iterated prospect $\mathscr{P}^n$ will pass from M_i to $\mathscr{M}_i$. Thus, each household will face a new prospect $\mathscr{P}^n = [\rho_{j,i}^{H_n}, p_{j,i}^{H_n}]$ depending on its evaluation period.

Prospect theory utility is defined over gains and losses, i.e., returns ρ^{H_n}, rather than levels of wealth. The value function for the ith household has the following form:

$$v_i\left(\rho_{j,i}^{H_n}\right) = \begin{cases} (\rho_{j,i}^{H_n})^{\alpha} & \text{if} \quad \rho_{j,i}^{H_n} \geq 0\,, \\ -\lambda_i(-\rho_{j,i}^{H_n})^{\beta} & \text{if} \quad \rho_{j,i}^{H_n} < 0\,, \end{cases} \tag{8}$$

where λ_i is the coefficient of loss aversion of household i. By means of behavioral experiments Kahneman and Tversky estimated α and β to be equal to 0.88 and λ to be equal to 2.25 [1].

Given the histogram of composed expected returns, the ith household may calculate the utility of asset j as,

$$U_{j,i} = \sum_{\mathscr{M}_i} p_{j,i}^{H_n}\, v(\rho_{j,i}^{H_n}), \tag{9}$$

where $p_{j,i}^{H_n}$ are the probabilities associated to $\rho_{j,i}^{H_n}$. These utilities are finally normalized and mapped into assets weights by means of a linear transformation. Once the assets weights are available, the household can build its desired portfolio and emit orders consequently. Orders are therefore submitted to a clearing house that determines assets new prices.

2.3 The banking sector

The commercial bank collects households deposits B_τ, provides loans L_τ to firms, and holds a buffer account C_τ at the central bank, which can be positive or negative. The commercial bank sets the lending rate r^L to firms according to a mark-up rule on the central bank policy rate r, i.e., $r^L = \mu_L r$, where $\mu_L > 1$ is the mark-up. The rate on households deposits r^B is determined by $r^B = \mu_B r$ where μ_B is lesser than one. Net earnings are given by

$$\pi^b_\tau = r_{\tau-1} C_{\tau-1} + r^L_{\tau-1} L_{\tau-1} - r^B_{\tau-1} B_{\tau-1} - T^j_\tau \tag{10}$$

where T^j_τ are taxes as a fraction of gross earnings paid to the Government. The capital structure of the bank is composed by both equity capital E^b and debt financing, i.e., the Central Bank account and households deposits. The bank equity is divided into shares among households and traded in the financial market. Given the amount of L and B set by firms and households, respectively, and the dynamics of equity $E^b_\tau = E^b_{\tau-1} + \widehat{\pi}^b_\tau$, where $\widehat{\pi}^b$ are the retained earnings, the bank adjusts C according to the budget constraint $C_\tau = E^b_\tau + B_\tau - L_\tau$.

The central bank implements monetary policy decisions by means of a policy rate r which is used both as a borrowing or lending rate for the commercial bank account.

2.4 The government

The Government runs a financial budget. Income is given by a mixture of different taxation policies, that include taxes on households wages, on corporate earnings, and on capital income. Expenditures depend on unemployment benefits b, that are expressed as a percentage of the current wage level, and on the interest rates on government debt. Taxation is adjusted adaptively in order to finance expenditures, running a zero budget target. The government may issue both short-term or long-term bonds in order to finance the budget deficit. Bonds have a face value which is paid at the maturity date, and pay fixed coupons to bondholders anchored to the central bank policy rate. The goal of both the Government and the central bank policies is the pursuit of low volatility in the asset market and of long-run growth in the economy by means of accumulation of physical capital by firms.

3 A fiscal policy experiment

The simulations we present refer to a model populated by 2,000 households and 3 firms. Five assets are traded in the financial market: three firms stocks, the bank stock, and a long term government bond. Firms are endowed with a constant physical capital and make no new investments. Productivity of physical capital is set equal for all firms at 0.05, o.e., $a^j = 0.05 \forall j$. Firms pay-out policy is characterized by $\theta_{step} = 0.1$ and $\theta_{var} = 0$. Among traders, fundamentalists and chartists are 5% each, while the rest are random traders. The commercial bank mark-up μ_L is 1.5, while μ_B is set equal to 0.8. The bank dividend policy is to pay 100% of its net

earnings. The government applies a fixed tax rate of 15% both on capital income for households and on corporate earnings of firms and bank. The government bond maturity date is set at the end of the simulation. Finally, each month is considered to be subdivided in five trading days.

Firms and bank balance sheets have been initialized in order to characterize all stocks by the same initial fundamental price, which have been set to 100. In particular, the initial equity for each of the three firms is equal to 10,000,000, while the bank equity has been set to 6,000,000; besides, the number of shares outstanding is 100,000 for each firm, and 60,000 for the commercial bank. Currency units are arbitrary. Each firm is endowed with an initial debt of 20,000,000 , so that the aggregate amount of loans by the commercial bank to firms is 60,000,000, which, given the bank equity, corresponds to a core tier 1 ratio of 0.1. Households are initially endowed with an equal number of shares for each asset and a bank account of 5,000.

We run a fiscal policy computational experiment where the government raises the unemployment benefits b from 60% to 70% of the current wage level. The government varies taxation rates and bonds emission adaptively, in order to reach a target of budget zero. This has many different implication in the overall picture of our financial economy.

In figure 2 the price levels of the five assets traded in the financial market (four stocks and a government bond) is presented. The black lines represent the assets prices when the unemployment benefits are 60% of the current wage, whereas the grey lines are the assets prices when benefits reach 70%. It can be noticed that the

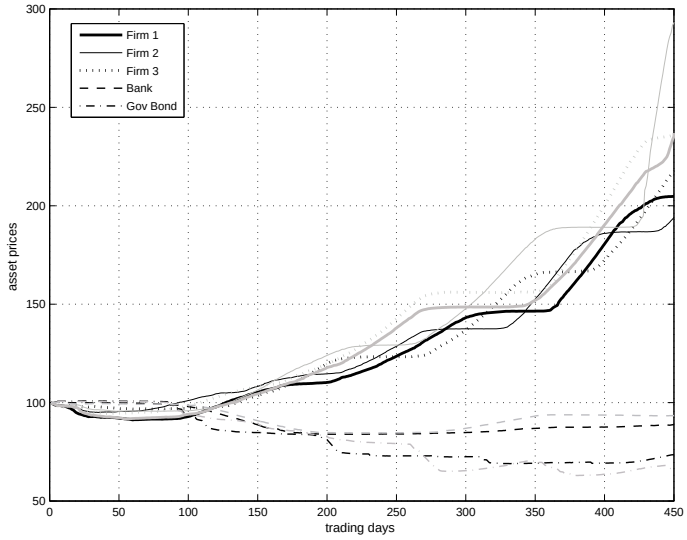

Fig. 2 Assets prices. The black lines represent the assets prices in the case of unemployment benefits b of the government set to 60% of the current wage level. The grey lines refer to the case of $b = 70\%$

bond price is lower in the case of higher unemployment benefits, while the stocks price levels are generally higher.

In order to explain these prices behaviors, let us introduce Figure 3 where the goods price level and the aggregate consumption are plot. The higher unemployment benefits give a stronger purchasing power to households, pushing up consumption and triggering an increase of prices. Being the equity of firms given by the nominal value of capital goods, a raise of prices determines a raise of equity. This influences directly the fundamental price of fundamentalist traders (see eq. 6), that pushes up stocks demand causing prices to rise. In order to comment bonds behavior, Figure 4 should be examined. It shows the government budget in

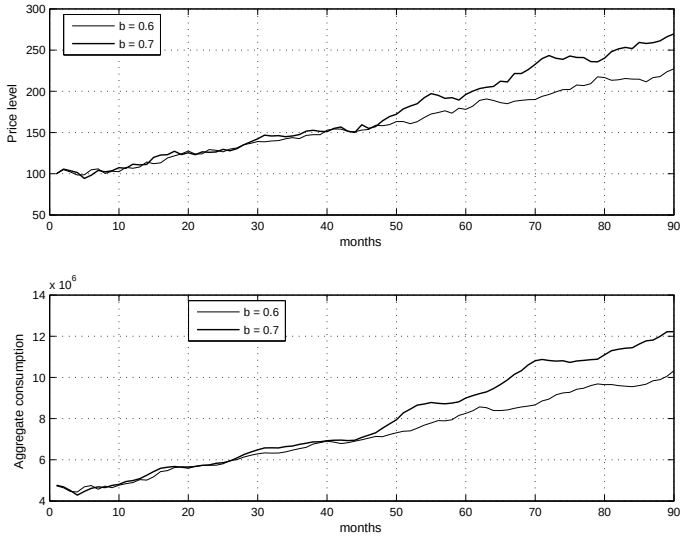

Fig. 3 Consumption good price levels. The thin line represents the case of unemployment benefits $b = 60\%$ while the thick line refer to $b = 70\%$

the upper part, along with the face value of government debt that is plot in the lower part of the figure. The adaptive taxation with target of zero budget clearly appears in Figure 4. The case of $b = 70\%$ highlights that the government budget has a negative trend that has to be faced with correspondent financing policies, i.e., taxes and new bonds emission. Indeed, examining the lower part of figure 4, it is worth noting that the government resorts to emission of new bonds when it is coping with a a period of excessively negative budget. In order to finance a higher level of unemployment benefits, the government is therefore compelled to emit more bonds (grey line), strengthening the offer side of the market, and therefore causing the fall of bonds prices that has been pointed out in Figure 3.

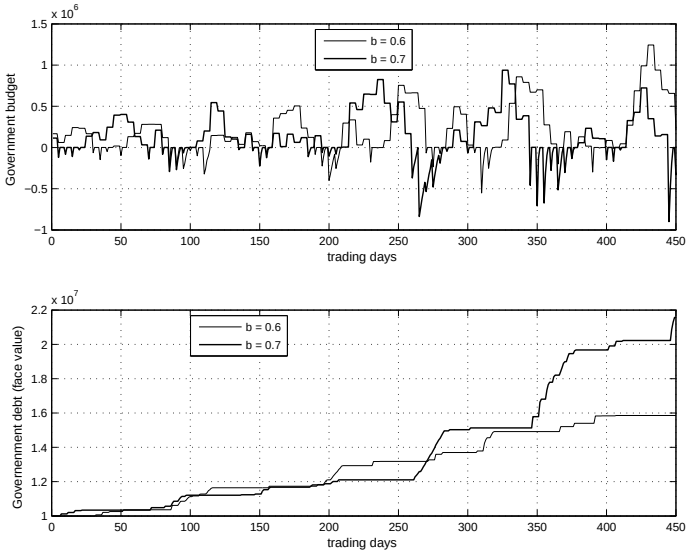

Fig. 4 The upper part of the figure shows the government budget. The lower part shows the face value of government debt. The black lines refer to the case of unemployment benefits set to 60% ($b = 60\%$) while the grey lines refer to $b = 70\%$

4 Conclusions

In this paper it has been presented a model of an artificial financial economy where the financial decisions of the agents are endogenously taken. The model is particularly complete in terms of agents and in terms of their economic interaction. The agents acting in the system are the government, a central bank, a commercial bank, some firms and many households. The main financial flows among the agents are represented in the model; including standing facilities that depend on the interest rate set by the central bank, loans to the firms from the commercial bank, deposits of household into the bank, bond coupons payments and tax collection by the gov-

ernment, and other interactions that has been described in the paper. The equity of both the commercial bank and the firms is traded in the financial market.

A particular attention has been devoted to the modelling of the beliefs formation mechanism of households trading in the asset market, and on their preferences structure that is designed according to *Prospect Theory*.

We propose a fiscal policy experiment where the government decides to increase the unemployment benefits, and we analyze the effects of this fiscal measure on the financial market. The higher expenditures level is financed by new bonds emission by the government, causing a reduction in bonds prices. On the other hand, a higher purchasing power of households pushes consumption and prices, thus raising the equity of the firms and their stocks price levels. Therefore, from our study it can be argued that the adopted fiscal measure has significant effects on the financial market.

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