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MONETARY POLICY AND DEBT DEFLATION: SOME COMPUTATIONAL EXPERIMENTS

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The paper presents an agent-based model to study the possible effects of different fiscal and monetary policies in the context of debt deflation. We introduce a modified Taylor rule that includes the financial position of firms as a target. Monte Carlo simulations provide a representation of the complex feedback effects generated by the interaction among the different transmission channels of monetary policy. The model also reproduces the evidence of low inflation during stock market booms and shows how it can lead to overinvestment and destabilize the system. The paper also investigates the possible reasons behind this stylized fact by testing different behavioral rules for the central bank. We find that, in a context of sticky prices and volatile expectations, endogenous credit creation can be identified as the main source of the divergent dynamics of prices in the real and financial sectors.

Keywords: Financial Fragility, Monetary Policy, Debt Deflation, Agent-Based Modeling, Complex Dynamics

1. INTRODUCTION

The chain of events that started with the global financial crisis is leading academics and policy makers to rethink the tasks and the instruments of monetary policy. In fact, a definition of the range of tools for achieving nonstandard goals, such as financial stability, has already occurred, at least with reference to the major world central banks. An interesting feature of the debate that these events provoked is that it involves elements typical of nonconventional thought that have now found a place in mainstream articles. Suggestions for a structured redefinition of monetary policy have been put forward from different perspectives. Gathering together some of these elements can provide a first list of the factors that an effective policy should take into account.

1. A growing number of mainstream authors have started to take an interest in the role of private debt in determining macroeconomic outcomes. The once dominant view that a debt deflation represents just a redistribution of wealth from borrowers to lenders,

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without a net effect in the aggregate [Bernanke (1995)], seems to have been definitely overturned. The aggregate level of private debt is now widely considered as a factor of fragility of the economic system [Minsky (2008b)]. In particular, Christiano and various co-authors[1] argue that monetary policy should also target the level of private debt.

2. The bankruptcy of an economic agent is not an isolated fact, as every economic actor has financial liabilities and claims against a number of others [Stiglitz and Greenwald (2003); Delli Gatti et al. (2010)]. Therefore policy makers should address the topology of the credit network and the possible effect of financial distress of single agents [Battiston et al. (2012); Di Guilmi et al. (2012)].
3. Although the heterogeneity and the interaction of economic agents [Gallegati and Kirman (1999); Kirman and Zimmermann (2001)] are progressively gaining more attention, the fact that different agents can follow different behavioral rules is relatively less explored by the theory. In particular, Koo (2008) illustrated, with reference to Japan, the risks that can arise when firms target their level of leverage in order to survive, rather than adopting optimizing behavior as conventionally represented in economic models.
4. The argument that the amount of credit, and consequently of broad money in the economy, cannot be effectively controlled by the central bank has been consolidated in the nonorthodox literature.[2] Consequently the monetary authority can only influence the credit conditions through the interest rate but not the actual supply of credit.
5. Inflation is typically low during stock market booms [Fama (1981)]. As stressed by Christiano et al. (2007), this can mislead the central bank, pushing interest rates down and fueling in this way a possible bubble.

In our opinion, the investment theory developed by Hyman Minsky (1975) provides an important reference for developing a model that can embody the elements mentioned. In this approach, business fluctuations are explained as the effect of periodic changes in expectations in a context of less than perfect foresight. During an expansion, banks can reduce the risk premium for loans, both because of the optimistic expectations about future repayment and because of the high evaluation of collateral. The increase in the availability of credit fuels new investment by firms and the prices of shares, as investors increase borrowing to exploit cheap credit and the forecast capital gains. Stock price inflation, in turn, provides for further new investment in the real economy. This positive feedback loop lasts until growing debt commitments cause insolvencies of the weakest units in the economy and a consequent reduction of the amount of liquidity in the system. Expectations will then worsen, reducing the value of enterprises' collateral. This leads banks to apply higher interest rates for the perceived higher risk of default, further worsening the financial condition of borrowers. The growth phase is now reversed into a negative spiral that eventually leads to a downturn.

This approach was later formalized within the post-Keynesian and the New Keynesian literature.[3] In the post-Keynesian camp, the works that most directly inspired the approach of this paper are Taylor and O'Connell (1985) and Franke and Semmler (1989), who present aggregative models in which the equilibrium in the capital market is determined within a Tobinian asset portfolio. The capital market drives the investment decisions of firms and, consequently, the business cycle. Within the New Keynesian literature the work of Minsky is related to two distinct approaches. The first one, known as the financial accelerator [Bernanke and Gertler (1989, 1990); Bernanke et al. (1999)], focuses on the process of asset deflation during recessions due to the tightening of the liquidity constraints of borrowers and the consequent fire sales of assets. The second [Greenwald and Stiglitz (1990, 1993)] studies the effect of financial distress at the micro level on the business cycle by introducing a bankruptcy constraint in the firm's optimization process.

Chiarella and Di Guilmi (2011) microfound the aggregative models of Taylor and O'Connell (1985) and Minsky (2008a) by introducing firms that are different in size and financial conditions. The model is solved both numerically, through computer simulations, and analytically, by means of the techniques proposed in Aoki and Yoshikawa (2006) and Di Guilmi (2008). Chiarella and Di Guilmi (2012b) extend that work by introducing a government that uses fiscal policy to stabilize the economy, putting a floor under the decline in private spending.

This paper builds on Chiarella and Di Guilmi (2011, 2012a, 2012b) and proposes an agent-based model with a central bank and financially heterogeneous firms. The model adopts Minsky's perspective in modeling investment: firms do not optimize but follow the market mood, quantified by the latest variation in stock prices. Firms' responses to the market mood are asymmetric. In fact, firms are exposed to idiosyncratic stochastic shocks and their ability to fulfil debt commitments depends on their different degrees of financial fragility. The public sector is composed of the government and the central bank. Following Chiarella and Di Guilmi (2012b), the government collects taxes and decides the level of expenditure to stabilize the economy and to avoid or lessen depressions. In particular, the government accumulates surpluses during expansions in order to have sufficient financial resources to counteract a downturn. The central bank adopts a modified Taylor rule that also includes the financial position of firms. By means of Monte Carlo simulation, we show the effects on the main macroeconomic variables of changes in the sensitivity of the central bank to the inflation gap, the output gap, and the level of firms' indebtedness.

The paper also analyzes a different scenario in which the central bank handles the supply of money directly. The goal of this last experiment is to assess the effects of endogenous credit on the correlation between stock prices and inflation.

The paper provides two main contributions. First, it fits into the debate on a reformulation of economic policy, which is urgent in the current macroeconomic climate. In this agent-based framework, consistent with the paradigm of complexity, the business cycle does not originate from external shocks but rather is an emergent property due to the interaction of heterogeneous agents. The dynamics of macroeconomic variables is determined by the behavior of economic units. The latter adjust their balance sheets as a consequence of the macroeconomic climate in a chain of feedback effects between the micro- and the macro-level of the economy. The reactions are different across the different units and different times, given the different preshock conditions. This setting can therefore provide more insights into the macroeconomic outcomes of policy interventions than do aggregative and representative agent models. Moreover, these chains of dynamic feedback can also be helpful in studying the effect of interactions, which are difficult to consider in dynamic stochastic general equilibrium (DSGE) models, even when they involve the heterogeneity of agents or financial frictions, as in Smets and Rafael (2007) and Christiano et al. (2011). In our approach the transition between the business cycle phases is not exogenous but emerges endogenously as a consequence of small idiosyncratic shocks that hit the agents. This can allow a better assessment of the effects of micro-financial fragility and of the increase in the number of financially distressed units in the economy.[4]

This paper is not the first attempt to use agent-based modeling for monetary policy.[5] In particular, Dosi et al. (2013) share much of the spirit of the present work. They study the effects of monetary and fiscal policies in an agent-based model in which the interaction of technological progress, income distribution, and financial fragility is at the root of the business cycle. This paper presents a different modeling approach, being rooted in the Minskyan tradition, and takes a different perspective, focusing more specifically on the policy implications of the cyclical phenomena of overinvestment and asset inflation, which played such a relevant role in the recent downturns.

The second contribution is that the paper attempts to offer an explanation for the evidence of low or declining inflation during stock market booms and to describe the channels through which it can destabilize the real economy. In our opinion, an analysis of this phenomenon cannot ignore the effects of endogenous credit. Some of the existing treatments, such as Christiano et al. (2007), do not consider this feature and need to resort to, in our view, quite audacious hypotheses to explain this feature, as illustrated in Section 6. From this perspective, this paper integrates the literature on the risk-taking channel popularized in the BIS working paper series.[6] According to this approach, the handling of the interest rate by the monetary authority can distort the investment decisions of agents. In particular, an accommodating policy in periods of low inflation can decrease the risk aversion of investors. This paper adds to this stream of the literature in three main ways. First, it explicitly models the joint dynamics of good and asset prices and studies their evolution under different policy scenarios. Second, the analysis of the effects of a supply of credit that accommodates the demand to different extents during the business cycle provides a suitable framework for studying the role of *liquidity*, which is emphasized by this literature. Third, the model provides an analytical and quantitative benchmark to assess the relevance of the risk-taking channel in the transmission of monetary policy.

Given our focus on monetary policy and debt deflation in the productive sector, our model abstracts from other sectors of the macroeconomy (most noticeably the household sector). As noted by Lengnick (2013), in macro-agent-based models with full detail, such as Cincotti et al. (2010), the causal links may be not easily identifiable because of computational complexity. This paper presents a framework that is flexible enough to be extended to include other subsystems at a later stage, once the analysis of the transmission mechanism is clarified in a simplified setting.

The paper is organized as follows. Sections 2 and 3 introduce the assumptions relating to the productive and the public sectors of the economy. The public sector is composed of the government and the central bank. The hypothesis regarding the financial sector and the equilibrium conditions in the credit and stock market are presented in Section 4. The results of the simulations are analyzed in Section 5. Section 6 presents an alternative scenario in which the central bank handles the supply of money; this section also presents and comments on the results of the simulations for this alternative setting. Section 7 offers some concluding remarks.

2. FIRMS

This section introduces the productive sector of the economy, which is composed of heterogeneous firms.[7] The variables referring to firms are indicated by a superscript i, whereas the variables without any superscript refer to aggregate variables. Aggregate variables (production, debt, investment, and equities) are obtained by summing up the firm-level variables at each time step. For the reader's convenience, the detailed timeline of the model is presented in the Appendix. The behavioral rules are as follows:

- In every period t the ith firm targets an amount of investment I_t^i. The new level of capital then determines the demand for labor and output. The investment is decided on the basis of the *shadow price* of capital, P_k^i [Tobin (1969); Minsky (2008a)], so that
$$I_t^i = a P_{k,t}^i, \tag{1}$$
where $a > 0$ is a parameter measuring the sensitivity of firms to the shadow price. The variable P_k is determined according to
$$P_{k,t}^i = \frac{\rho_{t-1}^i P_t}{r_{t-1}}. \tag{2}$$
The variable ρ_{t-1}^i measures the market sentiment (or *animal spirits*, in Keynes's words), r_{t-1} measures the nominal interest rate, both referred to the previous unit of time, and P_t is the goods price. As detailed in Section 4, ρ^i depends on the performance of the stock market, leading firms to invest more during bull market periods and less during bear market phases.
- Capital K_t depreciates in each period at a constant rate σ. The variation in the physical units of capital is then given by
$$\Delta K_t^i = I_t^i / P_t - \sigma K_{t-1}^i. \tag{3}$$
- Firms produce a good that can be used either for consumption or for investment. Assuming that the firms adopt a technology with constant coefficients, the amount of labor requested, L_t, is residually determined once the optimal

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level of investment, and hence of capital, is quantified. The supply of labor is infinitely elastic. The production function for all firms is written as

$$X_t^i = \min(K_t^i, L_t^i), \qquad (4)$$

where X_t^i is the total production of firm i. The constant capital-to-labor ratio is equal for all firms and is indicated by $v = K_t^i/L_t^i$. A firm will demand the amount of workforce needed to operate its capital, so that the demand for labor will be equal to

$$L_t^i = K_t^i/v. \qquad (5)$$

Assuming a perfectly elastic supply of labor and no technological progress, we can define the production function as[8]

$$X_t^i = \varphi\, K_t^i, \qquad (6)$$

where the output/capital ratio $\varphi > 0$ is a parameter that is constant across firms and in time.

- The selling price of the final good and investment is the same across firms and is a mark-up price on the cost of labor; hence

$$P_t = (1+\mu)w_{t-1}b, \qquad (7)$$

where $0 < \mu < 1$ is the mark-up, w_t is the nominal salary at time t, and b is the labor–output ratio. Because all firms use the same technology, the price is equal for all of them.

- The aggregate demand is given by

$$P_t X_t^d = w_{t-1}L_t + I_t + G_t, \qquad (8)$$

where $L_t = bX_t$ is the demand for labor, X_t is the total output (consumption + investment goods), and G_t is the government expenditure. We allocate aggregate demand among firms according to their sizes, so that

$$X_t^{id} = \frac{X_t^d}{K_t} K_t^i. \qquad (9)$$

- The nominal salary w is not the direct result of the interaction of individual firms, but is determined in a centralized process. Its level is set to partially accommodate the difference between demand and supply. If we set $X_t = X_t^d$, assume that $X_t = bL_t$, and substitute (7) into (8), we have that, in order to match demand and production in each period, the salary should be equal to

$$w_t = \frac{I_t + G_t}{b\mu X_t}. \qquad (10)$$

We assume that the salary is determined by two factors: one that tends to accommodate the demand to the supply according to (10) and a second that

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represents the nominal rigidity. Consequently, we can write

$$w_t = \eta w_{t-1} + (1-\eta)\frac{I_t + G_t}{b\mu X_t}, \quad \textbf{(11)}$$

where $\eta \in (0, 1)$ is a parameter quantifying the stickiness of salaries.
The goods are assumed to be nonperishable; therefore they can be stored as inventories whenever $X_t^i > X_t^{id}$. Inventories are used when current production is not sufficient to meet the demand. A control is introduced to make sure that inventories plus current production are always greater than or equal to current demand.

- Assuming that all the salaries are consumed, firms' profits π_t are given by

$$\pi_t^i = P_t X_t^{di} - wbX_t^i - r_t D_t^i, \quad \textbf{(12)}$$

where X_t^i is the output and D_t^i the outstanding stock of firms' debt. The government imposes a tax rate τ on gross profits.

- Firms are classified into the three categories of Minsky (1982a). In particular, a firm is defined as hedge if it is able to generate enough profit to repay its debt, speculative if the profit is enough at least to repay the service of debt, and Ponzi if the firm needs to roll over also the interest on the outstanding debt.

Accordingly, for *hedge* firms, the internal finance evolves according to

$$A_t^i = A_{t-1}^i + \pi_t^i(1-\tau), \quad \textbf{(13)}$$

where A_t^i is the cumulated past profit and τ is the tax rate on positive profit. For *speculative* firms, net profits are first used to repay the debt D_t^i and then accumulated for the remaining part. Accordingly, we have that

$$A_t^i = \pi_t^i(1-\tau) - D_{t-1}^i \text{ if } \pi_t^i(1-\tau) > D_{t-1}^i, \quad \textbf{(14)}$$

$$D_t^i = D_{t-1}^i - \pi_t^i(1-\tau) \text{ if } \pi_t^i(1-\tau) \leq D_{t-1}^i. \quad \textbf{(15)}$$

In the first case the firm becomes hedge, whereas in the second it is speculative.

Finally, for *Ponzi* units we have that

$$D_t^i = D_{t-1}^i - \pi_t. \quad \textbf{(16)}$$

As a consequence, we can write the classification criteria for the firms as follows:[9]

- hedge if $A_t^i > 0$;
- speculative if $D_t^i > 0$ and $\pi_t^i \geq 0$;
- Ponzi if $D_t^i > 0$ and $\pi_t^i < 0$.

- Firms finance investment first with internal funding A_t and then, for the remaining part, by a fraction ϕr_t with equities, where $\phi > 0$ is a parameter, and then the rest with debt. The dependence on the interest rate reflects the fact that in periods with a high interest rate, equities would be preferred. The parameter ϕ measures the sensitivity of firms to the interest rate for their decision about the source of financing. So, for each enterprise, the number of shares E_t^i evolves according to

$$\Delta E_t^i = \phi r_{t-1}(I_t^i - A_t^i)/P_{e,t-1}^i, \quad \textbf{(17)}$$

where $P_{e,t-1}^i$ is the price of shares for firm i. The newly issued equities sum up to the existing stock, so that $E_t^i = E_{t-1}^i + \Delta E_t^i$. Equities are destroyed only in case of bankruptcy.[10] As for the dynamics of debt, equations (15) and (16) should accordingly be redefined as

$$\Delta D_t^i = (1 - \phi r_{t-1})(I_t^i - A_t^i) - \pi_t^i(1 - \tau), \quad \textbf{(18)}$$

$$\Delta D_t^i = (1 - \phi r_{t-1})(I_t^i - A_t^i) - \pi_t^i. \quad \textbf{(19)}$$

The outstanding stock of debt is therefore given by the debt at the previous period plus the new issuance less repayment.

- The bankruptcy of a firm occurs when

$$\frac{D_t^i}{K_t^i P_t} > \gamma, \quad \textbf{(20)}$$

where $\gamma > 1$. A lower γ signifies a stricter bankruptcy rule, with a lower level of sustainable debt-to-capital ratio. A failed firm can be replaced or not, depending on the macroeconomic conditions. More precisely, a random number between 0 and 1 is associated with each inactive firm. If the normalized variation of aggregate demand in the previous period is larger than this number, the firm becomes active. As a consequence, the probability of a new firm entering is higher after a period of growth and lower during recessions.[11] The capital of bankrupted firms is acquired at no cost by the surviving ones in proportion to their size.

3. THE PUBLIC SECTOR

We consider a public sector composed of the government and the central bank. Fiscal policy is modeled as in Chiarella and Di Guilmi (2012b).

3.1. Fiscal Policy

The government decides the amount of the public expenditure countercyclically. For simplicity, during expansions, the public expenditure is assumed to be equal to 0. During recessions, the government supports private demand by filling the gap in investment and consumption. It finances with bonds B the part of public expenditure that exceeds taxes.

The reaction of the government to business fluctuations is quantified by the parameter $\theta \in [0, 1]$. It determines the strength of fiscal intervention in two ways. First, in the case of a negative variation of private expenditure, the government brings the level of public expenditure to a fraction θ of the loss, so that $G_t = \theta|\Delta X^d_{t-1}|$, where ΔX^d_{t-1} is the negative variation in aggregate demand at time $t-1$. We assume a lag of one period for the government intervention. With regard to the second way, once the cycle hits its trough and the economy starts to recover, the government keeps supporting aggregate demand until it is equal to at least a fraction θ of the peak before the recession.

The tax is levied on profit and it is defined as a fixed and constant share τ of positive firms' profits. The total amount of fiscal revenue is therefore equal to

$$T_t = \sum_{i=1}^{N} \tau \pi^i_t \ \forall \pi^i_t > 0. \tag{21}$$

When taxes are not sufficient to cover the expenditure, the government issues bonds, whereas surpluses are used to pay out existing bonds. Following Chiarella and Di Guilmi (2012b), the government does not face a budget constraint, in order to verify if there can be an explosive dynamics of public debt and under what conditions.

3.2. The Central Bank

The central bank determines the reference interest rate $r_{\mathrm{B},t}$ by applying a Taylor rule of the type

$$r_{\mathrm{B},t} = \theta_p(P_t - P^*_t) + \theta_x(X_t - X^*_t) + \theta_d(\mathrm{PS}_t - \mathrm{PS}^*_t), \tag{22}$$

where θ_p, θ_x, and θ_d quantify the sensitivity of the central bank to, respectively, the inflation gap, the output gap, andthe ratio of speculative plus Ponzi firms over the total number of firms, indicated by PS.[12] The target values P^*, X^*, and PS^* are calculated as moving averages on the past t_{MA} periods.

Three main transmission channels of monetary policy can be identified. The first relates to the choice of firms in matter of investment and is quantified by equations (1) and (2), which define a negative relationship between the interest rate and the level of investment. The second concerns the service on debt, which affects the firms' profits as for equation (12). The third channel is represented by the dependence of the choice of firms for the source of financing on the interest rate, as modeled in equations (17)–(19). The first channel can be categorized as a risk-taking channel [Borio and Zhu (2012)], whereas the second and third can be defined as credit channels [Bernanke and Gertler (1995); Hubbard (1995)].

Ceteris paribus, an increase in the policy rate should lead to lower investment, higher debt service, and a stronger preference for equities over bonds to finance firms' investment. However, the relevant variable for firms is the market interest rate and not the policy rate. As shown in Section 4, the market interest rate is determined by the financial sector by applying a mark-up h_t to the official interest rate as proposed by Rousseas (1985), so that

$$r_t = (1 + h_t) r_{B,t}. \tag{23}$$

The mark-up h_t is an endogenous variable as determined by system (28) in the next section.

4. CAPITAL MARKET

The capital market is modeled along the lines of Chiarella and Di Guilmi (2011). The most relevant difference is that in this treatment, the variable ρ does not depend only on an external stochastic shock but is determined within the system. In particular, this variable, which embodies the expectations of firms and determines their level of investment according to (1), is assumed to be dependent on the performance of the stock market.[13]

4.1. The Stock Market and the Expectations

Expectations are influenced by fluctuations in the stock market. For this reason we consider the variable ρ_t as dependent on the latest variation in the stock market index. Hence ρ_t is quantified by

$$\rho_t = 1/[1 + \alpha \exp(-\Delta P_{e,t}/P_{e,t-1})], \tag{24}$$

where $\alpha > 1$ is a parameter. Each unit in the system is subject to an idiosyncratic shock that affects both its expected profitability ρ^i and its share price P_e^i, so that

$$\rho_t^i = \tilde{u}_t^i \rho_t, \tag{25}$$

$$P_{e,t}^i = \tilde{u}_t^i P_{e,t}. \tag{26}$$

The idiosyncratic shock $\tilde{u}_t^i$ is uniformly distributed with $\mathbf{E}[\tilde{u}] = 1$.

4.2. Equilibrium in the Capital Market

The wealth of investors W_t is given by the value of the market capitalization $(P_{e,t} E_t)$, public and private bonds $(\mathrm{Bon}_t = B_t + D_t)$, and money (M_t), such that

$$W_t = P_{e,t} E_t + \mathrm{Bon}_t + M_t. \tag{27}$$

We assume that investors do not distinguish between private and public bonds. The equilibrium conditions in the capital market are set by a Tobinian asset portfolio that quantifies the price of equities, the interest rate, the amount of money, and the amount of total wealth. To allocate their wealth between bonds and equities, investors look at the performance of the equity market, quantified by ρ, and at

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the return from bonds, given by the market interest rate. The financial sector provides all the credit demanded by firms and liquidity demanded by investors by generating them endogenously. Investors have a constant propensity to keep part of their wealth in liquid assets. This propensity is quantified by the parameter $\psi > 0$. The allocation of assets and the determination of stock prices and interest rate follow the same procedure as in Chiarella and Di Guilmi (2011). As in that paper, the parameter ψ plays an important role: because the demand for credit is always accommodated (even though with a variable interest rate), a larger ψ implies a larger M and, as a consequence, aggregate wealth W. As shown by Chiarella and Di Guilmi (2011), this factor amplifies the magnitude of business cycle fluctuations.

Accordingly, the equilibrium conditions in the capital market can be expressed by the following system of equations:

$$\begin{cases} P_{e,t}E_t = \dfrac{W_t}{1+e^{r_t+\psi-\rho_t}}, \\ \mathrm{Bon}_t = \dfrac{W_t}{1+e^{\rho_t+\psi-r_t}}, \\ M_t = \dfrac{W_t}{1+e^{r_t+\rho_t-\psi}}, \\ W_t = P_{e,t}E_t + \mathrm{Bon}_t + M_t. \end{cases} \tag{28}$$

The system (28) is solved for the value of asset prices $P_{e,t}$, the market interest rate r_t, the amount of money M_t, and the total wealth W_t. The market interest rate has a floor given by the policy rate $r_{\mathrm{B},t}$ and the difference between the two rates quantifies the mark-up h_t as for equation (23). As remarked by Chiarella and Di Guilmi (2012a), the endogenous determination of the equity price (and consequently of wealth) makes the system generate more liquidity and cheaper credit during expansionary phases. Conditions are reversed in downturns with less availability of liquidity and worse credit terms. This cyclical sequence of euphoria and depression provides an analytical counterpart of the Minskyan idea of a financial origin of the business fluctuations.

5. RESULTS

We performed single-run simulations to define a benchmark scenario and test the ability of the model to replicate empirical evidence, and Monte Carlo simulations of 1,000 replications to study the different policy scenarios.

5.1. Baseline Scenario

The results of the single runs are shown in order to appreciate the dynamics of business cycles that are generated by the model, the impact of fiscal policy, and the pattern of evolution of the different types of firms across the cycle. The set of parameters used in the simulations are reported in Table 1. The parameters are calibrated to match the statistical regularities detailed hereafter and therefore

Table 1. Parameters and values used in the simulation

$\eta = 0.5$	Stickiness of salary
$\theta = 0.75$	Sensitivity of the government to negative variations in demand
$\theta_x = 1$	Sensitivity to the output gap in the Taylor rule
$\theta_p = 1.3$	Sensitivity to inflation in the Taylor rule
$\theta_d = 1$	Sensitivity to the share of Ponzi plus speculative firms in the Taylor rule
$\alpha = 0.5$	Sensitivity of ρ_t to variations in asset price
$\tilde{u} \in [0.1; 1.9]$	Idiosyncratic shock affecting ρ and P_k
$\tau = 0.2$	Share of tax on profit
$a = 0.25$	Sensitivity of firms' investment to ρ_t
$b = 2.8$	Labor–output ratio
$\mu = 0.3$	Price mark-up
$v = 1.1$	Constant capital–to–labor ratio
$\varrho = (b \cdot v)^{-1}$	Output–capital ratio
$\phi = 5$	Parameter for firms' decision between equity and debt
$\psi = 0.5$	Propensity of investors to liquid assets
$\sigma = 0.05$	Rate of capital depreciation
$\gamma = 9$	Bankruptcy parameter
$t_{\mathrm{MA}} = 30$	Period for calculation of the moving average for the Taylor rule
$\lambda = 1.3$	Sensitivity of the central bank to inflation when it targets the supply of money
$\zeta = 0.1$	Sensitivity of the central bank to the share of Ponzi firms when it targets the supply of money

to allow comparison with a real system. A more refined study of the calibration is part of our future research agenda. A simulation runs for 500 time steps and involves 1, 000 firms, between active and inactive. At time $t = 1$ the number of active firms is 500. The initially active firms and those that become active during the simulation are endowed with a random amount of capital. The burn-in phase concerns circa the first 100 periods.

The model is able to replicate some empirical evidence, in particular with reference to the business cycle. The firm size distribution, using capital as the dimensional variable, displays fat tails and can be approximated by a Pareto distribution, as empirically observed by Axtell (2001), among others. Figure 1 illustrates this result for a representative simulation and shows that the distribution is more skewed during upturns, as shown by Gaffeo et al. (2003) for real data. This micro-evidence causes a macro-pattern compatible with the empirical evidence. As shown by Figure 2, the variations in aggregate demand follow a Weibull distribution, matching the evidence reported by Di Guilmi et al. (2005) for GDP data in industrialized countries.

Figure 3 shows the typical results of a single-run simulation. It is possible to detect a growth trend for aggregate demand with irregular cycles around it. The contrast between aggregate demand and private demand (net of government expenditure) reveals that fiscal policy prevents the negative phases from becoming

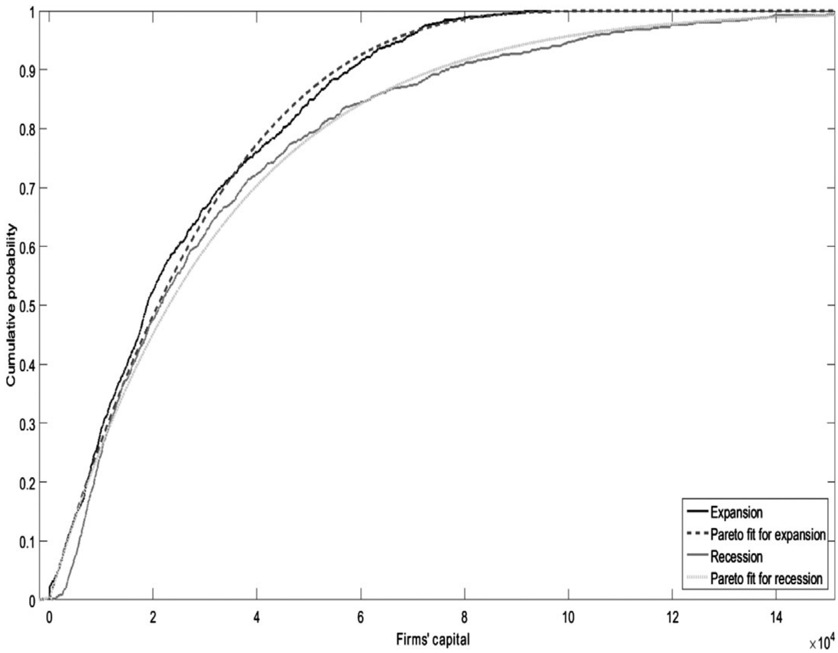

FIGURE 1. Cumulative distribution for firms' size during recessions and expansions with Pareto fit.

serious depressions. The sudden drops that are observable are due to the one-period lag in the implementation of fiscal policy.

An examination of Figure 3 illustrates how micro-financial variables are at the root of macroeconomic fluctuations. Expansion phases are accompanied by the transformation of hedge and speculative firms into Ponzi. In almost all booms, at the peak of the cycle, all firms are Ponzi. At this stage, the overleveraged firms begin to fail, causing a reduction in total demand and a downturn. This pattern is illustrated by the dramatic drop in the share of Ponzi firms. The less leveraged Ponzi firms become speculative or hedge and the cycle restarts. When the recovery after a bust is particularly short or weak, the percentage of hedge firms remains close to 0. The right-skewed distribution observed for firm size and its modifications during the cycle can be explained by the different rates of growth among firms. In particular, the transformation of hedge and speculative firms into Ponzi signals that they overinvest and this leads them to grow faster, determining a more skewed distribution at the peak of the cycle.

The correlation between the share of Ponzi firms and the detrended series of private demand is about 0.6, whereas it becomes close to 0.3 if we consider the total demand (inclusive of fiscal expenditure). Therefore, active fiscal policy proves to be to some extent effective in decoupling the business cycle from its micro-financial determinants.

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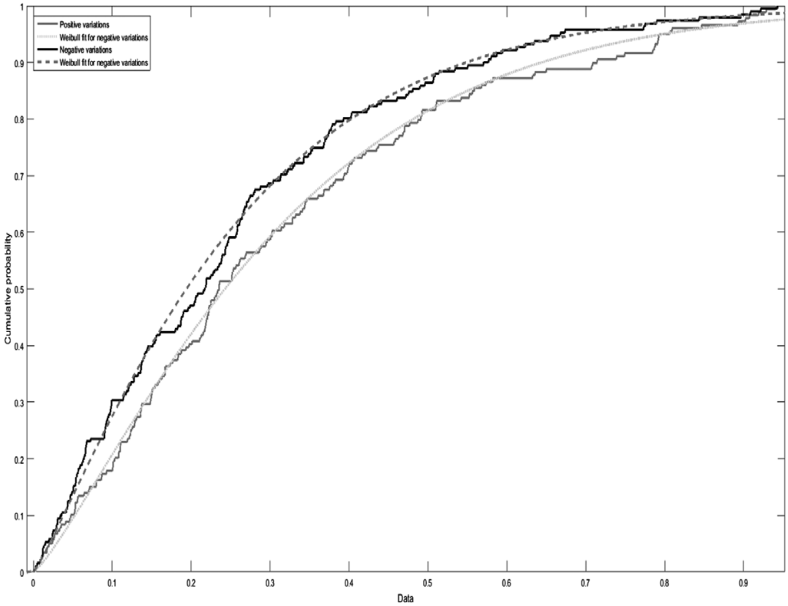

FIGURE 2. Cumulative distribution for positive and negative variations of aggregate demand with Weibull fit.

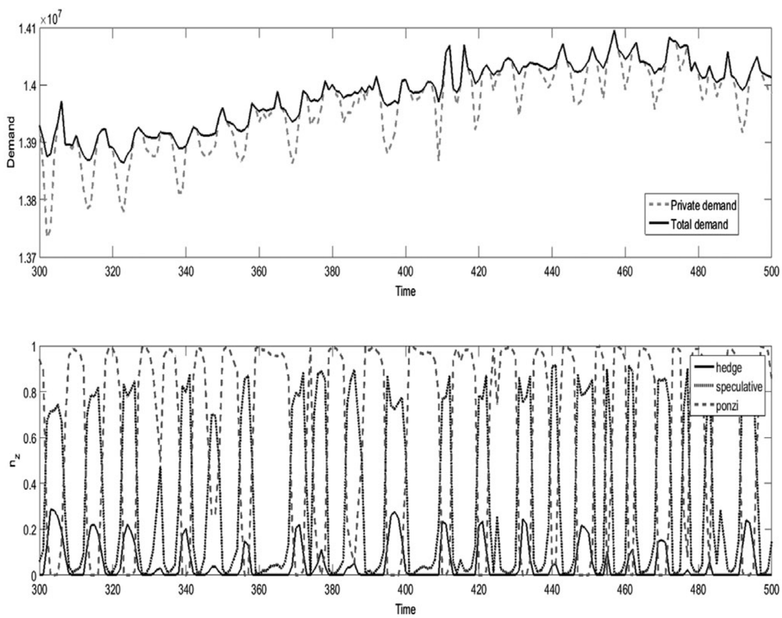

FIGURE 3. Aggregate and private demand (upper panel) and proportion of hedge, speculative, and Ponzi firms (lower panel).

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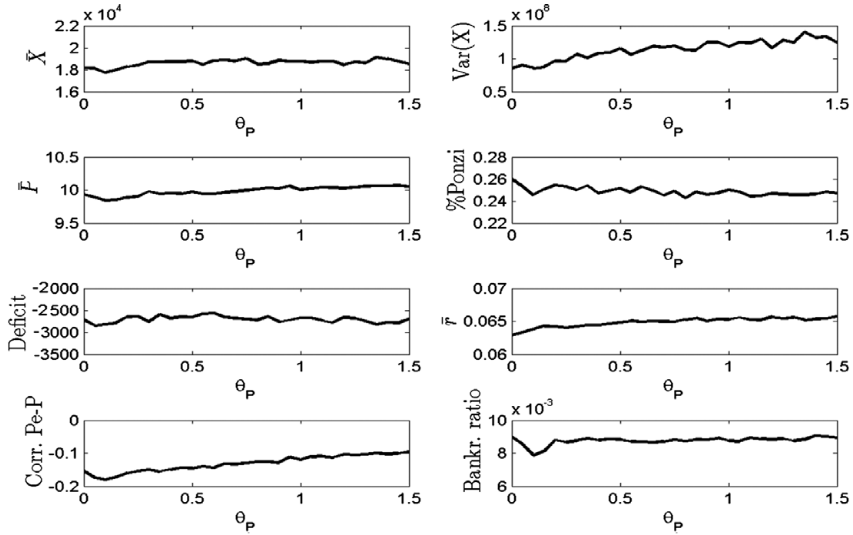

FIGURE 4. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of θ_p.

5.2. Monte Carlo Simulations

To study the effect of changes in the sensitivity parameters of the Taylor rule (22), we performed Monte Carlo simulations for different values of the parameters. We run 1,000 replications for each value of a parameter within a given interval, keeping the others constant. We study the effect on the following variables: average and variance of total demand, average price, average ratio of Ponzi firms, average government deficit, average interest rate, correlation between asset price inflation and good price inflation, and average bankruptcy ratio. The parameters in the Taylor rule (22) are varied in the interval [0, 1.5], whereas the parameter for the fiscal policy θ is varied in the interval [0, 0.9]. The range of variation of the variables under examination is relatively narrow, and in some cases the plots do not clarify whether the series generated by the various sets of Monte Carlo simulations are actually different. For this reason, we have run paired t-tests among all the series for the same variable generated by the different simulations.

In all cases the null hypothesis of normal distribution of the differences between two series has been rejected, confirming that the series are statistically different.

Figure 4 shows the results for the parameter θ_p. A change in the sensitivity to price appears to be more effective for low values of the parameter. For small increments of θ_p from 0, an increase in aggregate demand and a decrease in price are observable, together with a decrease in the share of Ponzi firms and bankruptcy ratio. For further increases of the parameter, no appreciable effect is noticeable, except for an increase in the variance of demand and a decrease in the

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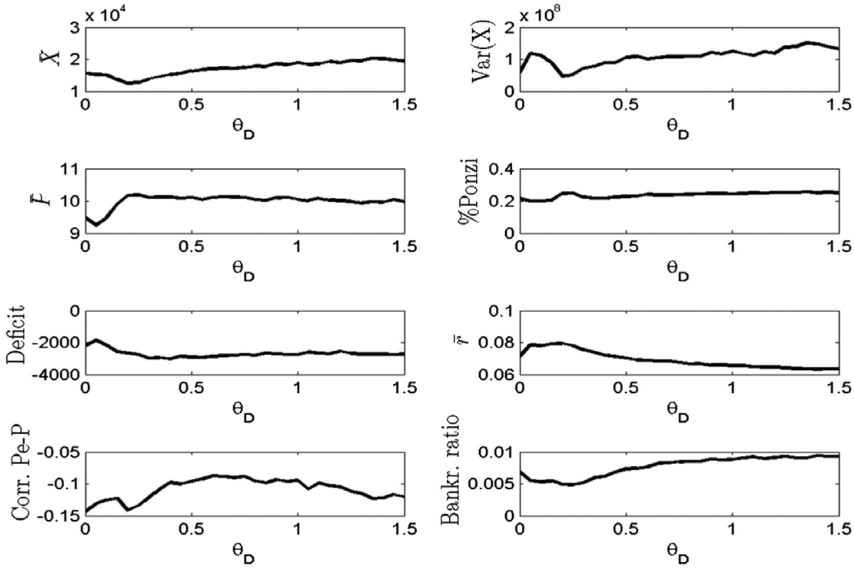

FIGURE 5. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of θ_d.

absolute level of correlation between goods and asset prices. These two effects are correlated, because they jointly reveal that the volatility in the financial market is increasing, with a negligible net effect on the average demand but with noticeable consequences on its variance through equations (1) and (2). The credit channel of monetary policy appears to be effective, because a constant average interest rate determines a constant average aggregate demand, bankruptcy ratio, and share of Ponzi. However, the increase in variance reveals that instability is transmitted from the financial to the real sector through the risk-taking channel. The swings in ρ_t, due to stock market fluctuations through equations (2) and (24), may not be balanced by interest rate changes, given the stronger focus on inflation. This result confirms the analysis of Christiano et al. (2007) and Borio and Zhu (2012) of the possible side effects through the risk-taking channel of a strong focus on inflation.

As for θ_d, Figure 5 shows that the effects on the variables under examination are nonmonotonic for values below 0.3, whereas for higher values a clear pattern emerges. A higher θ_d parameter can be interpreted as a stronger willingness of the central bank to burst a debt bubble. In this case, the central bank can be successful in increasing growth with a low interest rate and without inflation, with the downside of an increase in the volatility of aggregate demand. The increase in demand is an effect of the lower average interest rate thanks to the risk-taking channel in equation (1). The higher rate of bankruptcy (together with a slightly higher ratio of Ponzi and variance of demand) despite a lower interest rate signals some issues in

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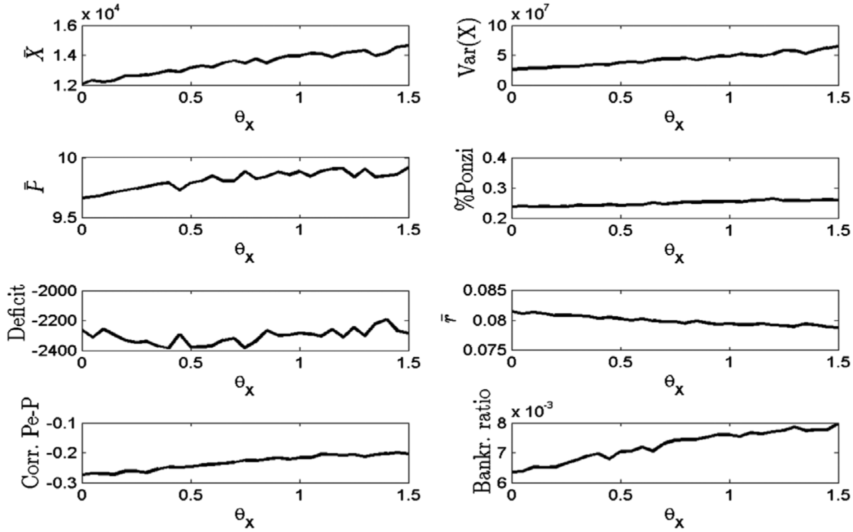

FIGURE 6. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of θ_x.

the credit channels. Ponzi firms can invest more during expansions (because of a lower interest rate), but they are driven into bankruptcy earlier because the central bank raises the interest rate and anticipates the tightening of credit conditions that in this model accompanies a recession. A strong focus on credit bubbles seems to have a perverse effect in particular through the risk-taking channel: a lower interest rate, on the average, drives firms to accumulate debt and then be pushed into bankruptcy when the central bank reacts to the overindebtedness by raising the policy rate.

The plots in Figure 6 reveal that an increase in θ_x brings about a decrease in the interest rate and an increase in almost all the other variables in exam, with the exception of public deficit and share of Ponzi firms. In particular, the increase in aggregate demand is a result of the risk-taking channel represented by equation (1). The credit channel makes possible an increase in demand without an increase in Ponzi, given the average lower debt service. At the same time, the larger investment determines an increase in the bankruptcy ratio. A more accommodating monetary policy therefore can have the side effect of making the system more unstable and financially fragile. Also, in this case, the risk-taking channel is at work, driving firms to overinvest in a period of recovery and creating the conditions for higher instability.

We perform Monte Carlo simulations also for the the parameter θ, which measures the extent of the intervention of fiscal policy in downturns. The results are illustrated by Figure 7. The simulations show that a "moderately" interventionist government (with θ below 0.3 circa) increases the average demand but, at the

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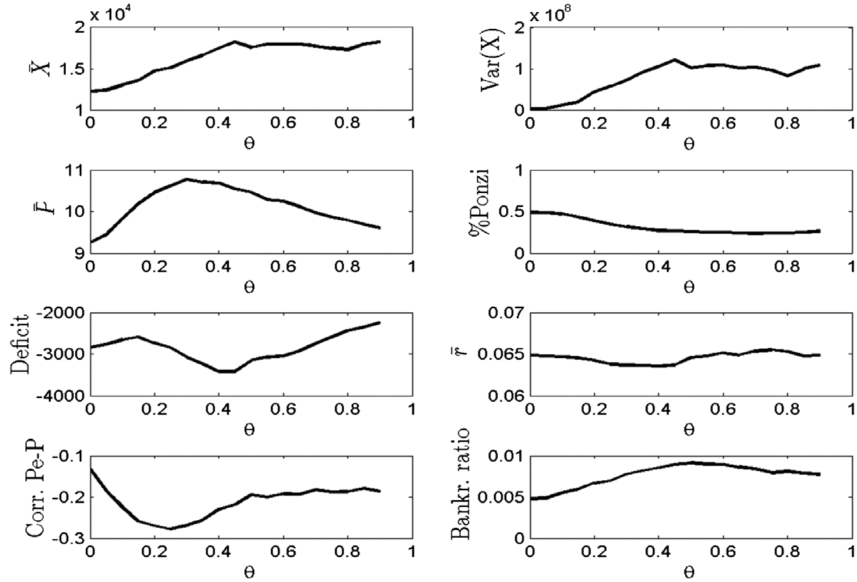

FIGURE 7. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of θ.

same time, can generate instability, as testified by the increase in the variance of aggregate demand, price, negative correlation of asset and goods price inflation, and bankruptcy ratio. A more active fiscal policy ($\theta > 0.4$), despite not having a noticeable influence on the average demand, can actually have positive systemic effects, as displayed in particular by the lower ratios of Ponzi units and bankruptcies. Apparently there is no crowding-out effect, because the interest rate shows a stable pattern for higher values of θ.

6. ENDOGENOUS MONEY, INFLATION, AND THE STOCK PRICE

It is noticeable that, at least to the best of our knowledge, the explanations provided by the literature for the negative correlation between asset and goods price inflation do not involve the mechanism of the creation of credit. In this section, our computational experiment focuses on identifying the effect of the endogenous creation of credit in the presence of overinvestment and sticky salaries. The assumptions for the productive sector and the government are the same as in Sections 2 and 3, whereas the behavior of the central bank is modified.

6.1. Behavioral Rules of the Central Bank

In this treatment, in order to study the effect of the endogenous money, we define a new behavioral rule for the central bank. The monetary authority targets the price

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level and the financial stability of the economy by handling the quantity of money. The supply of money is set according to the following rule:

$$M_t = (\beta_t - \zeta \text{Pon}_t)(B_t + D_t), \tag{29}$$

where ζ is a parameter, Pon_t is the share of Ponzi firms, B_t and D_t are the public and private bonds introduced earlier, and

$$\beta_t = \frac{1}{1 + e^{\lambda \Delta P_t / P_{t-1}}}. \tag{30}$$

In equation (30), λ is a parameter and ΔP_t is the variation in price at time t. Therefore λ measures the sensitivity of the monetary authority to inflation, whereas ζ quantifies the sensitivity to the systemic financial fragility, proxied by the share of Ponzi firms. According to the rule (29), the central bank buys on the secondary market an amount of private and public bonds that is inversely related to goods price inflation and the share of Ponzi firms, and injects an equivalent amount of currency into the economy. The intended effect is to reduce liquidity in the presence of growing inflation or an excessive level of indebtedness in the business sector, in order to prevent or deflate a possible speculative bubble.

In the first scenario, the actual supply of money in the system is defined by the central bank according to (29). In other words, the financial sector is unable to generate liquidity. The equilibrium value of the interest rate is therefore determined in a more Wicksellian setting by equating demand and supply of credit. It is determined simultaneously to the stock price by the Tobinian portfolio

$$\begin{cases} P_{e,t} E_t = \dfrac{(W_t + M_t)}{1 + e^{\varpi r_t - \rho_t}}, \\ D_t + B_t = \dfrac{(W_t + M_t)}{1 + e^{-\varpi r_t + \rho_t}}, \\ W_t + M_t = P_{e,t} E_t + D_t + B_t. \end{cases} \tag{31}$$

As before, W_t is the total wealth, M_t the supply of money, $P_{e,t}$ the asset price, and E_t the total number of equities. Because the supply of money M is exogenous in this setting, the system (31) presents only three equations.[14] The amount of wealth W is dependent on the stock price and therefore is quantified as well within the system (31).

In the second scenario, the assumption of endogenous money is reinstated. We use the behavioral rules (29) and (30) but assume that the private sector is able to provide a perfectly elastic supply of liquidity, as in Section 4. The central bank buys a share of public and private bonds in an attempt to regulate the supply of money, but this latter is endogenously determined within the system, so that the only effect is to reduce the quantity of bonds in the market. The equilibrium values of the stock price, interest rate, wealth, and amount of liquid assets are therefore calculated according to (28).

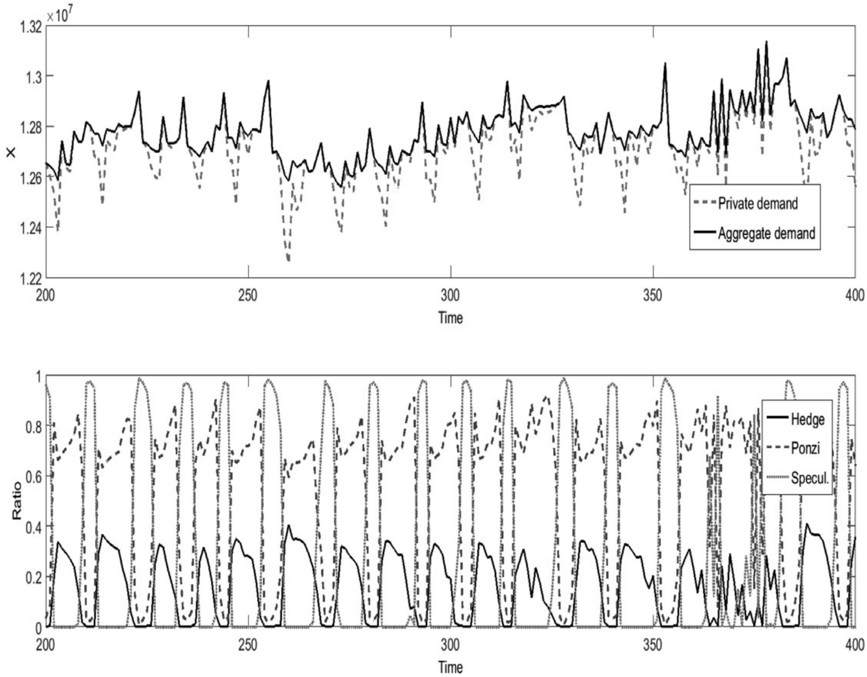

FIGURE 8. Aggregate and private demand (upper panel) and proportion of hedge, speculative, and Ponzi firms (lower panel). Simulation with exogenous money.

6.2. Results of the Simulations

Figures 8 and 9 present the results for a single run for the two different settings. The correlations between share of Ponzi firms with the detrended series of aggregate private demand and total demand are both about 20% in the case of endogenous money. When the money can be controlled by the central bank, fiscal policy is more effective in breaking this causal chain and the correlation between the share of Ponzi firms and total demand is close to 0, even though still significant.

The correlation between asset price and goods price inflation is, on the average, higher in the case of endogenous money. Monte Carlo simulations return an average correlation of -0.61 for the endogenous money case compared with -0.04 in the exogenous money case. The explanation of this statistical regularity involves the mechanisms of formation of the two prices. Equation (7) quantifies the goods price as salary plus a constant mark-up. According to equation (11), the salary is related directly to the autonomous component of the expenditure (investment plus government expenditure) and inversely to the production level. The reaction of salaries to the increase in investment and employment is delayed by the sluggishness in the adjustment of salary, quantified by η. In the endogenous money scenario, the dynamics of equity prices and, consequently, of investment

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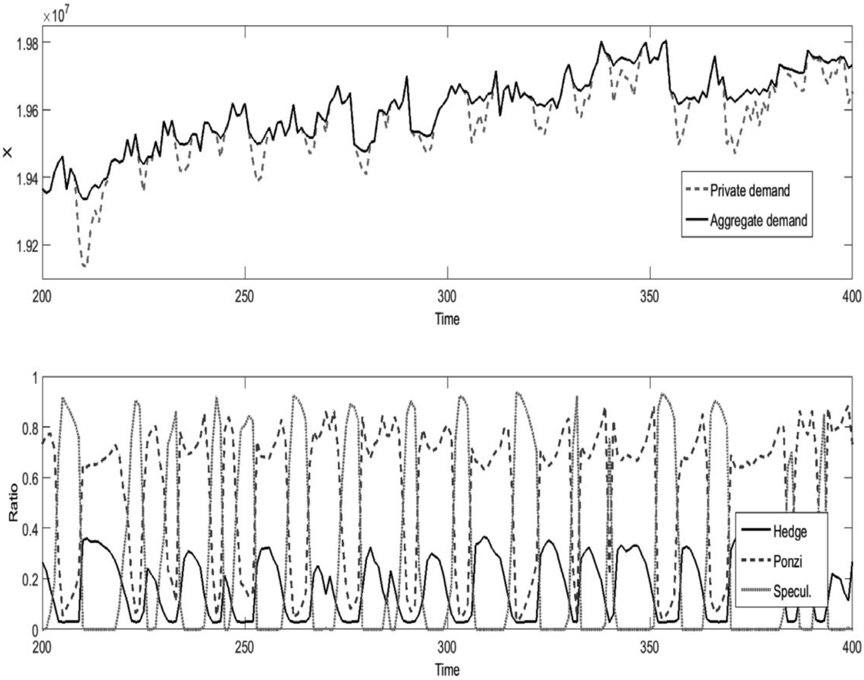

FIGURE 9. Aggregate and private demand (upper panel) and proportion of hedge, speculative, and Ponzi firms (lower panel). Simulation with endogenous money.

and production are accelerated by the increase in wealth and liquidity, which brings about a reduction in the interest rate. This liquidity effect further pushes investment up through equation (1) and drives more wealth into equities because of (28). During a recession, the reduction in liquidity, due to the unredeemed bonds and the destruction of equities, reduces wealth and increases the interest rate, depressing investment. The joint effect of public expenditure (which makes up for the reduction in investment) and sluggish salaries contributes to the divergent dynamics of asset and good prices also during the depression phase.

In the exogenous money scenario, the contraction in the supply of money during the building up of a bubble hampers this causal chain, reducing the availability of wealth to purchase equities and increasing the interest rate. In this second scenario, large stock market bubbles do not always accompany the expansionary phase of the cycle.

The model therefore explains the low inflation during stock market booms as the consequence of self-reinforcing positive expectations in the financial market that increase the availability of credit for the purchase of investment and financial assets. This in turn determines an increase in the induced expenditure larger than the increase in autonomous expenditure and, hence, a divergent dynamics of asset and good prices.

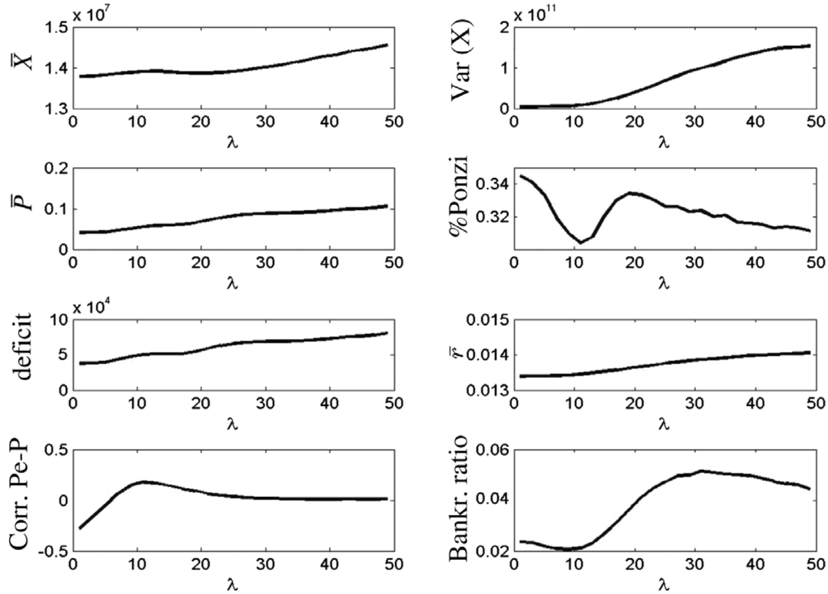

FIGURE 10. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of λ (exogenous money).

In both settings this correlation is typically higher (in absolute value) for a low λ and high ζ, as demonstrated by the Monte Carlo simulations (illustrated by Figures 10–13 and further discussed later). One possible explanation is that a policy that tries to burst the bubble by targeting the level of debt (the proportion of Ponzi firms) can possibly worsen the overall condition of firms, pushing them to demand more debt financing as a perverse effect.

To complete the presentation of the results, Figures 10–13 present Monte Carlo simulations for different values of λ and ζ. The plots are analogous to the ones discussed in Section 5. Comparison between Figures 10 and 12 shows that the consequences of an increase in λ are different between the exogenous and the endogenous money scenario. The most interesting finding is that, in the former case, a high sensitivity of the central bank to inflation has a positive effect only on the share of Ponzi firms and the bankruptcy ratio, whereas in the latter it also reduces the variance of fluctuations.

Figure 11 illustrates that, in the exogenous money scenario, a stronger reaction of the central bank to the ratio of Ponzi firms reduces it, but this effect is obtained through an increment of the bankruptcy ratio. In the second scenario, the effect of a larger ζ is noticeable only for high values of the parameter (about 0.7), in particular for the share of Ponzi firms, as shown by Figure 13. In this case the reduction does not involve a significant rise of the bankruptcy ratio.

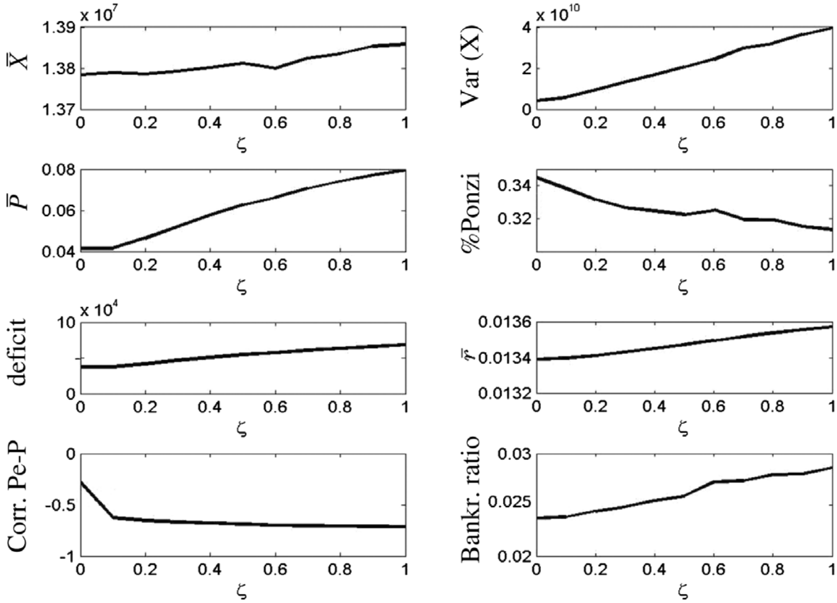

FIGURE 11. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of ζ (exogenous money).

Finally, the correlation between the share of Ponzi firms and the final demand is higher in the endogenous money setting (0.36 against 0.18 of the opposite case). This can be an effect of the higher interest rates, which push more firms into the Ponzi state during an expansion.

7. CONCLUDING REMARKS

This paper presents an agent-based model to test the effects of monetary policy when swings in the business cycle are caused by overinvestment and excessive leveraging. The aim is to contribute to the current debate about the redefinition and a broadening of monetary policy objectives in a financialized economic system.

The analysis mainly considers the systemic effects of variations in the parameters of a modified Taylor rule, which includes the ratio of financially unsound firms among the target variables. A rather complex picture emerges because of the interaction of the different channels through which the interest rate can impact the real sector. The Monte Carlo simulations reveal that an excessive focus on one particular target may add to systemic instability through the risk-taking channel by creating the incentive for firms to overinvest in periods of low interest rate. From this perspective the negative correlation between goods and asset prices proves to be a relevant factor, which must be taken into consideration in policy decisions [Borio and Zhu (2012); Christiano et al. (2007)].

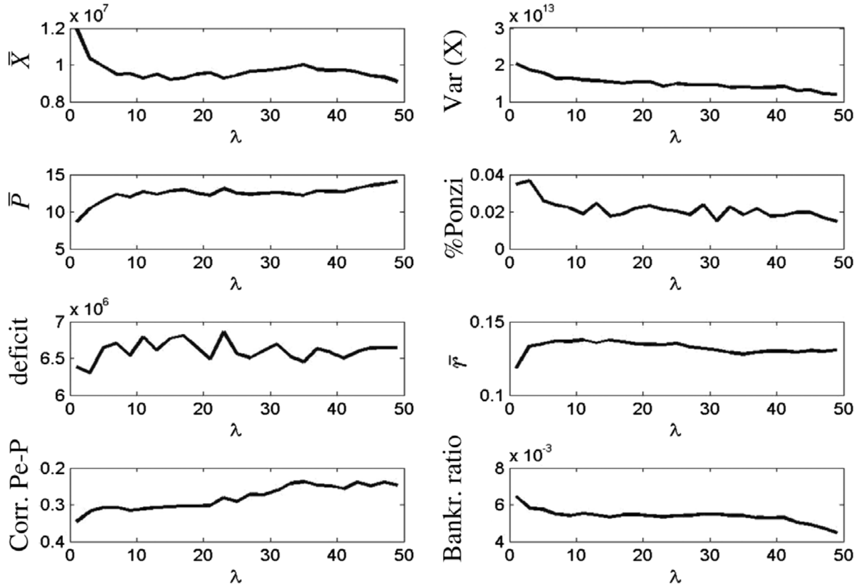

FIGURE 12. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of λ (endogenous money).

We performed the same experiment, varying the fiscal policy parameter. The results are somehow more predictable, given that, by construction, the fiscal policy acts on the aggregate output and does not originate complex feedback effects at the micro-level. In a representation of the economy as a complex system, in which small idiosyncratic shocks cause the transitions in the cycle, the effects of an intervention on aggregate expenditure can be calibrated more easily than in the case of a manipulation of the choice variable of agents (such as the interest rate). Interestingly, the higher levels of income reduce the demand for credit and stabilizes the interest rate.

A further experiment sheds some light on the puzzle of low inflation during stock market booms. In this second set of simulations, the central bank controls the supply of money. Within this setting, we define two different scenarios, depending on whether the financial system is able or not to generate endogenous credit. With endogenous credit, the correlation between asset and goods prices is always largely negative, in contrast with the alternative scenario. In a context of sticky wages, the fact that the financial system always accommodates the demand for credit can create a boom with growth in aggregate demand, mainly driven by firms investment, and declining salary.

Summarizing, our computational experiment reveals that agent-based modeling can provide significant insights into the different channels of transmission of monetary policy, by allowing interactions and complex feedback between the

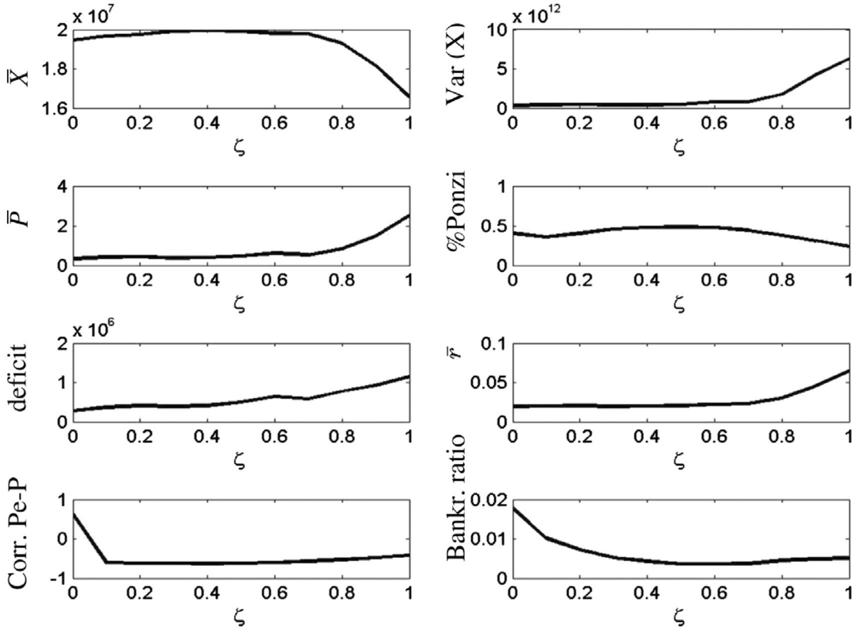

FIGURE 13. Aggregate production, variance of fluctuations, final goods price, share of Ponzi firms, public deficit, interest rate, equity price–goods price correlation, and bankruptcy ratio over 1,000 Monte Carlo replications for different values of ζ (endogenous money).

micro- and the macro-level. The simulations of different policy scenarios, even with relatively simple behavioral rules, can be useful in assessing the chain of effects caused by the change in a policy parameter that affects the decisions of agents. Agent-based models offer a perspective from which to investigate the mechanism of transmission, which is radically different from the spontaneous adjustment to the equilibrium postulated by standard representative agent models. For this reason, they can provide a relevant integration for the theoretical frameworks currently used in defining economic policies. The analysis confirms the necessity for central banks to broaden the scope of their action, given the possible distortion in incentives and risk aversion of agents that a narrower focus may entail. In particular, financial stability should be considered in order to prevent undesired effects through the risk-taking channel.

The business cycle in our artificial economy shares some statistical features with real data, but a more comprehensive effort at calibration is needed to provide more detailed policy implications. This represents the next extension of this model, together with a less mechanical definition of the central bank's responses.

NOTES

1. See, for example, Christiano et al. (2007), but also White (2009).
2. See in particular post-Keynesian authors such as Moore (1998).

3. See the surveys in Nasica (2000), Lavoie (2009), and Chiarella and Di Guilmi (2012a).

4. For a technical comparison of the DSGE and agent-based approaches see Fagiolo and Roventini (2012). Howitt (2012) focuses on the limits of current macroeconomic theory in providing a background for monetary policy with respect to the potential of agent-based modeling.

5. See, for example, Delli Gatti et al. (2005) and Dosi et al. (2013, 2014). Westerhoff (2008) use an agent-based pricing model to test the effectiveness of fiscal and monetary policy in stabilizing the financial market.

6. See, for example, Borio and Zhu (2012).

7. Firms are initially endowed with a random amount of capital. Despite operating in the same market and having the same behavioral rules, as the simulation evolves they grow different in size and financial condition, which lead to different paths of growth for each of them. Homogeneous behavioral rules and heterogeneous balance sheets are common features in agent-based models.

8. We are able to use a linear production function, as the accumulation of debt and the bankruptcy mechanism provide a ceiling on production.

9. The consideration of A, which is a stock, forces a difference between this classification and the original one by Minsky (1982a), which is specified in terms of flows.

10. Chiarella and Di Guilmi (2014) examine the effect of the buy-buck of shares in a simplified version of this model.

11. In the simulations, we set the interval for normalization of the variation in aggregate demand as $[-12\%, +12\%]$. So, for example, if the variation in aggregate demand is equal to or greater than 12%, all firms will become active.

12. We make the heroic assumption that the monetary authority is able to compute the shares of the different types of firms. This permits a quantification of the effect of the inclusion of microeconomic factors in the central bank's behavioral rule.

13. The dependence of firms' investment on stock prices has been extensively investigated in the empirical literature. See, for example, Barro (1990).

14. The supply of money appears on the left-hand side in the last equation because it is used by the central bank to buy bonds, decreasing their amount in the market.

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APPENDIX: TIMELINE OF STEPS

The sequence of events defined by the model can be summarized as follows:

1. Firms decide the amount of investment and, consequently, the amount of capital endowment for each firm is quantified.

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2. The amount of capital determines the level of output produced by each firm; the level of output in turn defines the demand for labor.
3. Wage and price are calculated.
4. The government calculates its expenditure as a function of the variation in aggregate demand in the previous year.
5. Current aggregate demand is determined as the sum of wage bill, investment, and government expenditure; demand is allocated among firms and their profit is quantified accordingly.
6. Firms decide about investment financing and issue new equities and new bonds.
7. The central bank decides the interest rate.
8. Equilibrium is determined in the capital market.