Heterogeneous Banks and Technical Change in an Evolutionary Model of Endogenous Growth and Fluctuations

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Abstract

We employ an evolutionary, agent-based model with an imperfect credit market composed of heterogeneous banks to analyze some features of the current global crisis by exploring the transmission mechanisms from finance to real dynamics at an economy-wide level.
The model describes an economy composed of capital- and consumption-good firms, workers, and banks. Capital-good firms perform R&D and produce heterogeneous machine tools. Consumption-good firms invest in new machines and produce a homogeneous consumption good. Banks finance firms production and investment plans.
Before carrying out policy analysis, we empirically validate the model showing that it is able to replicate a wide spectrum of macroeconomic and microeconomic stylized facts. In line with the literature on financial fragility, policies impacting on the financial side of the economy affect production and investment decisions of firms and can amplify or dampen business cycle fluctuations.

Keywords: Endogenous Growth; Business Cycles; Evolutionary Economics; Agent-Based Computational Economics; Empirical Validation; Monte-Carlo Simulations; Financial Constraints; Heterogeneous Banks; Imperfect Capital Markets.

JEL Classification: E32, E6, G21, O3, O4

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1 Introduction

We employ an evolutionary, agent-based model to analyze some features of the current global crisis by exploring the transmission mechanisms from finance to real dynamics at an economy-wide level. Our final goal is to explore the effects of ensembles of different policies that could contribute to put back the economy on its steady growth trajectory. The main contribution of the model is to expand the Dosi, Fagiolo, Roventini (Dosi et al. (2010)) and Dosi, Fagiolo, Napoletano and Roventini[1] with an imperfect credit market composed of heterogeneous banks and boundedly rational agents. Building on other agent-based models of credit (Delli Gatti et al. (2005), Gaffeo et al. (2008) and Ashraf et al. (2010)), we study how the structure of bank-firm relations affects selection and industrial dynamics and therefore business cycle fluctuations.
We use the insights of the economics of information literature (Stiglitz and Weiss (1981), Stiglitz and Weiss (1992a), Stiglitz and Greenwald (2003)) and the banking literature (Berger and Udell (1995); Petersen and Rajan (1994)) to develop sound microfoundations to the macroeconomic regularities we intend to replicate and understand.

Our model is a bridge between short-run Keynesian theories of business cycles and long-run Schumpeterian theories of economic growth. The model describes an economy composed of heterogeneous capital and consumption-good firms, workers, and banks. Capital-good firms perform R&D and produce heterogeneous machine tools. Consumption-good firms invest in new machines and produce a homogeneous consumption good. They finance their production and investments according to a financial pecking-order rule: if their cash flow cannot cover the costs, they can ask their bank for external finance, which is expensive. Banks finance firms production and investment plans using consumers and firms' savings. They allocate credit by ranking their finite number of clients according to a net worth to sale criterion.
The credit market is imperfect: credit is differentiated and access to information is costly (Stiglitz and Greenwald (2003)). First there is asymmetry of information between the lender and the borrower because the bank uses a proxy for firm financial fragility. Second, heterogeneity in the average quality of banks clients introduces inequalities in the allocation of credit among firms belonging to different banking networks. As a consequence, in a model with a multiplicity of heterogeneous banks, lenders can only evaluate and select projects that they receive, the quality of which can be lower or above the average in the economy, implying adverse selection effects, as observed in reality.

Before carrying out policy analysis, we empirically validate the model showing that it is able to replicate a wide spectrum of macroeconomic and microeconomic stylized facts,

[1] forthcoming LEM working paper

in the real as well as in the financial sector. Examples include the cross-correlations between output and credit and the cyclical behavior of firm bad debt and bankruptcy rates. Simulation exercises allow to test different scenarios and running policy experiments. Besides fiscal policies, we investigate how changes in the interest rate and in the supply of credit affect production and investment decisions and can amplify business fluctuations. Moreover, this model allows to experiment on market as well as structural changes in the banking sector, by studying the role of market concentration or changes in the regulatory system.

In a first section, we will focus on the stylized facts and empirical findings that will guide our modeling strategy, as explained in the second section. In the third section we will present the model, and finally the fourth section presents the results of preliminary policy experiments.

2 Literature review

2.1 Empirical literature

As a basis to any modelling exercise, a number of assumptions on agents' behavior and on the environment they are embedded in have to be made. This is why it is useful to draw them from the real world, or at least from what the empirical evidence tells us about it. Moreover, besides allowing the modeller to use realistic assumptions, gathering empirical evidence helps him to determine which are the stylized facts that the model should aim at explaining or replicating. Therefore, a good knowledge of empirical facts can be used to validate the results of the model. We present here the findings of the empirical literature on financial constraints to growth and imperfections on the credit market.

Studying firm performance and growth we often assume that negative profits yield to contraction of firm capacity and disinvestment. However a more realistic description of firm behavior may also take into account the possibility to access external resources in order to finance growth. But then, given the presence of imperfections in financial markets, firms with negative profits may encounter difficulties to get loans, whereas firms with positive profits may not, and therefore the latter may expand even more. Then, what is the impact of access to external resources on firm performance? Does it reinforce selection processes (growth of competitive firms and contraction of less competitive ones) or does it counterbalance them?
The main findings from the empirical literature on financial constraints are that, keeping investment demand fixed, investment is sensitive to changes in internal funds, and that

this sensitivity is stronger for more "financially constrained" firms (citetFHP88).
Since financial constraints can't be measured directly (there is no data on desired investment or on the amount of credit refused to firms at the micro level), different methodologies have been developed to fill this gap, following different theoretical frameworks (the neoclassical q theory, the imperfect markets theory, or the evolutionary theory[2]). Authors may either use survey data where firms give a self-assessment of the difficulty faced in accessing external funds (Angelini and Ferri (1998); Winker (1999) ; Becchetti and Trovato (2002)), use a proxy for financial constraints such as divident-payout ratio (Fazzari and Petersen (1988)), financial ratios (Altman (1968); Edmister (1972)) or even create composite indexes (Alessandrini and Zazzaro (2006); Musso and Schiavo (2008)). In their fundamental paper, Fazzari and Petersen (1988)), showed that financially constrained firms display higher investment-cash flow sensitivity [3]. Based on this finding, many authors now directly use the investment-cash flow sensitivity as a proxy for firm financial constraint (Bellone and Musso (2009)).
This is explained by the fact that according to the "financial pecking-order" theory (Myers (1984)) and supported by the assumption of asymmetric information (Myers and Majluf (1984)), there is an imperfect substitutability of internal and external sources of finance. Thus there exists a hierarchy in sources of funding, acquired at different costs, contrary to the statement suggested by the Modigliani-Miller theorem (1958). Changes in cash flow would therefore be positively associated with changes in investment. Indeed, in order to finance investment, firms preferably use their cash flow, and only when it is exhausted they turn to external sources of finance such as bank lending and if possible issue new shares (citetCarpenterPetersen2002). Therefore, in cases of low cash flow, firms that are credit-constrained (i.e. that cannot access as much external debt as they desire) have to reduce their desired investment to the amount that they can finance.

What we will retain from this literature is that:

- In order to finance production and growth, firms use first their internal funds, and if it is not enough they turn to external finance.
- The growth of credit-constrained firms is limited to the availability of internal finance.
- Selection processes should be harsher for credit-constrained firms, and smoothed for

[2]For a review of the theoretical literature, see Coad (2010), Stiglitz and Greenwald (2003) and Hubbard (1998b)). We don't intend to describe the theories in deep here, but we will try to see how the shortcomings of the evolutionary theory, as proven by Bottazzi and Tamagni (2006), Bottazzi and Tamagni (2009) and Coad (2010) can be explained by some of the findings of the imperfect information and banking literature.

[3]This is however a conflictual finding since Kaplan and Zingales (1995) opposed them in saying that firms may also be forced to withhold cash by the fact that they are unable to access external funds, and investment cash-flow sensitivity may equally occur because firms are sensitive to demand signals.

> the others. Indeed, the lower the cash flow, the slower is credit-constrained firms' capacity to grow. On the contrary, firms that have access to external finance (i.e. which characteristics match the requirements of the banks) can compensate a profit loss (and cash flow volatility) with external resources in order to reach the desired level of investment.

Then the major issue becomes to identify these credit-constrained firms, which leads us to analyze the supply side of the credit market: which are the information and criteria used by banks to allocate credit? Does firm behavior affect these judgments? We therefore turn to a review of the empirical findings on bank-firm relationships.

What type of information is used by banks in order to evaluate credit demand? Answering this is crucial to obtain a realistic representation of the credit market. Again the difficult access to data (besides studies based on central bank surveys, such as Albareto and Rossi (2008)) has led researchers to rely on indirect estimations, focusing one the demand side (firms) or on the supply side (banks) of the market.
Starting from the point of view of the firm, Petersen and Rajan (1994)) have tried to evaluate the range of actions firms have to improve their availability of finance. According to this view, one way a credit-constrained firm can improve its access to external finance is to build a reputation of good lender towards a particular bank. This statement assumes that the quality of the relationship between a firm and its bank affects the availability and cost of funds. Because of the asymmetry of information between the firm and its creditors and the related moral hazard issue, they show that firms gain from building close ties with their financing partners in terms of quantity, but not in terms of price. Indeed, close relationships between banks and borrowers over time have been shown to facilitate monitoring and screening and can overcome problems of asymmetric information. As a consequence, the duration of the bank-borrower relationship positively affects the availability of credit (Petersen and Rajan (1994); Berger and Udell (1995)).
What is the incentive for banks to do so? Well through repeated interaction with the same client, lending officers gain "soft" information on the fundamental quality of the borrower[4] which is not accessible to other financial institutions. This has two effects on the bank-firm relationship. First, the bank is able to reduce the uncertainty about the quality of the borrower and therefore manage its risk portfolio better, and second it generates an information monopoly that can allow the bank to increase the cost of lending for the "captured" firm in the future (Boot, 2000). This latter effect, called "hold-up cost", is however more theoretically than empirically proven, because it is compensated by the smoothing of contract terms for the long-term client.
Relationship banking has been modelled and tested in experimental settings, however it

[4] However, little is known about how banks obtain information, what type of information they acquire, and how they use this information.

has not yet been used in macroeconomic models with a credit market. With the tool of simulation, it will be easier to test how the dynamics of bank-firm relationships affect the availability of credit for firms.

Another issue empirically tested in the literature that we may be interested to analyze in our model is the effect of the banking market structure (and the competition intensity) on the total level of credit, its cost, and on relationship banking strategies. Indeed, Petersen and Rajan (2002) showed that an increase in the distance to the borrower (without any loss of quality) became possible thanks to the diffusion of information technology and the use of hard information through credit registries and credit scoring (Inderst and Mueller (2007)). Therefore the size of "natural" credit markets has increased and made the competition harsher. Moreover, the banking market has been consolidated in recent years, changing the structure from a decentralized market to an oligopoly. Finally, since the effects of increased competition on relationship banking are still ambiguous (Boot, 2000), experimenting on such changes in the model may be interesting from a policy point of view.

What we can expect is therefore that:

- Relationship lending improves credit-constrained firms' access to external funds, but there can be a cost in terms of price.
- The incentive to engage in a long-term relation with a bank can be reduced in case of a harsher competition on the credit market.

2.2 Models of credit

Many authors have attempted to model credit markets, using different theoretical frameworks and tools. If some authors focus on credit only, others, as we intend to, have chosen a wider perspective and introduced credit in macro-models.
Building on the empirical literature presented above, several models have addressed issues related to relationship lending or multiple lending (Diamond (1984);Williamson (1987); Detragiache et al. (2000); Kon and Storey (2003); Dell'Ariccia and Marquez (2004); Inderst and Mueller (2007)). The main difficulty they usually face is to represent information asymmetries between lenders and borrowers, as well as the bank decision function, since there is no clear information on how it works in reality. One way to go, as followed by Carling and Lundberg (2002), is to make banks compare the expected returns from lending with the opportunity cost of bank funds. Another one is to make banks rank their applicants according to a certain criteria of financial viability, and allocate funds to the best of them, as in Gaffeo et al. (2008)). We will follow this latter procedure in the model,

as presented in section 3.4[5].

Going one step further, Stiglitz and Weiss (1981), and Stiglitz and Weiss (1992a)) have applied the insights of the economics of information and the banking literature to micro-found their macroeconomic model. Showing that credit rationing may occur at the equilibrium[6], they opened a new path for monetary policy analysis. Closer to our methodology, Delli Gatti et al. (2005) and Gaffeo et al. (2008) have aimed at creating an endogeneous dynamic path of macro variables able to replicate the properties of business cycles, assuming imperfect information on the credit market. Indeed, the main objective of such macro models with a credit sector is to study the propagation of shocks between the real and the financial sector (Bernanke et al. (1999)). Therefore, we also intend to understand the role of banks in the firm selection process, introducing heterogeneity in the banking sector as well as the real sector.

Indeed, besides the heterogeneity of firms, we introduce in this model heterogeneity in the banking sector. What is important is not only whether firms get a loan or not, but where and why they got it. As put forward by Stiglitz and Greenwald (2003), because credit is highly differentiated and access to information costly, "what matters is not the total supply of credit"(p 142), but the supply of credit and the decisions of the bank the firm applies to. As a consequence, in a model with a multiplicity of banks, lenders can only evaluate and select projects that they receive, which quality can be lower or above the average in the economy, implying adverse selection effects, therefore creating imperfections in the lending market.

3 The Model

The economy is composed of a machine-producing sector made of F_1 firms (denoted by the subscript i), a consumption-good sector made of F_2 firms (denoted by the subscript j), L^S consumers/workers, a banking sector made of B commercial banks, and a public sector. Capital-good firms invest in R&D and produce heterogeneous machines. Consumption-good firms combine machine tools bought by capital-good firms and labor in order to produce a final product for consumers. The banks provide credit to firms using firms' savings. They use alternative rules to set the total credit provided to the economy. The level of credit supply and the dynamics of debt of economy can be influenced by policy using different instruments (capital requirements, mandatory reserves, interest rates).Finally, the public sector levies taxes on firms' profits and pay unemployment benefits.

[5]following the banking literature and contrary to Minsky (1992), we don't use profit as a selection criteria but the ratio of net worth over sales.

[6]although De Meza and Webb (1987) argued that on the contrary, asymmetries of information on the lending market may result in overinvestment at the macro level

3.1 The Timeline of Events

In any given time period (t), the following microeconomic decisions take place in sequential order:

1. Policy variables (e.g. discount rate, capital requirement, tax rate, unemployment benefits, etc.) are fixed.

2. Total credit provided by the banks to each of their clients is determined.

3. Machine-tool firms perform R&D trying to discover new products and more efficient production techniques and to imitate the technology and the products of their competitors. Capital-good firms advertise their machines with consumption-good producers.

4. Consumption-good firms pay the machines ordered in the previous period and they decide how much to produce and invest. If internal funds are not enough, firms borrow from their bank. If investment is positive, consumption-good firms choose their supplier and send their orders.

5. In both industries firms hire workers according to their production plans and start producing.

6. Imperfectly competitive consumption-good market opens. The market shares of firms evolve according to their price competitiveness.

7. Firms in both sectors compute their profits. If profits are positive, firms pay back their loans to their bank and deposit their savings.

8. Entry and exit take places. In both sectors firms with near zero market shares and negative net liquid assets are eschewed from the two industries and replaced by new firms.

9. Machines ordered at the beginning of the period are delivered and become part of the capital stock at time $t + 1$.

At the end of each time step, aggregate variables (e.g. GDP, investment, employment) are computed, summing over the corresponding microeconomic variables.

3.2 The Capital-Good Industry

The technology of a capital-good firms is (A_i^τ, B_i^τ), where the former coefficient stands for the labor productivity of the machine-tool manufactured by i for the consumption-good industry (a rough measure of producer quality), while the latter coefficient is the labor productivity of the production technique employed by firm i itself. The positive integer τ denotes the current technology vintage. Given the monetary wage w, the unit cost of production of capital-good firms is:

$$c_i(t) = \frac{w(t)}{B_i^\tau}. \tag{1}$$

With a fixed mark-up ($\mu_1 > 0$) pricing rule[7], prices (p_i) are defined as:

$$p_i(t) = (1 + \mu_1)c_i(t). \tag{2}$$

The unit labor cost of production in the consumption-good sector associated with each machine of vintage τ, produced by firm i is:

$$c(A_i^\tau, t) = \frac{w(t)}{A_i^\tau}.$$

Firms in the capital-good industry "adaptively" strive to increase their market shares and their profits trying to improve their technology both via innovation and imitation. Both are costly processes: firms invest in R&D a fraction of their past sales (S_i):

$$RD_i(t) = \nu S_i(t-1), \tag{3}$$

with $0 < \nu < 1$. R&D expenditures are employed to hire researchers paying the market wage $w(t)$[8]. Firms split their R&D efforts between innovation (IN) and imitation (IM) according to the parameter $\xi \in [0,1]$[9]:

$$IN_i(t) = \xi RD_i(t)$$

$$IM_i(t) = (1-\xi)RD_i(t).$$

We model innovation as a two steps process. The first one determines whether a firm obtains or not an access to innovation — irrespectively of whether it is ultimately a success or a failure — through a draw from a Bernoulli distribution, whose parameter $\theta_i^{in}(t)$ is given by:

$$\theta_i^{in}(t) = 1 - e^{-\zeta_1 IN_i(t)}, \tag{4}$$

[7]Survey data evidence summarized in Fabiani et al. (2006) show that European firms mostly set prices according to mark-up rules .

[8]In the following, we assume all capital-producing firms to be identical in their R&D propensity. This is not too far from reality: R&D intensities are largely sector specific and associated with the *sector-wide* nature of innovative opportunities and modes of innovative search (more in Pavitt, 1984; Dosi, 1988; Klevorick et al., 1995).

[9]Firms on the technological frontier, lacking anyone to imitate, obviously invest all their R&D budget in the search for innovations.

with $0 < \zeta_1 \leqslant 1$. Note that according to 4, there are some scale-related returns to R&D investment: access to innovative discoveries is more likely if a firm puts more resources into R&D. If a firm innovates, it may draw a new machine embodying technology (A_i^{in}, B_i^{in}) according to:

$$A_i^{in}(t) = A_i(t)(1 + x_i^A(t))$$

$$B_i^{in}(t) = B_i(t)(1 + x_i^B(t)),$$

where x_i^A and x_i^B are two independent draws from a Beta(α_1, β_1) distribution over the support $[\underline{x}_1, \overline{x}_1]$ with $\underline{x}_1$ belonging to the interval $[-1, 0]$ and $\overline{x}_1$ to $[0, 1]$. Note that the notional possibilities of technological advance — i.e. *technological opportunities* — are captured by the support of the Beta distribution and by its shape. So, for example, with low opportunities the largest probability density falls over "failed" innovations — that is potential capital goods which are "worse" in terms of costs and performances than those already produced by the searching firm. Conversely, under a condition of rich opportunities, innovations which dominate incumbent technologies will be drawn with high probability. As we shall show below, a crucial role of "Schumpeterian" technology policies is precisely that of influencing opportunities and micro capabilities.

Alike innovation search, imitation follows a two steps procedure. The possibilities of accessing imitation come from sampling a Bernoulli$(\theta_i^{im}(t))$:

$$\theta_i^{im}(t) = 1 - e^{-\zeta_2 IM_i(t)}, \tag{5}$$

with $0 < \zeta_2 \leqslant 1$. Firms accessing the second stage are able to copy the technology of one of the competitors (A_i^{im}, B_i^{im}). We assume that firms are more likely to imitate competitors with similar technologies and we use a Euclidean metrics to compute the technological distance between every pair of firms to weight imitation probabilities.

All firms which draw a potential innovation or imitation have to put it on production or keep producing the incumbent generation of machines. Comparing the technology competing for adoption, firms choose to manufacture the machine characterized by the best tradeoff between price and efficiency. More specifically, knowing that consumption-good firms invest following a payback period routine (see Section 3.3), capital-good firms select the machine to produce according to the following rule:

$$\min \left[p_i^h(t) + bc^h(A_i^h, t) \right], \qquad h = \tau, in, im, \tag{6}$$

where b is a positive payback period parameter (see Eq. 10 below). Once the type of machine is chosen, we capture the imperfect information pervading the market assuming that each firm sends a "brochure" with the price and the productivity of its offered machines to both its historical (HC_i) clients and to a random sample of potential new customers (NC_i), whose size is proportional to HC_i (i.e., $NC_i(t) = \gamma HC_i(t)$, with $0 <$

$\gamma < 1$).

3.3 The Consumption-Good Industry

Consumption-good firms produce a homogenous goods using capital (i.e. their stock of machines) and labor under constant returns to scale. Firms plan their production (Q_j) according to adaptive demand expectations (D_j^e):

$$D_j^e(t) = f(D_j(t-1), D_j(t-2), \dots, D_j(t-h)), \tag{7}$$

where $D_j(t-1)$ is the demand actually faced by firm j at time $t-1$ (h positive integer)[10]. The desired level of production (Q_j^d) depends on the expected demand as well as on the desired inventories (N_j^d) and the actual stock of inventories (N_j):

$$Q_j^d(t) = D_j^e(t) + N_j^d(t) - N_j(t-1), \tag{8}$$

with $N_j^d(t) = \iota D_j^e(t), \iota \in [0,1]$. The output of consumption-good firms is constrained by their capital stock (K_j). If the desired capital stock (K_j^d) — computed as a function of the desired level of production — is higher than the current capital stock, firms invest (EI_j^d) in order to expand their production capacity[11]:

$$EI_j^d(t) = K_j^d(t) - K_j(t). \tag{9}$$

The capital stock of each firm is obviously composed of heterogeneous vintages of machines with different productivity. We define $\Xi_j(t)$ as the set of all vintages of machine-tools belonging to firm j at time t. Firms scrap machines following a payback period routine. Through that, technical change and equipment prices influence the replacement decisions of consumption-good firms[12]. More specifically, firm j replaces machine $A_i^\tau \in \Xi_j(t)$ according to its technology obsolescence as well as the price of new machines:

$$RS_j(t) = \left\{ A_i^\tau \in \Xi_j(t) : \frac{p^*(t)}{c(A_{i,\tau}, t) - c^*(t)} \leq b \right\}, \tag{10}$$

where p^* and c^* are the price of and unit cost of production upon the new machines. Firms compute their replacement investment summing up the number of old machine-

[10] For maximum simplicity, here we use the rule $D_j^e(t) = D_j(t-1)$. In Dosi et al. (2006) we check the robustness of the simulation results employing more sophisticated expectation-formation rules. We found that increasing the computational capabilities of firms does not significantly change either the average growth rates or the stability of the economy. These properties still hold in the model presented here.

[11] We assume that in any give period firm capital growth rates cannot exceed a fixed maximum threshold consistent with the maximum capital growth rates found in the empirical literature on firm investment patterns (e.g. Doms and Dunne, 1998).

[12] This in line with a large body of empirical analyses (e.g., Feldstein and Foot, 1971; Eisner, 1972; Goolsbee, 1998) showing that replacement investment is typically not proportional to the capital stock.

tools satisfying Equation 10[13].

Consumption-good firms choose their capital-good supplier comparing the price and productivity of the currently manufactured machine-tools they are aware of. As we mentioned above (cf. Section 3.2) the capital-good market is systematically characterized by imperfect information. This implies that consumption-good firms compare "brochures" describing the characteristics of machines only from a subset of equipment suppliers. Firms then choose the machines with the lowest price and unit cost of production (i.e., $p_i(t) + bc(A_i^\tau, t)$) and send their orders to the correspondingly machine manufacturer. Machine production is a time-consuming process: capital-good firms deliver the ordered machine-tools at the end of the period[14]. Gross investment of each firm (I_j) is the sum of expansion and replacement investment. Pooling the investment of all consumption-good firms one gets aggregate investment (I).

Consumption good firms have to finance their investments and their production, as they advance worker wages. Firms can use internal funds (cash flow) or external funds (loans) to do so. In line with a growing number of theoretical and empirical papers (e.g. Stiglitz and Weiss, 1992b; Greenwald and Stiglitz, 1993; Hubbard, 1998a) we assume imperfect capital markets. This implies that the financial structure of firms matters (external funds are more expensive than internal ones) and firms may be credit rationed. Indeed, banks are unable to allocate credit optimally and perfectly evaluate the applicants due to imperfect access to information about the creditworthiness of the applicant. Therefore, firms first use their internal source of funding ($NW_j(t)$) and if it is not enough they borrow the remaining part from their bank paying a fixed interest rate r_L. This financing hierarchy defines the demand for credit of each firm, $L_j^d(t)$.

The maximum amount of credit lent by bank k to firm j ($TC_j, k(t)$) is a positive function of firm's stock of liquid assets as well as firm's size proxied by its past sales (see Section 3.4 below). Only firms that are not production-rationed can try to fulfill their investment plans employing their residual stock of liquid assets first and then their residual borrowing capacity[15].

Given their current stock of machines, consumption-good firms compute average productivity (π_j) and unit cost of production (c_j). Prices are set applying a variable markup (μ_j) on unit costs of production:

$$p_j(t) = (1 + \mu_j(t))c_j(t). \tag{11}$$

[13] Moreover, they also scrap the machines older than η periods (with η being a positive integer).

[14] Among the empirical literature investigating the presence of gestation-lag effects in firm investment expenditures see e.g. Del Boca et al. (2008).

[15] If investment plans cannot be fully realized, firms give priority to capital stock expansion, as compared to the substitution of old machines.

Markup variations are regulated by the evolution of firm market shares (f_j)[16]:

$$\mu_j(t) = \mu_j(t-1)\left(1 + \upsilon \frac{f_j(t-1) - f_j(t-2)}{f_j(t-2)}\right),$$

with $0 \leqslant \upsilon \leqslant 1$.

The consumption-good market too is characterized by imperfect information (antecedents in the same spirits are Phelps and Winter, 1970; Klemperer, 1987; Farrel and Shapiro, 1988; see also the empirical literature on consumers' imperfect price knowledge surveyed in Rotemberg, 2008). This implies that consumers do not instantaneously switch to products made by more competitive firms. However, prices are clearly one of the key determinants of firms' *competitiveness* (E_j). The other component is the level of unfilled demand (l_j) inherited from the previous period:

$$E_j(t) = -\omega_1 p_j(t) - \omega_2 l_j(t), \tag{12}$$

where $\omega_{1,2}$ are positive parameter [17]. Weighting the competitiveness of each consumption-good firms by its past market share (f_j), one can compute the *average competitiveness* of the consumption-good sector:

$$\overline{E}(t) = \sum_{j=1}^{F_2} E_j(t) f_j(t-1).$$

Such variable represents also a moving *selection criterion* driving, other things being equal, expansion, contraction and extinction within the population of firms. We parsimoniously model this market setup letting firm market shares evolve according to a "quasi" replicator dynamics (for antecedents in the evolutionary camp cf. Silverberg et al., 1988; Metcalfe, 1994):

$$f_j(t) = f_j(t-1)\left(1 + \chi \frac{E_j(t) - \overline{E}(t)}{\overline{E}(t)}\right), \tag{13}$$

with $\chi > 0$[18].

[16] This is close to the spirit of "customer market" models originated by the seminal work of Phelps and Winter (1970). See also Klemperer (1995) for a survey and the exploration of some important macro implications by Greenwald and Stiglitz (2003).

[17] Recall that consumption-good firms fix production according to their demand expectations, which may differ from actual demand. If the firm produced too much, the inventories pile up, whereas if its production is lower than demand plus inventories, its competitiveness is accordingly reduced.

[18] Strictly speaking, a canonic replicator dynamics evolves on the unit simplex with all entities having positive shares. Equation 13 allows shares to become virtually negative. In that case, the firm is declared dead and market shares are accordingly re-calculated. This is what we mean by a "quasi-replicator" dynamics. Note that an advantage of such formulation is that it determines at the same time changes in market shares and extinction events.

The profits (Π_j) of each consumption-good firm reads:

$$\Pi_j(t) = S_j(t) - c_j(t)Q_j(t) - r_L Deb_j(t) + r_D NW_j(t-1),$$

where $S_j(t) = p_j(t)D_j(t)$ and Deb denotes the stock of debt. The investment choices of each firm and its profits determine the evolution of its stock of liquid assets (NW_j):

$$NW_j(t) = NW_j(t-1) + \Pi_j(t) - cI_j(t),$$

where cI_j is the amount of internal funds employed by firm j to finance investment.

3.4 The Banking Sector

For the sake of simplicity we assume that credit is provided only to consumption-good firms. Firms in the machine-tool sector are constrained to finance their production plans through internal funds.

In the banking sector there are B commercial banks that gather deposits and provide credit to firms. In what follows, we first describe how total credit is determined by each bank, and how credit is allocated to each firm. Next, we move to describe the organization of the credit flow in the economy and the liquidity account of the banks. Finally, we describe how profits and net worth of banks are determined.

The number of banks is fixed and depends on the number of firms in the Consumption-good sector F_2:

$$B = \frac{F_2}{a}$$

where a depends on the level of competition on the banking market[19].

Bank-firm couples are drawn initially (the relationship holds for deposits of profits and credit links), and maintained fixed over time. Therefore, each bank k has a portfolio of clients Cl_k with clients listed as $cl = 1, ..., Cl_k$. This number is fixed although the portfolio changes when a firm dies and is replaced by an entrant (entry and exit dynamics are described below).

Banks' heterogeneity

All banks are initially the same (as firms are) but then they differentiate according to their fundamentals, their supply of credit, and their client portfolio. Indeed, each bank is characterized by its unique vector of variables (equity, profit...). Because the supply of credit is a function of the bank's lending history and/or its net worth, it is heterogeneous across banks. Indeed, the maximum amount of credit provided by each bank $TC_k(t)$ is determined by the bank according to a multiplier rule. More precisely, in each period the banks reinvest in credit the funds obtained through deposits from firms and through debt reimbursements from firms. This amount of credit returns to the banks in the form of deposits. The banks then subtract from this amount the mandatory reserve and lend the remainder, which returns again as deposits, and so on. If we let α_R be the mandatory reserve coefficient then the maximum credit obtained from the above procedure is determined as:

$$MTC_k(t) = \frac{Dep_k(t-1) + DR_k(t-1)}{\alpha_R}, \quad 0 \leq \alpha_R \leq 1 \tag{14}$$

where $Dep_k(t-1)$ and $DR_k(t-1)$ are respectively the deposits and the debt repayment at time $t-1$ of bank k.

We assume that in each period firms use their net-worth to pay back a fraction of their outstanding debt and deposit to their bank the remainder. This allows us to write the following:

$$Dep_k(t-1) + DR_k(t-1) = \sum_{cl=1}^{Cl_k} NW_{cl}(t-1) \tag{15}$$

and the credit multiplier equation (14) becomes:

$$MTC_k(t) = \frac{\sum_{cl=1}^{Cl_k} NW_{cl}(t-1)}{\alpha_R}, \quad 0 \leq \alpha_R \leq 1 \tag{16}$$

Credit allocation

Each Consumption-good firm needing credit applies for a loan to its bank. Banks take their allocation decisions (accept to give the loan or not) by ranking the applicants in terms of their quality, defined by the ratio between past net worth ($NW_j(t-1)$) and past sales ($S_j(t-1)$). Banks give credit as long as their supply of credit (TC_k) is not fully distributed.

Firms' probability to be given credit depends therefore on:

- their NW/S ratio which determines their ranking
- the financial situation of their bank which determines its supply of credit
- the general economic environment which affects the bank's and firms's financial situation

More precisely, the bank first ranks firms on the basis on their net worth-to-sales ratio, then it starts to satisfy the demand of the first firm in the rank, then the second one, etc. If total credit available is insufficient to fulfill the demand of the n firm in the pecking order than the firm goes bankrupt, and so do the remaining $N2-n$ firms. On the other hand, total demand for credit can be lower than total supply of credit. In this case all demands of firms in the pecking order are fulfilled and no firm goes bankrupt. It follows that in any period the stock of loans of the bank satisfies the following constraint: Since consumption-good firms may not fully use the total amount of credit allocated by the bank, the stock of loans of the bank ($Loan_k$) can be lower than TC_k:

$$\sum_{cl=1}^{Cl_k} Deb_{cl}(t) = Loan_k(t) \leqslant TC_k(t). \tag{17}$$

Interest rates

Banks are not differentiated by the interest rate they offer[20]. They all apply the same rule to determine the interest rate for deposits and for loans based on the central bank interest rate r. The deposits interest rate is labelled r_D(mark down) and the loan rate is labelled r_L (mark-up):

$$r_D = (1 - \psi_D)r, \quad 0 \leq \psi_D \leq 1 \tag{18}$$

$$r_L = (1 + \psi_L)r, \quad 0 \leq \psi_L \leq 1 \tag{19}$$

From the above hypotheses it follows that the expression for bank's profits, $\pi_k^b(t)$ is:

$$\pi_k^b(t) = r_L \left(Loan_k(t) - BD_k(t)\right) - r_D Dep_k(t) + r_D(Cash_k(t)). \tag{20}$$

where $BD_k(t) = \sum_{cl=1}^{Cl} BD_{cl}(t)$ is the bad-debt.

Bad-debt from client cl is equal to zero if the client does not go bankrupt in the period t, and it is equal to the firm's stock of debt if the firm j goes bankrupt in the period.

To complete the description of the banking sector, we need to determine bank's net-worth at the end of the period, $NW_k^b(t)$. The net-worth of the bank is equal to the stock of liquid assets of the bank minus the stock of bad debt. Liquid assets are given by the stock of cash accumulated up to time t plus the profits of the period. The stock of bad debt is given by the bad debt accumulated up to time t, $\sum_{\tau=0}^{t} BDk(\tau)$.
Accordingly the expression for the net-worth of the bank reads as:

$$NW_k^b(t) = Cash_k(t) + \pi_k^b(t) - \sum_{\tau=0}^{t} BD_k(\tau) = NW^b k(t_1) + \Delta Cash_k(t) + \pi_k^b(t) - \sum_{\tau=0}^{t} BD_k(\tau) \tag{21}$$

The bank goes bankrupt if its net-worth becomes negative. Note that this allows us to appreciate the difference between liquidity and solvency risks, which has been a hot topic during the current crisis. Similarly to what happened in the recent financial turmoil, we

[20]Indeed, we believe, following Stiglitz and Greenwald (2003) that interest rates changes are due to changes in the economic circumstances, not to variations of demand and supply.

assume that the insolvency of the bank is solved by allowing the public sector to partly buy the bad debt of the bank.

3.5 Schumpeterian Exit and Entry Dynamics

At the end of each period a firm exit for two reasons:

1. the firm has a (quasi) zero market share or
2. bankruptcy, i.e. firm's net worth becomes negative.

Note that bankruptcy in the model can occur in three well determined cases

1. If the net worth of the firm is not enough to pay the ordered machines and the firm is refused credit from the bank
2. If the net worth of the firm is not enough to pay production costs and the firm is refused credit from the bank
3. If the cash flow is negative, it is larger than the net-worth and the firm is refused credit from the bank

Finally note that may get a bad debt even when the firm exits because of competitiveness reasons. In the latter case the bad debt for the bank is equal to $\min\{0, Deb_j(t) - NW_j(t)\}$.

We keep the number of firms fixed, hence any dead firm is replaced by a new one. Furthermore, in line with the empirical literature on firm entry (Caves, 1998; Bartelsman et al., 2005), we assume that entrants are on average smaller than incumbents, with the stock of capital of new consumption-good firms and the stock of liquid assets of entrants in both sectors being a fraction of the average stocks of the incumbents[21]. Concerning the technology of entrants, new consumption-good firms select amongst the newest vintages of machines, according to the "brochure mechanism" described above. The process- and product-related knowledge of new capital-good firms is drawn from a Beta distribution, whose shape and support is shifted and "twisted" according to whether entrants enjoy an advantage or a disadvantage vis-à-vis incumbents[22]. In fact, the distribution of opportunities for entrants vs. incumbents is a crucial characteristics of different sectoral *technological regimes* and plays a role somewhat akin to the distance from the technological frontier of entrants discussed in Aghion and Howitt (2007).

[21] The stock of capital of a new consumption-good firm is obtained multiplying the average stock of capital of the incumbents by a random draw from a Uniform distribution with support $[\phi_1, \phi_2], 0 < \phi_1, < \phi_2 \leqslant 1$. In the same manner, the stock of liquid assets of an entrant is computed multiplying the average stock of liquid assets of the incumbents of the sector by a random variable distributed according to a Uniform with support $[\phi_3, \phi_4], 0 < \phi_3, < \phi_4 \leqslant 1$.

[22] More precisely, the technology of capital-good firms is obtained applying a coefficient extracted from a Beta(α_2, β_2) distribution to the endogenously evolving technology frontier $(A^{max}(t), B^{max}(t))$, where $A^{max}(t)$ and $B^{max}(t)$ are the best technology available to incumbents.

3.6 The Labor Market

The labor market is certainly not Walrasian: real-wage does not clear the market and involuntary unemployment as well as labor rationing are the rules rather than the exceptions. The aggregate labor demand (L^D) is computed summing up the labor demand of capital- and consumption-good firms. The aggregate supply (L^S) is exogenous and inelastic. Hence aggregate employment (L) is the minimum between L^D and L^S.

The wage rate is determined by institutional and market factors, with both indexation mechanisms upon consumption prices and average productivity, on the one hand, and, adjustments to unemployment rates, on the others:

$$\frac{\Delta w(t)}{w(t-1)} = g\left(\frac{\Delta cpi(t)}{cpi(t-1)}, \frac{\Delta \overline{AB}(t)}{\overline{AB}(t-1)}, \frac{\Delta U(t)}{U(t-1)}\right), \tag{22}$$

where cpi is the consumer price index, $\overline{AB}$ is the average labor productivity, and U is the unemployment rate[23].

3.7 Consumption, Taxes, and Public Expenditures

An otherwise black boxed public sector levies taxes on firm profits and worker wages or on profits only and pays to unemployed workers a subsidy (w^u), that is a fraction of the current market wage (i.e., $w^u(t) = \varphi w(t)$, with $\varphi \in (0,1)$). In fact, taxes and subsidies are the fiscal leverages that contribute to the aggregate demand management regimes.

Aggregate consumption (C) depends on the income of both employed and unemployed workers as well as on past savings:

$$C(t) = c[w(t)L^D(t) + w^u(L^S - L^D(t)) + r_D(1-c)C(t-1)]. \tag{23}$$

where $0 < c \leqslant 1$ is the marginal propensity to consume (in the present setup $c = 1$). The model satisfies the standard national account identities: the sum of value added of capital- and consumption goods firms (Y) equals their aggregate production since in our simplified economy there are no intermediate goods, and that in turn coincides with the sum of aggregate consumption, investment and change in inventories (ΔN):

$$\sum_{i=1}^{F_1} Q_i(t) + \sum_{j=1}^{F_2} Q_j(t) = Y(t) \equiv C(t) + I(t) + \Delta N(t).$$

The dynamics generated at the micro-level by decisions of a multiplicity of hetero-

[23]For simplicity, we assume in the following that $\frac{\Delta w(t)}{w(t-1)} = \frac{\Delta \overline{AB}(t)}{\overline{AB}(t-1)}$. Simulation results are robust to wage dynamics involving adjustment to inflation and unemployment. For more detailed modelizations of the labor market in a evolutionary/ACE framework see e.g. Tesfatsion (2000); Fagiolo et al. (2004); Neugart (2008).

geneous, adaptive agents and by their interaction mechanisms is the explicit microfoundation of the dynamics for all aggregate variables of interest (e.g. output, investment, employment, etc.).

4 Empirical Validation

The foregoing model does not allow for analytical, closed-form solution. This general ABM distinctive feature stems from the several non-linearities present in agent decision rules, and from their interaction patterns. Therefore, we resort to computer simulations for the analysis of its properties. In what follows, we perform extensive Montecarlo simulations and wash away across-simulation variability. Consequently, all results below refer to across-run averages over several[24] replications and their standard error bands.

As it should be clear from the previous sections, the model embodies both a *Schumpeterian engine* and a *Keynesian* one. The former rests in the generation of innovations by an ensemble of equipment producers which expensively search and endogenously differentiate in the technology they are able to master. The Keynesian engine has two parts: a direct one — through fiscal policies — and an indirect one — via investment decisions and workers' consumption. Bank credit is a key linchpin between these two engines, in that it allows firms to carry out production and investment activities, and therefore affects both technology diffusion and aggregate demand dynamics.

To better clarify the role of credit in the model we perform Montecarlo simulations under the "fractional reserve scenario" (or credit multiplier), where credit is entirely determined by total savings of firms, through the credit multiplier rule. Note that this credit scenario embodies strong elements of pro-cyclicality. Indeed, credit in the fractional reserve banking system hinges upon cash flows dynamics inside firms, which in turn in heavily affected by demand and technological dynamics.

In the presentation of model's results we first start with a "benchmark" setup and we check whether the model is "empirically validated", i.e. is able to reproduce a wide spectrum of macroeconomic and microeconomic stylized facts. Next we tune so to speak "up" and "down" the key fiscal and monetary policy variables in the model like e.g. tax rates, unemployment benefits, capital adequacy and mandatory reserve requirements, and we experiment their effect on the main aggregate avariables in the model (e.g. gdp growth and volatility, unemployment rates).

Let us therefore explore the ability of the model to reproduce under the different credit scenarios the major stylized facts regarding both the properties of macroeconomic ag-

[24]All results refers to MC=10 Montecarlo iterations of T=600 iterations. Preliminary exercises confirm that, for the majority of statistics under study, Monte-Carlo distributions are sufficiently symmetric and unimodal to justify the use of across-run averages as meaningful synthetic indicators

gregates and the underlying distributions of microeconomic characteristics (see also Dosi et al., 2006).

Growth and Fluctuations.

The model is able to robustly generate endogenous self-sustained growth patterns characterized by the presence of persistent fluctuations (cf. Figures 1. At business cycle frequencies, bandpass-filtered output, investment and consumption series (Bpf, cf. Baxter and King, 1999) display the familiar "roller-coaster" dynamics (see Figures 2) observed in real data (e.g. Stock and Watson, 1999; Napoletano et al., 2006). Moreover, in tune with the empirical evidence, both consumption and investment appear to be procyclical variables with the latter series being also more volatile than GDP. The insights coming from visual inspection of time-series data are confirmed from more quantitative analyses. Table 2 shows descriptive statistics on output, consumption and investment time-series. As the table clearly shows, output, consumption and investment display strictly-positive average growth rates[25] (cf. Table 2) and, according to Dickey-Fuller tests, they seem to exhibit a unit root. After detrending the series with a bandpass filter, we compute standard deviations and cross-correlations between output and the other series. In line with the empirical literature on business cycles (cf. Stock and Watson, 1999), also in our model investment is more volatile than output whereas consumption is less volatile; consumption, net investment, changes in inventories and employment are procyclical; unemployment is countercyclical. Consumption is also a coincident variable matching yet another empirical regularity on business cycles. Changes in inventories are instead slightly lagging. Informally, that means that both in our model and in reality relatively big "spurs of growth" and recessions occur much more frequently than it would be predicted on the grounds of normally distributed shocks (see also below on firm growth patterns). However, standard deviations values of GDP are significantly larger than what obtained in previously related work (see Dosi et al., 2008), using similar parameters' values. It follows then that credit dynamics can be a powerful amplyfing device of business cycles fluctuations.

Furthermore, the model is also able to match the business-cycle properties concerning productivity, the labor market, and price variables (see Fig. 3 and 4, which display across simulations average cross-correlations with GDP, together with GDP autocorrelation). Indeed, productivity is procyclical, prices are countercyclical and leading; inflation is pro-

[25] The average growth rate of variable X (e.g. GDP) is simply defined as:

$$\overline{GR}_X = \frac{\log X(T) - \log X(0)}{T+1},$$

where $T = 600$ is the econometric sample size. This value for T is a quite conservative choice, as the first iterative moments of growth statistics converge to a stable behavior well before such a time horizon. This means that the model reaches a relatively (meta) stable behavior quite soon after simulations start. Our experiments show that choosing larger values for T does not alter the main economic implications of the paper.

cyclical and lagging; markups are strongly countercyclical (for the empirics and discussion cf. Stock and Watson, 1999; Rotemberg and Woodford, 1999).

The model also matches the major business cycle stylized facts concerning credit. Indeed, (cf. Figure 5) firms' total debt and bank credit supply display a strong procyclical character. In addition, their fluctuations are either contemporaneous (firms total debt) or lagging (credit supply) output movements.

This behavior is mapping the dynamics the evolution of firms' financial health over the cycle. At the onset of an expansionary phase firms profits and cash flow improve. This pushes higher production and investment expenditures, therefore inducing a rise in firms debt. In turn the rise in debt costs gradually erodes firms' cash flows and savings, therefore leading to higher bankruptcy ratios and setting the premises for the incoming recession phase.

Distributions of Microeconomics Characteristics.

Together with the ability of the model to account for a rich ensemble of macro phenomena, how does it fare in replicating cross-sectional evidence on firms dynamics? Let us consider the regularities concerning firm-size and growth-rate distributions, and firm-productivity dynamics, firm-investment and firm-bankruptcy patterns which are generated by the model.

Figures 7 show the rank-size plot of the pooled firm-size in consumption good sector. As the plots indicate quite starkly, the firm size distribution is right skewed and thus in tune with empirical evidence (Dosi, 2007). In addition, this qualitative evidence is reinforced by the analysis of firms growth rates (not shown), that display fat-tails.
Turning to firm productivity, again in line with the empirical evidence (cf. the surveys in Bartelsman and Doms, 2000; Dosi, 2007), firms strikingly differ in terms of labor productivity (cf. standard deviations of labor productivity across firms plotted in Figure 8).
Furthermore, the model is indeed able to generate as an emergent property investment lumpiness (Doms and Dunne, 1998; Caballero, 1999). Indeed, in each time step, consumption-good firms with very low investment levels coexist with firms experiencing investment spikes (see Figure 6 and relate it to Gourio and Kashyap (2007)).
Finally, we have analyzed firm bankruptcy patterns. The recent evidence on this issue (e.g. Fujiwara, 2004; Di Guilmi et al., 2004) has pointed out that the distribution of bankruptcy rates is highly skewed to the right and fat-tailed, also displaying power-law like behavior. Besides, this also indicates and business cycles are typically characterized by episodes of large bankruptcy avalanches. As the plots in Figures 9 clearly shows, this empirical evidence is well replicated by our model.

5 Policy Experiments

The results described in the previous section indicated that the model is able to robustly account for a wide set of empirical stylized facts both at the aggregate as well as at the micro cross-sectional level. Encouraged by that empirical performance of the model, we now turn to policy experiments, by changing the values of the parameters associated with different policies.
Here we present the results from three different experiments, focusing on (1) Keynesian demand, (2) the role of the interest rate and (3) the role of the mandatory reserve rate.

Keynesian demand policies
Table 3 presents the results of the first experiment, where we raise the level of subsidies (the unemployment wage in the model) and taxes. First, the table shows that Keynesian policies have a strong triggering effect on long-run average growth rates of GDP, and above all on its volatility, and average unemployment. Robust keynesian policies must be well in place both to dampen to the fluctuations in output and to sustain growth in the long run. This pervasive effect follows from the fact that counter-cyclical keynesian policies act as a parachute during recessions, sustaining consumption and, indirectly, investment on the demand side.

Interaction between the interest rate and the mark-up
We also investigate the interplay of changes in the interest rate with market conditions (as proxied by the level of mark-up). Here we only consider changes in the mark-up of consumption-good firms because they are the ones affected by changes in the cost of credit. Indeed, in the model, a change in the interest rate affects the cost of external capital to consumption good firms, while the mark-up affects their revenues. The effect of the mark-up on firm revenues is not linear because of the trade-off between the revenue effect (higher revenues for the same amount of goods sold) and the price-effect (changes in demand due to changes in price). The intuition is that with higher mark-ups, consumption good firms can invest and produce using their internal finance, and therefore they will be less affected by changes in the interest rate. On the contrary, for lower values of the mark-up firms are more dependent on external finance and are more affected by changes in the cost of capital.
The results of the above described experiments are reported in Table 4. First we can note that for similar levels of the interest rate, rising the mark-up reduces GDP growth and increases business cycle fluctuations (GDP volatility, the unemployment level as well as the probability of crises).

Changing the reserve requirement rate
Now we turn to our last experiment which focuses on changes in the reserve requirement rate (i.e. changes in total allocated credit). Looking back at equation 14, the intuition is that with a lower requirement rate, total credit is mechanically increased. This relieves financially constrained firms and therefore increases investment and production. The trade-off is that the banking sector could become unstable and in case of large negative events (or high default rate among its clients), a bank could more easily fail. Indeed, higher debt and related debt costs erodes firms' savings and cash flow, which might lead to default. With higher bad debt and low levels of cash, banks' net worth is reduced and the credit institutions can be exposed to failure.

Table 5 shows that these expectations are confirmed here: lowering the reserve requirement rate increases the GDP growth rate (more credit leading to more production and investment), but also increases business cycle fluctuations (GDP volatility). Finally, the number of banking failures is largely affected by the level of the reserve requirement rate.

6 Concluding Remarks

Building on previous work of some of the authors Dosi et al. (2010) in this paper we have studied the properties of an agent-based model with both a real and banking sector that robustly reproduces a wide ensemble of macro stylized facts and distributions of micro characteristics.

The model entails the explicit account of search and investment decisions by populations of firms that are heterogeneous in the technologies which they master and, possibly, in their decision rules. Aggregate macro properties are emergent from the thread of interactions among economic agents, without any ex-ante consistency requirements amongst their expectations and their actions. In that sense, the model may be considered an exercise in *general disequilibrium analysis*. Firms in the model endogenously generate new technologies — embodied in new types of "machines" — via expensive and mistake-ridden processes of search. Inventions then diffuse via the adoption decisions of machine users. Hence, agents generate micro technological shocks and, together, micro demand shocks which propagate through the economy. The linchpin between these two engines is represented the credit provided by banks. Banks use savings of firms to finance firms' production and investment activities according to a credit multiplier rule.

After testing fiscal and monetary policy experiments, our ongoing research will address the issue of changes in the structure of the banking sector in terms of market concentration as well as firm lending behavior. Indeed, a clearer understanding about the interaction between firm debt, firm investment and firm growth is still needed. More precisely, the analysis of the links between firm financial decisions and the evolution of macroeconomic variables is an ongoing research.

References

Aghion, P. and P. Howitt (2007), "Appropriate Growth Policy: A Unifying Framework", *Journal of the European Economic Association*, 4: 269–314.

Albareto, B. M. M. S. P. M., G. and P. Rossi (2008), "L'organizzazione dell'attivit creditizia e l'utilizzo di tecniche di scoring nel sistema bancario italiano: risultati di n'indagine campionaria", Questioni di Economia e Finanza (Occasional papers) 12, Bank of Italy.

Alessandrini, P. A., P. and A. Zazzaro (2006), "Banks, Distances and Financing Constraints for Firms", Working Paper 266, Universita degli studi di Ancona.

Altman, E. (1968), "Financial Ratios, Discriminant Analysis and the Prediction of Corporate Bankruptcy", *The Journal of Finance*, 23: 589–609.

Angelini, D. S. R., P. and G. Ferri (1998), "Availability and cost of credit for small businesses: Customer relationships and credit cooperatives", *Journal of Banking and Finance*, 22: 925–54.

Ashraf, Q., B. Gershman and P. Howitt (2010), "Banks, Market Organization and Macroeconomic Performance: An Agent-Based Computational Analysis", Rough draft to be presented at Columbia University April 27, Columbia University.

Bartelsman, E. and M. Doms (2000), "Understanding Productivity: Lessons from Longitudinal Microdata", *Journal of Economic Literature*, 38: 569–94.

Bartelsman, E., S. Scarpetta and F. Schivardi (2005), "Comparative analysis of firm demographics and survival: evidence from micro-level sources in OECD countries", *Industrial and Corporate Change*, 14: 365–391.

Baxter, M. and R. King (1999), "Measuring Business Cycle: Approximate Band-pass Filter for Economic Time Series", *The Review of Economics and Statistics*, 81: 575–593.

Becchetti, L. and G. Trovato (2002), "The determinants of growth of small and medium sized firms. The role of the availability of external finance", *Small Business Economics*, 19: 291–306.

Bellone, F. and P. Musso (2009), "Contraintes financires et performances des firmes franaises", Documents de Travail 1, GREDEG, Universit/' Nice-Sophia Antipolis.

Berger, A. and G. Udell (1995), "Relationship Lending and Lines of Credit in Small Firm Finance", *Journal of Business*, 68: 351–81.

Bernanke, B., M. Gertler and S. Gilchrist (1999), "The Financial Accelerator in a Quantitative Business Cycle Framework", in J. Taylor and M. Woodford, (eds.), *Handbook of Macroeconomics*, Elsevier Science: Amsterdam.

Bottazzi, D. G. J. N. S. A., G. and F. Tamagni (2009), "Corporate performances and market selection. Some comparative evidence", Working Paper Series 2009-13, LEM, Sant'Anna School of Advanced Studies, Pisa.

Bottazzi, S. A., G. and F. Tamagni (2006), "Productivity, profitability and financial fragility: evidence from Italian business firms", Working Paper Series 2006-08, LEM, Sant'Anna School of Advanced Studies, Pisa.

Caballero, R. J. (1999), "Aggregate Investment", in J. Taylor and M. Woodford, (eds.), *Handbook of Macroeconomics*, Amsterdam, Elsevier Science.

Caves, R. (1998), “Industrial Organization and New findings on the Turnover and Mobility of Firms”, *Journal of Economic Literature*, 36: 1947–1982.

Coad, A. (2010), “Neoclassical vs Evolutionary Theories of Financial Constraints : Critique and Prospectus”, *Structural Change and Economic Dynamics*, 21: 206–18.

De Meza, D. and D. Webb (1987), “Too Much Investment: A Problem of Asymmetric Information”, *Quarterly Journal of Economics*, 102: 281–92.

Del Boca, A., M. Galeotti, C. P. Himmelberg and P. Rota (2008), “Investment and Time to Plan and Build: A Comparison of Structures vs. Equipment in A Panel of Italian Firms”, *Journal of the European Economic Association*, 6: 864–889.

Dell'Ariccia, G. and R. Marquez (2004), “Information and bank credit allocation”, *Journal of Financial Economics*, 72: 185–214.

Delli Gatti, D., C. Di Guilmi, E. Gaffeo, G. Giulioni, M. Gallegati and A. Palestrini (2005), “A New Approach to Business Fluctuations: Heterogeneous Interacting Agents, Scaling Laws and Financial Fragility”, *Journal of Economic Behavior and Organization*, 56: 489–512.

Detragiache, E., P. Garella and L. Guiso (2000), “Multiple versus Single Banking Relationships: Theory and Evidence”, *The Journal of Finance*, 55: 1133–1161.

Di Guilmi, C., M. Gallegati and P. Ormerod (2004), “Scaling invariant distributions of firms' exit in OECD countries”, *Physica A: Statistical and Theoretical Physics*, 334: 267–273.

Diamond, D. (1984), “Financial Intermediation and Delegated Monitoring”, *The Review of Economic Studies*, 51: 393–414.

Doms, M. and T. Dunne (1998), “Capital Adjustment Patterns in Manufacturing Plants”, *Review Economic Dynamics*, 1: 409–29.

Dosi, G. (1988), “Sources, Procedures and Microeconomic Effects of Innovation”, *Journal of Economic Literature*, 26: 126–71.

Dosi, G. (2007), “Statistical Regularities in the Evolution of Industries. A Guide through some Evidence and Challenges for the Theory”, in F. Malerba and S. Brusoni, (eds.), *Perspectives on Innovation*, Cambridge MA, Cambridge University Press.

Dosi, G., G. Fagiolo and A. Roventini (2006), “An Evolutionary Model of Endogenous Business Cycles”, *Computational Economics*, 27: 3–34.

Dosi, G., G. Fagiolo and A. Roventini (2008), “The Microfoundations of Business Cycles: an Evolutionary, Multi-Agent Model”, *Journal of Evolutionary Economics*, 18: 413–432.

Dosi, G., G. Fagiolo and A. Roventini (2010), “Schumpeter meeting Keynes, A Policy-Friendly Model of Endogenous Growth and Business Cycles”, *Journal od Economic Dynamics and Control*, 34: 1748–1767.

Edmister, R. (1972), “An Empirical Test of Financial Ratio Analysis for Small Business Failure Prediction”, *The Journal of Financial and Quantitative Analysis*, 7: 1477–1493.

Eisner, R. (1972), “Components of Capital Expenditures: Replacement and Modernization versus Expansion”, *The Review of Economics and Statistics*, 54: 297–305.

Fabiani, S., M. Druant, I. Hernando, C. Kwapil, B. Landau, C. Loupias, F. Martins, T. Mathä, R. Sabbatini, H. Stahl and A. Stokman (2006), “What Firms' Surveys Tell Us about Price-Setting Behavior in the Euro Area”, *International Journal of Central Banking*, 2: 3–47.

Fagiolo, G., G. Dosi and R. Gabriele (2004), “Matching, Bargaining, and Wage Setting in an Evolutionary Model of Labor Market and Output Dynamics”, *Advances in Complex Systems*, 14: 237–73.

Farrel, J. and C. Shapiro (1988), "Dynamic Competition with Switching Costs", *RAND Journal of Economics*, 19: 123–137.

Fazzari, H. R., S. and B. Petersen (1988), "Financing Constraints and Corporate Investment", *Brookings Papers on Economic Activity 1*, 1: 141–95.

Feldstein, M. and D. Foot (1971), "The Other Half of Gross Investment: Replacement and Modernization Expenditures", *The Review of Economics and Statistics*, 53: 49–58.

Fujiwara, Y. (2004), "Zipf law in firms bankruptcy", *Physica A: Statistical and Theoretical Physics*, 337: 219–30.

Gaffeo, E., D. Delli Gatti, S. Desiderio and M. Gallegati (2008), "Adaptive microfoundations for emergent macroeconomics", Working Paper 2, Universita degli studio di Trento.

Goolsbee, A. (1998), "The Business Cycle, Financial Performance, and the Retirement of Capital Goods", Working Paper 6392, NBER.

Gourio, F. and A. K. Kashyap (2007), "Investment Spikes: New Facts and a General Equilibrium Exploration", *Journal of Monetary Economics*, 54: 1–22.

Greenwald, B. and J. Stiglitz (1993), "Financial Market Imperfections and Business Cycles", *Quarterly Journal of Economics*, 108: 77–114.

Greenwald, B. and J. Stiglitz (2003), "Macroeconomic Fluctuations in an Economy of Phelps-Winter Markets", in P. Aghion, R. Frydman, J. Stiglitz and M. Woodford, (eds.), *Knowledge, Information, and Expectations in Modern Macroeconomics: In Honor of Edmund S. Phelps*, Princeton, NJ, Princeton University Press.

Hubbard, G. R. (1998a), "Capital-Market Imperfections and Investment", *Journal of Economic Literature*, 36: 193–225.

Hubbard, R. (1998b), "Capital-Market Imperfections and Investment", *Journal of Economic Literature*, 36: 193–225.

Inderst, R. and H. Mueller (2007), "A lender-based theory of collateral", *Journal of Financial Economics*, 84: 826–859.

Kaplan, S. and L. Zingales (1995), "Do financing constraints explain why investment is correltaed to cash flow?", Working Paper 5267, NBER.

Klemperer, P. D. (1987), "Markets with Customer Switching Costs", *Quarterly Journal of Economics*, 102: 375–394.

Klemperer, P. D. (1995), "Competition when Consumers have Switching Costs: An Overview with Applications to Industrial Organization, Macroeconomics and International Trade", *Review of Economic Studies*, 62: 515–539.

Klevorick, A. K., R. Levin, R. R. Nelson and S. G. Winter (1995), "On the Sources and Significance of Interindustry Differences in Technological Opportunities", *Research Policy*, 24: 185–205.

Kon, Y. and D. Storey (2003), "A Theory of Discouraged Borrowers", *Small Business Economics*, 21: 37–49.

Metcalfe, J. S. (1994), "Competition, Fisher's Principle and Increasing Returns to Selection", *Journal of Evolutionary Economics*, 4.

Minsky, H. (1992), "The Financial Instability Hypothesis", Working Paper 74, The Jerome Levy Economics Institute.

Musso, P. and S. Schiavo (2008), "The impact of financial constraints on firm survival and growth", *Journal of Evolutionary Economics*, 18: 135–149.

Myers, S. (1984), “The Capital Structure Puzzle”, *The Journal of Finance*, 39: 575–592.

Myers, S. and N. Majluf (1984), “Corporate financing and investment decisions when firms have information that investors do not have”, *Journal of Financial Economics*, 13: 187–221.

Napoletano, M., A. Roventini and S. Sapio (2006), “Are Business Cycles All Alike? A Bandpass Filter Analysis of the Italian and US Cycles”, *Rivista Italiana degli Economisti*, 1: 87–118.

Neugart, M. (2008), “Labor Market Policy Evaluation with ACE”, *Journal of Economic Behavior and Organization*, , special Issue on “Agent-Based Models for Economic Policy Design”, edited by Dawid, H. and Fagiolo, G., forthcoming.

Pavitt, K. (1984), “Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory”, *Research Policy*, 13: 343–373.

Petersen, M. and R. Rajan (1994), “The benefits of lending relationships: Evidence from small business data”, *Journal of Finance*, 49: 3–37.

Phelps, E. S. and S. G. Winter (1970), “Optimal Price Policy under Atomistic Competition”, in E. S. Phelps, (ed.), *Microeconomic Foundations of Employment and Inflation Theory*, New York, Norton.

Rotemberg, J. (2008), “Behavioral Aspects of Price Setting, and Their Policy Implications”, Working Paper 13754, NBER.

Rotemberg, J. and M. Woodford (1999), “The Cyclical Behavior of Prices and Costs”, in J. Taylor and M. Woodford, (eds.), *Handbook of Macroeconomics*, Elsevier Science: Amsterdam.

Silverberg, G., G. Dosi and L. Orsenigo (1988), “Innovation, Diversity and Diffusion: A Self-Organization Model”, *The Economic Journal*, 98: 1032–54.

Stiglitz, J. and B. Greenwald (2003), *Towards a New Paradigm in Monetary Economics*, Cambridge : Cambridge University Press.

Stiglitz, J. and A. Weiss (1981), “Credit rationing in markets with imperfect information”, *The American Economic Review*, 71: 393–410.

Stiglitz, J. and A. Weiss (1992a), “Asymmetric Information in Credit Markets and Its Implications for Macro-Economics”, *Oxford Economic Papers*, 44: 694–724.

Stiglitz, J. and A. Weiss (1992b), “Credit Rationing in Markets with Imperfect Information”, *American Economic Review*, 71: 393–410.

Stock, J. and M. Watson (1999), “Business Cycle Fluctuations in U.S. Macroeconomic Time Series”, in J. Taylor and M. Woodford, (eds.), *Handbook of Macroeconomics*, Amsterdam, Elsevier Science.

Tesfatsion, L. (2000), “Structure, Behavior, and Market Power in an Evolutionary Labor Market with Adaptive Search”, *Journal of Economic Dynamics & Control*, 25: 419–457.

Williamson, S. (1987), “Costly Monitoring, Loan contracts and equilibrium credit rationing”, *The Quarterly Journal of Economics*, 102: 135–146.

Winker, P. (1999), “Causes and Effects of Financing Constraints at the Firm Level”, *Small Business Economics*, 12: 169181.

Description	Symbol	Value
Number of firms in capital-good industry	F_1	50
Number of firms in consumption-good industry	F_2	200
Number of commercial banks	B	10
R&D investment propensity	ν	0.04
R&D allocation to innovative search	ξ	0.50
Firm search capabilities parameters	$\zeta_{1,2}$	0.30
Beta distribution parameters (innovation process)	(α_1, β_1)	(3,3)
Beta distribution support (innovation process)	$[\underline{x}_1, \overline{x}_1]$	$[-0.15, 0.15]$
New-customer sample parameter	γ	0.50
Capital-good firm mark-up rule	μ_1	0.10
Consumption-good firm mark-up rule	μ_2	0.20
Desired inventories	ι	0.10
Payback period	b	3
"Physical" scrapping age	η	20
Mark-up coefficient	υ	0.01
Competitiveness weights	$\omega_{1,2}$	1
Replicator dynamics coefficient	χ	1
Uniform distribution supports (consumption-good entrant capital)	$[\phi_1, \phi_2]$	[0.10,0.90]
Uniform distribution supports (entrant stock of liquid assets)	$[\phi_3, \phi_4]$	[0.10,0.90]
Beta distribution parameters (capital-good entrants technology)	(α_2, β_2)	$(2, 4)$
Wage setting $\Delta\overline{AB}$ weight	ψ_1	1
Wage setting Δcpi weight	ψ_2	0
Wage setting ΔU weight	ψ_3	0
Tax rate	tr	0.10
Unemployment subsidy rate	φ	0.40
Maximum debt/sales ratio	Λ	3
Interest Rate	r	0.025
Debt reimbursement rate	rep	0.05
Banks mark-up coefficient	ψ_L	0.50
Banks mark-down coefficient	ψ_D	1
Banks deposits reserve rate	α_b	0.05
Banks reserve requirement rate	α_R	0.5

Table 1: Benchmark Parameters

	Output	**Consumption**	**Investment**
Avg. growth rate	0.0277	0.0274	0.0299
	(0.0012)	(0.0011)	(0.0008)
Dickey-Fuller test (logs)	8.5282	11.1895	1.1578
Dickey-Fuller test (Bpf)	-6.0733^*	-5.8206^*	-7.1890^*
Std. Dev. (Bpf)	0.0685	0.0480	0.2752
	(0.0160)	(0.0087)	(0.0438)
Rel. Std. Dev. (output)	1	0.6997	4.0144

Table 2: Fractional Reserve Scenario. Output, Investment, and Consumption Statistics. Bpf: bandpass-filtered (6,32,12) series. Monte-Carlo simulation standard errors in parentheses.

Description	Avg. GDP Growth	GDP Std. Dev. (bpf)	Avg. Unempl.
benchmark scenario	0.0277	0.0685	0.035
	(0.001)	(0.016)	(0.079)
high benefits	0.0296	0.0286	0.0012
	(0.001)	(0.0019)	(0.0007)
high benefits	0.0299	0.0298	0.0017
and taxes	(0.001)	(0.0036)	(0.0014)

Table 3: Effects of Redistributive Policies. Monte-Carlo simulation standard errors in parentheses. *Note:* Large negative growth events are defined falls in output larger than 3%.

Description	Avg. GDP Growth	GDP Std. Dev. (fd)	Avg. Unempl.	Prob. of large neg. growth (<-3%)
Low Mark-Up (0.15)				
r=0.001	0.0287	0.0350	0.0038	0.0741
r=0.025	0.0294	0.0336	0.0042	0.0663
r=0.05	0.0295	0.0313	0.0038	0.0666
Baseline Mark-Up (0.20)				
r=0.001	0.0281	0.0516	0.025	0.1447
r=0.025	0.0277	0.0685	0.0350	0.1601
r=0.05	0.0278	0.0654	0.0378	0.1484
r=0.1	0.287	0.0605	0.306	0.1449
High Mark-Up (0.30)				
r=0.001	0.0274	0.1115	0.1549	0.2649
r=0.025	0.0274	0.1124	0.1464	0.2604
r=0.05	0.0275	0.1166	0.1591	0.2691

Table 4: Effects of changes of the interest rate for different mark-up levels

α_R	Avg. GDP Growth	GDP Std Dev. (fd)	Prob. large neg. growth (<-3%)	Prob. Bank failure
baseline	0.0277	0.0685	0.1601	0.015
low	0.0468	0.0860	0.1431	0.03
very low	0.0472	0.2272	0.1327	0.5

Table 5: Effects of changes in the reserve requirement rate

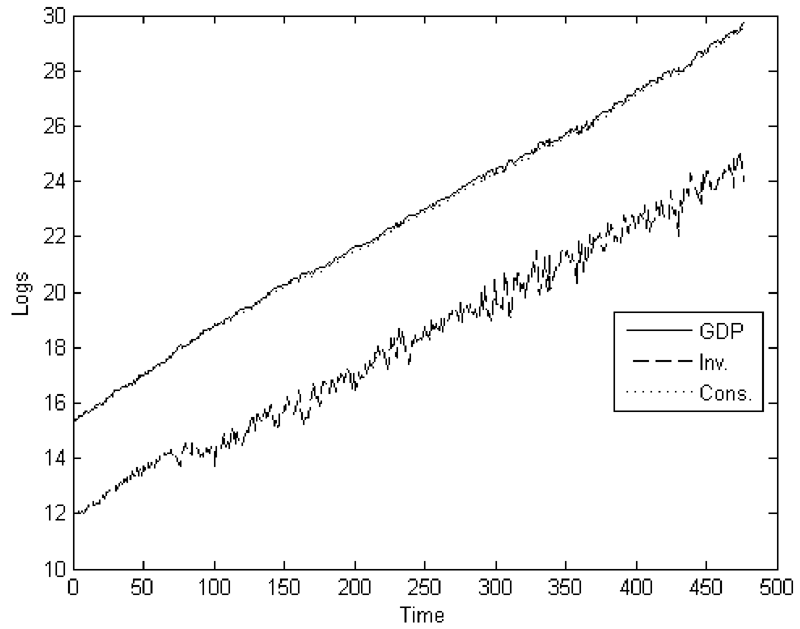

Figure 1: Fractional Reserve Scenario. Level of Output, Investment, and Consumption (logs)

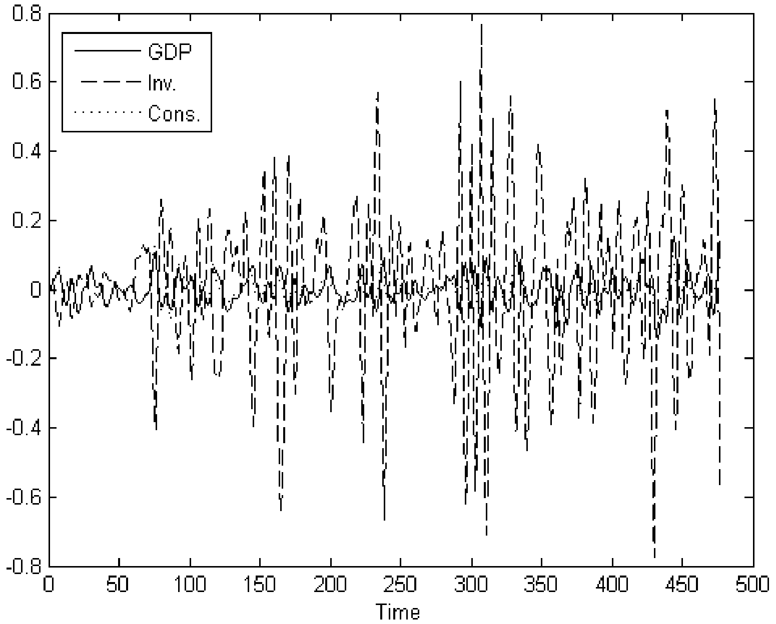

Figure 2: Fractional Reserve Scenario.Bandpass-Filtered Output, Investment, and Consumption

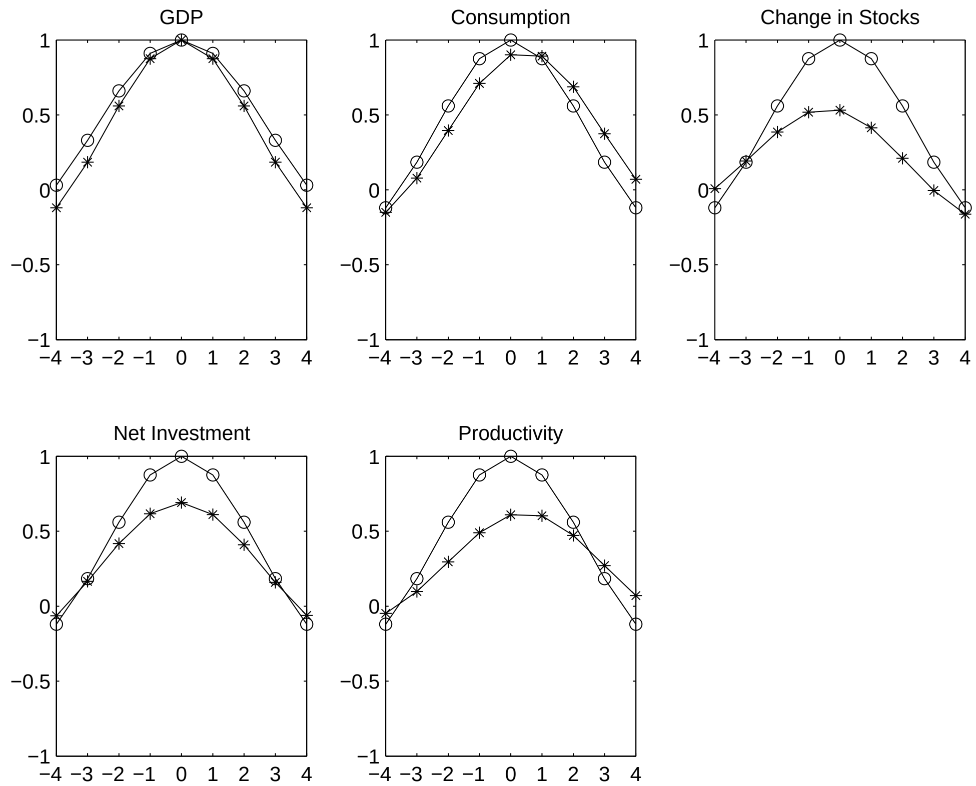

Figure 3: Fractional Reserve Scenario. Average cross-correlations with GDP at different leads and lags (circles) together with average GDP autocorrelation (diamonds). GDP, GDP components and Productivity variables.

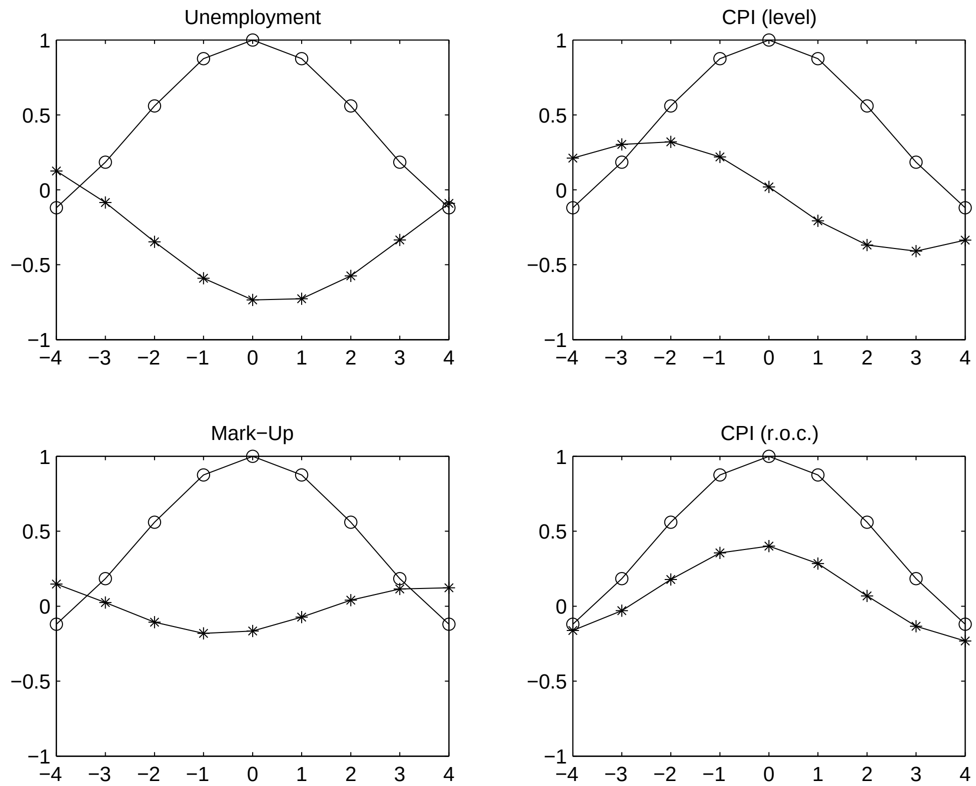

Figure 4: Fractional Reserve Scenario. Average cross-correlations with GDP at different leads and lags (circles) together with average GDP autocorrelation (diamonds). Labor market and price variables.

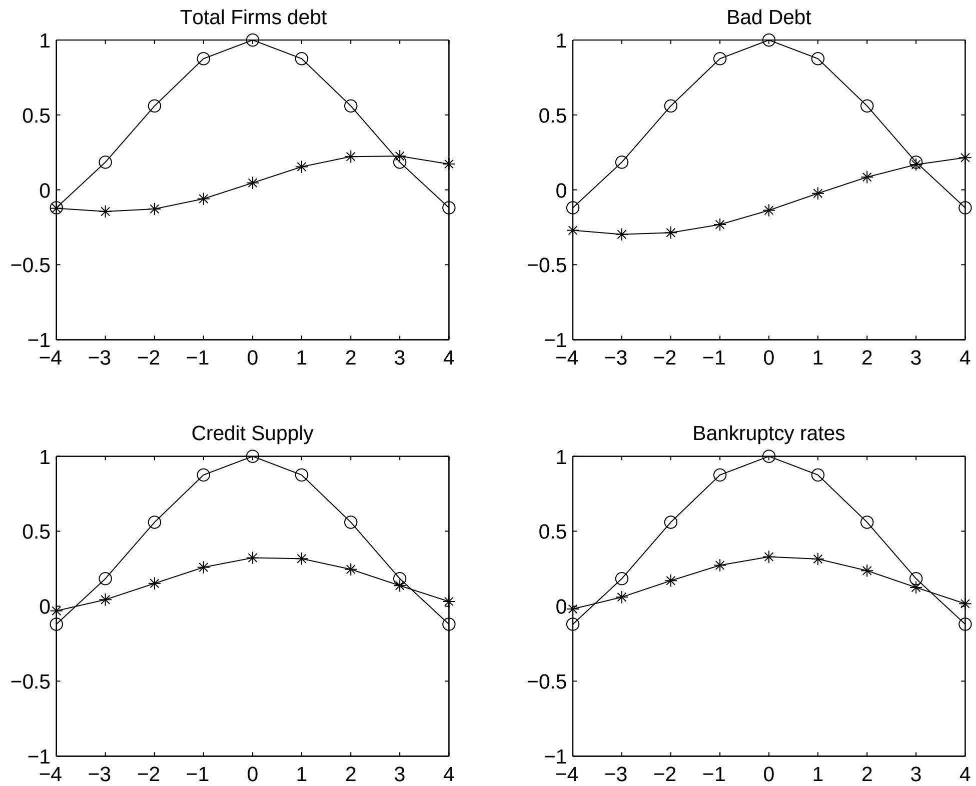

Figure 5: Fractional Reserve Scenario. Average cross-correlations with GDP at different leads and lags (circles) together with average GDP autocorrelation (diamonds). Credit variables.

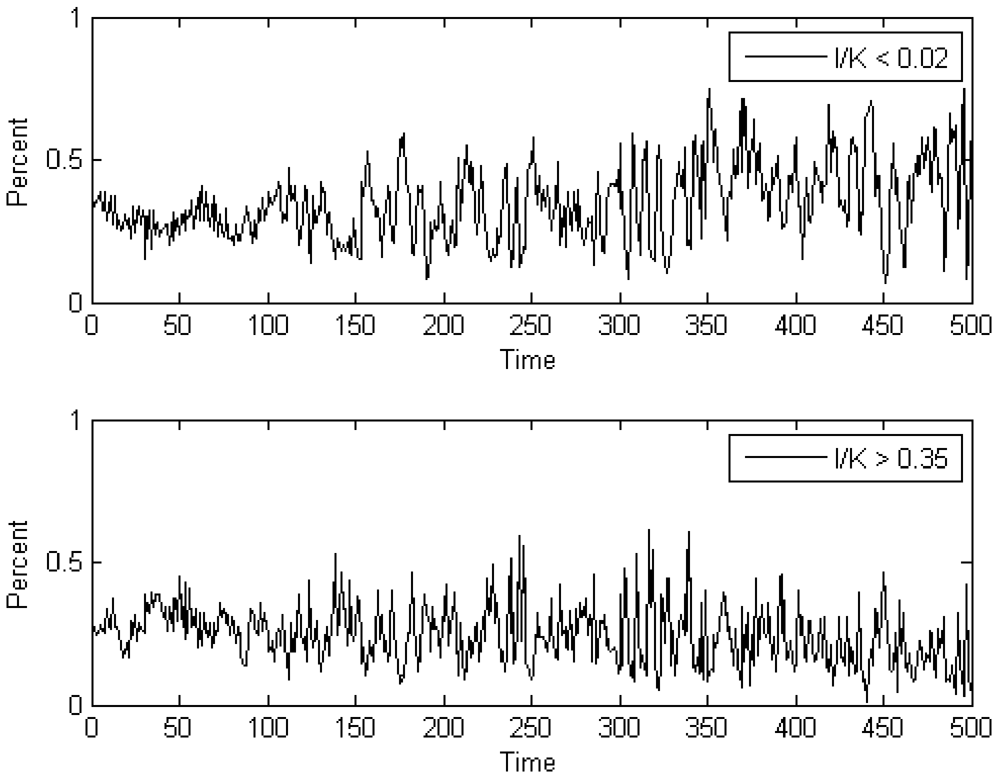

Figure 6: Fractional Reserve Scenario. Investment Lumpiness. First panel: share of firms with (near) zero investment; second panel: share of firms with investment spikes.

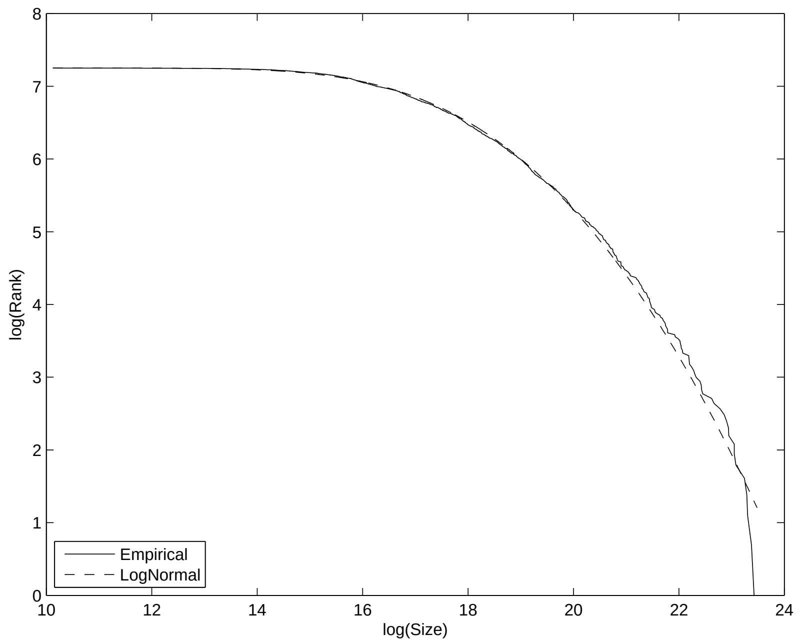

Figure 7: Fractional Reserve Scenario. Pooled (Year-Standardized) Capital-good Firm Sales Distributions. Log Rank vs. Log Size Plots.

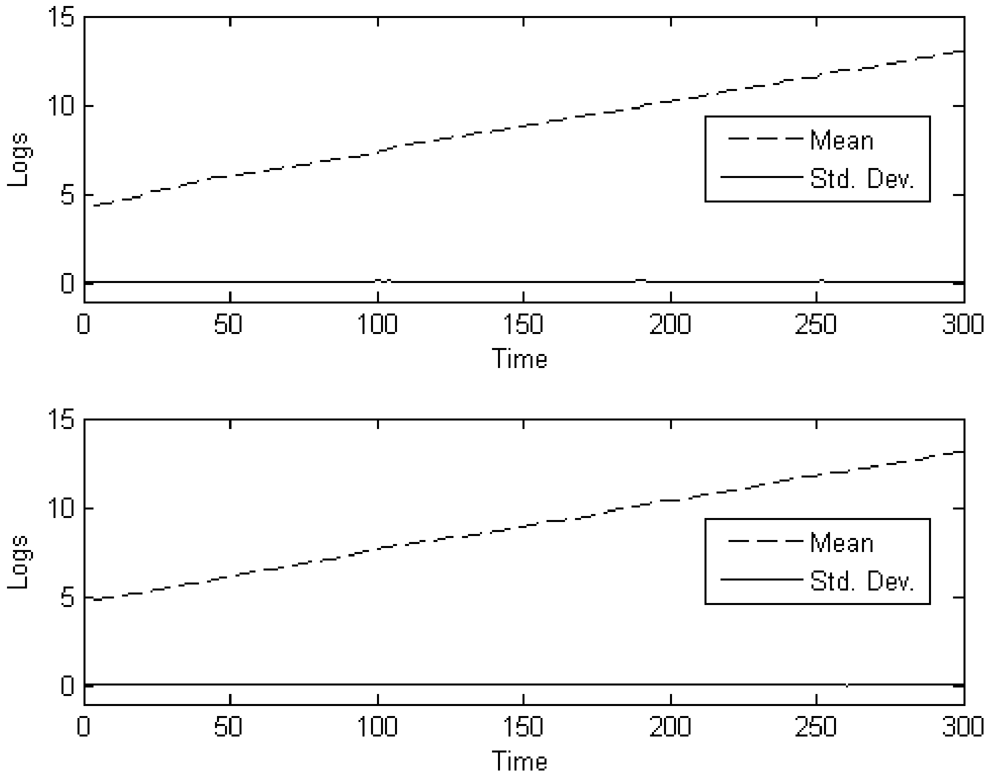

Figure 8: Fractional Reserve Scenario. Firms' Productivity Moments (logs). First panel: capital-good firms. Second panel: consumption-good firms.

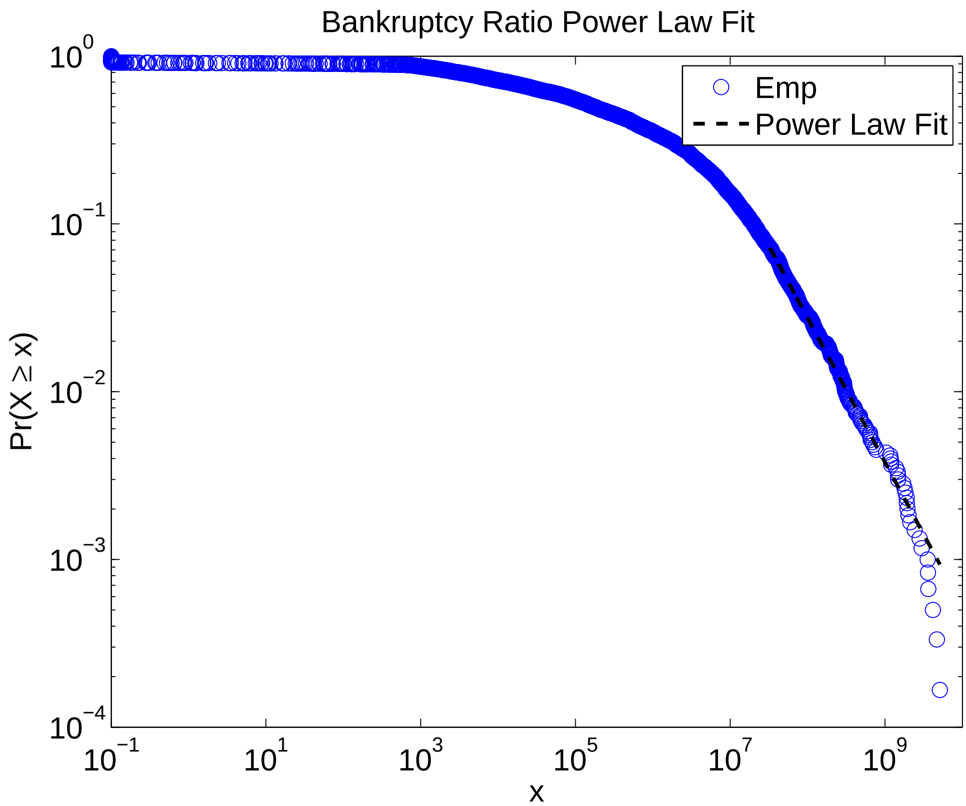

Figure 9: Fractional Reserve Scenario. Empirical distribution of bankruptcy rate together with power-law fit