Economic Policies with Endogenous Innovation and Keynesian Demand Management[*]

Giovanni Dosi[†]   Giorgio Fagiolo[‡]   Mauro Napoletano[§]

Andrea Roventini[¶]   Tania Treibich[‖]

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Abstract

We study an evolutionary, agent-based model, which is a bridge between Keynesian theories of business cycles and Schumpeterian theories of economic growth. We employ the model to analyze the properties of macroeconomic dynamics and the effects of supply and demand polices. The model describes an economy composed of capital- and consumption-good firms, workers, and a bank. Capital-good firms perform R&D and produce heterogeneous machine tools. Consumption-good firms invest in new machines and produce a homogeneous consumption good. The bank finances firm production and investment plans and collects firm savings. Before carrying out policy analysis exercises, we empirically validate the model showing that it is able to replicate a wide spectrum of macroeconomic and microeconomic stylized facts. Simulation exercises show a strong complementarity between factors influencing aggregate demand and drivers of technological change that affect both "short-run" fluctuations and long-term growth patterns. From a normative point of view, simulations show a corresponding complementarity between "Keynesian" and "Schumpeterian" policies in sustaining long-run steady growth paths characterized by milder fluctuations and relatively lower unemployment levels.

Keywords: Endogenous Growth; Business Cycles; Financial Instability; Growth and Stabilization Policies; Evolutionary Economics; Agent-Based Computational Economics; Empirical Validation; Monte-Carlo Simulations.

JEL Classification: E32, E6, O3, O4

[†]Corresponding Author. Sant'Anna School of Advanced Studies, Pisa, Italy and Visiting Professor, Friedrich-Schiller-Universität, Jena, Germany. Mail address: Sant'Anna School of Advanced Studies, Piazza Martiri della Libertà 33, I-56127 Pisa, Italy. Tel: +39-050-883326. Fax: +39-050-883344. Email: gdosi@sssup.it

[‡]Sant'Anna School of Advanced Studies, Pisa, Italy. Mail address: Sant'Anna School of Advanced Studies, Piazza Martiri della Libertà 33, I-56127 Pisa, Italy. Tel: +39-050-883282. Fax: +39-050-883344. Email: giorgio.fagiolo@sssup.it

[§]Observatoire Français des Conjonctures Economiques, Department for Research on Innovation and Competition, Sophia-Antipolis, France, and Sant'Anna School of Advanced Studies, Pisa, Italy. Mail Address: Observatoire Français des Conjonctures Economiques, Department for Research on Innovation and Competition, 250 rue Albert Einstein, 06560 Valbonne, France. Email: mauro.napoletano@ofce.sciences-po.fr

[¶]University of Verona, Italy and Sant'Anna School of Advanced Studies, Pisa, Italy. Mail address: Università di Verona, Dipartimento di Scienze Economiche, viale dell'Università 3, I-37129 Verona, Italy. Tel: +39-045-8028238. Fax: +39-045-8028529. Email: andrea.roventini@univr.it

[‖]Sant'Anna School of Advanced Studies, Pisa, Italy, Université Nice-Sophia Antipolis, France and Observatoire Français des Conjonctures Economiques, Department for Research on Innovation and Competition, Sophia-Antipolis, France. Email: tania.treibich@gmail.com

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1 Introduction

The current global crisis has not only strikingly shown the importance of banking and financial markets for the dynamics of real economies, but it has also revealed to be a "natural experiment" for economic analysis, showing the inadequacy of the predominant theoretical frameworks. The basic assumptions of mainstream models (e.g. DSGE models, cf. Woodford, 2003; Galí and Gertler, 2007), e.g. rational expectations, optimizing, representative agents etc. are to a large extent responsible for the failure to forecast the crisis and seem also unable to propose a therapy to put back economies on a steady growth path (Colander et al., 2008; Kirman, 2010). In fact, the crisis sets a tall challenge for alternative, evolutionary theories linking micro-behavior and aggregate dynamics.

In this work, we develop an evolutionary, agent-based model to try to fill the theoretical vacuum present nowadays in macroeconomics. The model addresses three major, interrelated, questions. First, it explores the processes by which technological change affects macro variables such as unemployment, output fluctuations and average growth rates. Besides this "Schumpeterian" question, we also ask how such endogenous, firm-specific changes in the supply side of the economy interact with demand conditions. This is a basic "Keynesian" issue. Finally, we explore the possible existence of long-term effects of demand variations. Is the long-term growth just driven by changes in the technology, or does aggregate demand affect future dynamics? Are there multiple growth paths whose selection depends on demand and institutional conditions?

To do so, we refine and expand the model contained in Dosi et al. (2010)[1], which we use also as a sort of "policy laboratory" where both business-cycle and growth effects of different public policies can be evaluated under different institutional scenarios. In this respect, the model allows to experiment with an ensemble of policies, related to the supply side of the economy (e.g. technology) as well as to the demand side macro-management (e.g. fiscal and monetary policies).

From an historical perspective, a separation has emerged in macroeconomics: growth theories have tried to explain the trends present in macro time series, whereas business cycle models have accounted for the observed fluctuations around the trend. The IS-LM interpretation of Keynes (Hicks, 1937) and growth models rooted in the seminal work of Solow (1956) are prominent examples of such a division of labor.

In the business cycle theoretical camp, different theories have been competing over time. On the one hand, "New Classical" and "Real Business Cycle (RBC) theories" have considered irrelevant any "Keynesian" feature of the economy. On the other hand, New Keynesians have stressed the importance of aggregate demand shocks in economic fluctuations relying often on nominal and real rigidities as well as on informational and behavioral frictions (see Blanchard, 2009, for an insightful overview), with just a small

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[1]See also Dosi et al. (2006) and Dosi et al. (2008).

subset of them considering such "imperfections" as structural, long-term characteristics of the economy (see e.g. Akerlof and Yellen, 1985; Greenwald and Stiglitz, 1993a,b; Akerlof, 2002, 2007).

More recently, the New Neoclassical Synthesis between Real Business Cycle and a major breed of New Keynesian models, rooted in the Dynamic Stochastic General-Equilibrium (DSGE) models (cf. Woodford, 2003; Galí and Gertler, 2007) has added modest quantities of Keynesian elements to an otherwise supply-side model of economic fluctuations. The backbone of DSGE models is indeed a RBC model augmented with sticky prices, imperfect competition, monetary-policy (Taylor-like) rules, and any other possible types of imperfections[2]. However, DSGE models are not suited to deal with long-run growth issues, since their RBC core prevents them to explore any Schumpeterian source of endogenous innovation.

At the opposite side, endogenous growth models (e.g. Romer, 1990; Aghion and Howitt, 1992; Dinopoulos and Segerstrom, 1999) have a Schumpeterian core, which makes innovation and the ensuing dynamics in technology endogenous. However, there is no room for demand-driven fluctuations in this set of models even if some of them (e.g. Aghion and Howitt, 1998; Aghion et al., 2010; Aghion and Marinescu, 2007; Aghion et al., 2008) allow for *equilibrium fluctuations* wherein Keynesian features do not have any role.

This issue is also present in evolutionary models (Nelson and Winter, 1982). They are driven indeed by a Schumpeterian engine with endogenous innovations, but they do not take sufficiently into account any demand-related forces affecting macroeconomic activity[3].

Our model has evolutionary roots and explicitly account for endogenous technological search, heterogenoeus "boundedly rational" agents and competitive dynamics entailing some form of market selection across firms and through that across technologies — all fundamental building blocks of evolutionary interpretations of economic dynamics (following the seminal Nelson and Winter, 1982). However, unlike most "first generation" evolutionary models it abandons any assumption of market clearing neither on the labour or the product markets and in line with some New Keynesians insights (cf. for example Stiglitz, 1994), it tries to study the feedbacks between the factors affecting aggregate demand and those influencing technological change. This allows us to develop a unified framework where one can jointly study long-term dynamics and business cycles.

The model belongs to the growing literature on *agent-based computational economics*

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[2]As Blanchard (2009, p. 26) puts it, "To caricature only slightly: a macroeconomic article today follows strict, haiku-like, rules: it starts from a general equilibrium structure, in which individuals maximize the expected present value of utility, firms maximize their value, and markets clear. Then, it introduces a twist, be it an imperfection or the closing of a particular set of markets, and works out the general equilibrium implications. It then performs a numerical simulation, based on calibration, showing that the model performs well. It ends with a welfare assessment."

[3]See, however, Dosi et al. (1994) for an exception. See also Dawid (2006) for an exhaustive survey of ABMs of innovation and technical change.

(ACE; see Tesfatsion and Judd, 2006; LeBaron and Tesfatsion, 2008) and it thus allows for many heterogeneous agents who interact without any ex ante commitment to the reciprocal consistency of their actions (e.g. market clearing)[4]. The model thus satisfies Solow's call fro micro heterogeneity (Solow, 2008).

Furthermore, the model, in line with most ABMs, is grounded on a "realistic" representation of what agents do, how they adjust, etc.. In that, it provides an explicit microfoundation of macro dynamics. At the same time, we try to describe microbehaviors as close as possible to the available micro empirical evidence. This is in line with Akerlof's plea for "behavioral microeconomics" (Akerlof, 2002). In this way, we reduce our degrees of freedom in modelling agents' behavior. Moreover, we test the capability of the model to jointly account for a large set of stylized facts related to "micro/meso" aggregates (e.g. firm size and growth-rate distributions, productivity dispersions, firm investment patterns) together with macro statistical properties (e.g. persistent output growth, output volatility, unemployment rates, etc.).

The model portrays an artificial economy composed of capital- and consumption-good firms, workers, a bank, and the public sector. Capital-good firms perform R&D and produce heterogeneous machine tools. Consumption-good firms invest in new machines and produce a homogeneous consumption good. Firms finance their production and investment choices employing internal funds as well as credit provided by the banking sector. Finally, the public sector levies taxes on firm profits and worker wages and pay unemployment benefits.

As every ABM, the properties of the model must be analyzed via extensive computer simulations. To overcome the usual problems, shared by many ABMs, related to parameterization sensitivity[5], we look for policy results that: (i) are robust to reasonable changes in the parameters of the model; (ii) stem from model setups and parametrizations wherein the output of the model is empirically validated (i.e., the statistical properties of simulated microeconomic and macroeconomic data are similar to those observed in reality). We think that this is a positive feature of our study, because very often in the literature no empirical validation constraints are imposed on policy experiments results (Fukac and Pagan, 2006; Canova, 2008; Fagiolo and Roventini, 2011). Moving to the normative side, different "control" parameters and institutional, market, or industry setups can mimic different public policies, whose impact is then quantitatively assessed by employing ensuing aggregates such as average output growth, output volatility, average unemployment, etc.

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[4]For ABMs with both some Keynesian and Schumpeterian features, see Verspagen (2002), Ciarli et al. (2008), Saviotti and Pyka (2008), and the discussion in Silverberg and Verspagen (2005). See also the EURACE large-scale ABM aiming at capturing the main characteristics of the European economy and addressing European-policy analyses (Dawid et al., 2008).

[5]See Fagiolo et al. (2007) for a discussion and the special issue on "Agent-Based Models for Economic Policy Design" of the *Journal of Economic Behavior and Organization*, 2008 (vol. 67, no. 2), edited by Herbert Dawid and Giorgio Fagiolo. More on that in Section 3.

Extensive empirical validation exercises show that the model is able to deliver self-sustaining patterns of growth characterized by the presence of endogenous business cycles. Moreover, the model is also able to replicate the most important stylized facts concerning macroeconomic dynamics (e.g. cross-correlations, relative volatilities) as well as microeconomic dynamics (e.g. firm size distributions, firm productivity dynamics, firm investment patterns).

Our policy-simulation exercises show a strong complementarity between Schumpeterian technology policies and Keynesian fiscal policies. Both types of policies are needed to put the economy onto a long-run steady growth path. Schumpeterian policies foster economic growth, but they are not able alone to sustain long-run high economic growth patterns characterized by mild business cycle fluctuations and low unemployment. If Keynesian policies are present, Schumpeterian policies affect also the performance of the economy in the short-run, contributing to reduce output volatility and unemployment. Moreover, Keynesian policies are the best instrument to tackle short-run problems, having a strong impact on output volatility and unemployment. Furthermore, we show that monetary policy can have strong effects on growth as well. In particular, high interest rates not only exacerbate volatility and unemployment rates, they are also able to worsen the long-run growth prospects of the economy. Our results also point to a strong interplay between monetary policy and the income distribution characteristics of the economy. More specifically, on the one hand, income distributions that are more favorable to wages stabilize aggregate consumption demand and lower both volatility and unemployment. On the other hand, lower profit rates magnify the effects of changes in interest rates by increasing the dependence of firms on external financing from the bank.

The rest of the paper is organized as follows. Section 2 describes the model. In Section 3 we perform empirical validation checks and in Section 4.2 we present results of policy exercises. Finally, Section 5 concludes and discusses future extensions.

2   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 bank, 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 bank provides credit to firms using firm savings. Credit is allotted to firms on a pecking-order basis according to their net worth. Moreover, the supply and the dynamics of debt of the firms in the economy can be influenced by various policy instruments (capital requirements, mandatory reserves, interest rates). Finally, the public sector levies taxes on firms' profits and pays unemployment benefits.

2.1 The Timeline of Events

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

1. Policy variables (e.g. central bank interest rate, reserve requirement, tax rate, unemployment benefits, etc.) are fixed.

2. Total credit provided by the bank to each firm 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 firms.

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 the 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 the bank and deposit their savings.

8. Entry and exit take place. In both sectors firms with near zero market shares and negative net worth are eschewed from their industry 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.

2.2 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[6], 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 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 $w(t)$[7]. Firms split their R&D efforts between innovation (IN) and imitation (IM) according to the parameter $\xi \in [0, 1]$[8]:

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

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

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:

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

with $0 < \zeta_1 \leqslant 1$. Note that according to 4, there are some scale-related returns to R&D

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

[7]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).

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

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 their 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 different technologies 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 2.3), capital-good firms select the machine to produce according to the following rule:

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

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 $0 < \gamma < 1$).

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2.3 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):

$$D_j^e(t) = f(D_j(t-1), D_j(t-2), \ldots, D_j(t-h)), \qquad (7)$$

where $D_j(t-1)$ is the demand actually faced by firm j at time $t-1$ (h positive integer)[9]. 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):

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

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[10]:

$$EI_j^d(t) = K_j^d(t) - K_j(t). \qquad (9)$$

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[11]. 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:

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

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-tools satisfying Equation 10[12].

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[9]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.

[10]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).

[11]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.

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

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 2.2) 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[13]. 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 as well as their production, as they advance worker wages. In line with a growing number of theoretical and empirical papers (e.g. Stiglitz and Weiss, 1992; Greenwald and Stiglitz, 1993a; Hubbard, 1998) 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. More specifically, consumption-good firms finance production using their stock of liquid assets (NW_j). If liquid assets do not fully cover production costs, firms borrow the remaining part from a bank paying an interest rate r_L. The maximum amount of credit lent by the bank to firm j ($TC_j(t)$) is a positive function of firm's stock of liquid assets as well as firm's size proxied by its past sales (see Section 2.4 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[14].

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:

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

Markup variations are regulated by the evolution of firm market shares (f_j)[15]:

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

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

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

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

[15]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).

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[16]. 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, expansions, contractions and extinctions 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, 1994a):

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

with $\chi > 0$[17].

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 $Deb_j(t)$ denotes the stock of debt. The investment choices of each firm and its profits determine the evolution of its net worth ($NW_j(t)$):

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

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[16]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.

[17]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.

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

2.4 The Banking Sector

In the banking sector there is only one commercial bank (or n commercial banks that are equal) that gathers deposits and provides credit to firms. In what follows, we first describe how total credit is determined by the 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 balance sheet of the bank. Finally, we describe how profits and net worth of the bank are determined.

The maximum credit available in the economy is set by the credit multiplier. More precisely, in each period the bank reinvests in credit the funds obtained through deposits from firms. This amount of credit returns to bank in the form of deposits. The bank then subtracts 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 total deposits obtained from the above procedure, $Dep(t-1)$, are determined as:

$$Dep(t-1) = \frac{\sum_{i=1}^{N1} NW_i(t-1) + \sum_{j=1}^{N2} NW_j(t-1)}{\alpha_R}, \quad 0 \leq \alpha_R \leq 1 \qquad (14)$$

where, $\sum_{i=1}^{N1} NW_i(t-1)$ and $\sum_{j=1}^{N2} NW_j(t-1)$ is total net worth of upstream and downstream firms at time $t-1$.

From the above equation, it follows that total credit available in the economy at time t, $MTC(t)$ is:

$$MTC(t) = (1 - \alpha_R)Dep(t-1). \qquad (15)$$

Total credit is allocated to each firm in the consumption-good sector on a pecking order basis, according to the ratio between net worth and sales, $\frac{NW_j(t)}{S_j(t)}$. 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 the total credit available is insufficient to fulfill the demand of all the firms in the pecking order list, the firms that are credit rationed go bankrupt. On the other hand, the total demand for credit can also be lower than the 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:

$$\sum_{j=1}^{N2} Deb_j(t) = Loan(t) \leqslant TC(t). \qquad (16)$$

The profits of the bank are equal to interest rates receipts from reedemable loans and from interests on reserves held at the central bank minus interests paid on deposits.

Furthermore, the bank fixes its deposit and loan rates applying respectively a mark-down and a mark-up on the central bank rate r. For simplicity we assume that bank reserves, $Cash(t)$, are remunerated at the same rate of deposits:

$$r_D = (1 - \psi_D)r, \quad 0 \leq \psi_D \leq 1 \tag{17}$$

$$r_L = (1 + \psi_L)r, \quad 0 \leq \psi_L \leq 1 \tag{18}$$

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

$$\pi^b(t) = r_L\left(Loan(t)\right) - r_D Dep(t) + r_D Cash(t-1). \tag{19}$$

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

$$NW^b(t) = Cash(t) + \pi^b(t) - BD(t) = NW^b(t-1) + \Delta Cash(t) + \pi^b(t) - BD(t) \tag{20}$$

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

2.5 Schumpeterian Exit and Entry Dynamics

At the end of each period a firm exit for two reasons: i) competition, i.e. the firm has a (quasi) zero market share; or ii) bankruptcy, i.e. firm's net worth becomes negative and the bank is not willing to provide additional credit. If a firm fail, the stock of bad debt of the bank is increased accordingly.

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 one of the incumbents[18]. Concerning the

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[18]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 $[\phi_3, \phi_4], 0 < \phi_3, < \phi_4 \leqslant 1$.

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[19]. 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).

2.6   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 a function of 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:

$$\frac{\Delta w(t)}{w(t-1)} = g\left(\frac{\Delta cpi(t)}{cpi(t-1)}, \frac{\Delta \overline{AB}(t)}{\overline{AB}(t-1)}, \frac{\Delta U(t)}{U(t-1)}\right), \tag{21}$$

where *cpi* is the consumer price index, $\overline{AB}$ is the average labor productivity, and U is the unemployment rate[20].

2.7   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 levers 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:

$$C(t) = c[w(t)L^D(t) + w^u(L^S - L^D(t)) + r_D(1-c)C(t-1)]. \tag{22}$$

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[19]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.

[20]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).

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 heterogeneous, 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.).

3   Empirical Validation

The foregoing model does not allow for analytical, closed-form solutions. This general ABM distinctive feature stems from the non-linearities present in agent decision rules and their interaction patterns, and it forces us to run computer simulations to analyze the properties of the stochastic processes governing the co-evolution of micro and macro variables[21]. In what follows, we therefore perform extensive Monte-Carlo analyses to wash away cross-simulation variability. Consequently, all results below refer to averages over one hundred Monte-Carlo replications[22].

Let us start from a sort of "benchmark" setup for which the model is empirically validated, i.e. it is studied in its ability to replicate a wide spectrum of microeconomic and macroeconomic stylized facts. Initial conditions and parameters of the benchmark setup are presented in Table 1. As already mentioned, 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. Hence, the benchmark model appropriately embodies all such Schumpeterian and Keynesian features.

Next, we tune so to speak "up" and "down" the key policy variables (e.g. tax rates and unemployment benefits, interest rates) and we experiment with different conditions

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[21]Some methodological issues concerning the exploration of the properties of evolutionary/ACE models are discussed in e.g. Lane (1993); Pyka and Fagiolo (2007); Fagiolo et al. (2007); Fagiolo and Roventini (2011).

[22]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.

affecting the access to and exploitation of new technological opportunities (e.g. the patent regime, anti-trust policies) or the distribution of income between profits and wages (mark-up rates of firms).

Let us first explore the ability of the model to reproduce the major stylized facts regarding both the properties of macroeconomic aggregates and the underlying distribution of micro characteristics (more on both in the direct antecedents to this model: cf. Dosi et al., 2006, 2008).

Growth and Fluctuations. The model is able to robustly generate endogenous self-sustained growth patterns characterized by the presence of persistent fluctuations (cf. Figure 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 Figure 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 by more quantitative analyses. Table 2 reports descriptive statistics on output, consumption and investment time series. As the table clearly shows, output, consumption and investment display strictly-positive average growth rates[23] (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 (see respectively Tables 2 and 3). 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, investment, change in inventories, and employment are procyclical; unemployment is countercyclical. Consumption and net investment are also coincident variables matching yet another empirical regularity on business cycles. Changes in inventories are instead slightly lagging[24].

Furthermore, the model is also able to match the business-cycle properties concerning productivity, labor market, and price variables (see Figs. 5-8, which display across simula-

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[23]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 experiment show that choosing larger values for T does not alter the main economic implications of the paper.

[24]In addition, aggregate growth rates of output display fat-tailed distributions (not shown) well in tune with the empirical evidence (see Castaldi and Dosi, 2008; Fagiolo et al., 2008). 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 discussion on firm growth patterns below).

tions average cross-correlations with GDP, together with GDP autocorrelation). Indeed, productivity is procyclical, prices are countercyclical and leading; inflation is procyclical and lagging; markups are strongly countercyclical (for the empirics and discussion cf. Stock and Watson, 1999; Rotemberg and Woodford, 1999).

The model is also in line with the major business cycle stylized facts concerning credit (cf. Table 3). Indeed, firms' total debt displays a strong pro-cyclical character. In addition, its fluctuations are contemporaneous to output movements. The cross-correlations in Table 3 also shed light on the characteristics of the credit dynamics underneath business cycles in the model, which has strong "Minskian" features (see Minsky, 1986). First, bank deposits are counter-cyclical and lagging GDP. Moreover, bankruptcy rates are procyclical and lagging GDP dynamics very closely. This behavior is mapping 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 the cost of debt 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, firm-productivity dynamics, firm-investment and firm-bankruptcy patterns which are generated by the model.

Figures 3 and 4 show the rank-size plot of the pooled firm-size in consumption good sector. As the plots indicate quite starkly, firm size distributions are right skewed in both cases 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 in both sectors.

Turning to firm productivity and investment, 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 in both sectors (cf. standard deviations of labor productivity across firms plotted in Figure 5). Furthermore, the model is 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. This implies that business cycles are typically characterized by episodes

of large bankruptcy avalanches. As the plots in Figure 7 clearly shows this empirical evidence is well replicated by our model.

4 Policy Experiments: Tuning Schumpeterian and Keynesian Engines

The model, we have seen, is empirically quite robust in that it accounts, *together*, for a large number of empirical regularities. It certainly passes a much higher "testing hurdle", as Solow (2008) puts it, than simply reproducing "a few of the low moments of observed time series: ratios of variances or correlation coefficients, for instance" (p. 245) as most current models content themselves with. Encouraged by that empirical performance of the model, we turn to experiments with different structural conditions (e.g. concerning the nature of innovative opportunities) and policy regimes, and we study their impact on output growth rates, volatility and rates of unemployment[25].

4.1 Alternative Innovation and Competition Regimes

Consider first the Schumpeterian side of the economy, holding the "Keynesian engine" constant as compared with the benchmark scenario[26]. In this framework, we first turn off endogenous technological opportunities. Note that by doing this, the model collapses onto a barebone 2-sector Solow (1956) model in steady state, with fixed coefficients and zero growth (absent demographic changes).

Opportunities and Search Capabilities. What happens if one changes the opportunities of technological innovation and the ability to search for them? Experiment 1 (Table 4) explores such a case. As compared to the benchmark, we shift rightward and leftward the mass of the Beta distribution governing new technological draws (i.e. the parameters α_1 and β_1, cf. Section 2.2). Note that the support of the distribution remains unchanged, so that one could informally states that the *notional* possibilities of drift in the technological frontier remain unchanged, too. However, the "pool" of opportunities agents actually face get either richer or more rarefied. We find that higher opportunities have a positive impact on the long-term rate of growth, reduce average unemployment and slightly increase GDP volatility (a mark of Schumpeterian "gales of creative destruction"?).

Somewhat similarly, higher search capabilities approximated by the possibilities of accessing "innovations" — no matter if failed or successful ones — (cf. the $\zeta_{1,2}$ parameters in

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[25]Interestingly, many statistical regularities concerning the structure of the economy (e.g. size distributions, fatness of firms growth rates, etc.) appear to hold across an ample parameter range, under positive technological progress, even when policies undergo the changes we study in the following.

[26]The full list of parameters under different policy scenarios is available from the authors on request.

Equations 4 and 5) positively influence the rates of growth and lower unemployment. Together, business cycle fluctuations are dampened possibly because a population of "more competent" firms entails lower degrees of technological asymmetries across them and indeed also lower degrees of "creative destruction". See experiment 2, Table 4.

Note that such role of innovative opportunities and search capabilities is in principle equivalent to that black-boxed into the more aggregate notions of "human capital" (Nelson and Phelps, 1966; Benhabib and Spiegel, 1994) and of "appropriate institutions" (Acemoglu et al., 2006)[27].

Appropriability Conditions. In many current models with a (neo) Schumpeterian engine, appropriability conditions play a key role via their assumptions on the forward looking rationality of the agent(s) investing into uncertain innovative search: the degrees of monopoly appropriation of the economic benefits from successful search parametrize the equilibrium relation between investment in R&D and rates of innovation. In this model, we took a much more behavioral route and assumed a fixed propensity to invest in R&D. Granted that, how do changes in appropriability conditions affect aggregate dynamics?

We try to answer to this question mimicing the effect of a patent system. Under a "length only" patent scenario, the innovative technology cannot be imitated for a given number of periods determined by the patent length (cf. experiment 3.1, Table 4). Such patenting possibility is *detrimental to long-run growth* and also augments the average rate of unemployment. The negative aggregate impact of the patent system is reinforced if each firm cannot innovate in some neighborhood of the other firms' technologies — i.e. in presence of a patent breadth: see experiment 3.2, Table 4[28].

Entry and Competition Policies. Important dimensions of distinct Schumpeterian regimes of innovation regard, first, the advantages/disadvantages that entrants face vis-à-vis incumbents and, second, the market conditions placing economic rewards and punishments upon heterogeneous competitors.

The first theme cuts across the evolutionary and neo-Schumpeterian literature and sometimes is dramatized as a "Schumpeterian Mark I" vs. a "Schumpeterian Mark II" scenarios, meaning systematic innovative advantages for entrepreneurial entrants vs. cumulative advantages of incumbents (cf. Malerba and Orsenigo, 1995; Dosi et al., 1995). In our model, technological entry barriers (or advantages) are captured by the probability distribution over the "technological draws" of entrants. Again, we hold constant the support over which the economy (i.e. every firm thereof) may draw innovative advances, conditional on the technology at any t. In this case we do it for sake of consistency:

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[27]In fact, given the increasing availability of micro data one can start thinking of disaggregated empirical proxies for our variables. The issue is however well beyond the scope of this work.

[28]On purpose, we did not introduce any feedback between changes in IPR regimes and propensities to search.

results, even more so, apply if different regimes are also allowed to entail different probability supports. Let us first tune the Beta distribution parameters α_2 and β_2 (cf. Section 2.5). Our results are broadly in line with the evidence discussed in Aghion and Howitt (2007): *other things being equal*, the easiness of entry and competence of entrants bears a positive impact upon long-term growth, mitigates business cycles fluctuations and reduces average unemployment. See experiments 4.1 and 4.2, Table 4. However, the *ceteris paribus* condition is equally important: the same aggregate growth patterns can be proved to be equally guaranteed by competent cumulative learning of incumbents (see, above, the exercises on search capabilities).

What about competitive conditions? We introduce antitrust policies by forbidding capital-good firms to exceed a given market share (75% in experiment 5.1 and 50% in experiment 5.2, Table 4): the outcome is a lower unemployment rate, smaller business cycle fluctuations and also higher GDP growth (on this point see also Fogel et al., 2008). Note that such a property has little to do with any static "welfare gains" — which our model does not explicitly contemplate — but it rather relates to the multiplicity of producers, and thus of innovative search avenues, which antitrust policies safeguard[29].

4.2   Fiscal and Monetary Policies

We now focus on the effects of Keynesian policies. More precisely, following Dosi et al. (2010) we check whether the "Schumpeterian" dynamics embedded in the model is enough to generate sustained and steady growth, or whether instead this can be reached only if Keynesian aggregate demand policies are also well in place. Table 5 and Figure 8 present the results of the experiments.

First, simulation results show that Keynesian policies have a strong triggering effect on long-run average growth rates. If both tax rate and unemployment subsidy are set to zero, the economy is trapped in an (almost) zero growth pattern characterized by extreme fluctuations and persistently high unemployment. Tuning up fiscal policies does delock the economy from the "bad" trajectory and brings it to the "good" (high growth) one, which also our benchmark scenario happens to belong to (cf. Table 5 and Figure 8). If one further increases both the tax rate and the unemployment benefits, average output growth rates do not change as compared to the benchmark scenario, but output volatility and unemployment significantly fall, and the economy spends more time in full employment (cf. again Table 5 and Figure 8)[30].

The above results confirm that the Schumpeterian engine alone is not enough to guar-

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[29]The thrust of our results on policies affecting entry, competition, and variety preservation are indeed broadly in tune with the advocacy for "evolutionary technology policies" in Metcalfe (1994b), while it runs against the so-called "Schumpeterian hypothesis" according to which degrees of industrial concentration should be conducive to higher rates of innovation.

[30]On the long-run growth-enhancing effects of countercyclical macroeconomic policies, see the empirical evidence provided by Aghion and Marinescu (2007).

antee steady growth in the model. Robust Keynesian policies must be well in place both to dampen output fluctuations and to sustain long-run growth[31]. This pervasive effect follows from the fact that counter-cyclical redistributive policies act as a parachute during recessions, sustaining consumption and, indirectly, investment on the demand side. In addition, the introduction and diffusion of new technologies in the economy rest upon sustained and stable investments in R&D and in new machines, which in turn are viable only in presence of stable consumption demand.

Distributional aspects also play an important role in shaping the aggregate dynamics of the economy in the model. In order to further explore this insight, we conduct experiments on monetary policy under different income distribution scenarios. More specifically, we ran several Monte-Carlo experiments by varying the level of the interest rate, and we repeat these experiments for high and low levels of consumption-good firms' mark-up rate. Note that firms' mark-ups have two important effects in the model. First, they tune the distribution of productivity gains between wages and profits. In particular, higher (lower) mark-up rates imply that firms (workers) appropriate a larger share of productivity gains in the economy. Second, by tuning the level of firm's profits, mark-up rates impact upon the growth pace of firms' internal funds, thereby determining the degree of dependence of firms from external financing. It follows that higher (lower) levels of firms' mark-up imply lower (higher) degrees of financial dependence of firms and therefore lower (higher) sensitivities of firms' balance sheets to changes in interest rates.

The results of the above described experiments are reported in Table 6. Let us discuss the main findings emerging from the table. First, interest rates have a significant effects on GDP volatility, unemployment and the probability of crises. Indeed, rising (lowering) the interest rate raises the levels of all the three foregoing variables. Furthermore, interest rates have an important effect on average growth rate as well. More precisely, raising interest rates has negligible effects on average growth rate up to a threshold — increasing with the mark-up rate — above which higher levels of interest rate lock the economy into a low-growth path. This outcome is in line with the above discussed results on fiscal policies and provides further support to the claim that active Keynesian policies (both fiscal and monetary) have not only a stabilizing effect, but they do also impact on the long-run performance of the aggregate economy.

Finally, the experiments in Table 6 reveal other interesting features regarding the interplay between income distribution and the overall dynamics of the economy. Indeed, low mark-up rates result, *ceteris paribus*, in a sharp reduction of the levels of output

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[31]We also ran Monte-Carlo experiments to check the robustness of Keynesian properties of the system to alternative institutional regimes governing the labor market captured by the parameters affecting the wage rate (cf. Eq. 21). In particular, we allow wages to move as a (negative) function of the unemployment rate. Under these "classical" circumstances, wages may fall during recessions, inducing price cuts, which in turn may increase output, supposedly weakening the case for Keynesian fiscal policies. However, these experiments suggest that the dynamics of the systems are largely independent of how wages are determined. More on that in Dosi et al. (2010).

volatility and average unemployment. In contrast, the effects of changes in interest rates is significantly magnified at lower mark-up rates. Two distinct mechanisms underly these results. The first one is real and is implied by the fact that lower mark-up levels move the distribution of income in favor of wages, thus stabilizing consumption dynamics (*redistributive effect*). The second mechanism is financial, and displays its effect via the higher financial dependence of firms implied by low levels of mark-up (*financial dependence effect*, see above). These results also militate in favor of the conjecture (e.g. Kaldor, 1955, and more recently Fitoussi and Saraceno, 2010) that more equal economies are also economies characterized by milder fluctuations and by a lower occurrence of crises. In addition, they hint to the fact that demand policies are much more effective in regimes characterized by low income inequality.

5   Concluding Remarks

In this paper we have studied the properties of an agent-based model that bridges Schumpeterian theories of technology-driven economic growth with Keynesian theories of demand generation.

The model is characterized by the presence of both a real and a banking sector. On the real side, 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 by the credit provided by the banking sector. The bank employs firm savings to finance firm production and investment activities according to a credit multiplier rule.

A central question that we address in the work is whether the "Schumpeterian engine" by itself is able to maintain the economy on a steady growth path characterized by full employment. We find that this is not the case: the endogenous innovation engine is able to do that only in presence of a "Keynesian" demand-generating engine, captured in the model by fiscal and monetary policies.

Our results cast serious doubts on the traditional dichotomy between variables affecting long-run growth (typically, technology-related changes) and variables impacting on short-run business fluctuations (traditional demand-related variables). First, we find that technological innovations appear to exert their effects at all frequencies. Second, Key-

nesian demand-management policies do not only contribute to reduce output volatility and unemployment rates, but for a large set of parameterization, they affect also long-run growth rates insofar as they contribute to "delock" the economy from the stagnant growth trajectory which is indeed one of the possible emergent meta-stable states. Finally, our results indicate that bank credit and monetary policies can heavily affects business cycles dynamics by amplifying micro level technology and supply shocks. In this respect, our results point to the different effects of monetary policies in presence of different income distributions between profits and wages.

In the future, we plan to further exploit the flexibility and modularity of our agent-based model to study new policies experiments under different institutional setups. In particular, given the current worldwide crisis, an obvious direction of development ought to deeply study credit and financial markets. More specifically, we will employ the model to assess i) how financial crises can emerge; ii) which policies (e.g. monetary vs. fiscal policies) are more suitable to cope with financial shocks; iii) how the regulatory framework of the banking and the financial sectors (e.g. Basel-like capital requirements) can prevent the formation of financial crises; iv) how the market structure of the banking sector (e.g. regional vs. big national banks) can amplify or dampen the effects financial shocks. To explore the last point, we will introduce heterogeneous banks in the model taking into account the emerging credit network structure between them and between banks and the firms.

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Description	Symbol	Value
Number of firms in capital-good industry	F_1	50
Number of firms in consumption-good industry	F_2	200
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
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
Bank mark-up coefficient	ψ_L	0.50
Bank mark-down coefficient	ψ_D	1

Table 1: Benchmark Parameters

	Output	Consumption	Investment
Avg. growth rate	0.0254	0.0252	0.0275
	(0.0002)	(0.0002)	(0.0004)
Dickey-Fuller test (logs)	6.7714	9.4807	0.2106
	(0.0684)	(0.0957)	(0.0633)
Dickey-Fuller test (Bpf)	-6.2564^*	-5.8910^*	-6.8640^*
	(0.0409)	(0.0447)	(0.0905)
Std. Dev. (Bpf)	0.0809	0.0679	0.4685
	(0.0007)	(0.0005)	(0.0266)
Rel. Std. Dev. (output)	1	0.8389	5.7880

Table 2: Output, Investment, and Consumption Statistics. Bpf: bandpass-filtered (6,32,12) series. Monte-Carlo simulation standard errors in parentheses. ($*$): Significant at 5%.

Series (Bpf)	Output (Bpf)								
	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4
Output	-0.1022	0.1769	0.5478	0.8704	1	0.8704	0.5478	0.1769	-0.1022
	(0.0090)	(0.0080)	(0.0048)	(0.0014)	(0)	(0.0014)	(0.0048)	(0.0080)	(0.0090)
Consumption	-0.1206	0.0980	0.4256	0.7563	0.9527	0.9248	0.6848	0.3394	0.0250
	(0.0123)	(0.0129)	(0.0106)	(0.0062)	(0.0017)	(0.0018)	(0.0038)	(0.0058)	(0.0072)
Investment	-0.2638	-0.3123	-0.2646	-0.0864	0.1844	0.4473	0.5950	0.5757	0.4206
	(0.0102)	(0.0137)	(0.0182)	(0.0210)	(0.0206)	(0.0175)	(0.0139)	(0.0123)	(0.0129)
Net Investment	-0.0838	0.0392	0.2195	0.4010	0.5114	0.5037	0.3850	0.2105	0.0494
	(0.0122)	(0.0167)	(0.0216)	(0.0235)	(0.0211)	(0.0153)	(0.0103)	(0.0112)	(0.0138)
Ch. in Invent.	0.0072	0.1184	0.2349	0.2948	0.2573	0.1331	-0.0199	-0.1319	-0.1640
	(0.0081)	(0.0070)	(0.0060)	(0.0072)	(0.0090)	(0.0098)	(0.0097)	(0.0085)	(0.0067)
Employment	-0.3240	-0.1901	0.0796	0.4083	0.6692	0.7559	0.6451	0.4067	0.1555
	(0.0087)	(0.0123)	(0.0151)	(0.0160)	(0.0149)	(0.0120)	(0.0084)	(0.0069)	(0.0082)
Unempl. Rate	0.3357	0.2084	-0.0596	-0.3923	-0.6607	-0.7550	-0.6489	-0.4112	-0.1583
	(0.0083)	(0.0118)	(0.0147)	(0.0158)	(0.0148)	(0.0120)	(0.0084)	(0.0070)	(0.0082)
Productivity	0.1180	0.3084	0.5316	0.7108	0.7672	0.6656	0.4378	0.1664	-0.0609
	(0.0097)	(0.0088)	(0.0092)	(0.0093)	(0.0076)	(0.0067)	(0.0097)	(0.0126)	(0.0128)
Price	0.2558	0.3181	0.2702	0.0916	-0.1645	-0.3950	-0.5067	-0.4688	-0.3249
	(0.0167)	(0.0218)	(0.0235)	(0.0216)	(0.0198)	(0.0212)	(0.0225)	(0.0210)	(0.0176)
Inflation	-0.1070	0.0841	0.3110	0.4456	0.4021	0.1966	-0.0628	-0.2478	-0.2900
	(0.0151)	(0.0135)	(0.0175)	(0.0226)	(0.0228)	(0.0188)	(0.0154)	(0.0146)	(0.0131)
Mark-up	0.2183	0.1599	0.0411	-0.0988	-0.2040	-0.2361	-0.1968	-0.1226	-0.0580
	(0.0118)	(0.0088)	(0.0128)	(0.0184)	(0.0213)	(0.0206)	(0.0174)	(0.0135)	(0.0107)
Total Debt	0.1225	0.2460	0.3793	0.4848	0.5250	0.4824	0.3691	0.2203	0.0763
	(0.0249)	(0.0229)	(0.0211)	(0.0216)	(0.0238)	(0.0253)	(0.0243)	(0.0212)	(0.0173)
Bank Deposits	-0.0907	-0.2375	-0.3659	-0.4322	-0.4154	-0.3264	-0.2001	-0.0760	0.0196
	(0.0215)	(0.0171)	(0.0127)	(0.0118)	(0.0144)	(0.0168)	(0.0171)	(0.0157)	(0.0138)
Bankruptcy Rate	0.1077	0.2667	0.3827	0.4104	0.3424	0.2132	0.0776	-0.0202	-0.0667
	(0.0082)	(0.0120)	(0.0159)	(0.0178)	(0.0170)	(0.0144)	(0.0127)	(0.0128)	(0.0132)

Table 3: Correlation Structure. Bpf: bandpass- filtered (6,32,12) series. Monte-Carlo simulation standard errors in parentheses.

Experiment	Description	Avg. GDP Growth Rate	GDP Std. Dev. (Bpf)	Avg. Unemployment
0	benchmark scenario	0.0254	0.0809	0.1072
		(0.0002)	(0.0007)	(0.0050)
1.1	low technological opportunities	0.0195	0.0794	0.1357
		(0.0001)	(0.0008)	(0.0050)
1.2	high technological opportunities	0.0315	0.0828	0.1025
		(0.0002)	(0.0007)	(0.0051)
2.1	low search capabilities	0.0231	0.0825	0.1176
		(0.0002)	(0.0008)	(0.0059)
2.2	high search capabilities	0.0268	0.0775	0.1031
		(0.0002)	(0.0008)	(0.0048)
3.1	patent (length only)	0.0242	0.0761	0.1132
		(0.0002)	(0.0008)	(0.0060)
3.2	patent (breadth, too)	0.0163	0.0631	0.1329
		(0.0001)	(0.0007)	(0.0067)
4.1	low entrant expected productivity	0.0183	0.0798	0.1402
		(0.0003)	(0.0012)	(0.0084)
4.2	higher entrant expected productivity	0.0376	0.0697	0.0853
		(0.0002)	(0.0006)	(0.0047)
5.1	weak antitrust	0.0265	0.0698	0.1036
		(0.0002)	(0.0006)	(0.0043)
5.2	strong antitrust	0.0273	0.0508	0.0837
		(0.0001)	(0.0005)	(0.0036)
6	Schumpeter-only, no fiscal policy	0.0110	1.5511	0.7855
		(0.0018)	(0.0427)	(0.0274)

Table 4: Schumpeterian Regime Technological and Industrial Policy Experiments. Bpf: bandpass-filtered (6,32,12) series. Monte-Carlo simulations standard errors in parentheses.

Tax Rate	Unemployment Subsidy (in % of wages)	Avg. GDP Growth Rate	GDP Std. Dev. (Bpf)	Avg. Unemployment
0	0	0.0035	1.5865	0.8868
		(0.0012)	(0.0319)	(0.0201)
0.05	0.20	0.0254	0.1539	0.1952
		(0.0002)	(0.0025)	(0.0086)
0.10	0.40	0.0252	0.0809	0.1072
		(0.0002)	(0.0007)	(0.0050)
0.15	0.60	0.0251	0.0630	0.0846
		(0.0002)	(0.0005)	(0.0034)
0.20	0.80	0.0254	0.0584	0.0602
		(0.0002)	(0.0006)	(0.0027)
0.25	1	0.0252	0.0564	0.0551
		(0.0002)	(0.0005)	(0.0023)

Table 5: Keynesian Regime Fiscal Policy Experiments. Bpf: bandpass- filtered (6,32,12) series. Monte-Carlo simulations standard errors in parentheses.

Description	Avg. GDP Growth	GDP Std. Dev. (bpf)	Avg. Unempl.	Prob. of large neg. growth $(< -3\%)$
High Mark-Up				
r=0.00001	0.0277	0.0749	0.0382	0.1618
r=0.05	0.0277	0.0739	0.0435	0.1488
r=0.1	0.0277	0.0760	0.0538	0.1431
r=0.15	0.0288	0.0777	0.0488	0.2102
r=0.2	0.0291	0.0898	0.0604	0.2799
r=0.35	0.0250	0.2056	0.1333	0.3699
r=0.4	0.0144	0.3633	0.3549	0.3878
Low Mark-Up				
r=0.00001	0.0274	0.0541	0.0191	0.1012
r=0.05	0.0281	0.0469	0.0145	0.0908
r=0.1	0.0290	0.0505	0.0180	0.1329
r=0.15	0.0298	0.0623	0.0217	0.2439
r=0.2	0.0288	0.1460	0.0586	0.3885
r=0.35	0.0099	0.4164	0.4546	0.4482
r=0.4	0.0010	0.4268	0.6346	0.4711

Table 6: Effects of Interest Rate for Different Mark-Up Rates
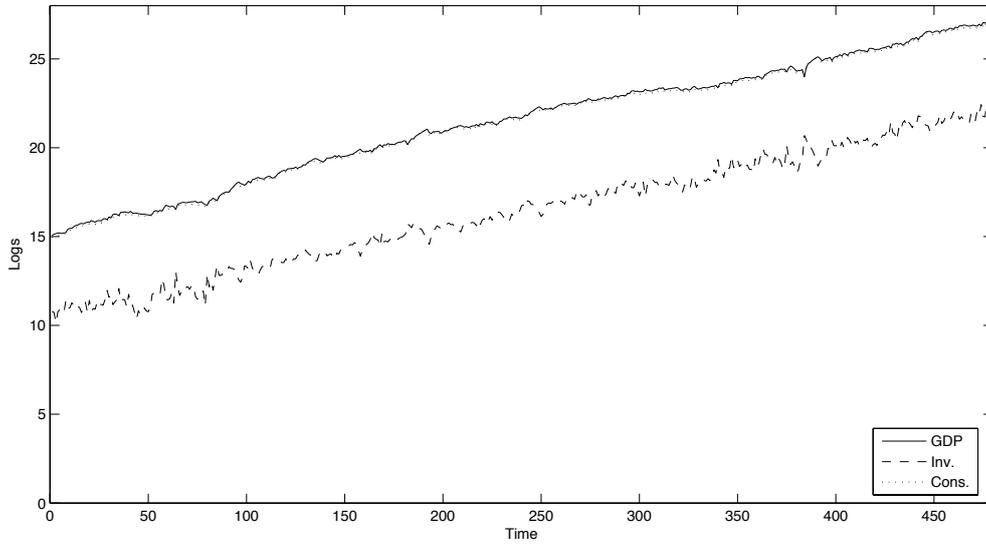
Figure 1: Level of Output, Investment, and Consumption (logs)
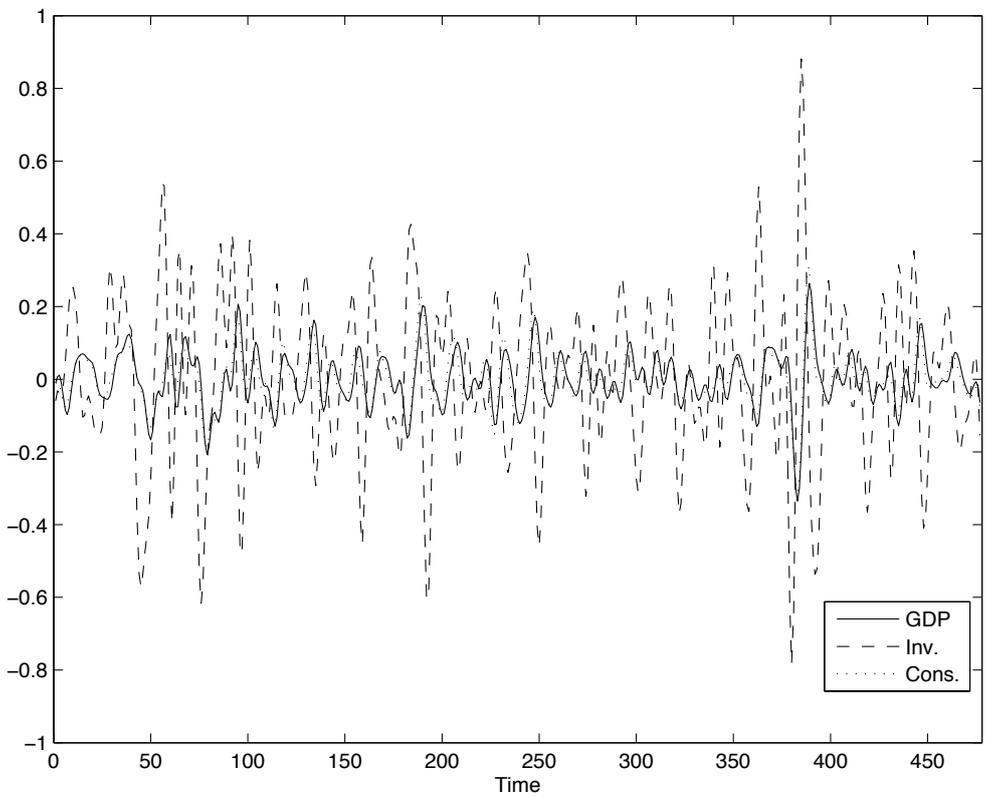
Figure 2: Bandpass-Filtered Output, Investment, and Consumption
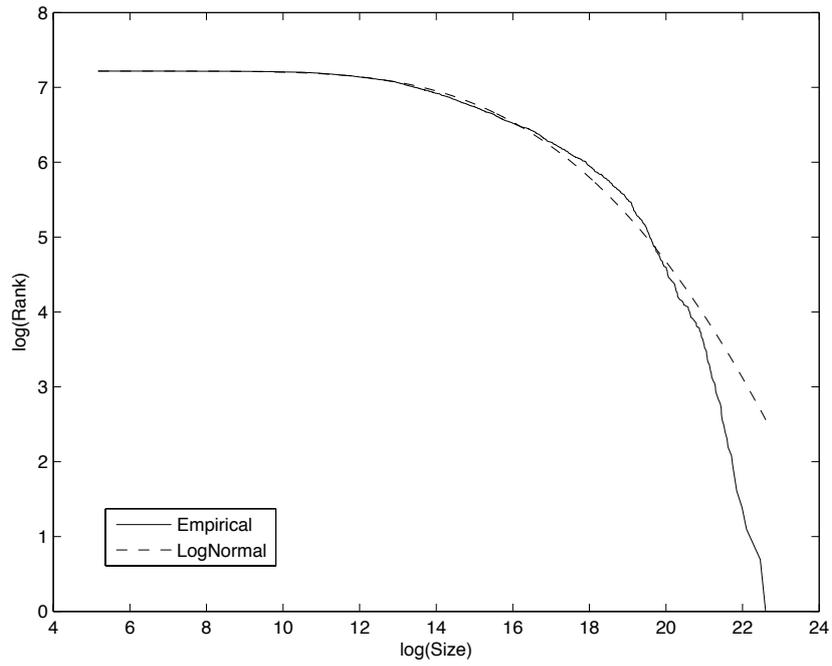
Figure 3: Pooled (Year-Standardized) Capital-good Firm Sales Distributions. Log Rank vs. Log Size Plots.
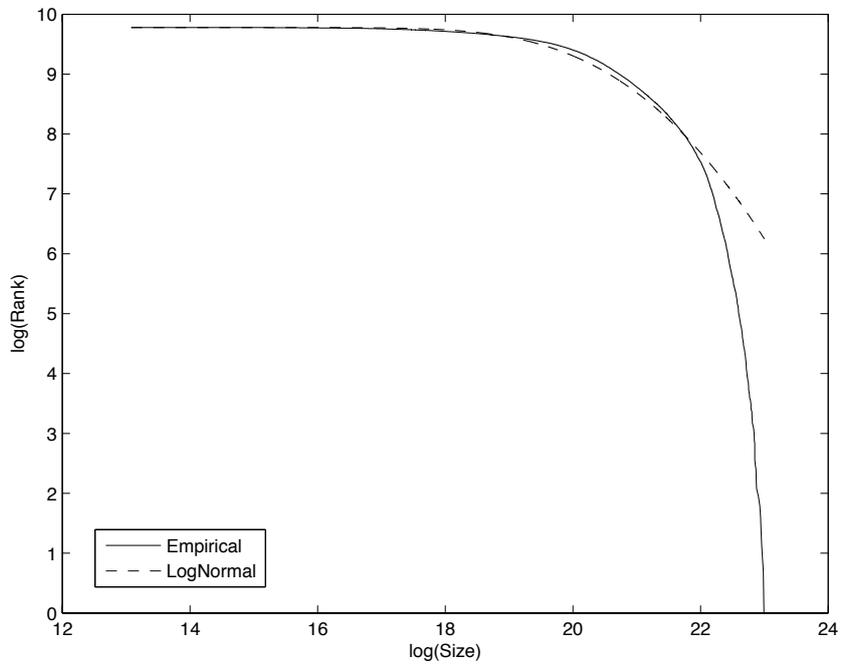

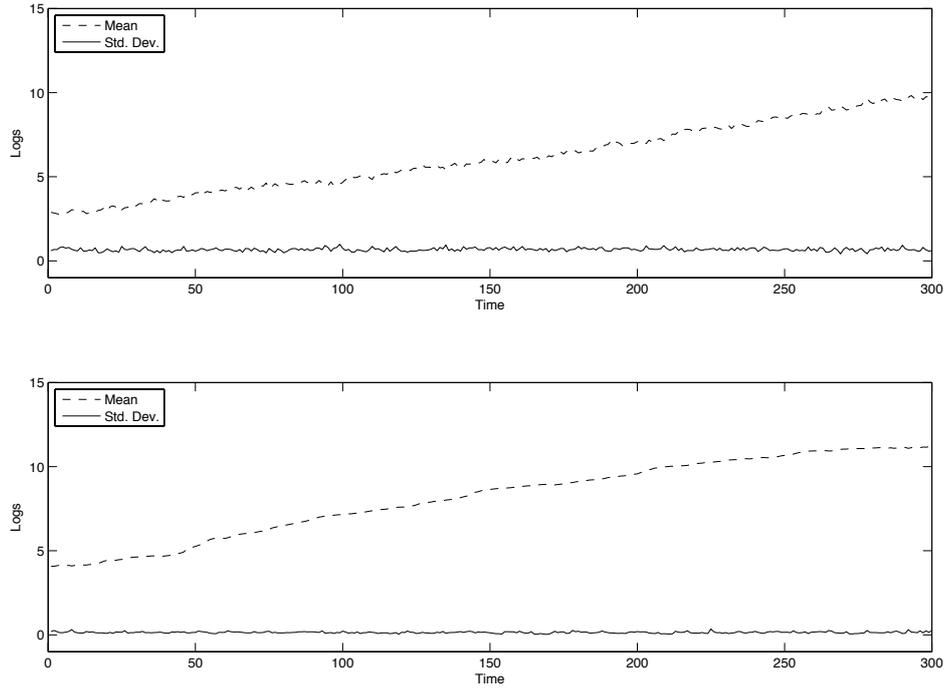Figure 4: Pooled (Year-Standardized) Consumption-good Firm Sales Distributions. Log Rank vs. Log Size Plots.

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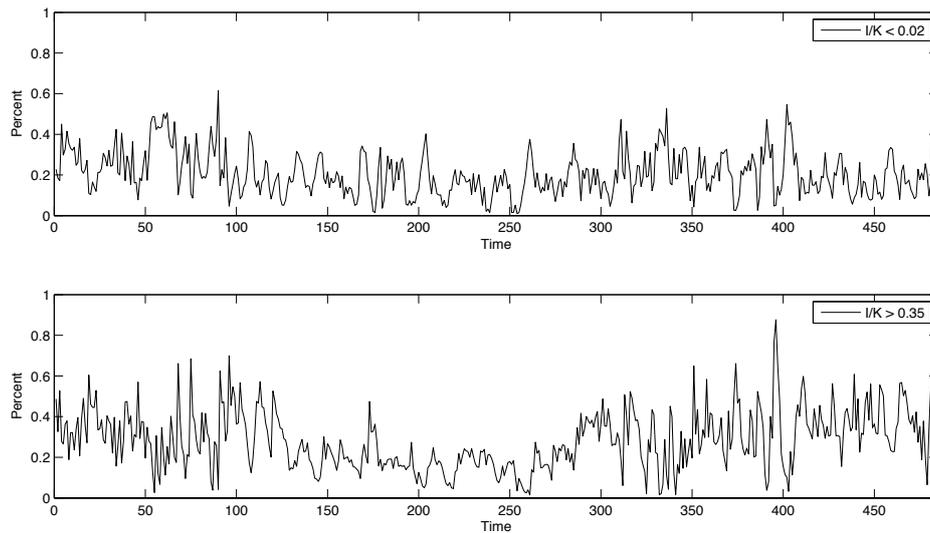Figure 5: Firms' Productivity Moments (logs). First panel: capital-good firms. Second panel: consumption-good firms.

Figure 6: Investment Lumpiness. First panel: share of firms with (near) zero investment; second panel: share of firms with investment spikes.
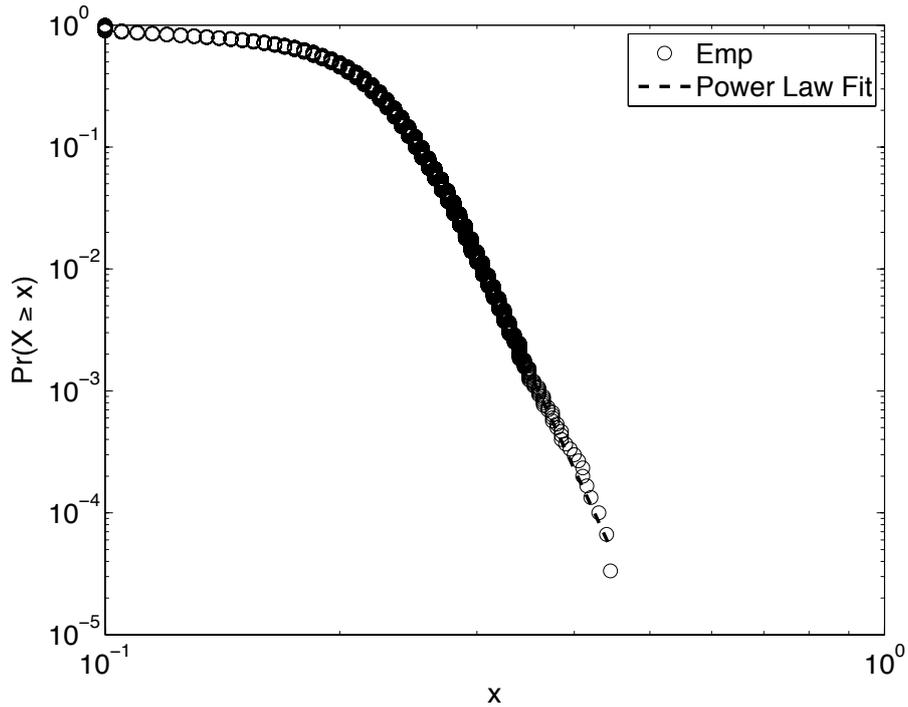
Figure 7: Empirical distribution of consumption-good firms bankruptcy rate together with power-law fit
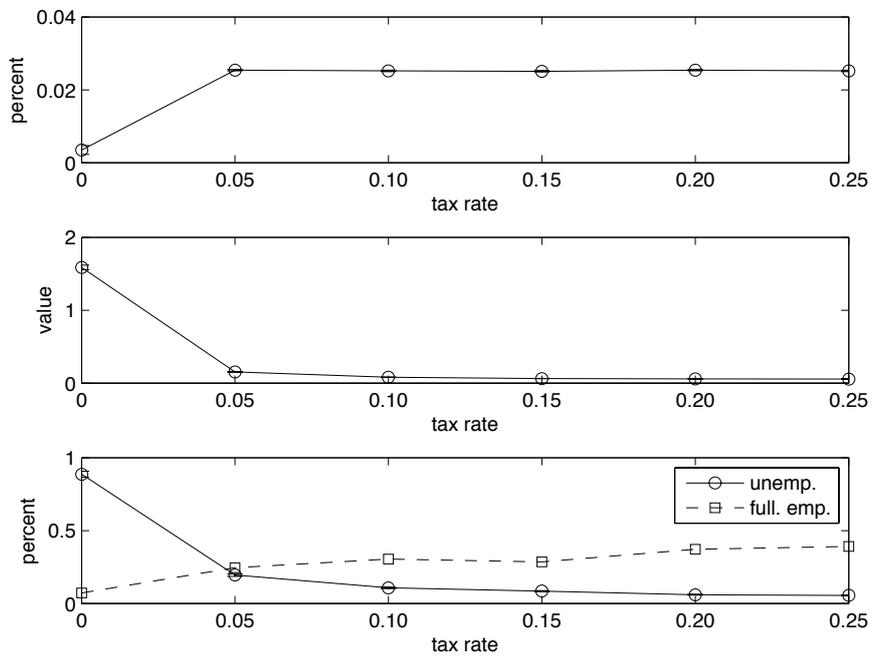

Figure 8: Fiscal Policy Experiments. First panel: average output growth rate. Second panel: bandpass-filtered output standard deviation. Third panel: average unemployment rate (unemp.) and full-employment frequency (full emp.). In such policy experiments, the unemployment subsidy rate (φ) is four times the tax rate.