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REGULAR ARTICLE

Micro and macro policies in the Keynes+Schumpeter evolutionary models

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Abstract This paper presents the family of the Keynes+Schumpeter (K+S, cf. Dosi et al, J Econ Dyn Control 34 1748–1767 2010, J Econ Dyn Control 37 1598–1625 2013, J Econ Dyn Control 52 166–189 2015) evolutionary agent-based models, which study the effects of a rich ensemble of innovation, industrial dynamics and macroeconomic policies on the long-term growth and short-run fluctuations of the economy. The K+S models embed the Schumpeterian growth paradigm into a complex system of imperfect coordination among heterogeneous interacting firms and banks, where Keynesian (demand-related) and Minskian (credit cycle) elements feed back into the meso and macro dynamics. The model is able to endogenously generate long-run growth together with business cycles and major crises. Moreover, it reproduces a long list of macroeconomic and microeconomic stylized facts. Here, we discuss a series of experiments on the role of policies affecting i) innovation, ii) industry dynamics, iii) demand and iv) income distribution. Our results suggest the presence of strong complementarities between Schumpeterian (technological) and

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Keynesian (demand-related) policies in ensuring that the economic system follows a path of sustained stable growth and employment.

Keywords Agent-based model · Innovation · Evolution · Innovation policies · Macroeconomic policies · Income inequality · Disequilibrium dynamics

JEL Classification C63 · E32 · E6 · E52 · G01 · G21 · O4

> While Schumpeter may be the source of great insights into the capitalist process, he did not leave a useful theoretical framework for the analysis of capitalism. On the other hand further progress in understanding capitalism may very well depend upon integrating Schumpeter's insights with regard to the dynamics of a capitalist process and the role of the innovative entrepreneurs into an analytical framework that in its essential properties is Keynesian. (Minsky 1983, p. 2)

1 Introduction

The work of Joseph Schumpeter emphasized innovation as the ultimate source of economic growth. More precisely, "Schumpeterian" growth models are characterized by three features: i) growth is fuelled by innovation and imitation processes, which lead to the emergence and diffusion of new products and more efficient production techniques; ii) innovation is motivated by (some) monopoly rents for the innovators themselves; and iii) "creative destruction" is incessantly at work, as new technologies replace old ones, provoking the growth and entry of some firms (and sectors) in the economy and the fall and exit of others.[1]

Schumpeter's insights are of paramount importance for the understanding of the processes driving changes in technology. However, his framework is incomplete when it comes to explaining how innovation translates into growth and how the effect of the inherent instability of technical change processes can be tamed (Minsky 1983; Dosi et al. 1988). In one direction, technological innovations may impact the long-term rate of growth of the economy, as well as the short-term evolution of output (and unemployment) over the business cycle. In the other one, macroeconomic conditions (i.e. aggregate demand, credit availability, etc.) are likely to modulate the creation and diffusion of technological innovations and the long-run performance of the economy. In that, the analysis of the (imperfect) coordination mechanisms[2] among a large

[1]According to such a paradigm, losses are inherent to the growth process, and also, normatively, technology policy measures should be expected to fail a good deal of the time, hoping for a few large successes (Scherer and Harhoff 2000).

[2]Such coordination is not to be mistaken for strategic interactions among a few forward-looking firms. The latter is indeed incompatible with a Knightian uncertainty (Knight 1921) concerning the future path of technology advances as well as of demand in complex evolving systems.

number of heterogeneous agents become essential for understanding the forces allowing the economic system to follow a relatively orderly growth path in presence of innovation and creative destruction processes.

A proper investigation of the above mechanisms requires us to go well beyond the Schumpeterian separation between coordination and change (Dosi 2012), and needs to be done in models able to account jointly for both business cycles arising from effective demand failures (Leijonhufvud 1973) and long-term growth dynamics. Unfortunately most economic research has not followed such a path. Even Schumpeterian growth models, including both evolutionary models rooted in Nelson and Winter (1982) and equilibrium models rooted in Aghion and Howitt (1992), have focused on technological and industrial dynamics, not considering the possible role of aggregate demand on the evolution of technology, let alone macroeconomic performance (few notable exceptions include Aghion et al 2010, 2014; Ciarli et al 2010). Much more so, DSGE models of business cycles (e.g. Woodford 2003) do not explicitly address any long-run instability issue, and take technology as an exogenous process. A major consequence is that policymakers are left empty-handed when they need to evaluate the potential long-term effects of their short-run responses to economic crises. Likewise, they may under-estimate the overall impact of structural policies, in the belief that the long-term benefits would be left unaffected by the temporary costs these policies may involve. A paradigmatic example in this respect is the apparent schizophrenia between fiscal and innovation policies implemented in Europe in the wake of the Great Recession (Fiscal Compact vs. Europe 2020).

The *Keynes+Schumpeter* (K+S) models (Dosi et al. 2010; Dosi et al. 2013; Dosi et al. 2015) explicitly address the multifaceted interactions between long-run processes of technical change and demand-driven dynamics. Accordingly, they are well-equipped to explore jointly the short and long-run effects of economic policies, affecting the technological landscape as well as aggregate demand. This paper discusses the large body of results generated by the K+S model so far. As such, it offers a comprehensive overview of i) the theoretical framework, ii) the stylized facts reproduced by the model and iii) the policy results.

Rooted in the evolutionary (Nelson and Winter 1982, see also; Dosi et al. 1988) and agent-based (e.g. Tesfatsion 2006) perspectives[3], the K+S models encompass both Schumpeterian and Keynesian elements. The former relates to the processes of technical change and market selection, the latter concerns coordination mechanisms and aggregate demand. Moreover, the models explicitly account for the interactions between the real and the financial sectors of the economy, thus reproducing the Minskian features of business cycles (Minsky 1986). The full-fledged version of the model describes an economy with heterogeneous firms (belonging either to a capital- or consumption-good industry), banks, a labor force, a Central Bank and a Government. Innovation and imitation routines performed by capital-goods firms investing

[3]For germane ABMs, see Ciarli et al. (2010), Mandel et al. (2010), Delli Gatti et al. (2005), Delli Gatti et al. (2010), Ashraf et al. (2011), Dawid et al. (2014a), Dawid et al. (2014b), Raberto et al. (2014), and Riccetti et al. (2013).

in R&D drive the process of technical change, resulting in cheaper and more productive machines sold to the consumption-goods sector. The latter firms produce a homogeneous final good and may use external financing from the banking sector if their internal resources do not cover production and investment expenses. Both firms and banks can go bankrupt if their net worth becomes negative, possibly triggering a crisis. The Government fixes taxes and unemployment subsidy rates and bails out bankrupt banks. The Central Bank sets the baseline interest rate for the economy.

The Keynes+Schumpeter models are able to generate endogenously long-run growth together with business cycles and major crises. Moreover, they reproduce a long list of macroeconomic and microeconomic stylized facts. They can be employed to assess the short- and long-run impact of a series of experiments concerning the role of policies affecting i) innovation, ii) industry dynamics, iii) aggregate demand, and iv) income distribution. Our results suggest the presence of strong complementarities between Schumpeterian (technological) and Keynesian (demand-related) policies in ensuring that the economic system follows a relatively ordered path of sustained growth. In addition, we find that increasing income inequality has detrimental effects on the short- and long-run performance of the economy (vindicating Stiglitz 2012), thus supporting the case for redistributive fiscal policies.

In what follows, we present the basic K+S model in Section 2 and its extensions in Section 3. Next, we report the micro and macro empirical regularities reproduced by the models (Section 4). The core of the paper presents the policy experiments (Section 5). Finally, in Section 6 we discuss the results, highlighting the feedback effects between the Schumpeterian, Keynesian and Minskian elements of the model.

2 The baseline Keynes+Schumpeter model

In the first vintage of the model (Dosi et al. 2010), the economy is composed of two sectors: a capital-goods sector including F_1 firms (denoted by the subscript i), and a consumption-goods sector with F_2 firms (denoted by the subscript j). In the former group, firms perform R&D investments and produce heterogeneous machines using labor. The consumption-goods firms buy machines from capital-goods firms and produce a homogeneous final good for consumers, using capital and labor. There are also L^S consumers/workers and a public sector that collects taxes on firm 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. 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. They then advertise their machines to consumption-goods firms.

2. Consumption-goods firms decide how much to produce and invest. If investment is positive, consumption-goods firms choose their suppliers and send their orders.
3. In both industries, firms hire workers according to their production plans and start producing.
4. The imperfectly competitive consumption-goods market opens. The market shares of firms evolve according to firm competitiveness following some sort of replicator dynamics.
5. Entry and exit take place. In both sectors, firms with (near) zero market shares and/or negative net liquid assets are eschewed from the two industries and replaced by new firms.
6. 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- and consumption-good sectors and industry dynamics

Capital-goods firms use labor to produce heterogeneous machine-tools. They invest a fraction of their past sales in R&D to search for process and product innovation and imitation, which are risky ventures. Successful process innovation/imitation increases their own labor productivity ($B_{i,t}$), while product innovation/imitation impacts the productivity of the machines they sell to consumption-goods firms ($A_{i,t}$), thus on the quality of their product.

Prices are defined with a fixed mark-up over unit cost. The market is characterized by imperfect information: machine-tool firms advertise their products' price and productivity characteristics by sending "brochures" to a subset of consumption-goods firms, which in turn change their suppliers if they are offered a combination of a lower price and unit production costs. Note that, in any given period, different types of machines are supplied in the market, also within the same "time vintage". The speed of diffusion of the best practice-types in the economy depends on the evolution of the market share of their supplier, on competitors' imitation rates, as well as on consumption-goods firms' investments.

Innovation and imitation processes are modeled as a two-step procedure. First, only a subset of capital-goods firms successfully innovate (or imitate), and the probability of such event is positively related to their R&D expenditures ($RD_{i,t}$). As investment in R&D is proportional to past turnover, firms have an increased chance of innovating and imitating in presence of buoyant demand and when their higher competitiveness increases their market share. More precisely, a draw from a Bernoulli distribution of parameter $\theta_{i,t}^{in}$ determines whether a firm successfully innovates:

$$\theta_{i,t}^{in} = 1 - e^{-\zeta_1 \xi RD_{i,t}}, \tag{1}$$

with $0 < \zeta_1 \leqslant 1$. Access to imitation is granted in a similar way, according to parameter $\zeta_2 \in]0; 1]$. The $\zeta_{1,2}$ parameters thus define firms' *search capabilities*.

The innovation process is not always successful: the technology embodied in the new machine discovered by the firm may be inferior to the one embodied in its current vintage. Indeed, the innovating firm draws a new machine embodying technology $(A^{in}_{i,t}, B^{in}_{i,t})$ according to:

$$A^{in}_{i,t} = A_{i,t}(1 + x^{A}_{i,t}) \tag{2}$$

$$B^{in}_{i,t} = B_{i,t}(1 + x^{B}_{i,t}),$$

where x^A_i and x^B_i 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]. By altering the shape of the Beta distribution, the parameters α_1 and β_1 capture the *technological opportunities* of the economy. Regarding imitation, in the second stage, the probabilities of firms to copy the technology of their competitors decrease in the technological distance (computed adopting Euclidean metrics).

Consumption-goods firms produce a homogeneous good using both capital and labor under constant returns to scale. They define their desired level of production according to adaptive demand expectations, given their current inventories. If their production capacity is not sufficient, firms invest to expand their capital stock. Moreover, firms invest to replace obsolescent machines. More precisely, each firm's stock of capital is made of a set of different vintages of machines $\Xi_{j,t}$, with heterogeneous productivities. Machines with technology $A^{\tau}_{i,t} \in \Xi_{j,t}$ are scrapped according to a payback period routine that considers their technology obsolescence and new machines' prices:

$$RS_{j,t} = \left\{ A^{\tau}_{i,t} \in \Xi_{j,t} : \frac{p^*_t}{c(A^{\tau}_{i,t}) - c^*_t} \leq b \right\}, \tag{3}$$

where $c(A^{\tau}_{i,t})$ is the production cost entailed by the machine under evaluation, p^*_t and c^*_t are the price and unit cost of production of new machines, and $b > 0$ is the payback period parameter. Total replacement investment is then computed at firm level as the number of scrapped machines satisfying Eq. 3, and those older/worse than η vintages $(\eta > 1)$. Firms' investment impacts their labor productivity level as the newly acquired machines embed a more "advanced" technology vintage. Consumption-goods firms pay the ordered machines and advance wages to workers. They finance their investments and production using preferably internal funds and, if necessary, credit. Capital markets are imperfect (in line with Stiglitz and Weiss 1981; Myers and Majluf 1984; Greenwald and Stiglitz 1993; Hubbard 1998, and indeed with common sense): external funds are more costly than internal ones. As firms can borrow up to a debt to sales ratio threshold Λ, credit rationing may occur.

Prices of final goods $(p_{j,t})$ are obtained by applying a variable mark-up $(\mu_{j,t})$ on consumption-goods firms' unit cost of production $(c_{j,t})$. More precisely, the mark-up is increasing in the firm's market "power", proxied by its revealed variations in market share. The latter evolves according to a "quasi" replicator dynamics:

$$f_{j,t} = f_{j,t-1} \left(1 + \chi \frac{E_{j,t} - \overline{E_t}}{\overline{E_t}} \right), \tag{4}$$

with $\chi > 0$. The above equation implies that firms with high competitiveness $E_{j,t}$ relative to the sector average ($\overline{E}_t$) expand their market shares. Firms' *competitiveness* ($E_{j,t}$) directly relates to their price, but also, inversely, to the possible amount of unfilled demand ($l_{j,t}$) inherited from the previous period:

$$E_{j,t} = -\omega_1 p_{j,t} - \omega_2 l_{j,t}, \tag{5}$$

where $\omega_{1,2} > 0$. All consumption-goods firms start with an initial (and homogeneous) mark-up $\overline{\mu}$, which evolves according to the dynamics of their market shares f_j:

$$\mu_{j,t} = \mu_{j,t-1}\left(1 + \upsilon \frac{f_{j,t-1} - f_{j,t-2}}{f_{j,t-2}}\right). \tag{6}$$

In both sectors, the difference between firm revenues and costs accounts for firms' gross profits, which are taxed at the flat rate tr. Net profits change the stock of liquid assets ($NW_{j,t}$) of firms. A firm goes bankrupt if $NW_{j,t} < 0$ or its market share falls to zero. In both cases, the firm exits the market and it is replaced by a new entrant. As a consequence, the number of firms operating in each market is fixed (a simplifying assumption, but not too far from the empirics). In line with the empirical literature on firm entry (Caves 1998; Bartelsman et al. 2005), new firms are typically smaller than incumbents: the stock of capital of new consumption-goods firms and the stock of liquid assets of entrants in both sectors are a fraction of the average stocks of incumbents.[4] Finally, the technology of new capital-goods firms is bounded by the one of the most productive incumbent and it is drawn from a Beta distribution of parameters α_2, β_2. Such parameters define the *technological opportunities available to entrants* and alter their distance to the technological frontier.[5]

2.3 Consumption and the Government sector

Workers in both capital- and consumption-goods sectors earn a wage that is consumed. The wage rate (w_t) evolves according to institutional factors, namely, changes in prices, in the unemployment rate and in average labor productivity. As a consequence, involuntary unemployment emerges endogenously whenever the sum of labor demand from all firms (L_t^D) is lower that the exogenous labor supply (L^S). The Government pays an unemployment subsidy (w_t^u), which is proportional to the current wage: $w_t^u = \varphi w_t$, with $\varphi \in [0, 1]$. Aggregate consumption is then:

$$C_t = w_t L_t^D + w_t^u (L^S - L_t^D).$$

[4]The stock of capital of a new consumption-goods firm is obtained by multiplying the average stock of capital of the incumbents by a random draw from a Uniform distribution with support[ϕ_1, ϕ_2], $0 < \phi_1, < \phi_2 \leqslant 1$.

[5]Here, as well as in Aghion and Howitt (2007), firms' distance to the frontier affects the impact of different sets of policies, as well as the overall performance of the economic system.

All aggregate variables (e.g. output, investment, employment, etc.) are the outcome of the complex interactions among heterogeneous agents' micro level decisions and dynamics. At the aggregate level, national account identities are satisfied: the sum of value added of capital- and consumption-goods firms (GDP_t) equals their aggregate production and final expenditures, namely, private consumption, investment (I_t) and change in inventories (ΔN_t):

$$GDP_t = \sum_{i=1}^{F_1} Q_{i,t} + \sum_{j=1}^{F_2} Q_{j,t} \equiv C_t + I_t + \Delta N_t.$$

3 Extensions: the credit-augmented K+S model

Building on the initial setup presented and tested in Dosi et al. (2010), the model has been extended (Dosi et al 2013, 2015) introducing a credit market populated by heterogenous banks in order to study the possible interplays between the real and financial sectors. Such addition allows us to investigate the role of credit in amplifying and triggering macroeconomic fluctuations, possibly leading to the emergence of bank and sovereign debt crises and deep downturns that could affect the long-run performance of the economy (see Levine 1997, explicitely opposing Schumpeter's view on that). The credit sector is populated by B heterogenous banks, which gather deposits, distribute loans and own sovereign bonds. In addition a Central Bank now sets the baseline interest rate following a Taylor rule.

Banks are heterogenous in their number of clients (drawn form a Pareto distribution). Credit supply is constrained by capital adequacy requirements inspired by Basel-framework rules. Besides the regulatory limit, we assume that banks maintain a buffer over the regulatory capital level, as indicated by the empirical evidence (BIS 1999). The size of such buffer evolves strategically in order to offset bank financial fragility along the business cycle and it is proxied by the ratio between accumulated bad debt (i.e. loans in default) and bank assets (i.e. sum of the stocks of loans, sovereign bonds and reserves held by the bank), $Bda_{k,t}$. Total credit supply available from bank k at time t therefore follows:

$$TC_{k,t} = \frac{NW^b_{k,t-1}}{\tau^b(1 + \beta Bda_{k,t-1})}, \tag{7}$$

where $\beta > 0$ is a parameter that measures the banks' speed of adjustment to its financial fragility, and τ^b is the macroprudential regulatory parameter. Credit supply therefore decreases in β and τ and is positively affected by banks' equity.

Banks allocate credit across firms by ranking them according to their creditworthiness, proxied by the ratio between firms' past net worth and sales. Loans are granted to firms as long as credit supply is not exhausted. As a consequence, consumption-goods firms may be credit-rationed. Firms' probability to get a loan depends on their credit ranking as well as on the financial health of their bank. Note that the lower performance of other clients improves firms' relative ranking, but also bears a negative impact on total credit availability, because firms' defaults weaken the equity of their bank, thus reducing the supply of credit.

We assume that the Central Bank follows a Taylor rule, which adjusts the interest rate to changes in inflation and, under some revealing policy scenarios, to unemployment, relative to their target levels:

$$r_t = r^T + \gamma_\pi(\pi_t - \pi^T) + \gamma_U(U^T - U_t), \qquad \gamma_\pi > 1,\ \gamma_U \geq 0 \tag{8}$$

where π_t is the inflation rate of the period, U_t the unemployment rate, and r^T, π^T, U^T are the target interest, inflation and unemployment rates, respectively. Banks fix the interest rate on loans applying a risk premium on the policy rate.

Bank revenues are composed of interests from loans, deposits at the Central Bank, and sovereign bonds. Gross profits are taxed at the rate tr. Massive loan losses may turn profits to negative, reducing the equity of banks and their credit supply. A bank goes bankrupt if firm bankruptcy shocks turn its net worth to negative. In such a case, the Government steps in and recapitalizes the bank. The public bail-out entails a cost ($Gbailout_{t,k}$), equal to the difference between the equity of the failed bank before and after the intervention, which affects the public budget.

Given government tax revenues (Tax_t) and expenses, public deficit reads:

$$Def_t = Debt_t^{cost} + Gbailout_t + G_t - Tax_t, \tag{9}$$

where G_t are unemployment subsidies and $Debt_t^{cost}$ is the cost of sovereign debt. Deficits are financed on the bonds market, where banks buy the bonds issued by the Government. Banks buy bonds with their net profits; if the total bank savings are lower than the stock of sovereign debt that needs to be refinanced, the Central Bank buys the residual part.

4 Macro and micro stylised facts

The Keynes+Schumpeter models are analyzed through Monte-carlo simulations.[6] To begin with, we study whether the models are able to reproduce *jointly* a wide range of macroeconomic and microeconomic stylized facts (SF, the "benchmark" parametrization is reported in Table 6 in the Appendix). If the K+S models successfully match empirical regularities concerning industrial dynamics as well as more structural relations between macroeconomic aggregates, this ought to be taken as a robust empirical validation (G. Fagiolo and Windrum 2007; Fagiolo and Roventini 2012), offering plausibility to its use as a "computational laboratory" to test different policy experiments. We report in Table 1 the list of empirical regularities that the K+S model is able to match (cf. Dosi et al, 2006, 2008, 2010, 2013, 2015). Note,

[6]The non-linearities present in agents' decision rules and their interaction patterns require extensive Monte-carlo simulations to analyze the properties of the stochastic processes governing the coevolution of micro- and macro- variables, washing away across-simulation variability. Consequently, all results below refer to across-run averages over 100 replications. Admittedly, this whole exercise involves a major puzzle: should one wash out the inherent path-dependency of evolutionary processes? Should one account for within-path long-run dependency? But these questions are well beyond the scope of this work.

Table 1 Stylized facts replicated by the K+S model

Stylized facts		Empirical studies (among others)
Macroeconomic stylized facts		
SF1	Endogenous self-sustained growth with persistent fluctuations	An extremely vast literature starting from Burns and Mitchell (1946); (Kuznets and Murphy 1966; Zarnowitz 1985; Stock and Watson 1999)
SF2	Fat-tailed GDP growth-rate distribution	(Fagiolo et al. 2008; Castaldi and Dosi 2009)
SF3	Recession duration exponentially distributed	(Ausloos et al. 2004; Wright 2005)
SF4	Relative volatility of GDP, consumption and investment	(Stock and Watson 1999; Napoletano et al. 2006)
SF5	Cross-correlations of macro variables	(Stock and Watson 1999; Napoletano et al. 2006)
SF6	Pro-cyclical aggregate R&D investment	(Walde and Woitek 2004)
SF7	Cross-correlations of credit-related variables	(Lown and Morgan 2006; Leary 2009)
SF8	Cross-correlation between firm debt and loan losses	(Mendoza and Terrones 2012; Foos et al. 2010)
SF9	Banking crises duration is right skewed	(Reinhart and Rogoff 2009)
SF10	Fiscal costs of banking crises to GDP distribution is fat-tailed	(Laeven and Valencia 2008)
Microeconomic stylized facts		
SF11	Firm (log) size distribution is right-skewed	(Dosi 2007)
SF12	Fat-tailed firm growth-rate distribution	(Bottazzi and Secchi 2003; 2006)
SF13	Productivity heterogeneity across firms	(Bartelsman and Doms 2000; Dosi 2007)
SF14	Persistent productivity differential across firms	(Bartelsman and Doms 2000; Dosi 2007)
SF15	Lumpy investment rates at firm-level	(Doms and Dunne 1998)
SF16	Firm bankruptcies are counter-cyclical	(Jaimovich and Floetotto 2008)
SF17	Firm bad-debt distribution fits a power-law	(Di Guilmi et al. 2004)

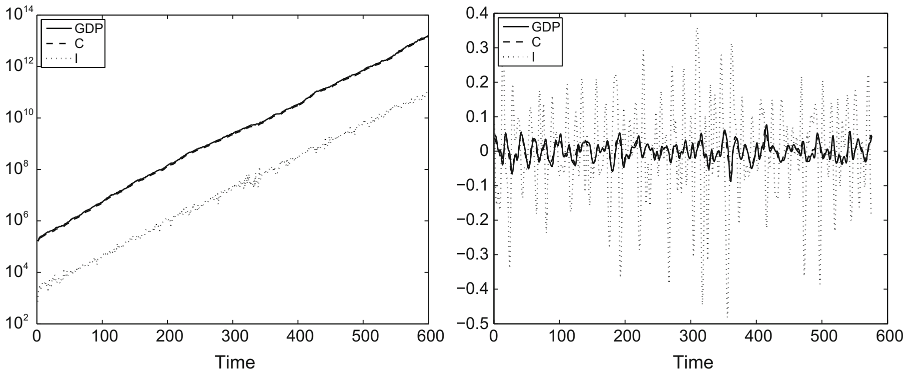

Fig. 1 Output, consumption and investment time series; *left:* logs; *right:* bandpass-filtered (6,32,12) series, reproduced from Dosi et al. (2015)

incidentally, that the fact that a large number of very different micro and macro stylized facts are reproduced by the model makes our empirical validation exercises far more demanding than a simple polynomial-fitting exercise in presence of some free parameters.

Let us start with *macroeconomic* empirical regularities. The K+S models are able to generate endogenously self-sustained economic growth with persistent fluctuations (**SF1**, cf. Fig. 1). Business cycles are punctuated by deep downturns (Stiglitz

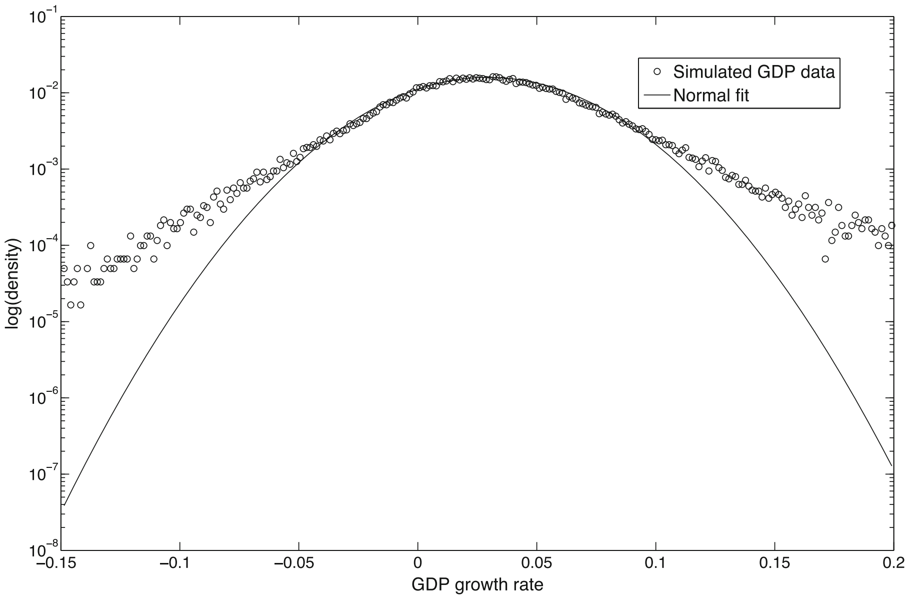

Fig. 2 Distribution of real GDP growth rates: binned simulated densities (250 bins, 59900 observations, circles) vs. normal fit (Dosi et al. 2015)

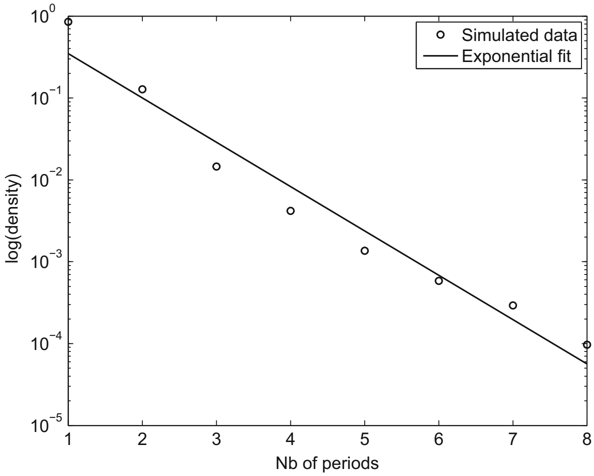

Fig. 3 Exponentail fit of recession durations (Dosi et al. 2015)

2014) and, in line with the empirical evidence (Fagiolo et al. 2008), the GDP growth-rate distribution exhibits fat tails (**SF2**, cf. Fig. 2). Moreover, most recessions are short-lived; few last for long periods of time. The distribution of the duration of recessions generated by the model is exponential (**SF3**, cf. Fig. 3) as found in empirical data (Ausloos et al. 2004; Wright 2005).

We then detrend the macroeconomics series to study their behavior at the business cycle frequencies. Well in tune with the empirical evidence (e.g. Stock and Watson 1999; Napoletano et al 2006), the fluctuations of aggregate consumption are smoother than those of GDP, whereas investment is more volatile than output (**SF4**, cf. Fig. 1, right). Moreover, the co-movements between GDP and the most important macroeconomic variables are in line with what found in real data (**SF5**): consumption is pro-cyclical and coincident, net investment, changes in inventories, productivity, nominal wages and inflation are pro-cyclical; unemployment, prices and mark-ups are counter-cyclical; the real wage is a-cyclical.[7] Finally, R&D investment is pro-cyclical (**SF6**, see e.g. Walde and Woitek 2004).

The K+S models match additional stylized facts concerning *credit dynamics* and *banking crises*. To begin with, we find that bank profits as well as firms' total debt are pro-cyclical, while loan losses are counter-cyclical (**SF7**, see e.g. Lown and Morgan 2006; Leary 2009). Moreover, in line with the empirical evidence (Mendoza and Terrones 2012), we find that credit surges anticipate banking crises: banks' loan losses are positively correlated with a lag with firm debt, suggesting that higher levels of credit precede bad debt, further depressing banks' equity (Foos et al. 2010, **SF8**). Finally, the duration of banking crises, defined as a period in which at least one bank

[7]Details of the validation exercise are not included here due to space limitations. See Dosi et al. (2006), Dosi et al. (2008), Dosi et al. (2010), Dosi et al. (2013), and Dosi et al. (2015) and (Napoletano et al. 2012) for more discussions.

fails, has similar qualitative properties as the empirical one (Reinhart and Rogoff 2009, **SF9**) and the distribution of the ratio of fiscal costs of banking crises to GDP is characterized by excess kurtosis and heavy tails (**SF10**).

The K+S models are also able to match a rather long list of *microeconomic* empirical regularities concerning the cross-sectional dynamics of firms (Bartelsman and Doms 2000; Dosi 2007). First, firm (log) size distributions are highly skewed and not log-normal (**SF11**). Moreover, firm growth-rate distributions are "tent-shaped" with tails fatter than the Gaussian benchmark (**SF12**, cf. Bottazzi and Secchi 2003, 2006). Firms are also extremely heterogeneous in terms of productivity (**SF13**) and such differences are persistent over time (**SF14**). In line with the empirical evidence (Doms and Dunne 1998), firms invest in a lumpy fashion (**SF15**). Finally, firms' bankruptcies are counter-cyclical (Jaimovich and Floetotto 2008, **SF16**, cf.), and the distribution of firms' bad debt at bankruptcy follows a power law (**SF17**), in tune with the empirical evidence (Di Guilmi et al. 2004).

5 Micro and macro policies

Given the extremely good interpretative performance of the model, let us employ it to assess the short- and long-run impact of different policies.[8] More specifically, we study the impact of changes in either parameter values or policy scenarios on the GDP growth rates, the ratio of public debt to GDP, output volatility, and the unemployment rate.[9] We consider here policies affecting the two main sources of economic change, namely innovation (Section 5.1) and demand (Section 5.2), that is, the "Schumpeterian" and "Keynesian" engines of growth. Finally, we consider the impact of the income distribution on the effectiveness of policies (Section 5.3). The full list of experiments introduced in Dosi et al. (2010), Dosi et al. (2013), and Dosi et al. (2015) and discussed here as well as their corresponding parameter values are spelled out in Table 7 in the Appendix.

5.1 Tackling with the Schumpeterian engine: Innovation policy matters

We start by considering how technology policies concerning firm search capabilities and technological opportunities affect the long-run performance of the economy and also its short-run dynamics (Section 5.1.1). Next, we study a set of policies targeting appropriability conditions and the industrial dynamics of the economy (entry and competition, cf. Section 5.1.2).[10]

[8]Interestingly, most statistical regularities concerning the structure of the economy appear to hold across an ample parameter range, under positive technological progress, even when policies undergo the changes we study in the following.

[9]In Napoletano et al. (2012) and Dosi et al. (2013) and Dosi et al. (2015) we also consider statistics related to the probability of large crises.

[10]The results of the experiments concerning technology and industry policies are drawn from Dosi et al. (2010).

5.1.1 Technology policies

In the first set of experiments, we alter the "innovation engine" and test the impact on growth as well as on business cycle indicators. The results are reported in Table 2, the entries in which are normalized by the statistics (output growth, GDP volatility or unemployment) obtained in the benchmark parameterization.

In the Keynes+Schumpeter models, the innovation process proceeds in two steps (cf. Section 2.2): first, a subset of capital-goods firms successfully draw an "innovation" (no matter whether good or bad), and second, these "innovators" draw the technology of the newly discovered machines. Thus, success in the first stage depends on firms' *search capabilities* (cf. Eq. 1). The level of *technological opportunities* affects the probability of firms to develop a machine-tool more advanced than their current vintages. Those are proxied by the characteristics (support and shape) of the Beta distribution from which the new productivity parameters are drawn (cf. Eq. 2). The first experiment alters the probability successfully to pass the first stage (through the $\zeta_{1,2}$ parameters, **E1**). In the second experiment (**E2**), we tune technological opportunities by shifting leftward and rightward the mass of the Beta distribution.

Our results support the notion that policies favoring innovation promote faster GDP growth: lower search capabilities and lower technological opportunities yield significantly lower growth rates than in the baseline, whereas high values have a positive impact on the performance of the economy. Seen from a policy perspective, this is to say that all measures affecting both corporate innovative capabilities and the overall "state of knowledge" of the industry bear an impact upon the long dynamics of the economy. And technology policies do affect also the short-run: in both experiments, faster growth is also associated with lower unemployment rates. Note also that the magnitude of the effects is larger when policies affect the richness of the pool of potential innovations.

Table 2 Technology policy experiments

Experiment	E1 Search capabilities		E2 Technological opportunities	
	low	high	low	high
GDP growth	0,917**	1,063**	0,774**	1,250**
	(7,425)	(5,657)	(25,491)	(22,274)
GDP volatility	1,020	0,958**	0,981	1,023*
	(1,505)	(3,198)	(1,411)	(1,919)
Unemployment rate	1,097	0.962	1,266**	0,956
	(1,345)	(0,592)	(4,031)	(0,658)

Normalized values compared to the benchmark across experiments, for 100 simulation runs. Absolute value of the simulation t-statistic in parentheses; (**) significant at 5 % level, (*) significant at 10 % level

Table 3 Industrial policy experiments

Experiment	E3 Patents		E4 Entrant expected prod.		E5 Market selection		E6 Antitrust	
	length	breadth	low	high	weak	strong	weak	strong
GDP growth	0,960**	0,647**	0,726**	1,492**	1,000	0,992	1,052**	1,083**
	(3,536)	(39,802)	(19,137)	(43,841)	(0,000)	(0,707)	(4,596)	(9,391)
GDP volatility	0,941**	0,780**	0,986	0,862**	1,038**	0,933**	0,863**	0,628**
	(4,515)	(17,981)	(0,792)	(12,148)	(2,916)	(5,857)	(12,040)	(94,626)
Unemployment rate	1,056	1,240**	1,308**	0,796**	1,169**	0,955	0,966	0,781**
	(0,768)	(3,074)	(3,376)	(3,191)	(2,364)	(0,659)	(0,546)	(3,814)

Normalized values compared to the benchmark across experiments, for 100 simulation runs. Absolute value of the simulation t-statistic in parentheses; (**) significant at 5 % level, (*) significant at 10 % level

5.1.2 Industrial policies

The second set of experiments concerns the impact of policies affecting appropriability conditions and industry dynamics (experiments **E3-E6** in Table 3). A tricky but important issue - both from the interpretative and normative points of view - regards the role of appropriability (and, in particular, patents) as an incentive or an obstacle to innovation. The notion that some departure from the competitive zero profit condition is necessary in order to motivate capitalists to undertake search with their own money is at the core of the Schumpeterian (but also, earlier, Marxian) view of endogenous innovation. But how big should be such a departure? Neo-Schumpeterian models, as known, tend to assume monotonicity between degrees of appropriability and intensity of search, and, thus, rates of innovation (Aghion and Howitt 1992).[11] The assumption, other things equal, in turn rests upon some form of "rational technological expectations". Conversely, evolutionary models abhor the latter and assume much more routinized search behaviors. Recently, a large body of theoretical and empirical literature (see e.g. the contributions to Cimoli et al 2014) have suggested that stricter property rights could be detrimental to innovation and growth. We test the two alternative hypotheses, introducing a patent system in the K+S model (**E3**). In the first patent scenario ("length only"), firms cannot imitate new technologies for a fixed number of periods. In the second patent regime ("breadth"), firms are also for-

[11] By replacing their leapfrogging assumption (the entrant innovator instantaneously takes over the entire market) with a "step-by-step" innovation process (the entrant has to catch-up with the technology - and tacit knowledge - of the incumbent before potentially becoming a leader), Aghion et al. (2013) explain that the effect of patent protection on innovation becomes more complex. In particular, the traditional incentive to innovate to escape competition is much attenuated in unleveled sectors, where laggards will prefer to catch-up with the leader by imitating than costly investing in R&D to innovate, given the remote probability that they may overtake the market.

bidden to innovate around newly discovered technologies. The results go against the view that patents are essential for innovation and good macroeconomic performance. Indeed, the introduction of a patent system significantly harms both the long-run GDP growth and the short-run performance of the economy, being conducive of persistently higher unemployment rates.

Furthermore, we test the effects of *entry* on competition and innovation by changing entrants' expected productivity (**E4**). We know empirically that most entrants are failures, but some are carriers of novel techniques and products (Dosi et al. 1997; Bellone et al. 2008; Aghion et al. 2009). How important are these successful entrants? That is, from the normative point of view, what is the impact of policies favouring the entry of new competent firms? We explore that question by increasing/decreasing the probability that entrants draw high productivity levels. In line with a "Schumpeterian Mark I" scenario, we find that higher easiness of "good" entry bears a positive impact upon long-term growth, and also dampens business cycles fluctuations and reduces unemployment.

Finally, we explore the effect of *competition* (and relatedly, competition policies) by altering market selection in the consumption-good industry (**E5**) and by introducing antitrust policies in the capital-good sector (**E6**). Recall that the strength of competition is captured by the χ parameter (cf. the replicator dynamics, Eq. 4) linking firms' competitiveness to their change in market shares: a lower value of the parameter proxies higher sluggishness in the selection process (Metcalfe 1994). Antitrust policies limit the maximum market share of capital-goods firms to 75% (weak case) or 50% (strong case). The results of both policy experiments overall support the view that long- and short-term macroeconomic performance positively respond to enhanced competition. It is important to notice, however, that the mechanism *does not* involve changes in firms' strategic behavior, but relates to the need for a variety of innovation search paths to be tested before a success can emerge.

5.2 The necessity of Keynesian fiscal policies: demand matters

The above sets of experiments clearly indicate that the sources of growth in the model lie in firms' ability to search efficiently and to develop improved products and processes. However, such results are obtained under an effectively working Keynesian engine of macro demand management. What happens if one constrains the dampening effect of Keynesian policies? A first rough but very robust answer comes from the comparison between the foregoing regime with a set-up whereby all "Keynesian" policies are turned off and the system lives under a "pure Schumpeterian regime", holding however constant technological opportunities, search rules, competition dynamics as in the benchmark model (**E7**, cf. Dosi et al 2010). Turning off the "Keynesian" component implies a major jump to a different phase of the system, characterized by nearly zero growth and enormous fluctuations (cf. Table 4, column 2). This is because, by sustaining demand during recessions, countercyclical Keynesian policies also smooth investment over the business cycle. Low demand indeed

Table 4 Keynesian policy experiments

Experiment	E7		E8			E9	
	Schumpeterian regime		Stabilizers			Fiscal rule	
	pure	strong	weak	strong	very strong	SGP	SGP_{ec}
Subsidy rate	0	0	0,2	0,6	0,8		
Tax rate	0	0	0,05	0,15	0,2		
GDP growth	0,139**	0.437**	1,008	0,996	1,008	0.527**	0.992**
	(17,837)	(7.841)	(0,707)	(0,354)	(0,707)	(6.894)	(1.388)
GDP volatility	19,611**	19,173**	1,902**	0,779**	0,722**	14.645**	1.624**
	(47,186)	(34,426)	(28,119)	(20,808)	(24,405)	(7.466)	(7.166)
Unemployment rate	10,962**	7,327**	2,413**	0,789**	0,562**	5.692**	1.948**
	(37,639)	(24,353)	(8,846)	(3,738)	(8,271)	(8.095)	(3.928)
Public Debt/GDP						$+\infty$	4.078**
							(2.472)

The "strong" Schumpeterian regime is set with high technological opportunities and high search capabilities. Normalized values compared to the benchmark across experiments, for 100 simulation runs. Absolute value of the t-statistic in parentheses; (**) significant at 5 % level, (*) significant at 10 % level

reduces both consumption-goods firms' investment and capital-goods firms' R&D expenses, thus rates of innovation and productivity growth. Such a vicious circle of low R&D, low economic growth and high volatility is in line with previous accounts by Stiglitz (1994) and Aghion et al. (2010) and Aghion et al. (2008), in particular in the presence of credit market imperfections (Aghion et al. 2014).

The experiments discussed above indicate that both Schumpeterian and Keynesian policies affect short-term economic indicators (GDP volatility, the unemployment rate) as well as long-term ones (GDP growth). Still, these experiments were implemented considering "everything else being equal": an active technology policy was tested taking fixed the fiscal side of the model, and the other way round. Could technology policies be a substitute for a lack of fiscal policies? We test this proposition by experimenting with a "strong Schumpeterian regime" (high search capabilities and technological opportunities) combined with a zero fiscal policy scenario (no taxes and unemployment subsidies). Table 4 (column 3) shows that in this case average GDP growth falls by 56 % with respect to the baseline. Notice that it is exactly the net effect from both policies. Indeed, the former increase the average GDP growth rate (respectively, by 6 and 25 %), while the latter has a negative impact amounting to a 86 % cut in the long-run rate of output growth. It follows that Keynesian policies are *complementary* to Schumpeterian ones, as the latter alone cannot sustain a stable growth path.

As a more sophisticated observation, let us analyze the impact of macro policies in the presence of some Keynesian element, and consider both the role of automatic stabilizers (taxes and unemployment subsidies) and the impact of austerity fiscal rules (mimicking the Eurozone Stability and Growth Pact).

In the K+S benchmark model, taxes and unemployment subsidies act as automatic stabilizers, dampening business cycle fluctuations. In experiment **E8** (Dosi et al. 2010), we jointly modify the intensity of these stabilizers by altering the tax and subsidy rates tr and φ (cf. Section 2.3). Results in Table 4 show the impact of Keynesian fiscal policies upon *long-run* economic growth. In the "good phase" of the system (i.e. with positive tax and subsidy rates, cf. Fig. 4), higher levels of automatic stabilizers do not affect average GDP, but they further stabilize output fluctuations: GDP volatility and unemployment rates fall as tax and subsidy rates are jointly increased.

We further test the impact of Keynesian fiscal policies by studying the impact of austerity fiscal rules *à la* European Stability and Growth Pact (SGP, cf. Dosi et al 2015). More specifically, the SGP rule constrains the public deficit to 3 % of GDP, forcing the Government to cut unemployment subsidies until the deficit-to-GDP target is reached. In presence of an escape clause (SGP_{ec}), the fiscal rule is frozen in

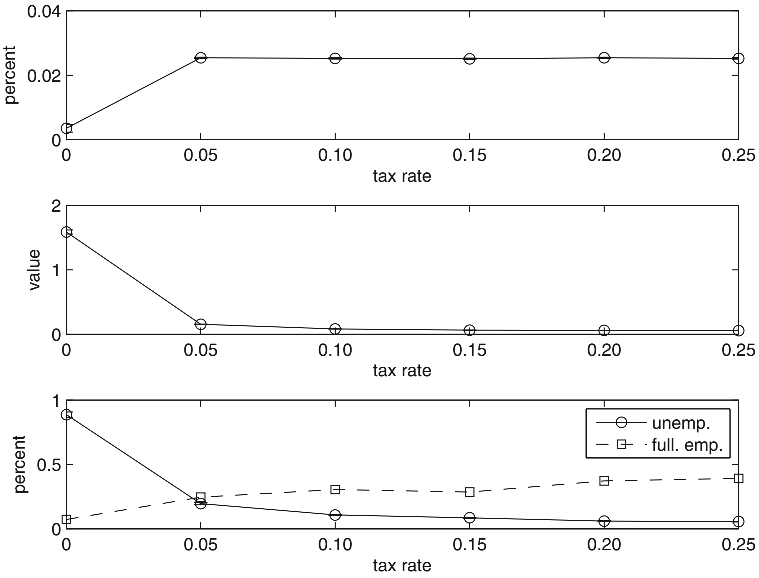

Fig. 4 Fiscal Policy Experiments (Dosi et al. 2010). *First panel:* average output growth rate. *Second panel:* bandpass-filtered output standard deviation. *Third panel:* average unemployment rate (unemp.) and full-employment frequency (full emp.). In such policy experiments, the unemployment subsidy rate (φ) is four times the tax rate

case of negative GDP growth. The results from the SGP and SGP_{ec} experiments (**E9**, see Tables 4 and 5) allow one to highlight further the necessity of active fiscal policy to achieve steady growth. Indeed, we find that in the “harsh” case, when the SGP fiscal rule is applied, average GDP growth is halved compared to the baseline scenario, and GDP volatility and unemployment are respectively 14 and 5 times higher. Moreover, the public debt to GDP ratio explodes due to the joint expansion of debt and the shrinkage of output, showing the self-defeating effect of fiscal discipline policies. The microeconomic indicators displayed in Table 5 study the underlying micro-level mechanisms at the origin of the aggregate outcomes. First, in

Table 5 Fiscal rule - microeconomic indicators

Experiment	E9 Fiscal rule
	SGP
Innovation creation in the capital-good sector	
Share of successful innovators	0.946**
	(2.762)
Productivity growth	0.980**
	(2.269)
Productivity dispersion	0.917**
	(6.538)
Innovation diffusion in the consumption-goods sector	
Productivity growth	0.889**
	(3.912)
Productivity dispersion	0.865**
	(3.429)
Investment rate	0.973
	(1.275)
Duration of best vintage	1.037**
	(3.927)
Productivity growth best vintage	0.954**
	(34.446)
Relative distance between best and worst vintages	0.970** (2.432)

Normalized values compared to the benchmark across experiments, for 100 simulation runs. Absolute value of the t-statistic in parentheses; (**) significant at 5 % level, (*) significant at 10 % level the consumption-goods sector, due to lower expected demand, firms' investment rate falls and with it, the productivity growth, thus slowing innovation diffusion. Relatedly, in the capital-good sector, innovation creation is less frequent: by constraining demand for final goods, and thus, the investment rate, austerity also reduces R&D investment, the innovation rate, and productivity growth. The slower creation and diffusion of innovations imply that the best vintage stays undisputed for a longer period, and the productivity frontier evolves more slowly. As a consequence, productivity dispersion is also lower in both sectors.

In the presence of a fiscal rule with escape clause (SGP_{ec}), the long-run harmful effects of fiscal discipline disappear, but volatility and unemployment rates are still significantly higher (see Table 4). These findings allow us to understand better the non-linear effects of fiscal policies on GDP growth (cf. Fig. 4): the halt to fiscal support during recessions is likely to transform them in depressions, as firms' cuts in their investment and innovation rates affect, also in the long-run, aggregate demand, innovation, output creation, skyrocketing public debt.

5.3 Income inequality and policy effectiveness: Distribution matters

In Dosi et al. (2013), we find that the level of income inequality affects both the short- and long-run performance of the economy,[12] increasing macroeconomic instability and reducing the growth potential. In line with the Keynesian tradition, income distribution in the K+S models is modulated by the level of the initial mark-up ($\overline{\mu}$, **E10**). More precisely, the role played by mark-up rates is twofold. On the one hand, the level of the mark-up determines the profits of the firms, and thus the level of internal resources available to finance production and investment expenditures. Higher mark-ups imply, *ceteris paribus*, higher profits and thus a lower dependence of firms on the external financing provided by banks. On the other hand, the mark-up regulates the distribution of income between profits and wages. Since aggregate consumption depends on wage shares, higher mark-up rates result in a lower level of demand for final-good firms.

On the policy side, we find a strong interaction between fiscal policies and inequality (i.e. high $\overline{\mu}$), and the latter exacerbates macroeconomic instability by reducing aggregate demand (Dosi et al. 2013; Dosi et al. 2015). This is shown in Figure 5, which compares short-run and long-run macroeconomic indicators under different fiscal policy scenarios (the benchmark and "SGP" scenarios) for different levels of the (initial) mark-up rate. As the figure starkly reveals, all effects of fiscal austerity are magnified when the mark-up is high and thus the income distribution is more skewed towards profits.

[12] This is in line with the intuitions of Stiglitz (2012) and Piketty (2014) about the existence of a vicious downward spiral of excessive inequality and economic instability.

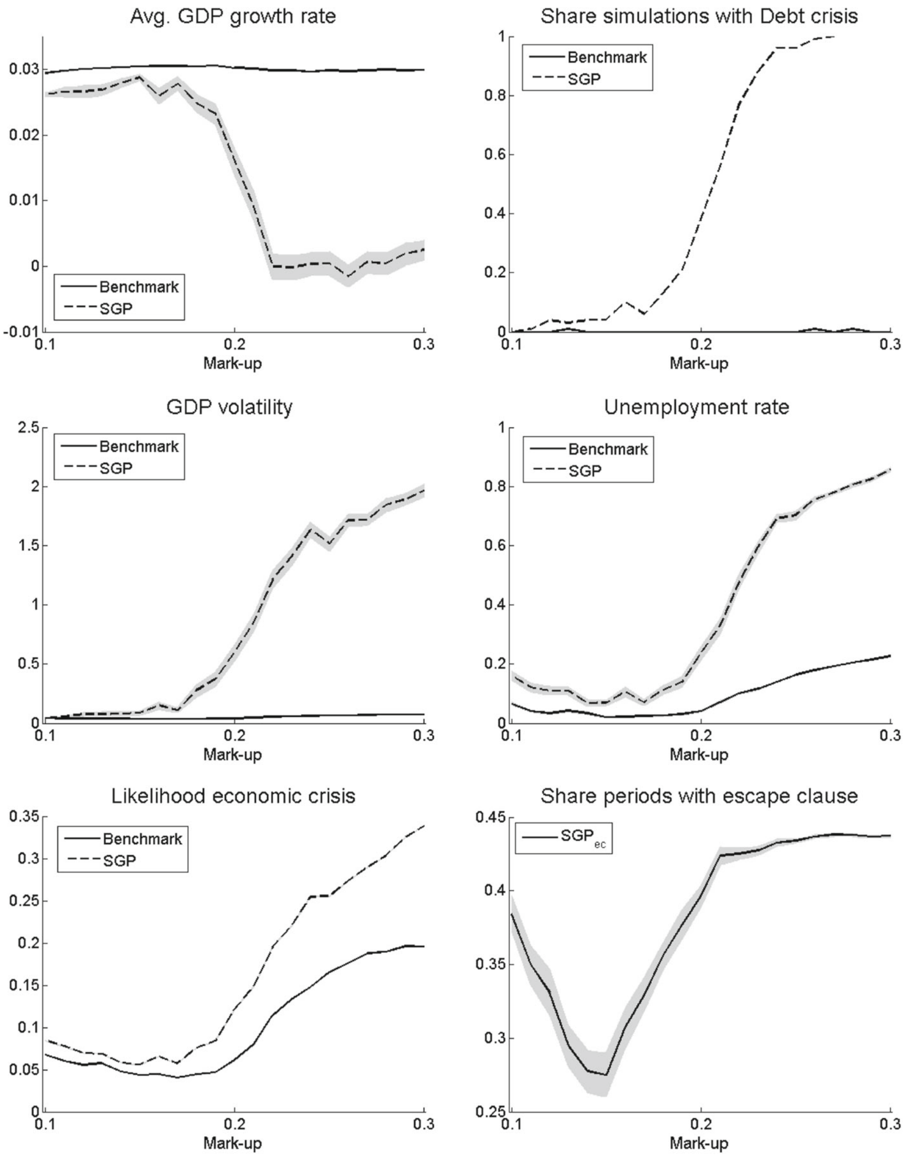

Fig. 5 Fiscal rules (Dosi et al. 2015). Confidence-interval bands are shown in a lighter colour and are computed as plus or minus twice Monte-carlo standard errors

More generally, in the K+S models (Napoletano et al 2012; Dosi et al 2013, 2015), we observe a U-shaped relation between short-run macroeconomic performance and income inequality. For high values of the initial mark-up, high unemployment and

GDP volatility correlate with the instability of demand. Conversely, when income distribution is too much skewed toward wages, firms become more dependent on external finance, and are more exposed to failure in the case of adverse shocks. In such scenarios, firms become more sensitive to changes in the cost and the quantity of credit.

In our models, in line with the general lack of any evidence, at least at the micro level, of a negative relationship between the cost of capital and investment, interest rates do not affect micro investment behaviors unless their desired levels cross a (high) threshold (**E11**). After such threshold, firms become highly dependent on external finance and higher firm bankruptcy rates are observed. In turn, higher bankruptcy rates weaken banks' balance sheets, and, in the presence of, say, the Basel rule, further reduce credit availability. The whole system becomes more volatile and less resilient to shocks. As we discuss at greater length in Napoletano et al. (2012), the emergence of two different growth regimes is due, given adaptive expectations, to the constraints on internal cash flows and credit availability.

6 Discussion and concluding remarks

The "Schumpeterian" growth literature written large, with different underlying inspirations, rooted in both the evolutionary literature tradition and the neoclassical paradigm (and various combinations thereof), has provided key insights about the sources and mechanisms driving technical change, industry and macroeconomic growth. At the same time, most "Schumpeterian" contributions have provided so far a limited account of how effective demand coordination mechanisms and creative-destruction processes can affect the performance of the economy.

In this work, we presented a family of evolutionary agent-based models, the "K+S" formalism, which combines both "Schumpeterian" (innovation-driven) and "Keynesian" (demand-driven) mechanisms. Encouraged by the K+S models' ability to reproduce several stylized facts relating to short- and long-run macroeconomic dynamics of an economy, as well as to the cross-sectional dynamics of firms, we employed the model to analyze the effects of an ensemble of *micro* and *meso* policies concerning the a) search capabilities of firms, b) the pool of technological opportunities available for innovation, c) the degree and breadth of patent protection, d) the strength of market selection and competition. In line with previous works in the Schumpeterian growth literature (e.g. Dosi and Nelson 2010; Aghion et al 2013), we find that an increase in technological opportunities and a higher entrant-carried search have a strong and positive effect on the long-run performance of the economy. Conversely, strengthening the patent protection deters growth. Together, we also find a positive, but much weaker effect of stronger market competition on long-run growth.

Furthermore, we analyzed the impact of different types of fiscal policy. We show that active fiscal policies have a positive effect on unemployment and output stabilization in the short-run. Moreover, the beneficial effects of fiscal policy persist in the long-run, as they allow the economy to reach higher growth paths. In contrast, fiscal austerity measures have a detrimental effect on the macroeconomic performance of an economy, both in the short- and in the long-run. In addition, austerity is self-defeating as it implies an explosion of government debt.

Overall, our experiments point to a strong complementarity between Keynesian and Schumpeterian policies. More precisely, when fiscal policies are not in place, the long-run growth of the economy collapses even in the presence of a strong Schumpeterian regime characterized by a high degree of technological opportunities and firms' search capabilities.

The presence of aggregate demand effects in the long-run (and the consequent beneficial role of fiscal policy) constitutes one of the key contributions of the K+S family of models. Two main transmission channels explain such results. The first is genuinely "Keynesian": investment of consumption-goods firms depends on (adaptive) expectations about future demand. In turn, such dynamics generate fluctuations in investment, the effects of which propagate to the long-run via their impact on capital-good firm sales and R&D expenditures. The second channel is essentially "Minskian" (see e.g. Minsky 1986): in good times, firms invest more and more, partly by raising their leverage, gradually weakening their balance sheet and leading to increased rates of bankruptcy. In that, the presence of a "Basel rule", linking credit supply to banks' equity, provokes a credit crunch right when the economy is entering a downturn. Active fiscal policy smoothes out the instability of the matching between demand-driven processes of production and investment, on the one hand, and Schumpeterian processes of technical change, on the other. In turn, the feedbacks between innovation and demand dynamics call for a coordinated set of policies, going against the peculiar schizophrenia between macro policies, if any, for the short-run and "structural" policies for the long-run.

The K+S family of models is currently being extended along three different lines. First, the possible connections between climate change, innovation and climate policies are studied by including an energy sector and carbon emissions in the standard K+S model (Lamperti et al. 2016). Second, Dosi et al. (2016b) provide an explicit microfoundation of the labor market, studying the performance of the economy under alternative labor market regimes characterized by different degrees of flexibility. Finally, we assess the role of different expectation rules on the dynamics of the economy in Dosi et al. (2016a).

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Appendix

Table 6 Benchmark Parameters

Description	Symbol	Value
Number of firms in capital-goods industry	F_1	50
Number of firms in consumption-goods industry	F_2	200
R&D investment propensity	ν	0.04
R&D allocation to innovative search	ξ	0.50
Beta distribution support (innovation process)	$[\underline{x}_1, \overline{x}_1]$	$[-0.15, 0.15]$
New-customer sample parameter	γ	0.50
Capital-goods firm mark-up rule	μ_1	0.04
Desired inventories	ι	0.10
Payback period	b	3
"Physical" scrapping age	η	20
Mark-up coefficient	υ	0.04
Competitiveness weights	$\omega_{1,2}$	1
Maximum debt/sales ratio	Λ	2
Uniform distribution supports (consumption-goods 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]
Bond interest rate mark-up	μ^{bonds}	-0.33
Shape parameter of bank client distribution	$pareto_a$	0.08
Bank capital adequacy rate	τ^b	0.08
Capital buffer adjustment parameter	β	1
Parameters used in the experiments (baseline values)		
Beta distribution parameters (innovation process)	(α_1, β_1)	(3,3)
Firm search capabilities parameters	$\zeta_{1,2}$	0.30
Beta distribution parameters (capital-goods entrants technology)	(α_2, β_2)	(2, 4)
Replicator dynamics coefficient	χ	1
Tax rate	tr	0.10
Unemployment subsidy rate	φ	0.40
Fiscal rule max deficit to GDP (SGP, FC)	def_{rule}	0.03
Interest Rate	r	0.01
Consumption-goods firm initial mark-up	$\overline{\mu}(0)$	0.30

Table 7 Parameters of interest in the policy experiments

Experiment		Model	Case	Parameter values
E1.	Search capabilities	(Dosi et al. 2010)	low	$\zeta_1 = 0.1, \zeta_2 = 0.1$
			high	$\zeta_1 = 0.5, \zeta_2 = 0.5$
E2.	Technological opportunities	(Dosi et al. 2010)	low	$\alpha_1 = 2.7, \beta_1 = 3.3$
			high	$\alpha_1 = 3.3, \beta_1 = 2.7$
E3.	Patents	(Dosi et al. 2010)	length	12 periods without imitation
			breadth	12 periods without imitation; no innovation close to other firms' technology (range 0.01)
E4.	Entrants' productivity	(Dosi et al. 2010)	low	$\alpha_2 = 1.8, \beta_2 = 4.4$
			high	$\alpha_2 = 2.2, \beta_2 = 3.6$
E5.	Market selection	(Dosi et al. 2010)	weak	$\chi = 0.95$
			strong	$\chi = 1.05$
E6.	Antitrust	(Dosi et al. 2010)	weak	$\max f_j = 75\,\%$
			strong	$\max f_j = 50\,\%$
E7.	Schumpeterian regime	(Dosi et al. 2010)	pure	$tr = 0, \varphi = 0$
			strong	$tr = 0, \varphi = 0$ and $\alpha_1 = 3.3, \beta_1 = 2.7, \zeta_1 = 0.50, \zeta_2 = 0.50$
E8.	Fiscal policy stabilizers	(Dosi et al. 2010)	(range)	$tr \in [0.05, 0.2], \varphi \in [0.2, 0.8]$
E9.	Fiscal rules	(Dosi et al. 2015)	SGP	$def_{rule} = 0.03$
			SGP_{ec}	$def_{rule} = 0.03$, suspended if negative GDP growth
E10.	Income distribution	(Dosi et al. 2013; Dosi et al. 2015)	(range)	$\overline{\mu} \in [0.10; 0.40]$
E11.	Monetary policy	(Dosi et al. 2013)	(range)	$r \in [0.001; 0.40]$

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