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Agent-Based Macroeconomics and Classical Political Economy: Some Italian Roots

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Agent-Based Macroeconomics and Classical Political Economy: Some Italian Roots*

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Abstract

In this work, we discuss how the rich academic milieu left by different Italian political economy traditions after WWII paved the way to the development of a new generation of macroeconomic agent-based models. The K+S (Dosi et al., 2010, 2016a), CATS (Delli Gatti et al., 2005, 2011) and EURACE (Cincotti et al., 2010; Teglio et al., 2012) families of agent-based models are at the frontier of an alternative macroeconomic research paradigm which considers the economy as a complex evolving system. The three families of models are presented in details and their empirical performance and policy exercises discussed.

Keywords: Agent-Based Macroeconomics, Classical Political Economy, Macrodynamics, Complexity Theory, L. L. Pasinetti, P. Sylos Labini.

JEL Classification: B22, B5, E00, E32, E6, O3, O4

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1 Introduction

It is with pleasure that we accepted the invitation to edit this Special Issue of the Italian Economic Journal on Agent-Based Models (ABM) and to introduce it with reference to the earlier Italian tradition in economic thought. As witnessed also by this Issue, Italian contributions to the ABM *genre* have been particularly rich and variegated. Here we shall argue that this has been also the consequence of a favorable academic terroir left by several Italian traditions (we use on purpose the plural) flourished after WWII. Even if one cannot talk about an "Italian School", some deep orientations have been shared by economists as diverse as Luigi Pasinetti, Paolo Sylos Labini, Piero Sraffa, Federico Caffeé, Giorgio Fuá and Luigi Spaventa, (we limit the list to scholars who are or would have been now eighty years old ...).

In the following, we shall flag some distinct features of such "Italian traditions" (cf. Section 2), which, we shall see, are mirrored by several building-blocks of Agent-Based Macro models (Section 4). Finally, we shall zoom on the main *Italian* contributions to the macroeconomic ABM literature, which have been blossoming in the last fifteen years, becoming one of the international benchmark for agent-based macroeconomics. In Section 4, we focus on the K+S family of models (Dosi et al., 2010, 2016a) originated at Scuola Superiore Sant'Anna (Pisa), the CATS family (Delli Gatti et al., 2005, 2011) developed between Ancona and Milan, and the EURACE model (Cincotti et al., 2010; Teglio et al., 2012) born in the University of Genova.[1] The models jointly account for endogenous growth, business cycles and rare deep crises and can reproduce a rather long and increasing list of micro and macro empirical regularities. Finally, they have been employed for different policy exercises concerning innovation, industry, monetary, fiscal and macroprudential policies.

2 The Italian "Political Economy" after WWII

As mentioned the Schools had many differences with each others, but they shared a profound *classical* spirit (as opposed to "neoclassical" one). First, they all shared a rejection for the two fundamental pillars of mainstream (neoclassical) economics, namely maximization at micro level, and equilibrium at aggregate one. Rather, the central theoretical quest has been the identification and sometimes the formalization of "laws of motion" of the system, while quite agnostic, or even skeptical about possible microfoundations (see among many Pasinetti, 1974, 1983, Spaventa, 1970, and later Amendola and Gaffard, 1988, 1998).[2] Indeed, on the micro side, an implicit or explicit trait in common was the distance from any "Benthamian" anthropology with its reduction of all behaviors to some utility-base driver. And on the system side, they all abhorred the idea that markets (beginning with the labor market) generally clear.

[1] In that we are aware of the neglect of other relevant, but less macro focussed contributions, including those by Pietro Terna and collaborators (see among many works, e.g. Beltratti et al., 1996; Gilbert and Terna, 2000; Fontana, 2010) and by Matteo Richiardi (e.g. Leombruni and Richiardi, 2006; Richiardi et al., 2006; Richiardi and Richardson, 2017).

[2] An exception, in our view, is the famous Sraffa (1960), which is in fact a sort of *equilibrium scaffolding* meant to study the relations between relative prices, wages and profits. This is a particular controversial issue, as it was at the core of at least of twenty years of sometimes bitter and ideology-ridden debates. However, after a long while, the older of us (G. D.) came to the doubt that, after all, Franck Hahn was not totally wrong in suggesting that "Neo-Ricardianism" is not too far from general equilibrium with the fixed coefficient restrictions (see the provocative Hahn, 1982).

Second, they were deeply inspired by classical economists - in primis, Adam Smith and Marx - and to varying degrees, by Ricardo, Keynes and Schumpeter.

Third, most of them had/have a keen interest in economic and political history, seen as undistinguishable from the theorizing tasks: see again, among many relevant others Fuá (1978-1983), Caffé (1978), Biasco (1979), Sylos Labini (1984), Salvati (2000). In that, they have all thaught us to be at the opposite side to the so-called (New) "Political Economy", by which there is basically an invariant stochastic growth generating process, from the Stone Age to the Space Age (and beyond), fueling a basically invariant "Production Function", where arguments may well change over time, from Zeus to the Protestant Ethic, from stones to computers, to even morally more troubling genetic endowments.[3]

Finally, most of them had/have a profound *civil political passion*: we are all here to understand the world, *but in order to change it to the better*. And that, we were thaught, and we still believe, means transforming institutions, changing balances of power, overturning "hegemonic ideologies" - in Gramsci's sense.[4] In all that, the contribution of e.g. Wilfredo Pareto was considered at best marginal or most often viral. Indeed, the Pareto on statistical distributions is a secular landmark. The Pareto on the "welfare" theorems is indeed analytically pathetic and socially dangerous. Unfortunately, the younger generations never learned what the theorems basically meant: an apology of almost every *status quo*.

Of course, there were also several downsides to the foregoing "classical" Italian perspectives. One was the excessive emphasis on income distribution and too little on technical change (with the outstanding exception of Sylos Labini). Naturally, it is better to discuss too much about income distribution than assuming a marginalist theory of value and completely neglect it (in that, the empirical works of e.g. Piketty are a breadth of fresh air). However, it was as if one zoomed on that part of Marx addressing value, surplus, and exploitation, while neglecting that other Marx on the "revolutionizing" role of capitalism.[5]

Another downside, in our view, was the quite general discard of microfoundations, seen by many as the equivalent to the rejection of methodological individualism. Of course, we are all against the latter: rational maximizing individuals are the wrong place to start, and in any case they are not there at all. But microbehaviors *are* important to account for aggregate dynamics. So, for example one can of course study the dynamics of a beehive as a whole, but it is important to ask also what is the distribution of behaviors of individual bees and their interaction patterns which are consistent with hive patterns (and survival).[6] This is precisely what agent-based models try to do. And notice that there is no "methodological individualism" in the exercise, in

[3]Unfortunately, we are not joking: some economists do claim - in top economic journals - that genetic diversity of countries can predict the success of their economies, and that one can find an optimal level of diversity (Ashraf and Galor, 2013). Not surprisingly, outside economics, such "Mengelian" studies (in which both native Americans and Africans do not possess optimal genetic diversity) have been harshly criticized and considered "deeply scientifically flawed" by prominent genetists, biologists and anthropologists. Of course, the Italian political economists would have been/are horrified too.

[4]Incidentally, how many under-40 Italian economists know who Gramsci is? And American ones?

[5]Macroeconomic agent-based models tend to do the opposite, and this is a weakness that has to be quickly addressed.

[6]The issue has been at the center of decade-long discussions of one of us (G.D) with Giorgio Lunghini: no agreement, but hopefully we have now clearer ideas. In fact, Marco Lippi has provided one of the path-breaking contribution to the discussion on the properties of micro-macro aggregation: see well before dynamic factor models, Lippi (1988).

that there is no "derivation" of the aggregate from an individual pursuing her objective: in fact, it may well be the case, as Kirman (2016) shows, that is the micro (what individual bees do) that is *macro*founded (i.e. determined by some system-level state variables such as the hive's temperature).

A third major downside has been (for many, not for all) the methods and the ways the arguments were constructed. Too much "critique of the neoclassical school",[7] too many exegetic exercises ("What did Ricardo actually mean at page x?" What did Keynes say in chapter y?") and too little by way of statistical and historical analysis, model building, case studies.

Last but not least, many of the major players of the "Italian tradition" had hypertrophic egos (incidentally a virus always widespread in the economic profession), which made the birth of lasting "schools" basically impossible.

However, despite all these drawbacks, the *Zeitgeist* in Italy was rich, stimulating, and allowed the persistence of "ecological niches" large enough to allow the survival and growth of an alternative theory to the mainstream one, part of which we are witnessing with agent-based models (a sample is contained in this Special Issue).

Certainly it faced hard times. This is partly associated with the return to Italy of young Italians sent to the U.S. for their graduate studies. Visiting the U.S. had been common earlier on, but mostly it meant interacting with great *and sensible* economists, even when in disagreement, from Solow to Modigliani to Tobin to Klein. With the wave beginning in '80s, the story is different and in many respects looks like a phenomenon of mass religious conversion. When graduate students came back, like "foreign fighters", many of them completely renegaded their theoretical roots for joyfully embracing market talibanism. And this also led to a profound change in the "ethos of the profession": from "I want to understand the world and possibly improving it", to "I want to publish in the top five journals, even at the cost of raping any perception of what is sensible, what is moral, and what is not".[8] And policy advices lost importance, as many thought it is not the job of economists, or, worse, often turned out to be even dangerous, with the fundamentalism of the neo-converted to the market religion.[9]

Come as it may, in Italy a fertile ground for an alternative paradigm focused on *the analysis of the economy as a complex evolving system*[10] *has remained*, and more specifically for its macroeconomic instantiation which we consider ABM to be. Before considering the latter in more details, let us discuss the building blocks of agent-based macroeconomic models.

[7]Finding logical inconsistencies in the adversary camp was a paramount activity: so, after the indisputable victory of Cambridge, England over Cambridge, Massachusetts on the aggregate production function, the search for some sort of mistake in general equilibrium involved such high expectations that one thought that the insurrection of the world proletariat was only waiting for that to be triggered!

[8]And even worse, in this banality of evil, we also guess that some of them do not even have a perception of civic sensibility and morality in doing economic research.

[9]In Dosi and Roventini (2017), we have discussed some of these perversions, spanning from freaky rational lovemaking to criminal welfare analysis of dynamic models of torture!

[10]For a discussion of the "grand evolutionary program, see the introduction to Dosi (2012) and Dosi and Virgillito (2017). For a comparison of macroeconomic agent-based models with standard DSGE one, see Fagiolo and Roventini (2012, 2017)."

3 Agent-Based Models

Agent-Based Computational Economics (ACE) can be defined as the computational study of economies thought as complex evolving systems (Tesfatsion, 2006a).[11] Agent-based models can be characterized by ten ingredients:

1. *A bottom-up perspective.* The aggregate properties of a decentralized economy must be obtained as the macro outcome of a possibly unconstrained micro dynamics going on at the agent level.

2. *Heterogeneity.* Agents are (or might be) heterogeneous in almost all their characteristics and behaviors

3. *The evolving complex system approach.* Agents live in complex systems that evolve through time. Therefore, aggregate properties are thought to emerge out of repeated interactions among simple entities, rather than from the consistency requirements of rationality and equilibrium imposed by the modeler.

4. *Non-linearity.* The interactions that occur in ABMs are inherently non-linear. Additionally, non-linear feedback loops exist between micro and macro levels.

5. *Direct (endogenous) interactions.* Agents interact directly. The decisions undertaken today by an agent directly depend, through adaptive expectations, on the past choices made by other agents in the population.

6. *Bounded rationality.* The environment in which real-world economic agents live is too complex for hyper-rationality to be a viable simplifying assumption. Agents are assumed to behave as boundedly rational entities with adaptive expectations.

7. *The nature of learning.* Agents in ABMs engage in an open-ended search in changing environments. This is due to both the ongoing introduction of novelty and the generation of new patterns of behavior; but also on the complexity of the interactions between heterogeneous agents (see point 5 above).

8. *"True" dynamics.* Partly as a consequence of adaptive expectations, ABMs are characterized by true, non-reversible, dynamics: the state of the system evolves in a path-dependent manner.

9. *Endogenous and persistent novelty.* Socio-economic systems are inherently non-stationary. There is the ongoing introduction of novelty in the systems and the generation of new patterns of behavior, which are themselves a force for learning and adaptation. Hence, agents face "true (Knightian) uncertainty" (Knight, 1921) and are only able to partially form expectations on, for instance, technological outcomes.

10. *Selection-based market mechanisms.* Agents typically undergo a selection mechanism. For example, the goods and services produced by competing firms are selected by consumers.

[11] This section is largely drawn on Fagiolo and Roventini (2012, 2017). For further details on ACE see Pyka and Fagiolo (2007), Fagiolo et al. (2007), Tesfatsion and Judd (2006), and Tesfatsion (2006b).

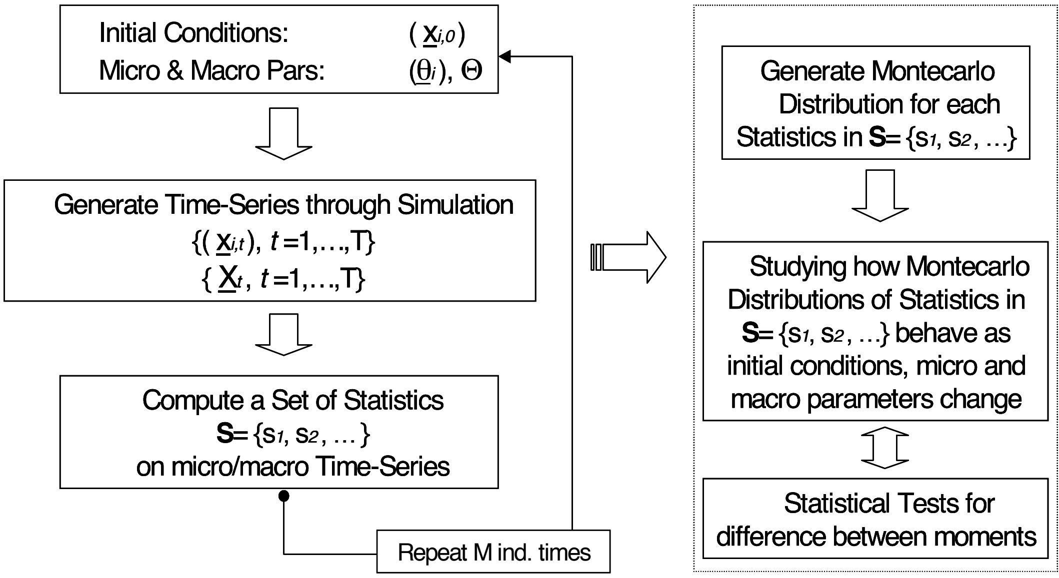

Figure 1: A schematic procedure for studying the output of an AB model. Source: Fagiolo and Roventini (2012, 2017)

The selection criteria that are used may themselves be complex and span a number of dimensions.

Agent-based models typically possess the following structure. There is a population – or a set of populations – of agents (e.g., consumers, firms, etc.), possibly hierarchically organized, whose number may change or not over time. The evolution of the system is observed in discrete time steps, $t = 1, 2, \ldots$. Time steps may be days, quarters, years, etc.. At each t, every agent i is characterized by a finite number of time-varying micro-economic variables $\underline{x}_{i,t}$ (e.g. wealth, technology, capital) and by a vector of micro-economic parameters $\underline{\theta}_i$ (e.g. mark-ups). Finally, there are also some macroeconomic parameters Θ, which often can be related to different policies (e.g. tax rate, unemployment subsidy rate, etc.).

Given some initial conditions $\underline{x}_{i,0}$ (e.g. income distribution, technology, etc.) and a choice for micro and macro parameters, at each time step $t > 0$, one or more agents are chosen to update their micro-economic variables. This may happen randomly or can be triggered by the state of the system itself. Agents selected to perform the updating stage collect their available information about the current and past state of a subset of other agents, with whom they typically interact, and about some macroeconomic variable (e.g. past GDP, inflation, unemployment rate, etc.). Given their updated information set, they adaptively behave employing heuristics or some form of local optimization. These rules, as well as interaction patterns, are designed so as to mimic empirical and experimental evidence. After the updating round has taken place, a new set of micro-economic variables is fed into the economy for the next-step iteration: aggregate variables $\underline{X}_t$ are computed by simply summing up or averaging individual characteristics.

The stochastic components possibly present in decision rules, expectations, and interactions will in turn imply that the dynamics of micro and macro variables can be described by some (Markovian) stochastic processes parameterized by micro- and macro-parameters. Hovever, non-linearities which are typically present in decision rules and interactions make it hard to analytically derive laws of motion, kernel distributions, time-t probability distributions, etc. for the stochastic processes governing the evolution of micro and macro variables. For these reason, researchers often resort to computer simulations in order to analyze the behavior of the ABM at hand. As the economy is by definition out-of-equilibrium in ABMs, one must look for long-run statistical equilibria and/or emergent properties of aggregate dynamics. If the dynamics behavior of the system becomes sufficiently stable after some time horizon T^* for (almost all) points of the parameter space, a possible procedure that can be implemented to study the output of the ABM runs as the one synthetically depicted in Figure 1.

Given some choice for initial conditions, micro and macro parameters, one can compute a set $S = \{s_1, s_2, \dots\}$ of statistics on micro and macro simulated variables. Given the stochastic nature of the process, each simulation run will output a different value for the statistics. Therefore, by performing a Monte Carlo exercise of M independent runs, one has a distribution for each statistics of interest, which can be summarized by its moments. As the moments depend on initial conditions and parameters, by exploring a sufficiently large number of points in the initial-condition and parameter space and computing the moments of the statistics of interest, one might get a quite deep *descriptive* knowledge of the behavior of the system (see Figure 1).

4 The Italian Families of Macroeconomic Agent-Based Models

4.1 The Keynes+Schumpeter Evolutionary Models

The Schumpeter meeting Keynes (K+S) family of models developed in Dosi et al. (2010, 2013, 2015) bridges Schumpeterian theories of technical change and endogenous growth with Keynesian insights of coordination failures and endogenous fluctuations. Starting from evolutionary roots (Nelson and Winter, 1982; Dosi, 1988), the K+S model embeds the Schumpeterian growth paradigm into a complex system of imperfect coordination among heterogeneous interacting firms and banks, wherein Keynesian (demand-related) and Minskian (credit cycle) elements feed back into the meso and macro dynamics. The model endogenously generates long-run growth and fluctuations puncutated by major crises and it is able to reproduce a rich ensemble of macro and micro stylized facts. The K+S model can be employed to perform policy analyses concerning innovation, fiscal, monetary, and industrial policies. A general and robust conclusion of policy exercises is the strong complementarity between Schumpeterian (technological) and Keynesian (demand-related) policies in ensuring that the economic system follows a path of sustained stable growth and employment.

Let us begin with the basic structure of the K+S model. A detailed survey is provided in Dosi et al. (2016a).

4.1.1 Model structure

The K+S model is populated by a fixed number of capital- and consumption-good firms. There is an invariant set of banks, constant number of households/workers, a central bank and a government.

Capital-good firms employ labor to produce heterogeneous machines, which are bought by consumption-good firms. The latter invest a fraction of their past sales in R&D to search for process and product innovations and to imitate their competitors. Both are risky ventures. Given the R&D investment, the discovery of new vintages of machines depends on the search capabilities of firms as well as on the current level of technological opportunities. Imitation is more likely to be succesful, the smaller the technological distance between two firms. Firms choose the machine to produce and fix prices as a mark-up on the unit cost of production. The capital-good market is characterized by imperfect information: machine-tool firms advertise their products' price and productivity characteristics to a subset of consumption-goods firms, which in turn change their suppliers if they are offered a better combination of price and unit production costs. In any given period, different vintages of machines coexist in the market. The speed of diffusion of the machines with the most advanced technology depends on the evolution of the market share of their producer, on competitors' imitation rates, as well as on consumption-goods firms' investments.

Consumption-goods firms produce a homogeneous good using both capital and labor under constant returns to scale. Given adaptive demand expectations and inventories, they define their desired level of production. If their production capacity is not sufficient, firms invest to expand their capital stock. Moreover, firms invest to replace obsolescent machines according to a payback period routine. Consumption-goods firms have to advance wages to employees and pay the ordered machines. As capital markets are imperfect, they finance their investments and production with internal funds first and, if necessary, relying on bank credit. Naturally, external funds are more costly than internal ones and firms can be credit rationed. Consumption-good market is characterized by imperfect competition. Firms fix the price applying a mark-up on their unit cost of production. The mark-up and the market power of firms evolve according to the dynamics of their market shares. Workers consume all the income they receive. As the market is characterized by imperfect information, consumption is allocated via a replicator dynamics: the most competitive firms (i.e. those producing the cheapest product and able to fully satisfy their past demand) will gain new customers, thus increasing their market shares.

At the end of the period, both capital- and consumption good firms compute their profits and update their stocks of liquid assets. Firms with zero market share or negative stock of liquid assets go bankrupt and a replaced by new entrants, so that the number of firms is kept constant over time.[12] Bankrupted firms do not pay back their loan to the bank, thus deteriorating the assets of the latter.

Heterogenous banks gather firms' deposits, provide loans to consumption-good firms and own sovereign bonds. Banks are heterogenous in their number of customers (drawn form a Pareto distribution), and their supply of credit is constrained by capital adequacy requirements inspired by Basel-framework rules. Banks also maintain a buffer over the regulatory capital level which evolve according to banks' financial fragility (proxied by the ratio between defaulted loans and assets). Banks provide credit to firms according to their creditworthiness (proxied by the ratio between firms' past net worth and sales). Once the supply of credit is exhausted, the remaining consumption-goods firms are credit-rationed. Finally, banks fix the interest rate

[12] In line with the empirical literature on firm entry (Caves 1998; Bartelsman et al. 2005), new firms are typically smaller than incumbents in terms of capital stocks and liquid assets.

applying a spread on the risk-free interest rate.

In the labor market, the supply is exogenous while demand depends on firms' production decisions. The wage is indexed on productivity dynamics, inflation and unemployment. As the wage does not necessarily clear the market, both involuntary unemployment and labor rationing can emerge.

The central bank fixes the interest rate according to a Taylor rule (not because one believes of any underlying theoretical justification of it, but just not to be accused of neglecting it: however, it does not matter!). The government sets the tax rate on firms' profits and provides a subsidy to unemployed workers. In case of banking crises, the government also step in and re-capitalize the "troubled" banks. 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.

4.1.2 Macroeconomic dynamics and stylized fact replication

The Keynes+Schumpeter model endogenously generate *long-run growth*, which is the outcome of the innovative activity of capital-good firms and the diffusion of new technologies in the economy via the imitation of competitors and the investment of consumption-good firms. However, the growth process is far from steady: the dynamics of the economy exhibits recurrent *business cycle fluctuations* and rare *deep crises*. This is one of the major advantages of agent-based models vis-á-vis traditional ones, which cannot jointly account for mild and deep recessions (Stiglitz, 2011, 2015; Ascari et al., 2015). Business cycles are endogenous and have a genuine Keynesian origin. The production and investment choices of firms can lead to coordination failures in the goods markets which in turn affect aggregate output and unemployment dynamics.

In line with Minsky (1986), banks' activity can amplify fluctuations via credit cycles. During expansions, banks are more willing to finance firms, thus supporting their possibly over optimistic choices. However, during the subsequent recessions, they shrink their credit supply when firms mostly need it. Moreover, whenever defaulted-loan losses are higher than bank's net worth, a banking crisis occurs and the government must step in to bail out the bankrupted banks. This can possibly trigger a deep downturn as banks' failures are conducive to credit crunch, which further reduces firms' production, and increase government deficit, possibly leading to a sovereign debt crisis.

At the *macroeconomic level*, the Keynes+Schumpeter model accounts for other empirical regularities (see e.g. Stock and Watson, 1999; Napoletano et al., 2006). At the business cycle frequencies, investment is more volatile than GDP, while consumption fluctuations are milder. Moreover, the co-movements between GDP and other macroeconomic variables (e.g. unemployment, productivity, mark-ups, real wage, credit, etc.) are in line with the empirical evidence. This occurs also for the properties of recessions and banking crises. More specifically, recession duration is exponentially distributed; GDP growth rate distribution is fat-tailed (Fagiolo et al., 2008), i.e. mild and deep downturns coexists; banking crises duration is right skewed and the distribution of their fiscal cost over GDP is fat-tailed.

The K+S model can also jointly reproduce a rather long list of *microeconomic stylized facts* (Dosi, 2007). This is one of the major advantage of agent-based models vis-á-vis DSGE ones, which by assuming a representative agent cannot account for microeconomic regularities. First, firm size distributions are right skewed and significantly depart from the Gaussian benchmark. Firm growth-rate distributions are fat-tailed. Firms are heterogenous in terms of productivity and such differentials tend to be persistent over time. The model generates lumpy investment patterns at the firm level. Finally, firm bad-debt distribution is well approximated by a power law and firm bankruptcies are counter-cyclical.

4.1.3 Policy analysis

Given its good empirical performance, the Keynes+Schumpeter model can be employed to study the effects of different policy combinations. In particular, as the model generates both endogenous growth and business cycles, one can study the effects of different policy interventions across the whole spectrum of frequencies.

The first set of experiments concerns *technology policies* (Dosi et al., 2010). Improving the search capabilities of firms and technological opportunities spur long-run economic growth, but they also reduce the unemployment rate. Thus innovation policies do affect the short-run dynamics of the economy.

One can then consider the impact of *industrial policies.* The introduction of a patent system harms both the long- and short-run performance of the economy. On the contrary, endowing entrant firms with better technologies has a positive impact on GDP growth and it reduces output volatility and the unemployment rate. Finally, increasing competition in capital- or in consumption-good sector improves both the short- and long-term dynamics of the economy.

Fiscal policies appear not only to dampen business cycles fluctuations, but to cast their effects also in the long-run. Indeed, if one jettisons fiscal policy from the economy, by setting the tax rate and the unemployment benefit to zero, the unemployment rate and GDP volatility skyrocket, but also the long-run output growth rate collapse. Such a results is robust also when one replaces fiscal policies with technological ones. How do fiscal policies affect the long-run performance of the economy? Countercyclical Keynesian policies, by sustaining demand during recessions, smooth investment and production during the business cycles, thus fostering the R&D investment of capital-good firms and the diffusion of machine-tools embodying state of the art technologies. To sum up, the first set of experiments on fiscal policies show that Keynesian policies are *complementary* to Schumpeterian ones, as the latter alone cannot sustain a stable growth path (Dosi et al., 2010). Fiscal policies are required more so with high income inequality: the higher latter, the higher economic instability, and the stronger the case for distributive policies supporting wages and aggregate demand (Dosi et al., 2013). Finally, austerity fiscal policies (e.g. Fiscal Compact) have a negative impact on both the short-run performance of the economy (Dosi et al., 2015), as well as on the technological innovation and diffusion, thus reducing long-run GDP growth (Dosi et al., 2016b). Austerity policies are also self-defeating as they are not able to stabilize the public budget.

On the *monetary policy* side, simulation results performed with the K+S model show that the interest rates does not affect investment unless a rather high threshold is crossed (Dosi et al., 2013). A dual-mandate Taylor rule focused on inflation and unemployment outperform a conservative one concerned only with price stability (Dosi et al., 2015). However, the transmission of monetary policy impulses occur via the credit channel instead of the interest rate one. Indeed, a dual-mandate Taylor rule increases the interest rate during booms, when unemployment fells at the minimum level. This in turn boosts banks' profitability and their balance sheets, thus allowing them to provide more credit to firm in the next recessionary phase.

4.1.4 Extensions

In the last years, the K+S model has been extended along two directions. First, the labor market has been microfounded to study the impact of structural reforms and flexibilization policies on employment as well as on the whole economy. Second, the model has been supplemented with an energy sector, greenhouse gasses emissions and a "climate box" to analyze the co-evolution of economic growth and climate change.

In a series of papers (Dosi et al., 2017b, 2016c, 2017a), the K+S model has been endowed with a labor market characterized by decentralized interaction among heterogenous firms and workers. The latter consider open vacancies and queue to find a job or to get a higher wage. Workers can also be characterized by different level of skills that improve by learning by doing when they are employed and decays when they are unemployed (Dosi et al., 2017a). Firms observe in every period the job applications of a subset of workers and hire them according the requested wage and their skills. The labor market is also characterized by different institutions: firing rules, wage indexation schemes, minimum wage, unemployment benefits. The institutional set up of the labor market allows to compare a rigid "Fordist" archetype, where wage growth is indexed to productivity, vis-á-vis a flexible market one. Simulation results show that the model is able to reproduce a new set of stylized facts concerning labor market (e.g. Wage, Okun, and Beveridge curves). On the policy side, structural reforms aimed at injecting flexibility into the labor market increase the unemployment rate and inequality. Moreover, they always increase economic instability and, if flexibilization is extreme, they may affect the long-run growth of the economy (see also Napoletano et al., 2012). When workers have time-varying skills (Dosi et al., 2017a), structural reforms are even more harmful as they lead to the emergence of hysteresis (Blanchard et al., 2015) in unemployment and GDP time series. Contrary to the "conventional wisdom", but in line with Stiglitz (2011, 2015), higher flexibilization in the labor market weakens aggregate demand, thus increasing unemployment and output fluctuations.

The Dystopian Schumpeter meeting Keynes model (DSK, cf. Lamperti et al., 2017) extends the K+S model to account for climate change. More specifically, in the DSK model, firms need energy to produce capital- and consumption-goods. The energy is supplied by a firm relying on a portfolio of "dirty" and green power plants. The production activities of capital- and consumption-goods firms and dirty plants release in the atmosphere greenhouse gasses, which in turn increase the temperature. Global warming leads to microeconomic climate shocks affecting firms' productivity, capital stock, inventories and energy efficiency. The variability and intensity of climate shocks is non-linearly increasing in the temperature level. Simulation results show that DSK model can account for a new set of empirical regularities linked to the climate-economy co-evolution (e.g. cointegration between GDP, energy consumption and emissions, temperature projections, etc.). Moreover, in the business-as-usual scenario, where there are no policies tackling climate change, the damages stemming from temperature increases can be substantial and much higher than those forecasted by standard integrated-assessment models. The impact of climate shocks is also heterogenous: productivity shocks mainly harm the growth performance of the economy, while capital stock shock exacerbate its fluctuations. Finally, the model shows strong path-dependency and lock-in in the energy sector: timely large policy interventions are needed to put the economy on a green growth path and avoid the catastrophic consequences of climate change.

4.2 The CATS Financial-Fragility Model

The work of Hyman Minsky on financial instability theory (Minsky, 1982, 1986) stimulated the development of the CATS model (Delli Gatti et al., 2005, 2011). The model studies how the leverage decisions of firms and banks can increase the financial fragility of the economy (see also Greenwald and Stiglitz, 1993), possibly leading to bankruptcy waves, economic instability and rare crises. The Minskyan dynamics interacts with the decentralized interaction of heterogenous firms and workers in the goods and labor markets. In turn, possible frictions and Keynesian feedbacks can amplify financial and economic instability. The CATS model can account for a long list of micro and macro empirical regularities and it can be employed to study the effects of fiscal policies and different interventions in financial markets (including monetary policy) with significant overlappings and complementarities with the K+S model.

4.2.1 Model structure

In the CATS baseline model (Delli Gatti et al., 2011), there are a fixed number of firms, consumers/workers and banks which locally interact in the goods, labor and credit markets. Such interactions, give raise to networks which evolve over time. As in the K+S model, markets are characterized by imperfect informations and agents behave adaptively, employing heuristics which are mostly grounded on empirical and experimental evidence.

Firms produce an homogenous goods under constant returns to scale employing labor only.[13] In each period, firms can update either their price or thier production according to past information. More specifically, if the firm sold all its production in the previous period, it will increase production keeping the price constant if the latter is higher than the market average, wheres it will do the opposite if its price is cheaper than the market one. Similarly, if firm accumulates inventories, it will curb production, keeping the price constant if the latter is lower than the average one, whereas it will cut its price (keeping production fixed) if it is higher than the market one.

Firms then compute their labor demand and open vacancies at a certain wage. Unemployed workers send job applications to a subset of firms and choose to work for the one offering the highest wage. Labor contracts last for a fixed number of periods and wages ought to be higher than a minimum level. As the labor market is characterize by local, decentralized interactions, involuntary unemployment and labor rationing can arise.

Firms must pay wages to workers in advance. If their financial resources are not enough, they

[13] In some versions of the model, firms produce also by buying intermediate products from un upstream sector (Delli Gatti et al., 2010) or employing capital bought from capital-good producers (Assenza et al., 2015; Caiani et al., 2016).

will search for a loan. Again, as the credit market is characterized by imperfect information, firms send a loan request to a subset of banks. The supply of bank credit is determined by capital requirements, i.e. it is a multiple of bank equity. Banks allocates credit according to a pecking order rule, providing loans first to the firms with more solid balance sheets. Banks fix the interest rate applying a spread on the risk free interest rate. The spread depends on the financial fragility of the borrower as well as on a stochastic element. Naturally, if two or more banks are willing to provide credit to the same firm, the latter chose the one with the lowest interest rate. At the same time, some firms may end up being credit rationed.

Once production is complete, the goods market opens. Demand stems from the consumption of households, whose income comes from wages and dividends. The marginal propensity to consume is decreasing in households' wealth. Firms post their price and consumers visit a randomly chosen subset of firms. Households choose to buy from the firm with the lowest price, and if the residual stock of goods is not sufficient to satisfy their demand, they goes to the next one in their ranking. At the end of the process, the residual production is lost as the good is assumed to be perishable.

At the end of the period, firms compute their profits. If the latter are still positive after paying back the loan and the interest to the bank, firms pay dividend. In some version of the CATS model (Russo et al., 2007; Delli Gatti et al., 2011, e.g.), firms invest a part of the profits in R&D to increase labor productivity. Firms with negative net worth default from their loan and exit the market. They are replaced by new entrants, whose size is smaller than the one of incumbents. Non-performing loans reduce banks' equity. If the latter becomes negative, the bank is insolvent and it is bailed out by the government.

Finally, the central bank fixes the baseline interest rate and eventually lend money to banks, while the government levy taxes on firms' profits and workers' wage and can perform fiscal policies.

4.2.2 Macroeconomic dynamics and stylized fact replication

The CATS model is able to account for endogenous business cycles punctuated my major crises. The main source of fluctuations lie in Minsky's financial instability theory (Minsky, 1982, 1986). Expansions sew the seeds of the next recessions, as firms increase their liabilities and risks over time, thus reducing their capability to fulfill future payments (i.e. starting as hedging units they became speculative and then "Ponzi" ones). As the financially fragility of the economy increases, small variations in firms' cash flow due e.g. to a fall in profits or a surge in the interest rate, are sufficient to trigger a recession. Firms' defaults worsen the balance sheet of banks, which react by cutting the credit supply and raising their spreads. This, in turn, via a financially accelerator mechanism (Bernanke et al., 1999), further reduces production and increase unemployment. Finally, whenever the equity of some banks are lower than bad debt, a banking crises occur, possibly leading to a deep downturn. In the CATS model, goods and labor market frictions amplify the foregoing dynamics.

When firms are allowed to invest in R&D to spur their labor productivity (Russo et al., 2007; Delli Gatti et al., 2011, e.g.), endogenous growth emerges. Naturally, in this case, financial fragility crises can also impact on the long-run performance of the economy.

The CATS family models can jointly account for many macro and micro stylized facts as the K+S one. First, the model can reproduce the co-movements between GDP and major macroeconomic variables along the business cycles. Once fitting an AR(2) model to the output time series, the ensuing impulse response functions to transitory shocks are hump shaped. The CATS model can also endogenously reproduce the Phillips, Beveridge and Okun curves.

At the microeconomic level, firm size distribution are right skewed and follow a power law, while firm growth-rate distributions are well fitted by Laplace densities. Moreover, in line with the empirical evidence, the frequency of firms' exit and bad debt distribution are exponentially distributed; profits follow a power law; expansions and recessions are well approximated by a Weibull distribution.

4.2.3 Policy analysis

The policy exercises performed with the family of CATS models pay special attention to their impact on financial market fragility as this is the main source of downturns and crises.

Fiscal interventions have been firstly studied in Russo et al. (2007), where, in a balanced-budget framework, the government employs the collected taxes to provide either unemployment benefits or R&D subsidys to firms. Simulation results show that redistributive policies have a negative impact on long-run economic growth as they reduce firms' investment in innovation. On the contrary, public R&D subsidies to firms spur the long-run performance of the economy. Different results emerge when the vintage of the CATS model developed in Riccetti et al. (2014) is employed to study the impact of unemployment benefits on the short-run dynamics of the economy. They find that unemployment subsidies stabilize aggregate demand and in turn improve the financial conditions of firms (Riccetti et al., 2013b). Finally, given the negative impact of inequality on economic dynamics (as in Dosi et al., 2013), more progressive tax regimes can improve the short- and long-run performance of the economy (see the stock-flow consistent model in Caiani et al., 2017).[14]

The interaction between inequality and *financial market deregulation* is studied in (Russo et al., 2016). They find that financial market liberalization in the form of buoyant consumer credit is not a panacea for inequality as it dampen its negative effects in the short-run, but it leads to severe crises in the long-run. The increasing role of financial markets has also a negative impact on economic dynamics when firms and banks increase the dividends distributed to their shareholders (Riccetti et al., 2016). Indeed, the simultaneous reduction in banks' equity and firms' net worth increase both the reliance of credit of the latter and their possibility of being credit rationed, thus increasing the financial fragility of the economy. Relatedly, in presence of higher banking deregulation, the introduction of a counter-cyclical capital buffer as in the Basel III macroprudential regulation can reduce the financial fragility of the system, thus dampening output volatility and the occurrence of economic crises (Riccetti et al., 2017).[15]

Finally, *monetary policy* strategies have been studied in Giri et al. (2016). They find that

[14] In line with (Dosi et al., 2017b, 2016c, 2017a), they also find that higher wage rigidity has a positive impact on economic dynamics.

[15] The positive impact of the counter-cyclical capital buffer and more generally on the fully-fledged Basel III framework on the economic performance is also found in the agent-based model developed in Popoyan et al. (2017).

when the central bank fixes the interest rate according to a dual mandate Taylor rule, cold-turkey like surges of the policy interest rate can trigger recessions. Moreover, a monetary policy strategy that keeps the interest rate close to the zero lower bond after a deep crises can avoid the occurrence of "double dip" recessions.

4.2.4 Extensions

A rich stream of research has extended the CATS model to study the emergence and evolution of credit networks linking firms trading intermediate goods, firms and banks via the supply of loans, and banks in the interbank market. The seminal contribution is Delli Gatti et al. (2010). They find that the emergent *network-based financial accelerator* can trigger bankruptcy avalanches thus amplifying shocks. In particular, the evolving network structure synthetically captured by the third and fourth moments of its degree distribution can increase the probability of bankruptcy chains involving large banks or firms. In such a framework, increasing leverage spurs the financial fragility and instability of the economy and monetary tightening interventions should be implemented only if banks are well capitalize (Riccetti et al., 2013a). However, the evolving credit network properties can be exploited to build early warning indicators as in Catullo et al. (2015).

Another line of research has tried to increasingly simplify the CATS model in order to compare it with standard macroeconomic ones (Assenza and Delli Gatti, 2013; Assenza et al., 2015).[16] Finally, a new contribution (Caiani et al., 2016) has combined the agent-based and stock-flow-consistent approaches.

4.3 The EURACE Large-Scale Model

The K+S and CATS are medium scale models designed to account in a parsimonious way for macroeconomic phenomena. On the contrary, the EURACE family of models (Cincotti et al., 2010) has been designed to capture the dynamics of the European economy. Nevertheless, it shares with the K+S and CATS models, the same evolving complex system philosophy: macroeconomic dynamics ought to be studied starting from the interactions of heterogenous, adaptive agents, whose behaviors should be possibly microfounded according to the available empirical and experimental evidence.

4.3.1 Model structure

The EURACE model (Cincotti et al., 2010, 2012; Teglio et al., 2012), is characterized by heterogenous households, capital- and consumption-good firms, banks, the government and a central banks. Agents' interactions occur in the consumption- and capital-goods markets, the labor markets, the credit market, and the financial market. In the model, agents are always connected via their balance-sheet entries, which can be considered as their state variables.

Consumption-good firms produce employing labor and capital according to a Cobb-Douglas technology under constant returns to scale. Labor productivity depends on the vintage of capital goods employed as well as on workers' skills, which evolve according to a learning curve. Firms

[16] On a similar vein, see the agent-based model in Guerini et al. (2017).

set production according to standard inventory planning and fix prices via a mark-up rule. Given the expected demand, firms plan investment according to the net present value approach. Capital-goods firms produce on demand employing labor only.

According to the level of production, firms compute their labor demand and post vacancies in the labor market. Both unemployed and workers access the labor market. Matching is decentralized: both workers and firms rank vacancies and job applications according to the posted wage (involutionary unemployment and labor rationing can occur). Workers accept a job if the offered wage is higher than their reservation one. The reservation wage correspond to the last earned one and it is revise downward when the worker in unemployed.

If their internal resources are not enough to pay for production and investment plans, firms apply for a loan to a subset of banks in the credit market. Banks operate under a Basel II-like regulatory regime and may also hold a precautionary capital buffer. Banks fix the interest rate adding a spread on the reference rate. The spread depends on the solvability of the firm. If none of the contacted banks satisfy the request of the firm, the latter can try to issue shares in the financial market. In the latter market, households employ part of their wealth to trade firm shares and government bonds according to the insights coming from behavioral finance and prospect theory.

In the consumption-good market, firms send their (homogenous) goods to "malls", which are visited by households on a regular basis. Households allocate their income (composed of wages, dividends and interest on government bonds) between consumption and savings according to the buffer-stock saving theory. Consumers collect information about the prices of goods in the mall and, in line with the marketing literature, they apply a logit model to decide which good to buy.

The central bank fixes the macroprudential framework and the policy interest rate. It also provides liquidity to banks in short supply of funds. Finally, in some policy experiments it can buy government bonds in financial markets.

The government levies taxes on corporate profits, household labor and capital income. Taxes are dynamically updated to achieve a balanced budget. The collected revenues are employed to pay unemployment benefits, households transfers and the interest rates on the stock government bonds, which are issued to finance the public deficit. Bonds are perpetual and their interest rate is fixed adding a spread to the policy interest rate.

Firms can go bankrupt. In this case, they default from their loans, fire all their employees and stay out of the market for a fixed number of periods trying to raise new capital in the financial market. Naturally, firms bankruptcy worsen the balance sheet of banks.

4.3.2 Macroeconomic dynamics and policy analysis

The EURACE model deliver GDP time series characterized by endogenous growth and business cycles. Long-run economic growth stems from capital accumulation and increasing workers' skill. Business cycles result from coordination failures in the consumption-good market, investment instability and firms bankruptcies, which disrupt the supply chain and increase unemployment. In turn, the financial conditions of firms is intimately linked to their real choices (e.g. investment) as well as on their survival probability. So also in the EURACE model, both the financial and the real side of the economy are responsible for fluctuations..

The patterns of model-generated time series (GDP, unemployment, inflation, etc.) qualitatively resemble those observed in real ones. As simulation exercises do not typically try to match the macro and micro empirical regularities as in the K+S and CATS models, let us consider the policy results.

The first set of policy experiments concerns the dynamics of credit and financial markets and focus on *macroprudential regulation* and *monetary policy.* The impact of different capital adequacy ratios in a Basell II framework has been studied in Teglio et al. (2012). They find a strong connection between macroprudential regulation, credit dynamics and economic activity. Indeed, looser capital adequacy ratios improve the short-run performance of the economy, but the credit bubbles fueled by increasing banking leverage can trigger deep crises in the medium run. The strong link between credit and economic fluctuations is also reveled by a battery of experiments that study the dividend policies of firms (Cincotti et al., 2010). Simulation results show that more generous distributions of dividends to shareholders force firms to rely more on credit to finance their investment and production plans, thus increasing the amplitude of business cycles. In such a framework, the introduction of minimum capital requirement in the spirit of Basel III macroprudential regulation can improve the performance of the economy by dampening the pro-cyclicality of credit (Cincotti et al., 2012). Finally, by allowing the central bank to buy government bond, the EURACE model has also been employed to study the impact of some form of quantitative easing (QE). Simulation results show that QE allows to loose the stance of fiscal policy improving the performance of the economy, but it increases inflation in the medium-run.

The impact of *fiscal policies* is studied in Teglio et al. (2015). More specifically, in line with Dosi et al. (2015, 2016b), the impact of austerity rules incarnated in the Stability and Growth Pact and Fiscal Compact is assessed with the EURACE model. Such policies are also studied introducing escape clauses, which suspend austerity rules in case of deep recessions, and with quantitative easing, where the central bank buy government bonds. They find that austerity policies have a negative impact on the economy. On the contrary, counter-cyclical fiscal policies cum accommodating monetary policies allow to achieve steady growth.

4.3.3 Extensions

The EURACE model has been further developed along two lines of research. The first one studies the interplay among real asset price dynamics, mortgage lending and economic fluctuations. The second one explores the possible paths to achieve sustainable growth.

Along the first line of research, in Ozel et al. (2016) households can now buy and sell houses in a market, thus affecting the evolution of real asset prices. Buyers can ask banks for mortgage loans, which are granted if their income is sufficient to satisfy their debt service. Alternatively, banks erogate a mortgage loan if household's wealth to real asset ratio is higher enough (stock control regulation). Simulation results show that too loose mortgage requirements have a destabilizing impact on macroeconomic dynamics by fueling housing market bubbles. The introduction of stock control regulation can help to stabilize the market. When mortgage securitization is introduced in the model (Mazzocchetti et al., 2017), banks can supply more credit, but the negative impact of shocks is amplified by wider waves of firm and household bankruptcies, which in turn drys up the supply of loans. The securitisazion propensity and the time span considered determine whether the positive or negative effect of securitization prevails.

The transition from fossil fuels to renewable energies has been studied in Ponta et al. (2016), where the EURACE model is supplemented with an energy sector which provide electricity to firms and households employing a mix of dirty and green sources. Energy firms fix prices and undertake investments according to the price of fossil fuel and government regulation. Simulation results show that feed-in-tariff policies successfully support the sustainability transition of the economy with a smaller impact on government finances and the unemployment rate. "Green" macroprudential regulation, which encourage banks to lend to firms investing in capital-good with higher energy efficiency, spur investment and firm energy efficiency, but the crowding out of consumption limits its effects in the long-run (Raberto et al., 2016).

5 Concluding Remarks

The last part of the twentieth century has been one of the hardest test for genuinely *Classical Political Economy.* Around the beginning of the eighties, civilized dialogue across different perspectives — and even rather *uncivilized*, like that between the two Cambridge (U.K. vs. U.S.) on capital theory — stopped. And it did because the most hardcore talibans declared victory on the American side. It was a victory which at the beginning no sensible adversary of Cambridge (U.S.) took seriously. On the contrary, Bob Solow, the outstanding economist on the other (U.S.) side, when asked as early as 1983 about "New Classical (?!?)" economics, replied:

Suppose someone sits down where you are sitting right now and announces to me that he is Napoleon Bonaparte. The last thing I want to do with him is to get involved in a technical discussion of cavalry tactics at the Battle of Austerlitz. If I do that, I'm getting tacitly drawn into the game that he is Napoleon. Now, Bob Lucas and Tom Sargent like nothing better than to get drawn in technical discussions, because then you have tacitly gone along with their fundamental assumptions; you attention is attracted away from the basic weakness of the whole story. Since I find that fundamental framework ludicrous, I respond by treating it as ludicrous — that is, by laughing at it — so not to fall in the trap of taking it seriously and passing on matters of technique. (Solow in Klamer, 1983, p. 146).

Unfortunately, very few scholars took Bob Solow seriously, and we ended up forced on the contrary to take e.g. DSGE models seriously![17]

In those hard times through, the "Italian ecology" was conducive enough to allow a critical mass of competent and alternative economists to survive a period wherein Bob Lucas (2003) like a nouveau Pangloss was proclaiming that the "central problem of depression prevention has been solved, for all practical purposes, and has in fact been solved for many decades". Of course, no access to Econometrica, Quarterly Journal of Economics, or American economic Review, but in Europe, and in Italy in particular, a wide niche allowed survival as it did not happen in the

[17]On the many fallacies of DSGE models vis-á-vis ABM ones see Fagiolo and Roventini (2012, 2017).

U.S., where the intellectual extermination was almost complete. Then came the Big Crisis: the consequent loss of intellectual respectability of the "hard" mainstream macroeconomics implied also a novel window of opportunity for an alternative agent-based macro addressing the economy as a complex evolving system.

The resilience of the Italian political economy schools allowed the development of (at least) three of the most respected macroeconomic agent-based models, namely the K+S, CATS and EURACE families (see e.g. Turrell, 2016; Haldane, 2016; Dilaver et al., 2016). Such models can account for endogenous growth, business cycles, deep crises and reproduce a rather long list of macro and micro empirical regularities. The models share significant overlappings, but there are many complementarities and specificities. For instance, in the K+S model (Dosi et al., 2010, 2016a), Schumpeterian dynamics and Keynesian coordination failures co-evolve with possible amplifying financial feedbacks, while the CATS model (Delli Gatti et al., 2005, 2011) has a Minskyan core supplemented by aggregate demand fluctuations and innovation shocks. The K+S and CATS families are medium-scale agent-based models, while the EURACE has been designed to represent the dynamics of the European economy. Such a higher degree of complexity makes the details of the model less easy to learn and it leads to higher computational costs. Nonetheless, we think that it is the right time for a more fruitful integration of the three Italian families of agent-based models to strengthen and spread an alternative complexity paradigm in macroeconomics.

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