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An agent-based "proof of principle" for Walrasian macroeconomic theory*

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Abstract

Macroeconomic models are typically solved through the imposition of a top-down general equilibrium solution constraining agents' rational behavior. This is customarily obtained by recurring, explicitly or not, to the Walrasian auctioneer (WA) artifice. In this paper we aim at contributing to the small but burgeoning literature that deals with the consequences of removing it from the start by means of agent-based techniques. We let the textbook full-employment neoclassical macroeconomic model be populated by a large number of bounded-rational, autonomous agents, who are repeatedly engaged in decentralized transactions in interrelated markets. We set up a computational laboratory to perform several experiments, whose designs differ as regards the way we treat learning on the one side, and the institutional arrangement determining who - between firms and workers - is bound to bear the risk associated to incomplete markets on the other one. We show that our fully decentralized multi-market system admits the possibility to attain the WA full-employment solution, but also that serious coordination failures emerge endogenously as learning mechanisms and institutional settings are varied.

Keywords: Agent-based computational economics; Decentralized exchange process; Microfoundations of macroeconomics

JEL Classification: B40; D51; E17

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If the economy were always in macroeconomic equilibrium then perhaps the full-employment money-and-growth models of recent vintage would suffice to explain the time paths of the money wage and the price level. But since any actual economy is almost continuously out of equilibrium we need also to study wage and price dynamics under arbitrary conditions.

(Edmund Phelps, 1968, p. 678)

1 Introduction

In the basic neoclassical macroeconomic (BNM) model, a representative firm and a representative household strive to maximize their objective functions by demanding and offering productive factors and consumption goods in competitive markets.[1] In spite of its simplicity, the BNM circular flow framework is almost universally believed to represent a successful story. As soon as the technology and preferences are well-behaved, its general equilibrium solution can parsimoniously and elegantly explain a wealth of facts and provide a set of testable implications. For instance, the BNM model allows us to understand what forces operate in a market economy to determine long-run aggregate output, employment, saving, investment, real wages and interest rates; the importance of technological innovations as an engine of growth; and how productivity shocks can generate fluctuations of aggregate activity at the business cycle frequency. By imposing fully flexible wages and prices and rational expectations, in turn, the model predicts monetary and Ricardian neutrality and a vertical Phillips curve.

Since it purposely applies to the long-run, the BNM model rests on two simplifying assumptions that normally go undisputed. First, the market processes through which individual plans can be made mutually consistent are totally concealed by exogenously imposing that all markets are continuously in equilibrium. Economic agents take actions only after they become fully aware of the equilibrium values of key variables (typically, prices and quantities), values that in turn someone else must have computed a priori without the employment of scarce resources. Second, frictions in decision processes due to imperfect knowledge or to cognitive limits are irrelevant. Since the long-run social consequences of individual actions can be rationally conceived in advance - at least in a probabilistic sense - optimization can guarantee the correspondence of substantial and procedural rationality. By combining these two conjectures, the BNM model implicitly restricts its applicability to Walrasian-type economies with centralized markets and no real-time learning, while the Friedmanesque *as if* methodological picklock secures that it possesses general applicability.

As emphasized in the quotation by Edmund Phelps that opens the paper, however, to appreciate whether this theoretical construction has also an empirical content we need to answer an additional question: are contextualized

[1] For standard handbook treatment, see e.g. Wickens (2008, Ch.2-4).

macroeconomic processes taking place in real time self-adjusting as the BNM circular flow model suggests? Real economies consist of a large number of heterogeneous buyers and sellers, who are repeatedly engaged in massively parallel local transactions without any global top-down controller. How can it happen that they can manage to stay even approximately coordinated over time, so that relevant macroeconomic variables - say, GDP, unemployment and inflation - fluctuate within relatively narrow bands, and their relationships display the regularities observed in real data? From this viewpoint, we argue that three important issues should be explicitly taken into account if one wants the BNM model to be empirically relevant. First, while in the BNM general equilibrium model the formation of equilibrium prices logically precedes - instead of being the result of - the process of exchange, real markets work the other way round.[2] Furthermore, real-world transactions typically occur in posted offer markets, in which each seller posts a price, and each buyer chooses a seller. Finally, market actions are actually decentralized and ex-ante uncoordinated, and individuals are typically unaware of the aggregate consequences of their actions. As a result, purposeful microeconomic units can be regularly engaged in transactions at disequilibrium prices.

In this paper we focus on the decentralization/coordination features left obscured in the BNM model, by recurring to computational agent-based techniques. The key idea consists in performing a computational study of a simple macroeconomy modeled as a dynamic system of autonomous interacting agents, each one of them represented by an algorithm that determines actions on the basis of the local data generated in the economy. Once the initial conditions and the rules of interaction are set up, we let the artificial world develop over time without any further outside intervention.[3] According to the taxonomy offered in Tesfatsion (2006), our objective is that of using agent-based economics (ACE) to provide qualitative insight and theory generation,[4] by assessing whether the introduction of realistic procurement processes regarding production, pricing and trading may affect the model's key results and predictions. In other words, simulation results should be interpreted as a proof of principle regarding the basic features of the BNM model as soon as any exogenously-driven tâtonnement is suppressed.

We set up a computational laboratory, in which a large number of autonomous households and producers operate adaptively in two fully-decentralized, interconnected markets: *i*) a market for labor services, in which each household offers inelastically one unit of labor per period, while producers' demand depends on planned production; *ii*) a market for a perishable consumption good, in which households spend labor income, and firms post take-it-or-leave-it prices.

[2] The logical inversion between price formation and actual trades at the root of the Walrasian approach to macroeconomics does not depend on the market structure. It holds true also for monopolistic competition models, where transactions occur only after the Bertrand-Nash equilibrium price has been somehow calculated by all players.

[3] Leijonhufvud (1993; 2006) and Howitt (2006) strongly advocate this approach for macroeconomic analysis.

[4] Tesfatsion (2006) argues that ACE models could also be used to provide: *i*) empirical understanding; *ii*) normative understanding; *iii*) methodological advancement.

While in principle our artificial economy admits a full-employment equilibrium (used below as a benchmark) which is attained if all agents successfully coordinate their plans, we let actual aggregate outcomes be generated by bilateral disequilibrium transactions. All trades require the use of fiat money, while production takes time. As a result, the institutional arrangement defining whether wages are paid at the beginning or at the end of the production stage (alternatively, who between the employers and the employees take on the risk that a fraction of the final output remain unsold) matters. Trading opportunities on both markets are discovered through a sequential process characterized by (parameterized) search costs. Agents are allowed to learn, either adaptively or by imitating the strategies of successful mates.

We present simulation results on aggregate real outcomes, on the average price and wage dynamics, and on static comparative analysis. We find that in spite of the system being modeled in terms of dispersed and ex-ante uncoordinated actions aimed at discovering prices, the economy can in fact attain full employment without any external intervention. The WA equilibrium is generated as a steady long-run solution only for a particular combination of the institutional setting and the type of learning among those analyzed, however. In all other cases, the economy displays large endogenous fluctuations due to coordination failures. The system displays self-organizing properties, here defined as the ability to achieve autonomously global behaviors as simple agents interact inside a given institutional and market structure. For instance, two cornerstones of neoclassical competitive economics - that is, that profit maximization implies that the real wage equates productivity, and that the free-entry condition dictates that profits must be zero along the perfect competition equilibrium - are here generated endogenously without the need of individual optimization. Finally, several experiments aimed at testing the comparative statics properties of the agent-based economy show that the predictions of the BNM model are quite robust to the suppression of the WA mechanism. The key lesson we gather from these findings is that the adoption of the BNM model as a first-order theoretical approximation to the working of a competitive macroeconomic system can be deemed as acceptable, especially if the research question involves the dynamic responses to demand or supply shocks, only if the institutional framework shaping transaction protocols and contractual arrangements is explicitly defined. In general, the preoccupation with states of equilibrium of modern macroeconomic theory represents an unnecessary limit to our comprehension of market-based coordination mechanisms. Agent-based computational economics is grown up enough to represent a viable alternative approach.[5]

The remainder of the paper is organized as follows. In the next section, we motivate the paper, discuss some methodological issues and review the results available in the literature. In the third section we outline the structure of our agent-based model, and discuss its main features. In the fourth section, we present some results from computerized experiments. A sensitivity analysis is performed in section five. Finally, section six summarizes and concludes.

[5] On this point see also Howitt (2012).

2 Overview and motivation

This section addresses three questions: First, why is it important to have a theory that explains macroeconomic issues without recurring to a fictitious Walrasian auctioneer (WA) (sub-section 2.1)? Second, how could agent-based methods enhance our ability to explore the relationship among individual behaviors, transaction costs and institutional constraints, and their role in shaping macroeconomic outcomes (sub-section 2.2)? Third, what does our model add to the existing literature (sub-section 2.3)?

2.1 The case for modern macroeconomics

The key message conveyed by the BNM model - as well as by the whole body of macroeconomics built on it, including the fashionable dynamic stochastic general equilibrium (DSGE) model - is that aggregate variables can be best understood by musing over the details of consistent decision-making by individual households and firms. This represents the core of the so-called neoclassical microfoundation research program (Lucas and Sargent, 1979), whose building blocks - rational choices and expectations, costless impersonal groping, and continuous general equilibrium compose a triad which is completely inserted into the Walrasian tradition (Bowles and Gintis, 2000). In spite of the remarkable support this methodological approach (and its representative agent substantiation in primis) has won during the last forty years (Blanchard, 2009; Woodford, 2009), it must be recalled that it represents the outcome of a detour[6] along the time-honored intellectual journey aimed at providing sound microeconomic underpinnings to standard aggregative Keynesian models. In his 1977 survey on the microeconomic foundations of macroeconomics, Roy Weintraub noted that:

> The Phillips curve literature [...] weakened a number of established truths. The explanations for the presence of trade-offs between wage rate changes and unemployment changes focused detailed attention on the labor market, specifically on market failures; imperfect information and decisions made “out of equilibrium” resulted in a lack of coordination of economic activity [...]. It began to appear that a number of real macroeconomic issues could not be phrased in timeless, perfect-information, maintained equilibrium models. (Weintraub, 1977, p.6)

Thirty years later, in commenting on the motivations which lead to the “island model” of imperfectly communicating markets (Phelps, 1969) and the path-breaking analysis contained in the so-called “Phelps volume” (Phelps *et al.*, 1970), Edmund Phelps clarifies that:

> My approach to the relation between "(effective) demand" and activity started from the observation that [...] the market place of

[6] One characterized, in the parlance of John Maurice Clark, by an *irrational passion for dispassionate rationality.*

> the modern economy was not just "decentralized", as neoclassical economists liked to say. The beliefs and responses of each actor in the economy are uncoordinated: Walras's deus ex machina, the economy-wide auctioneer, is inapplicable to a modern economy in which much activity is driven by innovation and past innovation has left a vast differentiation of goods. This led to the point that the expectations of individuals and thus their plans may be inconsistent. (Phelps, 2007, p.545)

According to this view, a modern economy is buffeted by incessant innovations generating Knightian uncertainty not only on the future, but also about the present: since novelty – new products, new behaviors, new exchanges, new market organizations - occurs unevenly from place to place and from industry to industry, the general picture is unobservable in real time by people at different locations. A modern economy is therefore inherently characterized by incomplete and asymmetric information, while individuals possess diverse beliefs which must be continuously revised. In addition to prices, quantities and expectations, the set of endogenous state variables of any dynamic economic model must include trading relationships, which are costly and time-consuming to form and sever.

The bad news for adherents to the WA approach is that in this evolving world the general equilibrium solution which is commonly employed for explanation, prediction and policy prescriptions (i.e., Brouwer and Kakutani fixed-points) is practically unattainable under general conditions.[7] As shown by Saari and Simon (1978) and Saari (1985), a price adjustment mechanism may always converge towards an equilibrium if and only if it involves essentially infinite information and computation requirements on the part of the agents. But even if we admit that the Walrasian general equilibrium is reached by chance (or if we are kind enough to postulate complete information), the problem of instability is particularly tough for macroeconomic models. A well-known result by Saari (1992) states that the instability of the general equilibrium may be a property of an economic system even if it is not a problem in any of its parts or subsets. To grasp the intuition behind this result, consider an n-commodity economy. Saari proves that even if every subset of the economy with n-1 or fewer commodities admits a stable equilibrium, it is still possible to have an unstable solution as we move to its n-commodity version, admittedly an annoying property for any growing system.

This issue is just one example from a wider catalog offered by the literature. The weaknesses of the mainstream neoclassical approach to macroeconomics have been highlighted repeatedly, with different targets in sight and from several quarters.[8] Here, it suffices to recall another key criticism leveled against the

[7] See Axtell (2005) for an introduction to this issue, as well as for some computational analysis linked to the literature on Edgeworth k-lateral re-contracting schemes, which were originally conceived as a valid alternative to Walrasian microfoundations of macroeconomic analysis (Weintraub, 1977), but that have apparently felt into oblivion thereafter.

[8] See Howitt *et al.* (2008) and Colander *et al.* (2009) for two recent items from a quite long list. A comprehensive parade of arguments is presented in Colander (2006).

BNM/DSGE model, that is the one resting on the idea that a proper macroeconomic analysis should be focused not only on the characteristics of individual behaviors, but also on the structure of their (market and non-market) interactions. At odds with the mainstream WA equilibrium approach - whose focus on the mutually consistency of plans requires that all choices have to be reconciled before anyone's choice can be made - the alternative vision proposed in the above quotations points towards a description of the economy as a dynamically complete adaptive system (Tesfatsion, 2006), one that allows us to specify what will happen from any given set of initial conditions, including those in which agents act on the basis of inconsistent beliefs. When this occurs, individual decisions may become uncoordinated and aggregate outcomes can diverge from individual intentions. In the jargon of the complexity science, macroeconomic outcomes are emergent phenomena.

Building models along these lines requires a constructive, or generative (Epstein, 2006), approach. One must prove not only that an equilibrium exists, but also that it can be constructed moving from the uncoordinated actions of a large number of autonomous individuals on a time scale of interest for human beings. Furthermore, the issue of whether disequilibrium may represent a persistent state of affair or not should be explicitly addressed.

Our proposal rests on a postulate which deserves to be evaluated by means of a proper methodology, and an operational conjecture to be used as a basis for generative theorizing. Let us see them in turn.

> **Classical Stability Postulate** (CSP) (Clower and Howitt, 1998). Coordination issues matter in the short-run only, as price stickiness and informational imperfections are just temporary hurdles to the full disclosure of individual rational behavior. In the long-run, an economy will necessarily converge to a coordinated state.

An operational definition of "coordinated state" in its weakest form is that of a viable self-regulating mechanism possibly affected by short-run oscillations, which in any case must let the system within few percent points from its long-run path. Accordingly, we argue that the CSP holds if the endogenous system dynamics is stationary, in that it is not bound to explode or implode as time increases.[9] It must be noticed that a persistent distance of stationary trajectories from a market-clearing equilibrium is not in itself a signal of inapplicability of the CSP, since it obviously depends on the presence of structural frictions (e.g., non-competitive markets, search costs, nominal and real rigidities) which would open a wedge between the actual and the first-best solution even if the WA were at work.

The second ingredient of our constructive proof for Walrasian macroeconomic theory rests on the removal of the exogenously given WA coordination device, by adopting the following.

> **Axel's Conjecture** (AC) (Leijonhufvud, 1993). An economy is best conceived as a network of interacting processors, each one with

[9] For a growing economy, stationarity should be clearly defined in terms of great ratios.

> less capability to process information than would be required of a central processor set to solve the overall allocation problem for the entire system.

We will argue that the validity of the BNM model is proved in principle if CSP in its weakest form holds true in a model built on AC. While in the traditional (neoclassical) approach it is enough to demonstrate that a given macro-configuration exists, in the generative approach we adhere to a target macrostructure and its dynamic properties must be effectively computed (albeit unconsciously) by a population of decentralized heterogeneous autonomous agents. The coordination properties of an economy can be satisfactorily studied if and only if the model comes to grasp with the fact that most transactions in actual economies are not mediated by a central coordinator. Assuming it from the start, as in the Walrasian tradition, makes the CSP simply a tautology.

Implementing such an approach has nowadays become much easier than it was when the issue was first acknowledged. In particular, two powerful tools to model complex systems in which individual economic agents engage in trading on a strictly do-it-yourself basis have become increasingly familiar to the economics profession, namely multi-sectoral human-based experiments[10] and agent-based simulations. In this paper, we shall focus on the latter. In fact, several interesting results have been obtained so far in the literature, and we will briefly review them momentarily. Before that, however, we must pause to methodologically set the stage for the analysis that follows.

2.2 Rationality, structure and human behavior

The theoretical description of the economic agent we endorse is rooted in the so-called program-based behavior paradigm (Mayr, 1988; Vanberg, 2002), according to which goal-seeking, purposeful activities are guided by encoded algorithmic programs or instructions, telling agents what to do (or not to do) when facing certain contingencies. These rules for action may sometimes be sophisticated enough to integrate multiple sources of information into the building of mental models, that is internal representations that the agent creates to interpret and manipulate her own problem space; or to form aspirations and commitments into the future; or finally to sign forward contracts or other arrangements with terminal dates in the future (Denzau and North, 1994). More generally, however, evolutionary argumentations suggest that the real-time rules for action adopted by human beings are more often than not consistent – and compelled to be in line with - much more rapid decision making than the ones based on evolving mental models. It appears that not always human adaptation is guided by internal models of the world which the brain takes as defining the constraints for logic calculations aimed at solving analytical problems. In some situations, it would simply take too much time and it would employ too many neural resources. Rather, actions must respond to very simple rules aimed at coping promptly and effectively with the environment.

[10] See, for instance, Lian and Plott (1998) and Noussair *et al.* (2007).

This is precisely the point raised by a body of active research at the intersections between artificial intelligence, robotics, cognitive sciences and connectionist philosophy, of which Minsky (1986), Churchland and Sejnowski (1992) and Clark (1997) represent outstanding examples. Their thesis is that it is critically misleading to model the human mind as a kind of logical reasoning device apt to symbolic manipulation, joined to a memory bank of facts. The process of natural selection – with its call for speedy responses in real-world situations, where mere survival is at stake - has forced human intelligence to operate in a completely different way than a central computer program solving a maximization problem does.

At odds with the theoretical position which portrays the mind as a logical symbol-processing machine, in fact, human intelligence emerges from the use of very simple rules and strategies to cope quickly and effectively with environmental hazards – like the need for food, the presence of predators, and the like – and strong uncertainties on the behavior of other members of the social group. Accordingly, human intelligence is ultimately a means for controlling the body's set of behaviors to help it survive in the particular environment it happens to live in or, in other terms, it provides a form of embodied, environmentally embedded cognition (Clark, 1997). The bulk of the connectionist approach relies on a computational architecture consisting of a mass of interacting "neurons" – simple autonomous processing units receiving inputs from neighboring units and passing on output to other neighbors – usually organized in layers. Activity is then propagated through the network by weighted connections between units, so that the system as a whole allows knowledge in terms of distributed encoding. This does not amount to discard the role of large hierarchical structures operating specialized processing duties (visual cortex, hippocampus, etc.), but simply to recognize that the main job is eventually done by single units:

> The anatomy of the frontal cortex and other areas beyond the primary sensory areas suggests an information organization more like the Athenian democracy than a Ford assembly line. Hierarchies typically have an apex, and following the analogy, one might expect to find a brain region where all sensory information converges and from which motor commands emerge. It is a striking fact that this is false of the brain. Although there are convergent pathways, the convergence is partial and occurs in many places many times over, and motor control appears to be distributed rather than vested in a central command center. (Curchland and Sejnowski, 1992, pp.24-25)

The brain is thus a massively parallel system, in which control and information processing are distributed among autonomous but interacting units, who appear to an external observer as coordinating themselves to jointly solve some identifiable problem, through some kind of emergent computation. Connectionist scientists argue that this is the real essence of intelligence, and this position has profound implications for the concept of rationality as it is usually applied in economics.

This vision can be easily escalated to an aggregate multi-market economic system composed of a myriad of heterogeneous agents, each one of them muddling through a truly uncertain environment, where the word “social” should be now substituted to “individual” as an attribute for intelligence and coordination. Its relevance for macroeconomics can be easily appreciated in the argumentation put forth by Phelps to reject the applicability of rational expectations as a solution concept for imperfect-information models of the natural rate of unemployment:

> In a highly innovative economy and thus one subject to change, firms – even firms in the same industry and location – are all thinking differently. So a firm would have no grounds to reason, as it implicitly does in rational-expectations theory, that “since I have calculated I must raise my wages by x percent, I should now take into account that my competitors are planning to do the same; so I must now adjust my wage increase even more . . . ”. This kind of inductive reasoning to arrive at the right expectations is inapplicable. [. . .] More fundamentally, the public cannot form “rational expectations” about future probability distributions when the future is being created currently by the new ideas and consequent plans of entrepreneurs to which the public has no access and of which the entrepreneurs themselves are uncertain. (Phelps, 2007, p.548)

Accordingly, an uncoordinated decentralized competitive economy – that is, one which gets rid of any WA central planner - can be described as a higher-order massively parallel system composed of many autonomous individual economic processors, namely intelligent human beings, who use (simple) rules to set prices, make production and consumption decisions, search, communicate and exchange in order to improve their welfare. The decentralization characterizing real competitive markets is the key: it works as a powerful distributed algorithm to collectively solve computationally complex allocative problems which are far beyond the cognitive capabilities – and even the awareness - of individual agents (Rust, 1998). While it has not been formally proven yet that this type of distributed computational device is able to reach efficiency under general conditions, previous research has shown clearly that the coordination performance of a multi-market system depends on the market (e.g., double auction, limit orders, etc.) and non-market (e.g., customs, norms, etc.) institutions providing structure to human actions and interactions (Gode and Sunder, 1993). Agent-based modeling is a natural candidate for further explorations along this direction.

2.3 Related literature

The idea of exploiting agent-based techniques to provide proof-of-principle foundations to multi-sector general equilibrium models has been recently adopted by several researchers. Gintis (2007) focuses on the convergence to a stable steady state in a multi-sector decentralized Walrasian economy with production and exchange, where individual reservation prices are private information and agents are allowed to imitate successful mates. Sprigg Jr. and Ehlen (2007) consider an agent-based overlapping-generation model with markets for goods, labor and money. They explore whether the system of autonomous adaptive agents can find and maintain a macroeconomic Nash equilibrium as decision rules and other protocols are experimentally varied. Galand (2009) analyzes the issue of money neutrality in a bottom-up circular-flow model with rationally-bounded consumers and firms learning adaptively from experience.

The material offered in this paper complements this literature by introducing novelties along several margins. Contrary to the models by Gintis (2007) and Sprigg Jr. and Ehlen (2007), in our search for aggregate regularities emerging from a multitude of dispersed and ex-ante uncoordinated market interactions we do not endow agents with utility or profit functions to be maximized. The simple heuristics they employ merely respond to the forces of want (i.e., behavior is purposeful) and scarcity (choices are taken within the opportunity set defined by the budget constraint). This is the approach followed by Bosch-Domènech and Sunder (2000), who extend the microeconomic literature on zero-intelligent traders (Gode and Sunder, 1993) showing that want and scarcity are indeed sufficient to attain a competitive equilibrium even for an economy consisting of multiple interrelated markets, as soon as all markets are organized as double auctions. In our model, pricing occurs on a take-it-of-leave-it basis (posted-offer pricing), so that we are in a good position to assess whether the double-auction exchange institution is in fact necessary for convergence when the assumption of substantive rationality is relaxed, or the same result can be attained by means of other institutional arrangements regulating exchanges. Furthermore, we explicitly model the labor market and consider its interaction with the goods markets. This allows us to augment the analysis of macroeconomic resilience to monetary disturbances put forth by Galand (2009) with shocks to labor productivity and labor supply, and to track the dynamics of additional aggregate variables like nominal and real wages. Finally, at odds with previous contributions we compare the performance of alternative learning methods on the one hand, and of alternative institutional arrangements defining who between employers and employees is going to bear the risk associated with incomplete markets, on the other one.

This paper is also clearly related to the strand of literature which addresses typical macroeconomic issues - namely, business cycles, long-run growth, the trade-off between unemployment and inflation, and so on - by means of agent-based computational models. A list of the most representative works belonging to this line of investigation includes Ashraf and Howitt (2008), Delli Gatti *et al.* (2011) and Dosi *et al.* (2010). While in general these studies claim from the start their adherence to a *post-Walrasian* view[11] and elaborate on this accordingly, the material we present in this paper should be seen as a preliminary methodological step, aimed at testing the robustness of the Walrasian predic-

[11] The collection of papers contained in Colander (2006) provides a definition and a comprehensive discussion of the topic.

tions in macroeconomic environments characterized by routine-based behaviors and decentralized trading protocols.

3 A computational laboratory

Following Smith (1982), the design of our computerized experiments can be conceptually separated into three distinct components: *i*) the induced economic environment (subsection 3.1); *ii*) the market institutional structures (subsection 3.2); *iii*) the behavior of buyers and sellers in each market as the institutional structure varies (subsection 3.3).

3.1 The economic environment

We set up an agent-based circular flow model, in which two classes of autonomous agents - households/workers and entrepreneurs/firms - use fiat money to trade in two interrelated markets, one for labor services and one for a perishable consumption good. A typical macroeconomic flavor emanates from the model, as we are interested in the aggregate dynamics emerging from the close interdependence of input demand, input prices, output demand, output prices, incomes and fiat money. The entrepreneurs are indexed by i, $i = 1, ..., I$, while the households are indexed by j, $j = 1, ..., J$. Both markets are decentralized and characterized by sequential search-and-matching processes. In describing their functioning, let us start from the labor market.

Contractual arrangements between employers and employees last one period. The entrepreneurs set their labor demand n_{it}^d (measured in terms of the number of employees) on the basis of their desired level of supply (determined below), to be produced by means of a constant returns technology, $y_{it}^d = f\left(n_{it}^d\right)$. The households supply inelastically one unit of labor per period, and their productivity is homogeneous and costant, equal to α. At the start of any time period t, each worker sends M job applications: if employed during the previous period, the first one is sent to the firm for which he actually worked in t-1, while the remaining M-1 are sent randomly to as many potential new employers, with a probability proportional to the employees' vacancies. The rationale for this hiring strategy is that workers, while loyal to their actual employers, aim at insuring themselves against the risk of unemployment by building a portfolio of diversified hiring opportunities. All M applications are sent at random if the household were unemployed in t-1. Each application reports the nominal reservation wage asked by the worker.

The i^{th} firm organizes all received applications in two blocks: the first one is composed by the applications sent by its actual workforce, while the other one is filled in by all other applicants. Inside each block, applications are sorted in ascending order according to the asked reservation wages.

After all applications have been received and sorted, the firm i may face three alternative situations:

a) $n^d_{it} < n_{it-1}$. The desired labor demand at time t is lower than the number of people employed during the previous period. In this case, a certain number of workers late in the queue (i.e., the ones asking for higher wages) in the first block are fired, while the remaining are kept. Fired workers have other M-1 opportunities to find a job elsewhere before the new stage of production starts.

b) $n^d_{it} > n_{it-1}$. The firm i wants to increase its workforce. In this case, that firm keeps all its past employees and looks for new workers, who are selected from the second block of the queue, starting from the one asking for the lowest wage.

c) $n^d_{it} = n_{it-1}$. The workforce remains unaffected.

All decentralized labor markets (i.e., one for each firm) are closed sequentially according to an order randomly chosen at each time step. Given that each worker is allowed to sign just one labor contract per period, severe coordination failures could arise as the number of workers actually available does not necessarily correspond to the one enrolled in queues, especially for firms which are called to hire their workers late in the sequence.

At any time t, the aggregate demand on the market for goods is equal to the total wage bill paid to households and by the wealth (retained profits) of entrepreneurs in t-1. In other terms, the system is intertemporally closed, in that all the income generated is equal to the distributed one. We assume that an entrepreneur cannot consume the output he produces. Given the lack of any aggregate market-clearing mechanism, and due to the fact that bargains on the goods market are fully decentralized, consumers have to search for a satisfying deal. Information acquisition is defined according to a fixed-sample search technology, which determines the number Z of shops a consumer is allowed to visit. In other words, search costs are null as the consumer remains confined into his local market of size Z, but they become prohibitively high as soon as the consumer tries to search outside it.

Consumers enter the market for goods sequentially, the picking order being determined randomly at any time period t. Each buyer is allowed to visit Z sellers, one of which is the seller with the lowest price the buyer visited in the period t-1, while the other Z-1 are chosen at random, with a probability proportional to the employers' production. The buyer observes the posted price of the Z sellers and sorts them (and the corresponding sellers) in ascending order, from the lowest to the highest one. Each consumer tries to spend all his income at the cheapest shop. If the cheapest shop does not have enough output to satisfy his needs, the consumer tries to spend the remaining part of his income in the second-price shop, and so on. If consumers do not succeed in spending their whole income after they visit Z firms each, they save (involuntary) what remains for the periods to follow. For the sake of simplicity, the interest rate on savings is assumed to be zero.

As the market for goods closes, firms calculate their nominal profits (or losses). If the total amount of cash flow (new profits/losses plus what have been retained from the past) a firm can count on is negative, that firm goes bankrupt, and it is replaced at the start of the next period by a brand new firm.

3.2 The market institutional structure

As discussed in the previous paragraph, transactions in both markets are organized according to a posted-offer auction mechanism (Smith, 1981). Sellers independently select a price and a maximum amount of units to be sold at that price, and the price is publicly announced on a take-it-or-leave basis. Each period is divided into four sub-periods: *i*) sellers move first by posting prices, according to a given decision rule; ii) buyers search for sellers in a pre-defined search space, and rank them according to the posted price; *iii*) once buyers and sellers are matched, transactions occur; *iv*) sellers evaluate the profit generated by the pricing rule currently used, and with a given probability they update it.

In modern economies, markets operating according to posted-price protocols represent the rule for a vast majority of retail transactions. In the experimental literature, the performance of this market institution is usually compared with that of more symmetric trading mechanisms, like the double auction (Ketchman *et al.*, 1984; Plot, 1986). The two main results emerged so far are that, compared to double auctions, in posted-offer markets the price converges to the prediction of competitive equilibrium quite slowly, if not at all; and that traders tend to waive a significant amount of total surplus even in competitive designs. Both these findings have interesting implications for macroeconomic research, as they suggest the possibility of Keynesian implications from demand or supply shocks due to endogenous price sluggishness and multiplers effects generated by trading protocols, insted of market power or adjutment costs (Davis and Holt, 1996).

There are two main differences regarding the functioning of the two markets analyzed in our macroeconomic experiment. First, while in the market for goods the price is posted by sellers and the search is operated by buyers, in the market for labor sellers (i.e., households) both post prices (reservation wages) and search for buyers (employers). Second, the quantity offered by each single seller is not known in advanced by buyers in the goods market, while it is always equal to one unit in the labor market.

All transactions require a commonly accepted medium of exchange, or fiat money: firms make monetary payments to their employees, who use the money received to purchase goods. In this world, fiat money is created by a centralized monetary authority (MA).

We recur to simulations to compare three different institutional environments. In *Experiment I* workers are paid a nominal wage only after the market for goods has been closed and firms have collected revenues. In other terms, wage payments occur at the end of sub-period (*iii*). If a firm receives an amount of revenues which is not enough to compensate the contractual payroll, it goes bankrupt and its former employees share equally what remains before the firm is closed down. The next period a new firm enters the market. We dub this institutional setting *risk on workers* (RW).

In *Experiment II*, workers are paid before the production starts (that is, in sub-period (*ii*)). If an incumbent firm does not hold the money balances required to pay the desired wage bill, it can borrow from the MA, who lends all the nominal money balances needed at a zero interest rate. As the market for goods closes, firms must pay back the money they borrowed. If it proceeds are not enough, it goes bankrupt and generate an amount of bad debt equal to the difference between the payback due to the MA and the internal resources available for payments. To collect revenues for financing the total bad debt generated in each period, the MA levies a proportional tax on the nominal incomes of every agent. This institutional environment is dubbed *risk on firms with sterilization* (RFS). In this case, bankruptcies are the source of aggregate liquidity shortages, which can propagate and amplify local dislocations.

Notice that we are introducing an asymmetry as regards the market for credit works, as firms can borrow before the production period starts but are prevented from funding net operating losses by recurring to additional debt. This assumption is a shortcut for a well-known phenomenon, that is that the volume of lending is a negative function of the riskness of borrowers. Clearly, while the probability of a net operating loss is bounded below one before the production starts, after the loss has materialized the negative event is certain. All else equal, the disclosure of information makes the firm more risky after the fact.

Experiment III has the same institutional environment as *Experiment II*, but for the detail that the bad debt due to the MA by failed firms is not collected by proportional taxation, so that the amount of money is effectively increased by the amount of aggregate bad debt. We define this institutional environment as *risk on firms with perfect accommodation* (RFA).

3.3 Behavior

The last ingredient of the experimental design consists in a description of the behavioral traits characterizing households and entrepreneurs, as well as their interactions with the institutional environment.

For each experiment, simulated time series are collected under two main experimental conditions. In *Treatment A*, households and firms are allowed to revise their strategies adaptively. In particular, workers revise their nominal reservation wage W according to their recent employment history. If in t-1 the j^{th} worker was employed, the period after he increases his reservation wage by a random term φ extracted from a normal distribution defined over a positive support. Namely,

$$W_{jt} = W_{jt-1}\left(1+\varphi\right) \tag{1}$$

If, on the contrary, j has experienced unemployment in t-1, the current period reservation wage is obtained by decreasing the old one by a random term extracted by the same normal distribution:

$$W_{jt} = W_{jt-1}\left(1-\varphi\right) \tag{2}$$

Firms have the opportunity to revise adaptively both their posted price and the quantity they want to produce. New prices are set considering unsold quantities (i.e., involuntary inventories S_{it-1}) during the last period, the labor costs incurred in production, and the deviation of individual prices from the average price index during the last transaction round. Internal conditions are private knowledge, while the aggregate price index P_{t-1} is common knowledge. More precisely, the i^{th} entrepreneur sets his satisficing new selling price according to the following rule:

$$P_{it} = \left\{ \begin{array}{ll} \max\left[P_{it}^{l}, P_{it-1}\left(1+\eta_{it}\right)\right] & \text{if} \quad S_{it-1}=0 \quad \text{and} \quad P_{it-1} < P_{t-1} \\ \max\left[P_{it}^{l}, P_{it-1}\left(1-\eta_{it}\right)\right] & \text{if} \quad S_{it-1}>0 \quad \text{and} \quad P_{it-1} \geq P_{t-1} \end{array} \right\} \tag{3}$$

where η_{it} is an idiosyncratic random variable distributed according to a normal distribution defined on a positive support, while P_{it}^{l} is the reservation price, that is the lowest price at which the firm i is able to cover average costs:

$$P_{it}^{l} = \frac{B_{it}}{y_{it}} \tag{4}$$

where B_{it} represents total payroll. If the price is adjusted, the quantity remains anchored at the level of the last period, that is $y_{it} = y_{it-1}$.

The remaining combinations of signals regarding involuntary inventories and relative prices trigger adjustments of quantities, with prices fixed. In this case, the level of production planned at the beginning of period t (y_{it}^{d}) depends on expected demand, $y_{it}^{d} = D_{it}^{e}$. Expectations on future total orders are revised adaptively according to:

$$D_{it}^{e} = \left\{ \begin{array}{ll} y_{it-1}\left(1+\rho_{it}\right) & \text{if} \quad S_{it-1}=0 \quad \text{and} \quad P_{it-1} \geq P_{t} \\ y_{it-1}\left(1-\rho_{it}\right) & \text{if} \quad S_{it-1}>0 \quad \text{and} \quad P_{it-1} < P_{t} \end{array} \right\} \tag{5}$$

where ρ_{it} is an idiosyncratic shock normally distributed on a positive support. Thus, expectations are revised upward if the entrepreneur observes excess demand for his output and the price is already above the average price on the market, and downward when the opposite holds true.

In *Treatment B*, households and entrepreneurs revise their strategies by imitating successful competitors. Firm i has a given probability to observe a given number of competitors. If the sample contains a firm which in the past obtained on average higher profits, the firm i copies (with a small random mutation) the last quantity and price of this successful competitor. When the firm i is not involved in imitation, it mantains its price and quantity unchanged. As regards households, each one of them has a given probability to observe a given number of mates. If in the sample of the consumer j there exists at least one mate κ who in the past has experienced on average a consumption higher than his own, j copies (with a small random mutation) the last reservation wage request by κ.

4 Results

The value of parameters in baseline simulations are reported in Table 1. Given the constellation of parameters chosen for the baseline, the model admits a full-employment symmetric WA equilibrium characterized by a real GDP equal to

Parameter	**Value**
Number of households - J	1000
Number of firms - I	100
Fixed sample search for workers - M	3
Fixed sample search for consumers - Z	3
Productivity - α	1
Number of observed workers for imitation	3
Number of observed firms for imitation	3
Probability to copy the strategy of the fittest worker	0.1
Probability to copy the strategy of the fittest firm	0.1

Table 1: Parameters value for baseline simulations

1000 units of the final consumption good, an aggregate nominal price index equal to 1 and a real wage equal to 1. Along such an equilibrium, each firm employs 10 workers to produce 10 units of the good, nominal and real profits are 0 due to competition, and unemployment is null. Let us call this situation the efficiency frontier (EF). The level of production inefficiency registered by the fully decentralized agent-based economy PI_t is then defined as:

$$PI_t = 1 - \frac{\sum_{j=1}^{J} y_{jt}}{1000} \tag{6}$$

which turns out to be comprised between 1 and 0.

As discussed by Gintis (2007; 2012) and Izquierdo *et al.* (2009), from an analytical point of view an agent-based simulation model is a high-dimensional time-homogeneous Markov chain. The system can be appropriately defined in terms of a finite number m of states $S = (s_1, s_2, \ldots, s_m)$ and a squared m-dimensional transition matrix $P = \{p_{\nu\xi}\}$, where $p_{\nu\xi}$ represents the probability that the system makes a transition from state ν to state ξ. According to the Decomposition Theorem for Markov processes,[12] a time-homogeneous Markov chain can always be expressed as the disjoint union of its classes, S = $C_1 \cup C_2 \cup ... \cup C_k \cup T$, where $C_1, C_2, \ldots, C_k$ are irreducible (a.k.a. closed communicating) subprocesses, while T is the union of all other transient classes. In other words, assuming that both transient and irreducible classes exist, once the system enters one irreducible class it cannot leave it, and its dynamics depends on the limiting probability distribution characterizing that particular irreducible Markov sub-chain. Such an ergodic distribution may possess one (unimodal) or more (multimodal) attracting states, which in our case can be defined in terms of average values of key macroeconomic variables.[13] If the distribution is unimodal, the economy settles in the neighborhood of a unique steady state after some transient periods. If, on the contrary, the ergodic distribution of the Markov sub-chain which absorbs the system dynamics is multimodal, the system

[12] See Theorems 3.7 and 3.8 in Kulkarni (1995).

[13] A third obvious possibility is that the ergodic distribution is degenerate, in that the absorbing class contains just one state.

itself is allowed to switch among different attracting states, where the fraction of time spent around each one of them depends on the relative magnitude of their basins of attraction.

Findings from previous research based either on simulations (Vriend, 2000) and game-theory analysis (Golman, and Page, 2010) suggest that in the presence of multiple equilibria how agents learn matters for equilibrium selection. As agents are allowed to update their strategies and actions recurring alternatively to individual-based (when agents learn exclusively on the basis of their own experience) or to population-based (when agents learn on the experience of other players) procedures, the system converges towards different long-run solutions starting for common arbitrary conditions. In terms of the Markov chain approach to agent-based modelling, this means that depending on the type of learning one is considering the process remains entrapped in different closed communicating classes, each one with its own limiting distribution characterizing the fraction of time that the process spends in each state of the absorbing class. Therefore, the inference one can obtain from simulating the model by limiting himself to just one type of learning could be seriously biased, as it could hide the presence of a multiplicity of long-run solutions.[14] This motivates the choice to design our computational experiment in terms of a comparison between two learning procedures belonging to the individual-based (*Treatment A*) and the population-based (*Treatment B*) classes, respectively.

Results obtained from representative simulations for each one of the six combinations *Experiment-Treatment* are presented in Figures 1 to 6, where the the time series for the real GDP, the average real wage, the nominal average price index, the cross-sectional standard deviation of posted prices, average real profits and the rate of bankruptcy are presented respectively. Simulation sessions last 1000 periods each. Several findings are worth stressing, highlighting interesting interactions between the allocation of resources, the evolution of nominal variables and the income distribution.

Figure 1 presents results for real GDP. The simulated system attains firmly the theoretical EF in just one case, that is when agents learn by imitation under the RFA institutional environment (lower-right panel). In all other cases, the absorbing class of the underlying Markov chain contains the EF state, which is attained repeatedly, but the economy is characterized by large endogenous fluctuations. Prolonged recessions are not caused by negative aggregate shocks, which are indeed absent in our model. On the contrary, they result from a pecuniary aggregate demand externality which works as an in-built amplification and propagation mechanism of idiosyncratic shocks. While this feature is usually associated to macroeconomic models with monopolistic power due product differentiation (Blanchard and Kiyotaki, 1988; Murphy *et al.*, 1989), our simulations show that the combination of search costs and posted-offer pricing returns the possibility of large collective coordination failures even in homogeneous markets. The level of production inefficiency PI_t is particularly strong for both

[14] Of course, the result one obtains from allowing agents to learn according to different mechanisms is univocal when the Markov chain admits just one aborbing class C.

treatments of the RFS experiment, with the occasional emergence of very deep crashes involving output losses as large as 65% below the potential. In spite of this, the economy displays a substantial degree of resilience, with aggregate activity eventually bouncing back to full employment in finite times without any external intervention. Finally, when agents update their strategies according to individual-based procedures and the MA accommodates by absorbing profit losses (lower-left panel), the system displays a significative degree of persistence, measured by the contiguous fractions of time spent in correspondence of the EF and below it, respectively.

The key lesson we gather from this piece of evidence is that models built on the AC condition do not prove in principle that the CSP holds true. As soon as the economy is inhabited by dispersed agents engaged in uncoordinated search-and-matching activities and endowed with trading protocols reflecting those observed in real retail markets, in order to reach a fully coordinated long-run solution one needs to combine hypothesis regarding how individuals learn and the institutional environment in which they operate.

Cyclical adjustments occur mainly via quantities and not prices, as can be appreciated by inspecting the six panels of Figure 2, where we report the time series for the average real wage in all the experiment-treatment combinations here considered. In spite of the fact that dispersed labor contracts are all signed in nominal terms, on the aggregate real wages remain entrapped in a compact corridor large at most 5 percentage points. The upper bound of the corridor is systematically lower than the theoretical value predicted by the WA solution, however, and the average surplus loss bare by workers is in general between 1 and 3 percentage points of the total attainable along the symmetric general equilibrium solution.

An interesting variability in correspondence of different institutional frameworks and learning procedures emerges as regards the dynamics of the average nominal price for the consumption good. Simulated time series for our three computational experiments are pictured in Figure 3. Under the ROW scenario (upper panels), the price level settles down on the WA prediction with a remarkable accuracy, regardless of how households and firms learn. On the contrary, the economy is characterized by a sustained price inflation in the RFA case, once again without any qualitative difference between the two treatments (lower panels). Alternative types of learning - invidual-based versus social-based - generate completely different scenarios in the RFS experiment. The two panels in the middle row of Figure 3 clearly show that adaptive learning is conducive to an inflationary environment, while under imitative updating the aggregate price level fluctuates around a mean value of 1, that is the symmetric WA solution.

Figure 4 presents results on price dispersion in the consumption good market, measured as the per-period cross-sectional standard deviation of the prices posted by the I firms. A large theoretical literature on on the link among imperfect information, search and pricing has highlighted three results. First, when consumers have common positive search costs, the equilibrium price in homogeneous markets is unique, but at the monopoly than the competitive level (Diamond, 1971). Second, if consumers are heterogeneous as regards the

	$\langle PI \rangle$	**Inflation rate**	**Real wage**
Exp. I - Treat. A	0.038	0.000	0.987
Exp. I - Treat. B	0.031	0.000	0.988
Exp. II - Treat. A	0.513	0.002	0.978
Exp. II - Treat. B	0.520	0.000	0.983
Exp. III - Treat. A	0.050	0.003	0.971
Exp. III - Treat B	0.000	0.005	0.993

Table 2: Averages over 1000 Montecarlo replications for each experiment/treatment. EF = 1000.

amount of information they possess, the equilibrium is characterized by price dispersion (Salop and Stiglitz, 1977). Third, from an evolutionary perspective the monopoly solution is dynamically stable while the dispersed price equilibria are ustable from a wide class of learning dynamics (Hopkins and Seymour, 2002). In our simulations we find that the law of one price does not hold in general even if all consumers are homogeneous as regards the width of their information set and of the sample of sellers they can visit for free, regardless of the system being characterized by inflation or not.

Time series for total real profits are presented in Figure 5. In line with our findings for real wages, the path for real profits is always stationary, also for the experimental designs in which nominal prices increase steadly. The dynamics is reverting to the average value of 0, wich corresponds to the competitive benchmark.

The last variable we track is the rate of bankruptcy, whose time series are reported in the six panels of Figure 6. Again we observe stationarity in all cases, without any significant difference between treatments. It must be noticed, furthermore, that the average rate of business failures over the whole simulation run is sensibly lower in the RFA scenario, that is when MA ia allowed to absorb profit losses.

In order to control for the generality of our findings, we generated a large sample of independent (Montecarlo) simulations[15] and computed the average for all the relevant endogenous aggregates. In Table 2 we report results for three key variables: *i*) the average distance from the EF, $\langle PI \rangle$; *ii*) the average period-on-period rate of inflation; *iii*) the average level of the real wage over the simulation time horizon. All the findings discussed with reference to representative simulations are confirmed.

5 Sensitivity analysis

In this section we discuss some robustness checks conducted with regards to: *i*) the influence of search costs on PI; and *ii*) comparative statics. As regard

[15] We performed 1000 repetitions with different seeds and took averages over time series, for the model with a parameterization identical to the one presented in Table 1.

the latter, for ease of exposition the experimental data are presented for the *Experiment II-Treatment A* case only. All the qualitative features discussed below remain unaffected in all the other cases.

5.1 The width of the searching space

In our model the degree of the real friction associated with informational incompleteness has been parameterized in terms of the width of the sampling space in which households are allowed to search for transactions in the labor and the good markets. Since real frictions are usually connected to productive inefficiency, it seems interesting to explore how different combinations of search costs affect the performance of the economy in correspondence of alternative institutional frameworks. Results are presented in the six panels of Figure 7, where we report the average value of real output over simulation runs lasting 1000 periods, for any combination of M and Z in the space grid (2, 3, 4, 5, 6).

In the RW scenario, the two treatments yield different outcomes as regards the interaction between values of M and Z. While in the individual-learning treatment the progressive approaching of the efficient frontier occurs mostly when the sample Z over which consumers are allowed to search is enlarged for any value of M (Panel (a)), the opposite holds true when agents learn according to a social-based procedure (Panel (b)).

In the other two experiments we observe surface graphs which do not qualitatively vary with the treatment variable, although the institutional environment affects sensibly how the efficiency frontier is attained. In particular, while for the RFS experiment the full-employment solution requires a contemporaneous decrease of search costs in both markets, under the RFA institutional framework the two surface in Panels (e) and (f) are both flat, although anchored at different levels of efficiency.

5.2 Responses to permanent shocks

As a last exercise, we let the system be disturbed by permanent shocks to labor productivity, labor supply and the money supply. Simulation results are presented in Figures 8 to 10, respectively, with shocks occurring at period 500 in each case.

We consider first a shock to productivity, modelled as a 100% increase of the technology parameter α (Figure 8) with respect to its baseline value. After the shock, the real GDP jumps immediately to a new absorbing class, whose upper bound coincides with the new full-employment equilibrium. A similar story holds for real wages, signaling that the fully decentralized economy endogenously configures itself around a solution in which nominal wages and prices adjust to so that the average real wage equates the average labour productivy. In particular, the nominal price level adjusts abruptly in correspondence of the distrubance, with the inflation rate returning immediately to its pre-shock long-run. The long-run averages for all the other variables - price dispersion, profits and the bankruptcy rate - remain unaffected.

In the second comparative statics exercise, the population of workers is doubled at once at period 500 (Figure 9). The response of real GDP and prices to a positive shock to the labor supply is the same as before (albeit the drop in prices is sensibly lower), and entirely in line with the predictions of the standard BNM model. The average real wage and total real profits are not affected by the sudden increase in the labor force. It could be noticed, however, that the dynamics of the real profits display a higher volatility around the constant mean (equal to the competitive value) after the shock.

Third, we present simulation results for a positive permanent shock to money supply (Figure 10), modeled as an outside injection of liquidity means doubling one-shot the money balances in the hands of consumers. By looking a the time series for GDP and the average price level we find a confirmation for the hypothesis of long-run money neutrality, while in the short-run the expansionary policy forces the economy to settle straightly on the full-employment frontier. The transmission mechanism of monetary policy causing the short-run non-neutrality operates through a compression of real wages and an consequent expansion ot the share of income going to profits. The increased profitability of firms is reflected in a sudden drop of the bankruptcy rate, which converges to an average value well below that registered before the shock occurs.

6 Conclusions

Modern macroeconomic theory is Walrasian in nature, in that it exogenously imposes an aggregate equilibrium solution instead of deriving it constructively. The "proof of principle" referred to in the title is aimed at assessing whether the predictions of a general equilibrium model – competitive or not – have an empirical content which can be trusted as a consistent foundation for macroeconomic theorizing, as soon as the WA coordination mechanism is explicitly abandoned and alternative procurement processes regarding pricing, trading and learning protocols are considered.

We address this issue by offering results from several computational experiments conducted with an agent-based, bounded-rational, fully decentralized version of the standard two-market BNM model. The richness of behaviors emerging from repeated decentralized out-of-equilibrium individual transactions goes well beyond the standard results one can obtain by limit the analysis to an equilibrium-based approach.

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Figure 1: Real GDP.

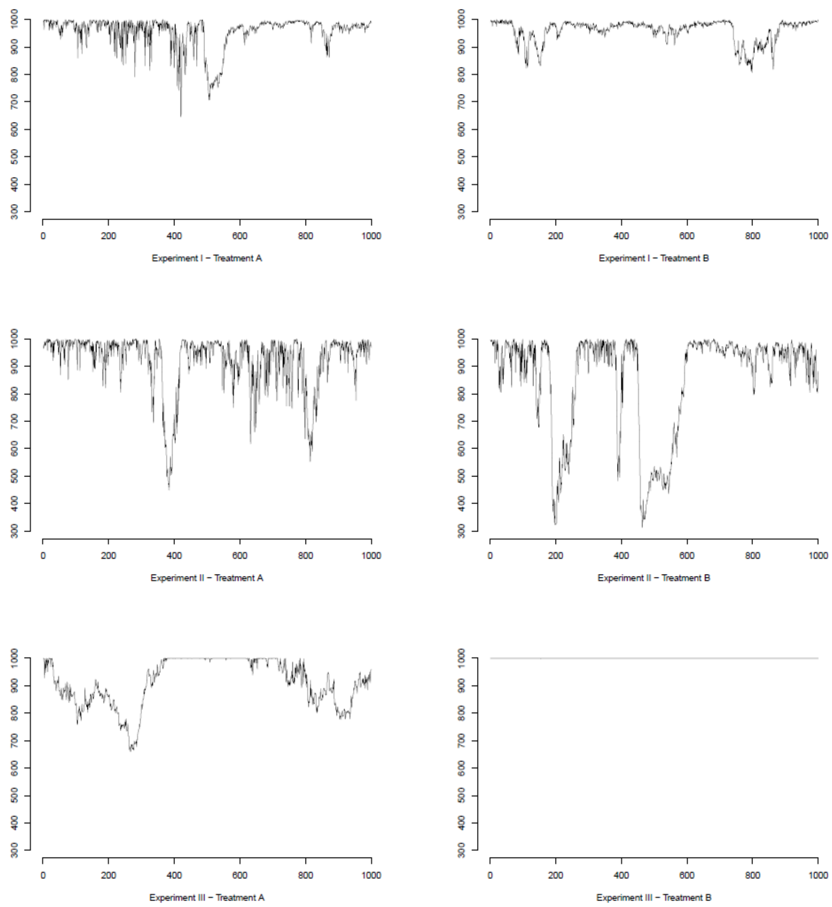

Figure 2: Average real wage.

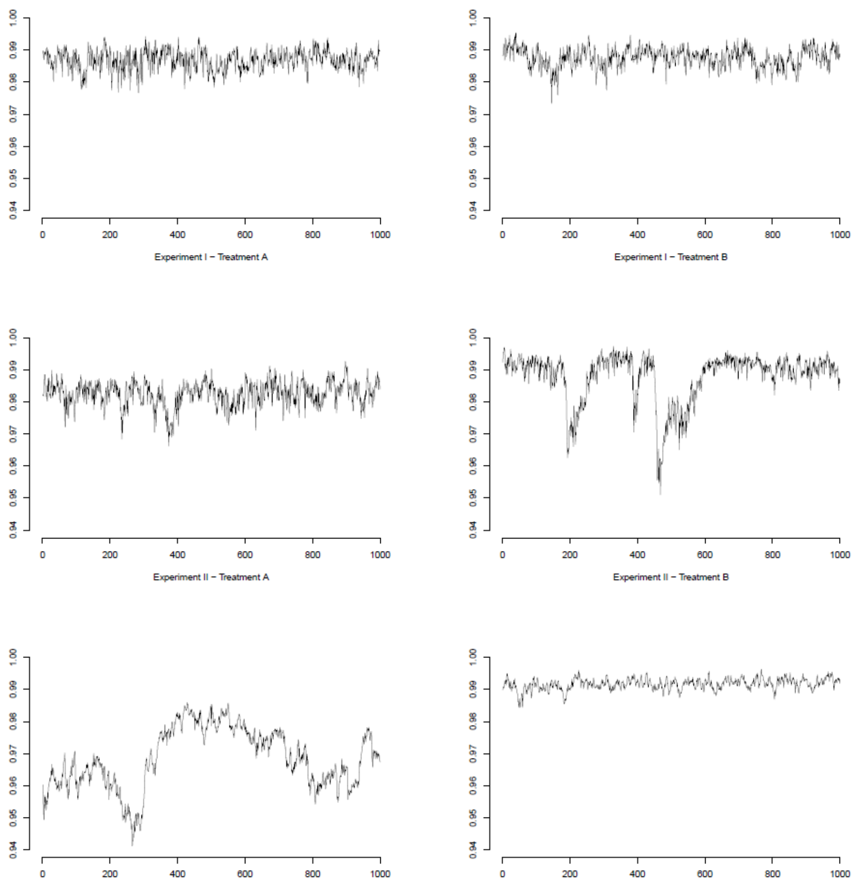

Figure 3: Average price level.

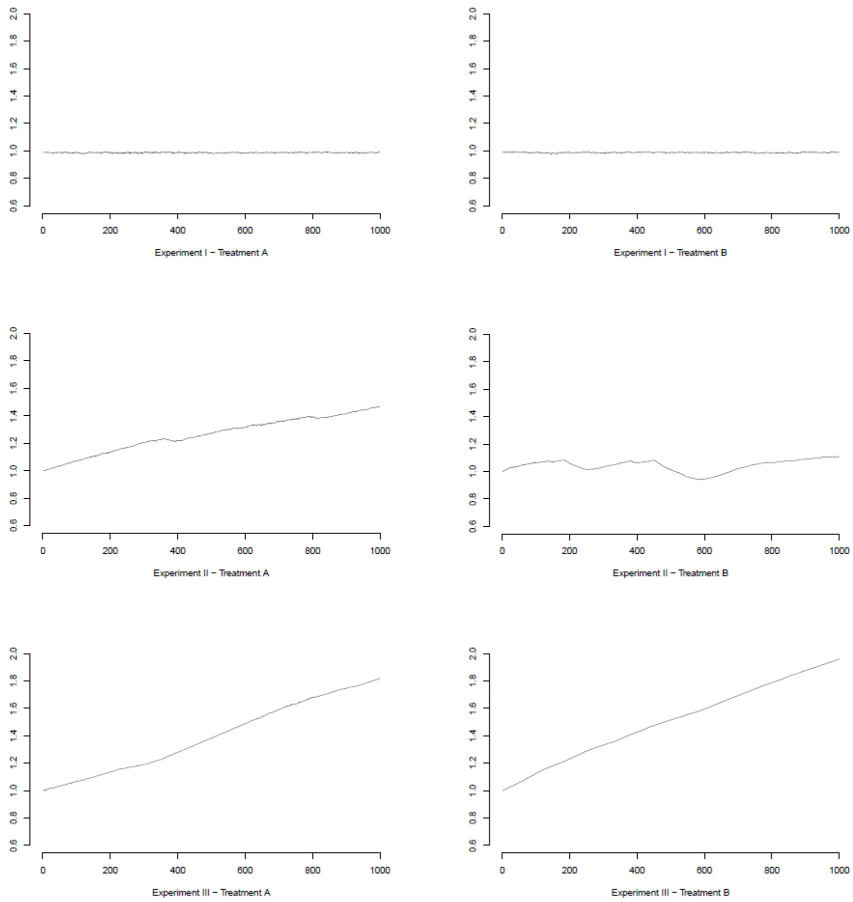

Figure 4: Price dispersion (cross-section standard deviation).

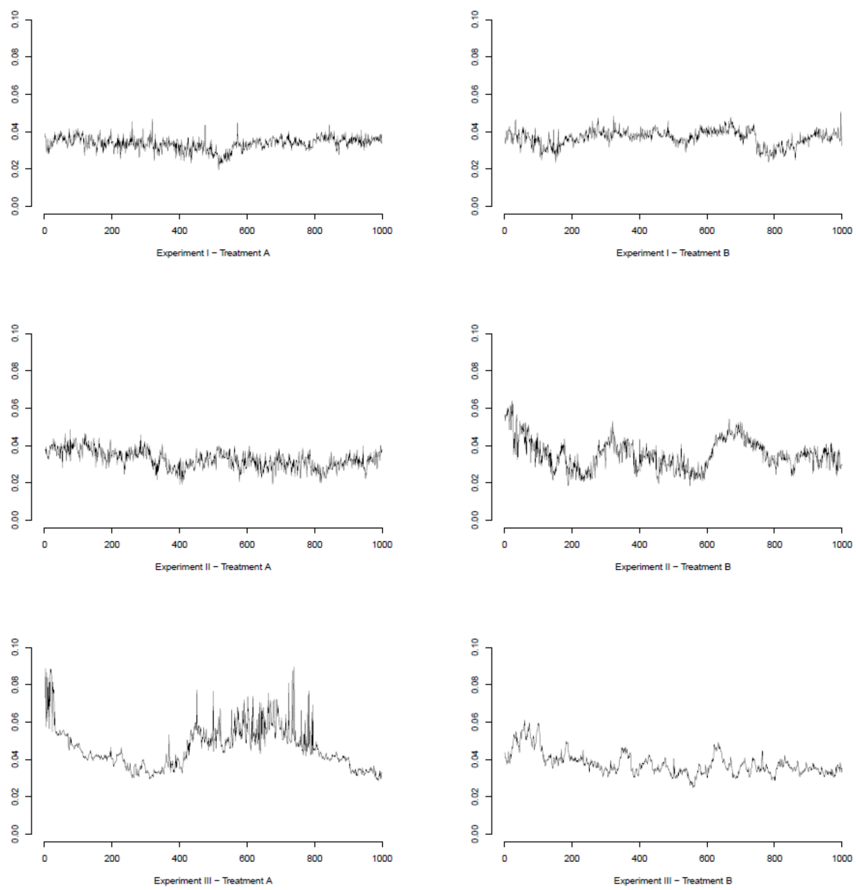

Figure 5: Total real profits.

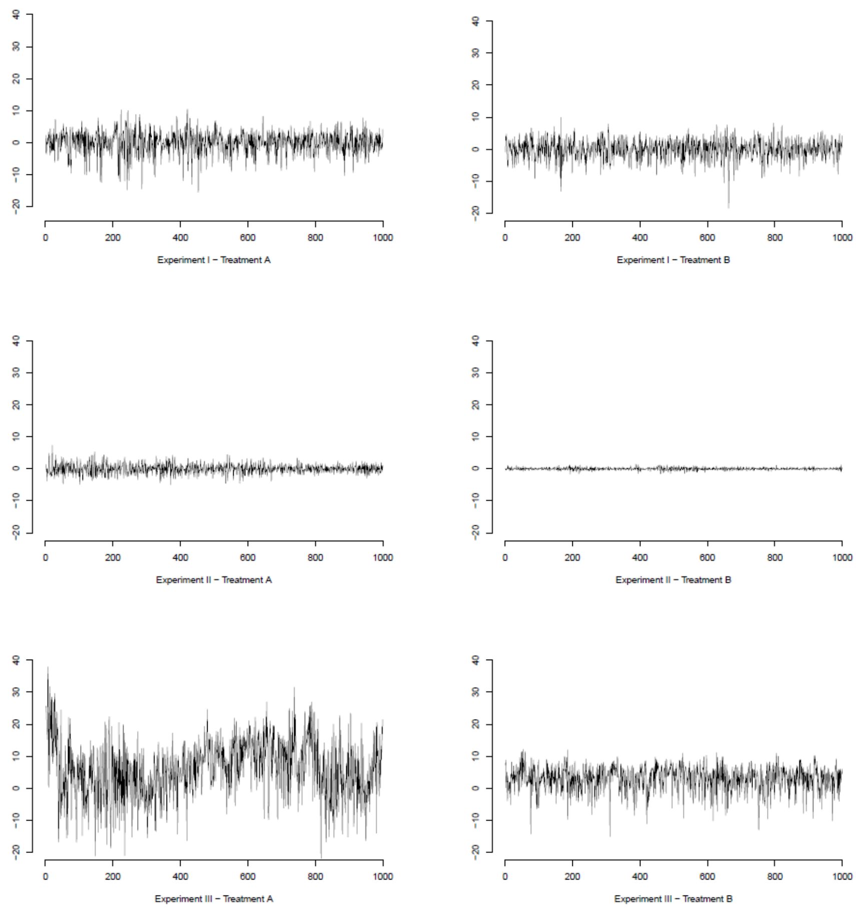

Figure 6: Bankruptcy rate.

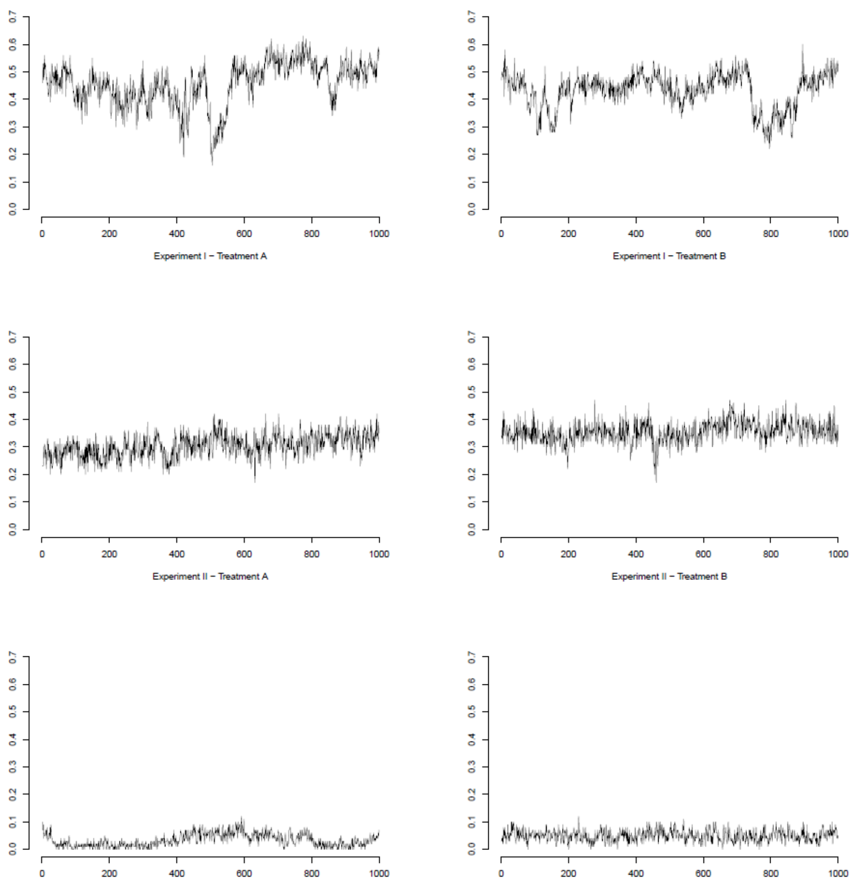

Figure 7: Montecarlo means of average real GDP for different combinations of M and Z.

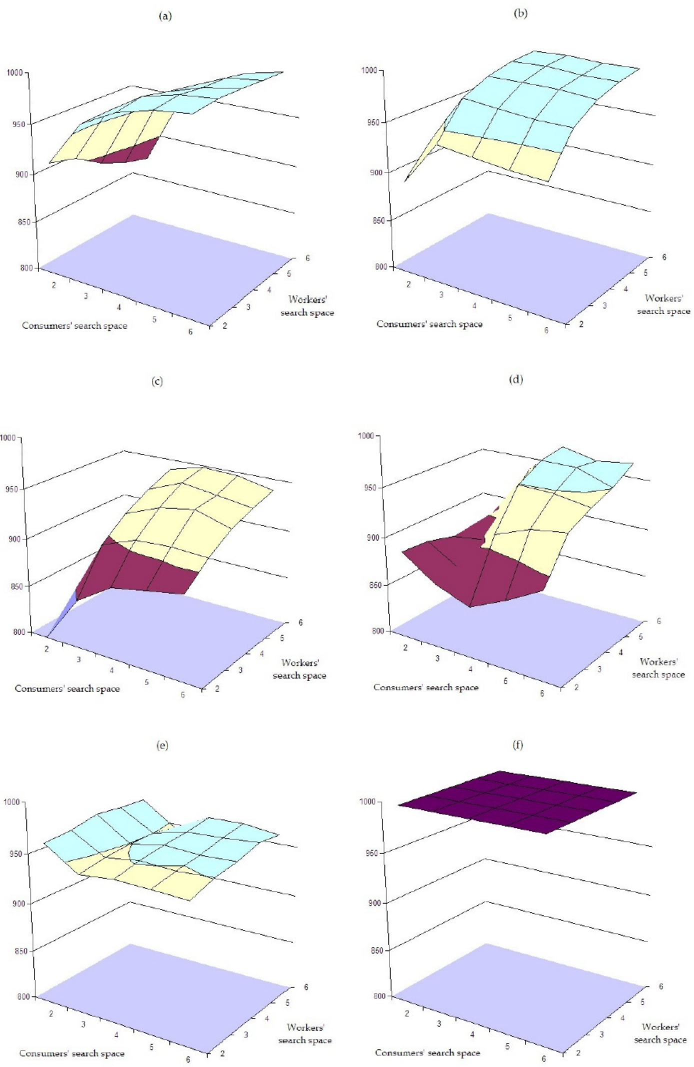

Figure 8: A positive shock to labour productivity. First line: Gdp, average real wage. Second line: average prive level, price dispersion. Third line: total real profits, bankruptcy rate.

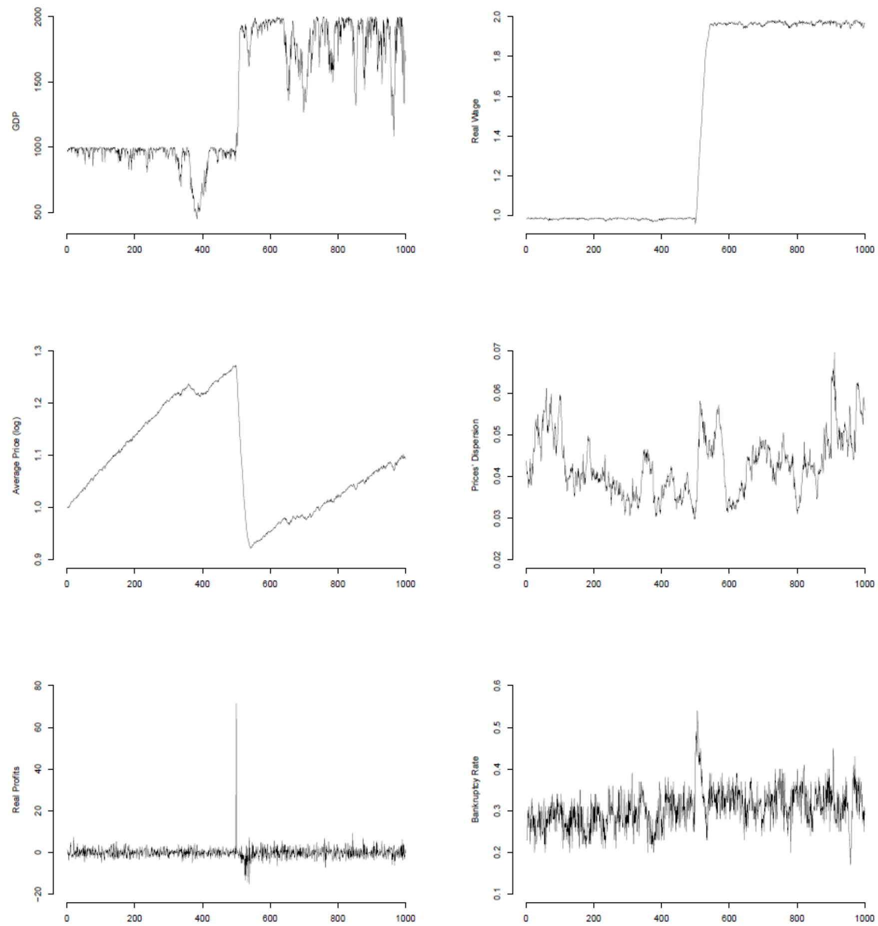

Figure 9: A positive shock to labour supply. First line: Gdp, average real wage. Second line: average prive level, price dispersion. Third line: total real profits, bankruptcy rate.

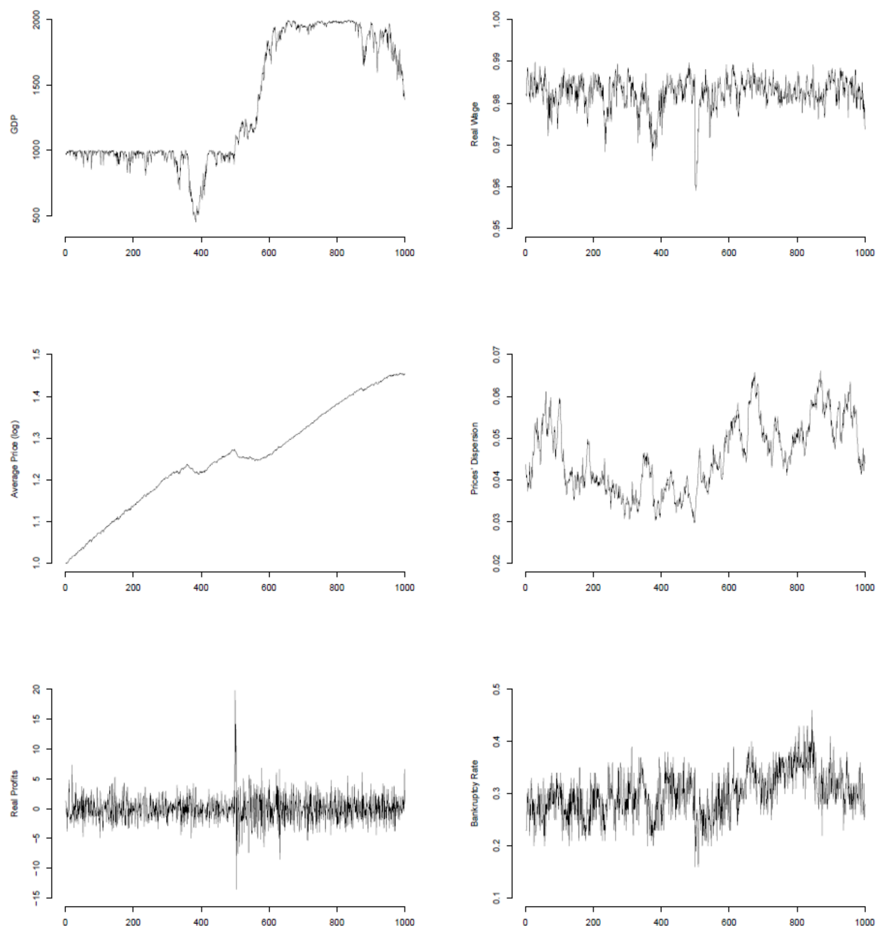

Figure 10: A positive shock to money supply. First line: Gdp, average real wage. Second line: average prive level, price dispersion. Third line: total real profits, bankruptcy rate.