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Decentralized Markets in a Two-Sector Economy

An Agent-Based Simulation

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a Dajana

The road to wisdom? - Well, it's plain
and simple to express:
Err
and err
and err again
but less
and less
and less.

Piet Hein

Introduction

My work concerns the realization of two Agent-Based simulation Models (ABMs) of a two-sector economy, consisting of heterogeneous agents. The first model is based upon equilibrium good markets, while the second is characterized by decentralized markets in a disequilibrium setting.

The purpose is twofold. On the one hand, we will compare the two models and their outcomes. On the other hand, we will assess the consistency of inferences from generated time series with each underlying model structure.

The argumentation is structured as follows:

In chapter one, we will review some of the main methodological issues concerning economic modeling, inference, and the role of explanation in Economics. Moreover, we will critically review some features of Dynamic Stochastic General Equilibrium (DSGE) models and compare them with those proper of a disequilibrium framework, as defined by Franklin M. Fisher and Frank Hahn.

In chapter two, insights from Behavioral Economics and Neuroeconomics are explored, in order to infer their possible implications for economic theory and modeling of agents' *behavior*. We will then report the Making of the simulation model and describe how the two versions have been developed, by making use of the Swarm-Like Agent Protocol in Python (SLAPP).

Chapter three is devoted to the development of version one, which is characterized by equilibrium good prices. Moreover, we will generalize version one by allowing for wage fluctuations through a variable-wage determination mechanism.

In chapter four, version two is described. It consists of a pure disequilibrium model of the over mentioned economy. We will point to differences with respect to version one and outline modeling choices for agent behavioral rules.

After the description, model dynamics are outlined and model outcomes assessed and compared in chapter five.

Part I

The Economy as Complex System

Chapter 1

Methodological Notes

1.1 Introduction

In this chapter, we review some of the main methodological issues concerning economic modeling and inference. We start from a rather philosophical argumentation, and trace an historical overview on how economics as a science developed to what it is today. We then look at the role of explanations in economics methodology and their implication for the economic profession.

1.2 Methodological Individualism

Economics is a social science. Most economists recognize its object of research along the lines of Lionel Robbins' well known definition: economics is "the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses" (1932, p. 15). The focus is posed on human behavior.

This has been a generally accepted view since the time of classic economists, although with some caveats. Colombatto (2011, chapter 2) offers a clear overview of how the economic theory has devolved between the 18th and the 20th century and, in what follows, the main points of his account are briefly summarized.

1.2.1 Historical Development of Methodological Individualism

In the 18th century, economics gained slowly existence as a field of study, by looking at the natural order of a man-ruled society. Political economy was a valid "instrument" in order "to understand how Providence and Nature *had given* man resources (...)" (*ibidem*, p. 17, emphasis added). At the time, the aim of economic inquiry was to understand how individuals' interaction, mutual sympathy and the

power of local ruling authorities contributed to the functioning of a society (p. 18).

Before the industrial revolutions, economic problems were defined in terms of equilibrium between demand and supply within a rather *static* economy. For instance, GDP growth in the U.K. has been estimated about few percent decimals per annum[1]. The object of exchange was still largely composed by agricultural harvest and cattle stocks[2], and hit by exogenous shocks like adverse weather condition, sickness or war.

Generality of such an equilibrium was not concerning the equalization of relative prices within the economy, but rather a framework in which natural (God's) laws governing the economy could have been formulated as "absolute" and "perfect". Because of this cultural background, two things emerged: the idea of laissez-faire – from the purpose of letting natural laws work properly in the long run – and a mechanistic vision of the economic system. This early classical conception of equilibrium is static. Nobody competes but merely survives by following instinct, not utility, nor profit maximization.

Colombatto continues outlying how equilibrium gradually acquired a man-made conception. The cultural *milieu* in which this idea developed stemmed from an interplay of the new European order after the Westphalia treaties (1648), the Enlightenment and two industrial revolutions. Within this context and during the 19th century, we assist at the formation of two main theoretical cores of subjectivism – one related to the French Liberal School, the other to the so called Marginalists.

On the one hand, the authors of the French Liberal School reconsidered the role of the individual and her/his behavior. Among them we recall Jean-Baptiste Say (theory of entrepreneurship), and C.-Frédéric Bastiat (entrepreneurial growth, failure of government intervention to promote welfare), (p. 22).

On the other hand, the Marginalists (mainly Léon Walras, William S. Jevon, and later Francis Y. Edgeworth) promoted inductive theories, along the lines of contemporary developments in mathematics and the hard sciences.

At that time, economists sought a hard, scientific status for their discipline and started an inquiry for general laws. Therefore, mathematics was added to economics in order to translate economic phenomena into laws. The Marginalists defined price as index of scarcity (putting aside labor value theory) and introduced Hermann H. Gossen's theory of demand into static equilibrium models. The result has been a coherent economic theory, which not only met the scientific standards of the time, but also conceptualized equilibrium as an outcome of human interaction

[1] Actually, 0.2% in average between 1300 and 1700 (max: 0.64%, min: −0.32%); see Apostolides *et al.*, 2008, p. 22).

[2] About 40%, according to Apostolides *et al.* (2015, p. 194).

(p. 23).

Nonetheless, such a strong focus on inductive laws, together with a mechanistic view of the representative agent, drove economic research into a methodological *impasse*, known as the Problem of induction (which we will outline later on), and let economics depart from its very object of study – *i.e.* human behavior (p. 24).

Among the first group, Jean-Baptiste Say had a clear view of the economy as an interdependent system of human interactions (1840, in Colombatto, 2011). Particularly relevant is Say's analogy with the human body:

> L'économie politique n'est pas autre chose que l'économie de la société. (...) L'étude que l'on a faite de la nature et des fonctions du corps humain, a créé un ensemble de notions, une science à laquelle on a donné le nom de *physiologie*. L'étude que l'on a faite de la nature et des fonctions des différentes parties du corps social, a créé de même un ensemble de notions, une science, à laquelle on a donné le nom d'économie politique et qu'on aurait peut-être mieux fait de nommer économie sociale (1840, p. 1).

Moreover, we can notice how Say conceived the subject-matter of economics in a broader sense than what concerns causes of *material* welfare (Marshallian conception) more than ninety years before L. Robbins' Essay[3] and the following debate between him and E. Cannan on the same topic:

> [L'économie politique] tient à tout dans là société. Depuis qu'il a été prouvé que les propriétés immatérielles, tels que les talens et les facultés personnelles acquises, forment une partie intégrante des richesses sociales, et que les services rendus dans les plus hautes fonctions ont leur analogie avec les travaux les plus humbles; depuis que les rapports de l'individu avec le corps social et du corps social avec les individus, et leurs intérêts réciproques, ont été clairement établis, l'économie politique, qui semblait n'avoir pour objets que les biens matériels, s'est trouvée embrasser le système social tout entier (p. 4).

Interestingly, Say was concerned with a quest for explanation of economic phenomena, which had (*lato sensu*) both, an inductive and a deductive component:

> L'économie politique, en s'attachant à faire connaître la nature de chacun des organes du corps social, nous apprend à remonter des effets aux causes, ou à descendre des causes aux effets (...), (p. 5).

[3] "For rationality in choice is nothing more an nothing less than choice with *complete awareness* of the alternatives rejected. And it is just here that Economics acquires its practical significance" (p. 136, emphasis added).

He viewed the entrepreneur as promoter of economic activity and value creation, as well as a proxy for the application of knowledge:

> Afin de rendre les choses, quelles qu'elles soient, propres à satisfaire les besoins des hommes, il faut en concevoir le dessein, en former le project, et s'occuper ensuite des moyens de l'exécuter. Si je juge qu'une étoffe faite d'une certaine façon sera propre à vêtir les hommes ou les femmes, et qu'une fois l'étoffe terminée, elle paraîtra assez utile pur qu'on y mette un prix; si je juge que ce prix sera suffissant pour m'indemniser de mes frais et me récompenser de mes peines, je rassemble et je mets en œuvre les moyens d'exécuter cette production: telle est l'origine d'une entreprise industrielle (p. 92).
>
> Je vous ferai remarquer que l'entrepreneur d'industrie est l'agent principal de la production. Les autres opérations sont bien indispensables pour la création des produits, mais c'est l'entrepreneur qui les met en oeuvre, qui leur donne une impulsion utile, qui en tire des valeurs. C'est lui qui juge des besoins et surtout des moyens de les satisfaire, et qui compare le but avec ces moyens; aussi, sa principale qualité est-elle le jugement (p. 100).
>
> Vous voyez que la production se compose non-seulement de la science ou des notions, mais en outre de l'application de ces notions aux besoins de l'homme. Je sais que le fer peut se forger, se modeler, par l'action du feu et du marteau; voilà la science. Quel parti puis-je tirer de ces connaissances pour créer un produit, dont l'utilité soit telle que le prix qu'on y mettra soit suffisant pour m'indemniser de mes déboursés et de mes peines? Voilà ce qu'enseigne l'art de l'application (p. 96).

This theoretical framework has been further developed later on by Frank Knight, with particular emphasis on risk and uncertainty (1921, chapter 9).

1.2.2 Menger and Methodological Individualism

Between these two versions of subjectivism, a fundamental theoretical work has been provided by Carl Menger. Together with Walras and Jevons, he is one of the fathers of Marginalist theory. At the same time, he is founder of the Austrian School of Economics. Indeed, Menger red Say and shared some theoretical underpinnings as a subjective theory of value (notice the similarity between Say's Law and Menger's "*Absätzfähigkeit*" principle), as Campagnolo points out (2008, p. 62), or the classification of goods in different orders, as related to the satisfaction of *needs* (Menger, [1871] 1976, chapter 2).

In light of this, we can reconsider Menger's difference in the use of mathematics with respect to Walras or Jevons – which may sound otherwise puzzling, as Mensik (2015) claims:

> [A]lthough in his ontology Menger indeed describes the world as being mathematical, in his economics he is drawing on numerous natural language concepts instead of purely mathematical ones. The reason seems to be Menger's implicit reliance on the general human knowledge in his economics (p. 480).

On this topic, Klein maintains [4]:

> While Menger shared his contemporaries' preference for abstract reasoning, he was primarily interested in explaining the real world actions of real people, not in creating artificial, stylized representations of reality. Economics, for Menger, is the study of purposeful human choice, the relationship between means and ends. "All things are subject to the law of cause and effect," he begins his treatise. "This great principle knows no exception"(p. 51), (p. 7).

From a methodological point of view, Menger framed the world as made of kind of *archetypes*, which he calls 'pure types'. For him, these simpler elements are features of actual situations; they match repeating patterns of behavior and empirical forms recurring in variations of individual phenomena. As Heath states: "Menger defended his individualistic method in terms of conceptual gains achieved by "reducing complicated phenomena to their elements" " (Menger, [1883] 1985, p. 93, in Heath, 2005).

1.3 Explanation in Economic Methodology

1.3.1 Laws

Simply put, an explanation is "an answer to a *why* question", which may also identify a phenomenon as "an instance of a fundamental law" (Boumans and Davis, 2016, p. 15). A law is a logical connection between two statements, where the first *necessarily* implies the second. For decades, a law had been the only meaning of a *scientific* explanation.

Universal laws differ from simple regularities because the former is not spatially, nor temporally restricted; not even to a particular instance of an object. Instead, regularities are. As Boumans and Davis state, such a generality requirement of a

[4] Foreword to the 2007 reprint, in Menger, [1871] 1976.

law implies time invariance – *i.e.* a law must hold in the past, as well as into the future (symmetry thesis, p. 17). If this is the case, a law can be inferred from particular instances – *i.e.* inductive reasoning successfully outlines the law – and, at the same time, prediction is possible, by applying the induced law (deduction). If, on the contrary, time invariance does not apply, the symmetry thesis is refuted. Therefore, the supposed law does not constitute an explanation of the phenomena under inquiry and there cannot be a valid prediction thereupon. In this case, only a description of the phenomena is possible (p. 18).

Statistically, a law can be inductively derived from observations of an underlying phenomenon, if time invariance still applies and observations are not systematically biased. For instance, we can consider a time series made of random draws from a (trend-) stationary stochastic process, which we can consider as our "law". In this case, it is possible to infer statistical properties of the series by its sample moments (ergodicity holds), and predictions based upon these estimates can be made. If there is no time invariance, sample moments do not return consistent estimates of the respective parameters (ergodicity does not hold) – *i.e.* the probability distribution of the process changes with time, and prediction is not possible.

1.3.2 The Problem of Induction

From an empirical perspective, David Hume posed what is known as the "problem of induction" – *i.e.* whether it is indeed possible generalize some properties of a phenomenon, on the basis of repeated observation. In his words ([1739] 2007):

> Let men be once fully perswaded of these two principles, *that there is nothing in any object, consider'd in itself, which can afford us a reason for drawing a conclusion beyond it*; and, *that even after the observation of the frequent or constant conjunction of objects, we have no reason to draw any inference concerning any object beyond those of which we have had experience;* (p. 95).

As pointed out by Vickers (2006), we should recall how Hume does not use the term "induction" directly, and his concern was about *causal* relations, derived from experience[5]. However, we can see that his answer is in the negative.

[5] "The only connexion or relation of objects, which can lead us beyond the immediate impressions of our memory and senses, is that of cause and effect; and that because 'tis the only one, on which we can found a just inference from one object to another. The idea of cause and effect is deriv'd from *experience*, (...)" (Hume, [1739] 2007, p. 63)

1.3.3 Implications for Economics

The problem of induction implies the impossibility of inferring general laws from experience and has posed a major threat to the validity of logical positivists' claims on the existence of a clear demarcation of scientific knowledge in modern times. In Economics, their position has developed in two different ways.

On the one hand, "instrumentalists", as Milton Friedman, have shifted the focus on predictive power of a law, regardless to truthfulness of its underlying hypotheses.

On the other hand, "confirmationists" reduced the importance of a law by weighting it by a "degree of confirmation", which is defined on the basis of empirical research.

Thereafter, the role of laws has been generally revisited by introducing limiting conditions for their domain of applicability and scope. Laws were reduced to regularities and are, since then, interpreted as "broad tendencies", "empirical constancies", or "stylized facts".

To this methodological *impasse*, we can relate three modern debates, which all stem from the inapplicability of time invariance to empirical inferences, or from the instrumentalists' stance, on hypotheses: First, the Keynes-Tinberger debate on the role of Econometrics in advancing economic theory. Second, the "Measurement-without-theory" debate between T. Koopmans (Cowles Commission) and W. Mitchell (National Bureau of Economic Research) on the usefulness of Real Business Cycle (RBC) research. Third, the "descriptivism debate" between P. Samuelson and M. Friedman on the validity of a "false" theory, which produces "true" consequences (Boumans and Davis, 2016, pp. 37-57).

Nonetheless, the problem of demarcation feasibility remains, for some theoretical concepts cannot be operationalized – or there is more than one way to do it. Moreover, it is not clear how a degree of confirmation of an empirical law should be set and by whom (pp. 19-20).

On top of this, external validity of experimental results has to be assessed by repeated trials of the same experimental format in different places, in order to identify whether a theory fails *per se* or because its underlying hypotheses are violated. This is known as the Duhem-Quine thesis (p. 90).

1.3.4 A Possible Way Out of the Problem of Induction?

Although several philosophers maintain a sort of irrationality of induction itself, Armstrong (1983, in Vickers, 2006) suggests a way out of the problem of induction, by holding a weaker conception of rationality, which is similar to the ordinary meaning as "exercising (...) one's reason in a proper manner; having sound judgment". A similar interpretation of rationality can be found in Rob-

bins' Essay[6]. Under this definition, induction becomes an "inference to the best explanation" (Harman, 1965) and, in this sense, regularities may be maintained, even though as hypotheses. Vickers points out the similarity of this conception with C. Peirce's abduction. Hoover (2016) describes abduction as a weaker form of inference, which allows for the introduction "of a new idea".

The example made by Peirce (1934, §188, in Hoover, 2016) is:

> The surprising fact, C, is observed.
>
> But if A were true, C would be a matter of course.
>
> Hence there is reason to suspect that A is true (p. 1351).

If Armstrong's solution is accepted, one could follow Swedberg (2014) and Peirce by combining philosophy and logic into (consistent) "tentative explanations" of the form of empirical models (Hoover, 2016, p. 1351-1352). Swedberg indeed maintains that theory is a rather fuzzy concept and models are characterized as "sometimes true theory" – in the sense that "they are true only derivatively, as they successfully guide and structure observation and explanations" (p. 1352).

1.3.5 Causality and Explanation

Before moving forward, let us ask ourselves: what is actually an explanation? This simple question has no "straightforward" answer. Faye acknowledges that we can identify "many different types of answers to why-questions which do not make any references to causes" and suggests the following classification (1999):

(A) Causal explanation appeals to the actual cause of a certain phenomenon.

(B) Nomic explanation refers to a law of a certain phenomenon.

(C) Functionalistic explanation refers to the actual effect of a certain phenomenon, in the sense that a certain phenomenon is favorable or appropriate for the reproduction or succession of an individual or a society.

(D) Functional explanation appeals to the actual effect of a certain phenomenon, but in the sense that a certain phenomenon is favorable or appropriate for the survival or cohesion of an individual or a society.

(E) Intentional explanation appeals to the intended effect of a certain phenomenon by referring to the literal meaning of a certain human action.

[6] *op. cit. 3*

> (F) Interpretative explanation appeals to the consciously or unconsciously intended effect of a certain phenomenon by referring to a certain metaphoric meaning of an action, a text, or a symbol.
>
> (p. 65)

If we then just restrict the domain to causal explanations, as Hume suggested, we can notice three things. First, not every law is a causal explanation, and *vice versa*. Second, the term "causal" is not univocal. Third, different kinds of explanation can be an *actual* "cause of a certain phenomenon".

An example for the fist point, are the rules of deductive logic. As Keuzenkamp (2000) states, they "prohibit drawing a general conclusion, if this conclusion is not entailed by its propositions" (p. 3).

Concerning the second point, Fafchamps (2015) claims that the notion of causality, as understood by economists, is rooted in the statistical concept of "Randomized Controlled Trials", (RCTs), and considers such a concept as a narrow view of causality (p. 658). To illustrate the case, he reports this example:

> [A]primitive tribe observes people entering their room in a recently built tourist hotel. They note that, most of the time, light appears in a room shortly after someone enters. To ascertain whether the effect is causal, they run an RCT and randomly assign people to rooms. Results confirms that people entering a room cause light to appear. They try this in their home village, but with no success. (...) They go back to the hotel and note that two things typically happen before light appears: 1) the person says something – such as "it is so dark in here!"; and 2) they activate a switch in the wall. They do not know whether it is the words (the incantation) or the action (or both) that cause light to appear – or if the incantation is required before they can touch the switch. They run more RCTs – sometimes preventing people to speak when entering the room, sometimes covering the switch, sometimes both. From their research, they conclude that speaking is not necessary. But touching the switch is nearly always essential. Based on there findings, they install switches in their huts – but again have no success in creating light (pp. 559-660).

Clearly, causation is composed by a channel of several joint causes. Fafchamps argues that RCTs may be adequate in order to estimate reduced-form coefficients of a model, but they turn ineffective when the purpose of inquiry is to study the underlying *structural* model. Causation "channels" of a more complex system are "multiple" and become "complex" themselves. In order to achieve a more-comprehensive causal explanation, a better theoretical understanding of the

channels of causation and their functioning in a structural model is needed (p. 659).

The third point is particularly relevant for economic phenomena – as for those proper of all social sciences, for intention and perception enter into play as human beings are concerned. Indeed, a channel of causation may comprehend unintended consequences of human actions as well. Furthermore, and on the contrary, even intended consequences may be "caused" by a biased perception of a signal, which we can think of as an instance of the well known theorem of Thomas and Thomas (1928):

> If men define situations as real, they are real in their consequences (p. 572).

1.4 Equilibrium and Disequilibrium Economics

1.4.1 Equilibrium

With Marginalism, the use of mathematics pervaded Economics and formality has become a necessary requirement. Weintraub (2002, chapter 1 and 6) offers an historical overview of how this process took place and, with particular respect to general equilibrium theory, of how Arrow and Debreu's (1954) proof of the existence of a general equilibrium within a Walrasian framework shaped economist's profession.

The excitement following the publication of their 1954 paper paved the way for the development of (Dynamic Stochastic) General Equilibrium (GE and DSGE) models, which are rooted into the same Neoclassical framework. This framework comprehends the following devices and hypotheses:

- representative agent (RA);
- rational expectation hypothesis (RE);
- clearing and complete markets; which entail:
  - perfect information;
  - finite number of goods;
  - no trade costs;
  - trade only at equilibrium prices;
- constraint maximization of RAs' objective function (and intertemporal optimization);

- (stochastic shocks).

In the last twenty years, DSGE models have been merged with RBC ones. Moreover, they have been modified in order to acquire some features of New Keynesian models as imperfect competition and costly price adjustment. The resulting framework constitutes what is known in the literature as New Neoclassical Synthesis (NNS[7]), (Fagiolo and Roventini, 2012, p. 71).

Fagiolo and Roventini briefly summarize the features of these models. Theoretically, NNS models hinge upon "monopolistic competition, nominal imperfections and a monetary policy rule" and they are based on three equations: an "expectation-augmented IS equation", a "New Keynesian Phillips curve, and a monetary policy rule" (p. 71). Moreover, they provide an overview of the modeled economy:

> The economy is populated by an infinitely-lived representative household, who maximizes its utility under an intertemporal budget constraint, and by a large number of firms, whose homogenous production technology is hit by exogenous shocks. All agents form their expectations rationally (...).
>
> The New Keynesian flavor of the model stems from three ingredients: money, monopolistic competition and sticky prices. Money has usually only the function of unit of account and its short-run non-neutrality is guaranteed by the nominal rigidities introduced by sticky prices. As a consequence, the central bank can influence the real economic activity in the short run by manipulating the interest rate.
>
> The RBC scaffold of the model allows one to compute the “natural” level of output and of the real interest rate, that is the equilibrium values of the two variables under perfectly flexible prices. The “natural” output and interest rate constitute a benchmark for monetary policy", (p. 71).

For NNS models can provide very precise measures of how such an economic system responds to exogenous shocks, they have been widely used for forecasting and policy analysis.

Nonetheless, this class of models has, following Fagiolo and Roventini, some relevant limitations on the (I) theoretical side, (II) empirical one, as well as on the (III) political economic one, which have proved critical after the Great recession. The main points of their argumentation are here reviewed.

[7]See Goodfriend and King, 1997, p. 255, in Fagiolo and Roventini (2012).

I – Theoretical issues Among the theoretical issues, there are some proper of the initial conception of GE models.

A) As for GE models in general, uniqueness and stability of a general equilibrium:

1. are not implied by its existence;
2. cannot be induced by restricting agents' characteristics;
3. "cannot be recovered" "even if agents are almost identical (i.e., same preferences and almost identical endowments)" (p. 76).

B) The RA hypothesis imposes stronger conditions as actually observed in reality, and consequently alters the behavior of the dynamical system represented.

> First, individual rationality does not imply aggregate rationality: one cannot provide any formal justification to support the assumption that at the macro level agents behave as a maximizing individual.
>
> Second, even if one forgets the previous point and uses the RA fiction to provide micro-foundations to macroeconomic models, one cannot safely perform policy analyses with such models, because the reactions of the representative agent to shocks or parameter changes may not coincide with the aggregate reactions of the represented agents.
>
> Third, even if the first two problems are solved, there may be cases where given two situations a and b, the representative agent prefers a, whereas all the represented individuals prefer b (p. 77).

C) A test of such a model's result implies a test of the RA hypothesis as well (p. 77).

D) If heterogeneous agents are added, micro-level properties of heterogeneous agent models do not rensemble those of RA based models.

On this point, they make reference to the work of Forni and Lippi (1997, 1999) where it is shown that "basic properties of linear dynamic microeconomic models are not preserved by aggregation if agents are heterogeneous" (Fagiolo and Roventini, p. 77).

In particular, Hartley (1999) gives a more exhaustive account of Forni and Lippi (1999):

> Forni and Lippi provide a considerable advance in our understanding of the extensiveness of the aggregation problem. They demonstrate that aggregation has important effects when (1) agents are heterogeneous in the sense that they have different responses to exogenous shocks and (2) there is more than one shock process affecting the economy. In such cases, the authors demonstrate that relationships between variables at the individual level do not generate the same relationships at the aggregate level (...). [N]either co-integration nor unidirectional Granger causality at the micro level generates the same at the aggregate level. Overidentifying restrictions in a microeconomic model do not result in overidentifying restrictions in the corresponding aggregate model. The coefficients of an aggregate VAR cannot be interpreted as averages of the corresponding micro coefficients. In fact, the pattern also runs the other way. For example, two variables can be cointegrated at the aggregate level even though there is no such relationship at the microeconomic level (p. F225).
>
> With Forni and Lippi's work, it is now even more difficult to justify the use of a representative agent model for macro-economic study. One wonders when macroeconomists will notice (p. F226).

II – Empirical issues When it comes to empirical issues, Fagiolo and Roventini mention the identification problem – due to non-linearities of model parameters or to under/partial identification, the related issues in their estimation by Maximum Likelihood, and possible misspecification of the underlying statistical model. When it comes to the evaluation of model result, the comparison of the latter with historical data is not good enough to reproduce descriptive features of real time series. Nonetheless – and quite unsurprisingly, NNS modesls are not able to reproduce an economic crisis, for agents always know what a "best response" to the state of the economy is, given (perfect) information they have (pp. 81-83).

III – Political-economy issues Problems of political economy concern the issue of how DSGE conception actually constrains model dynamics (p. 83).

Fagiolo and Roventini focus on two points: behavioral assumptions and internal inconsistencies.

As first point, they argue that DSGE models constitute a rather unrealistic set of hypotheses concerning human behavior (p. 83). This recalls most of

the criticism moved to the original GE framework, which we have seen at page 20. In particular, agents:

(a) form RE and make decisions by applying dynamic programming techniques;

(b) have a perfect information on the economy *and* "understanding" thereof;

(c) can reach a solution of the problem above "without making mistakes";

(d) know that everyone else is perfectly rational – *i.e.* rationality is common knowledge (CKR[8]).

On top of this, they argue that "[t]he representative-agent (RA) assumption prevents DSGE models to address distributional issues, which are one of the major cause of the Great Recession and they are fundamental for studying the effects of policies" (p. 84).

Concerning the second point, they highlight two internal inconsistencies of NNS models. One concerns the incompatibility between a strong reliance on formalization of the DSGE framework, and the use of imperfections, which are introduced "without any theoretical justification" for a data-matching purpose (p. 85). Another inconsistency provided hinges upon the fist one. Because the RBC component of DSGE models is exogenous, the resulting business cycles is simulated without any justification of the underlying shocks, other than data-matching (p. 86). This criticism is linked as well to the lack of time invariance in economic time series.

Fagiolo and Roventini conclude that:

> These problems are so deep that impede DSGE models even to conceive the possibility of the current crisis and to propose possible solutions to policymakers. We think that such difficulties are so hard to solve within the neoclassical paradigm that a different research avenue, which attempts to replace the basic pillars of neoclassical economics (rationality, equilibrium, etc.), would be more fruitful (p. 105).
>
> [O]ne can safely test the macroeconomic implications of microeconomic theories *only if* careful and explicit modeling of agents' heterogeneity is carried out (p. 78, emphasis added).

For a deeper insight, a broader and more technical set of issues is posed by Farmer and Geanakoplos (2009). At the same time, they stress the importance

[8] On this topic, see Sugden (1991), pp. 764-76, and Hodgson (2012).

of non-equilibrium (or disequilibrium) theory (§7) for the explanation of economic phenomena, together with an emphasis on models of heterogeneous agents with bounded rationality (or even Zero intelligence, p. 30) and their structural interaction with modeled institutions.

We turn now our attention to disequilibrium theory and outline some link with equilibrium analysis and clarify some concepts.

1.4.2 Disequilibrium

From the late seventies onwards, some authors as Frank H. Hahn, Franklin M. Fisher, and Jean-Pascal Benassy developed generalizations of the Walrasian framework to allow for the study of disequilibrium phenomena. These authors maintained profit/utility maximization, in order to define market demand and supply quantities of their agents, but they point to a broader set of problems and pursue two different research paths.

On the one hand, Hahn (1962, 1978) and Fisher (1983) aim at laying foundations for stability theory, in order to understand how an economic system can achieve an (and what) equilibrium.

On the other hand, Benassy (1986, 2002) is more interested in defining core features of a non-Walrasian approach – *i.e.* an approach to market functioning without a Walrasian Auctioneer (WA). He (1986) defines it as

> a number of microeconomic concepts that allow the rigorous formalization of the functioning of individual markets and of the whole economy when demand and supply do not balance, and the mixed price-quantity adjustments that result from such situations (p. 2).

This definition is in line with the more concise one by Hahn (1978):

> I shall call an economy non-Walrasian whenever the trading possibilities of agents cannot be described as the set of trades which at given prices make the value of purchases no greater than the value of sales (p. 1).

Benassy (1986) highlights some features of this approach. Among them, the possibility for economists "to study, both at the microeconomic and macroeconomic levels, the consequences of numerous schemes of price formation, ranging from full rigidity to total flexibility, including various intermediate forms of imperfect competition, and allowing, moreover, different schemes on different markets" (pp. 2, 3).

In these models, price making becomes "internal to the system", as well as expectation formation, where "[e]ach agent may have his own expectations scheme, “rational” or not, so that this covers the largest number of specifications" (p. 3).

In pursuing such an approach, he recalls several concepts, as the distinction between demand and transactions – which can clearly differ in such a setting (p. 15), the definition of effective demand – depending on both, price and quantity signals from the market (p. 23, as in Clower, 1965), price formation – based on announcement (*i.e.* "called", as in Hahn and Negishi, 1962, p. 463) or as a result of bargaining (as in Rubinstein, 1982, p. 100, in van den Elzen, 1993), spillover effects – *i.e.* effects of rationing/constraints in one market, which affect supply/demand in another one (p. 21), and the perceived demand/supply curve, which returns the quantity of goods that an agent expects to buy/sell (p. 54).

While Benassy outlines more general model features, Fisher (1983) poses attention to the implications of shocks on equilibrium convergence and overall system response. Indeed, in this case "it is not immediately obvious that *all* that is happening is convergence to new equilibria; still less it is obvious that such convergence is instantaneous or so rapid that the transient disequilibrium behavior of the system responding to such shocks is unimportant" (p. 4).

Moreover, he underlines the importance of studying whether the equilibrium toward which the system converges is stable or not, and in what extent it depends on the adjustment path itself. He claims that, if the adjustment process takes place *fast*, comparative statics may be a good approximation of it. Conversely, the system deviates from the original path, as soon as, in the meanwhile, there is a shift in another parameter (for instance, as a result of an exogenous shock). Carrying this to extremes, if shocks are frequent and persistent – *i.e* the system is unstable, "convergence *never* take place, then what will matter will be the "transient" behavior of the system as it reacts to disequilibrium" (p. 3) and welfare analysis – which is based thereupon – would become irrelevant (p. 9).

Therefore, Fisher maintains that:

> To sum up, the standard treatment of economic theory as an equilibrium subject is very incomplete without a stability proof (and an analysis of adjustment speeds).
>
> In brief, the question of what, if any, disequilibrium stories have equilibrium endings (...) is a question of paramount interest for [economic][9] theorists especially if the world is stable" (pp. 4-5).

For instance, he points out that the issue of persistent underemployment – to which J. M. Keynes (1936) devoted much attention in the General Theory – may be indeed interpreted as a case when the system path approaches (and gets stuck at) an equilibrium, which is different from the full employment one (Fisher, 1983, p. 9).

[9] "such" in original, author's note.

Conditions for a satisfactory theory, comprehends the possibility of assessing model's dynamic of adjustment over time. If adjustment takes place very slowly, comparative dynamics may represent a better tool for analysis (p. 10). "[N]o satisfactory theory can stop without *explaining* how such points are reached and why maintained, if indeed they are" (p. 10).

Although with regard to functional forms, Fisher stresses the importance of model adherence with agents' behavior in disequilibrium:

> [I]t is a mistake to ground disequilibrium theory in the *equilibrium* behavior of agents. Rather, the theory of the household and the firm must be reformulated and extended where necessary to allow agents to perceive that the economy is not in equilibrium and to act on that perception. Without this, we cannot hope to provide a theory of what happens when arbitrage opportunities appear, for the essence of the appearance of such opportunities is that agents see and act on them (p.11).

Because of this, Fisher maintains that whatever disequilibrium theory for agent agency we may choose, it will have consequences on the adjustment speeds, *via* the way markets are organized. Therefore, a theory of comparative dynamics is needed, in order to study these issues (p. 13).

At the time, Fisher claimed that "[w]e often do not know that particular convergent processes are *ever* consistent with a sensible story about the behavior of individual agents" (p. 14). With today's computer power and simulation tools, this is luckily not the case anymore.

At this point, Fisher provides a lucid account of how agents' everyday actions can affect the path of the economy and introduces the concept of hysteresis, as well as the difference with *tâtonnement*.

Hysteresis happens when the set of equilibria that an economic system may achieve are indeed dependent on the historical path – *i.e.* on the initial state *and* on the dynamic adjustment out of equilibrium. This implies that the path on which the economy converges results shifted as well, on the basis of historical happenings within the economy. The interesting question is whether the economy reaches an equilibrium, and what kind of.

The second concept, *tâtonnement*, defines just equilibrium dynamics and system transition to an equilibrium, without disturbances. Under equilibrium analysis, only *tâtonnement* can be assessed. This is due to the instantaneous price adjustment, and to the "no-trade-out-of-equilibrium" hypothesis.

On light of these two definitions, comparative statics acquires meaning only under the second, but provide wrong approximations under the first, for, because of the hysteresis effect, the system has moved away in between (p. 15). In particular, hysteresis is driven by agents' actions out of equilibrium. If agents understand that

a disequilibrium situation is at play and act on it, the system path shifts. This is the case, for instance, when agents save today in order to acquire a good, which will be available in the *future* (Present Action Postulate, PAP). Therefore, so Fisher, "[s]tability analyses that take off from the economics of individual behavior by way of deriving unsatisfied or excess demands must concern themselves with the question of *when* and *how* the participants attempt to exercise those demands" (p. 22, emphasis added).

In order to assess whether path dependence and hysteresis effects are small – *i.e* we can apply comparative statics, a stability proof is required (p. 16).

Some Concepts on Stability In chapters 2 and 3, Fisher clarifies some basic principles of stability and outlines how to set up a stability proof.

With respect to the price of a commodity i, he defines the following price *adjustment process*, which recalls in principle the original Hahn process (Hahn and Negishi, 1962, p. 465):

$$\dot{P}_i = \begin{cases} F^i\big[Z_i(\mathbf{P})\big] & \\ 0 & \text{if} \quad P_i = 0 \text{ and } Z_i(\mathbf{P}) < 0 \end{cases}$$

where P_i is the price of commodity i, function $F^i(.)$ preserves sign, the Z_i represents the excess of demand and $\mathbf{P}$ is the price vector (p. 20).

To this process some definitions are added, concerning a more general one:

$$\dot{\mathbf{x}} = F(\mathbf{x})$$

as defined in this footnote[10] and in Fisher (1983) at pages 219-227. These definitions are so here reported:

- A *rest point* of an adjustment process is "a point at which the process does not move" – *i.e.* "a point $\mathbf{x}$ such that $F(\mathbf{x}) = 0$.

- *Global stability* of a rest point:

  A rest point, $\mathbf{x}^*$, is said to be *globally stable* if the system converges to it from every set of initial conditions (p. 24).

  More formally: $\mathbf{x}^*$ is said to be a *globally stable rest point* if and only if,

$$\forall \ \mathbf{x}_0, \qquad \lim_{t\to\infty} \quad \phi(t, \mathbf{x}_0) = \mathbf{x}^*$$

[10]Given an initial n-dimensional vector, and $\mathbf{x} = \mathbf{x}_0$ at $t = 0$, a solution to the process "is a function $\phi(.,.)$ with $\mathbf{x}_0 = \phi(0, \mathbf{x}_0)$, such that, if $\mathbf{x} = \phi(t, \mathbf{x}_0)$, then $\mathbf{x}$ satisfies" the process $\dot{x} = F(\mathbf{x})$ (p. 219).

- *Global stability* of an adjustment process:

  A process is globally stable "if, for any set of initial conditions, there is *a* rest point to which the system converges", which may not be the same one. (p. 25, emphasis added).

  Formally: the process is called *globally stable* if and only if, $\forall$ initial vector, $\mathbf{x}_0$, there exist some rest point $\mathbf{x}^*(\mathbf{x}_0)$, such that:

$$\lim_{t\to\infty} \quad \phi(t, \mathbf{x}_0) = \mathbf{x}^*(\mathbf{x}_0)$$

- Slightly different is the concept of *quasi-stability* of an adjustment process, which implies that for any initial condition, the sequence of prices (in this case) has some *limit points* - *i.e.* "points to smaller and smaller neighborhoods of which the sequence keeps returning. If every limit point of every such sequence is a rest point of the adjustment process, then that process is said to be quasi-stable" (p. 25).

  Formally: $\forall$ initial vector, $\mathbf{x}_0$, choose a sequence of times $\{t_\lambda\} \to \infty$. Choose a corresponding sequence of points $\{\mathbf{x}_\lambda\}$, where $\mathbf{x}_\lambda \equiv \phi(t_\lambda, \mathbf{x}_0)$. Suppose the sequence $\mathbf{x}_\lambda$ converges to a point $\mathbf{x}^*$. The process is called *quasi-stable* if and only if every $\mathbf{x}^*$ constructed in this way is a rest point.

In order to prove stability, Fisher outlines a three step procedure. As first, Lyapunov's ([1892] 1992) Second Method[11] is applied in order to prove *quasi-stability*. Then, a check of the compactness of variables is required. The third point can be a demonstration of local uniqueness of the rest points (p. 25).

The reason why we need Lyapunov's Second Method is rather intuitive, as Fisher (1983) describes it:

> [T]hink in terms of prices. (...) Suppose that we can find a function, $V(\mathbf{P})$, continuous in the prices, bounded below, and monotonically

[11] (also called Lyapunov's Direct Method):
"Consider a real-valued function, $V(.)$, whose domain is the set of possible values of $\mathbf{x}$ for all possible initial vectors $\mathbf{x}_0$. Suppose $V(.)$ has the following properties:

(a) $V(.)$ is continuous;

(b) For each initial vector, $\mathbf{x}_0$, the set of values taken on by $V(.)$ is bounded below;

(c) $V(.)$ is decreasing through time unless $\mathbf{x}$ is a rest point of [the process]. That is, for all $t > 0$,

$$V(\phi(t, \mathbf{x})) \leqslant V(\mathbf{x})$$

with equality holding only if $\mathbf{x}$ is a rest point of [the process]. Then $V(.)$ is called a *Lyapounov function* (for the process (...))" (Fisher, 1983, p. 225, proof *ibid.*).

> decreasing through time except at rest points. Then the adjustment process is quasi-stable. Lyapounov's Second Method consists in finding such functions $V(\mathbf{P})$ (p. 26).

Fisher recalls that, as soon as we drop the "no-trade-out-of-equilibrium" hypothesis, we need to specify a trading process. This can be done by focusing on reasons for agents' disequilibrium behavior and allowing for excess of demand/supply.

He outlines two examples: the Hahn process (Hahn and Negishi, 1962) and the Edgeworth process (Uzawa, 1962, both in Fisher, 1983). Here we summarize a simplified version of the first one.

The Hahn Process (an Overview) The Hahn process is based on the central assumption that, at the end of each trade cycle, there may be either unsatisfied buyers or unsatisfied sellers of one commodity. In this conception, markets are sufficiently developed, so that willing counterparts can come together ("no regionalization").

Recall the price adjustment process seen at page 28. If, at the end of the market interaction, there are still some agents with positive demand, the aggregate excess of demand function, $Z_i(\mathbf{P})$ turns positive. Therefore, the price of commodity i increases of $\dot{P}_i$, where the value of $\dot{P}_i$ depends on both, the magnitude of $Z_i(\mathbf{P})$ and $F^i(.)$. The interpretation is straightforward: an agent left with positive demand/supply "finds that, outside of equilibrium, the things [s/]he wishes to buy and cannot buy become more expensive, while the things [s/]he wishes to sell and cannot sell are getting cheaper unless they are already free" (p. 31).

Although simple, the Hahn process points to a problem, as soon as the number of markets become greater than two. Indeed, the buyer needs a medium for exchange (*e.g.* money, or a commodity that the buyer wants to have) in order to complete the transaction. This problem has been first recognized by Clower (1965, *ibid.*) and has become known as the "Positive Cash assumption". The PAP and this latter assumption form the core drivers of disequilibrium behavior. In particular, agents react to either future commodity availabilities, or by (for instance, as in Arrow and Hahn, 1971, *ibid.*) money shortenings on the basis of *today* prices, where prices are about to change in the next period. Therefore, they contribute even more to disequilibrium dynamics (p. 34). Moreover, Fisher recalls that, in equilibrium, agents have no incentive for saving money, for they maximize their utility by expanding their purchases (p. 35).

Therefore, when production and consumption take place out of equilibrium, it is easy to notice that "the set of competitive equilibria at any moment is not merely path-dependent" (...), but "depends on the past history of the system. We have a hysteresis effect, which does not even vanish asymptotically" (p. 42).

Fisher then outlines other issues, as the problem of dated commodity pricing (*e.g.* inventories or second-hand goods) and selling mechanisms. Concerning this last point, seller may behave as auctioneers or set individual prices at each cycle (indivisual price adjustment – as the in Hahn process.).

He concludes that, even if an individual price-adjustment process "is compatible with stability, whether or not the system converges to a *competitive* equilibrium depends heavily on the specifics of" this process (p. 50).

1.5 Conclusion: Movingo to Models

In this chapter we have outlined some methodological issues concerning induction and explanation for what concerns Economics as a science.

We have seen some criticism to GE and DSGE modeling approach and analyzed Fisher and Hahn argumentations in favor of a disequilibrium one. Making use of some of their hints, we will set up a disequilibrium model in chapter four, based on a similar trading process as the Hahn process.

Concerning modeling of causal relationships, we may ask ourselves the following. What is therefore a good theoretical framework for economic modeling? As we have seen, methodological individualism represents a starting point, as individuals face similar economic problems. An economic system is kept in motion by individual action and their interaction. However, we shall argue that this setting is not sufficient, if the aim of economic inquiry is to explain.

Our agents must interact within an environment which we, as modelers, define. Intuitively, each agent necessarily contributes to the determination of system dynamics, as s/he actively change the state (stock level or flow rate) of her/his (or somebody else's) means, or even simply induce others to change attitude towards theirs. Therefore, it can be studied as a dynamical system. Anyway and as long as economics is concerned, properties of the economic system itself cannot be ascribed to the "economy" as a separate *entity*. Aggregate behavior must be free to emerge from agents' interaction at the meso-level, which we will analyze in chapter five.

For model boundaries have to be defined, and causal channels outlined, a model can be built for a particular purpose and must be limited in its extension. Therefore, another criterion is usefulness (Barlas and Carpenter, 1990, p. 162). In recent years there has been a discussion between economic methodologists concerning the link between models and explanations (see for instance van Riel, 2017).

We will make use of some of these concepts in the making of the model, as well as in the analysis of model dynamics.

In the next chapter, we will concentrate on human behavior and look at Behavioral Economic and Neuroscience in order to gather some functional insights

of human behavior and brain activity. In doing so, we focus on implication for Economic theory.

Chapter 2

Behavioral Assumptions and Implications from Neuroeconomics

2.1 Behavioral Economics

In January 2016, Richard Thaler addressed the one hundred twenty-eighth meeting of the American Economic Association by pointing out economists' need for relaxing some of the assumption made in Neoclassical economic theory and move toward a study of human beings in real life situations. In his own words (2016):

> To many economists these assumptions, along with the concept of "equilibrium", effectively define their discipline; that is, they study Econs in an abstract economy rather than Humans in the real one (p. 1578).
>
> [T]he many arguments that have been put forward in favor of retaining the idealized model of Homo economicus (...) have been refuted, both theoretically and empirically, including in the realm where we might expect rationality to abound: the financial markets (p. 1577).

Indeed, economic theory, so Thaler, is called to accomplish two tasks: define optimal behavior and predict actual one (p. 1591). Therefore, he maintains that economists needs more descriptive (positive) theories of human behavior, if their aim is indeed to predict it (pp. 1582 and 1586).

A more gereneral framework Common experimental findings as the importance of "Supposedly Irrelevant Factors", heuristic biases, or framing effects, together with overconfidence in personal success, loss aversion, and self-control issues, seem to constitute a more general framework for human behavior as an

instrumental-rationality-based Weberian pure-type. As Thaler illustrates, "even experts are unable to optimize when the problems are difficult", and propose chess players as an example (p. 1581).

We may add that some of these phenomena are not only linked with individual ability in calculus (or backward induction), but with the more general understanding of 1) the problem at play, and 2) the rules of the game. On this line of reasoning, Sterman (2002, pp. 509-511) points out how even MIT students incorrectly understand some key elements of dynamical systems as stocks and flow rates, as the difficulty of a simple problem increases. The same exponential increase in difficulty can be found by everyone while realizing a simulation model, or assessing its dynamics. The challenge is therefore to integrate these aspects, without jeopardizing model understandability.

How can economists move toward the study human beings in the real economy? In the future, Thaler expect forthcoming behavioral theories to be "more like engineering, a set of practical *enhancements* that lead to better predictions about behavior" (2016, p. 1592, emphasis added). Such enhancements are expected to be centered around topics of preferences and beliefs formation.

Concerning the latter, a more subjectivist approach is advanced, by allowing agent heterogeneity in belief formation over possible future states of the world (expectations), on the basis of different exogenous factors. This approach is justified by experimental evidence that shows differences between actual expectations and rational ones (p. 1593).

Regarding the former, enhancements are expected to come on the topics of other-regarding preference and intertemporal choice (*e.g.* along the lines of Two-self and Beta-delta models).

In what follows, we outline some reasons why these enhancements are and will still be on the descriptive level of analysis in the near future, even if we would expect a broader *understanding* of human behavior as object of economic inquiry. Nonetheless, findings of neuroscientific research have already important implications for economics and may radically change economist's perspective in a longer time horizon. Therefore, we turn now our attention to recent developments in neurosciences and, in particular, neuroeconomics.

2.2 A Focus on Neuroeconomics

In the last decade, development in Neuroscience has been posing a major challenge to choice theory. Neuroeconomic research, as a bridge discipline, is gradually providing positive insights about brain functioning and irreversibly shaping

economists' understanding of mental processes, which underlie intertemporal decision making and consumer choice.

However, the quest for an explanatory theory of choice is still unaccomplished - and it seems in some respects out of reach. Indeed and after a great initial excitement, neuroscientists have failed to provide a dynamic theory of brain functioning, which can be used as a comprehensive and interdisciplinary framework for choice theory. Nonetheless, outcomes of neuroeconomic research point to two things: the need for a radical re-thinking of economists' substantial beliefs concerning human behavior, as well as for a paradigm shift toward complexity theory and system thinking.

2.2.1 Why Neuroeconomics?

Rustichini (2005) argues that most of neuroscientific evidence about brain functioning is substantially useless, if the purpose of neuroeconomics is to develop a predictive model of choice (p. 202). He invokes some classical model requirements advocated by Milton Friedman (1953) as simplicity, generality, and independence of individual variability. According to this view, a model may be factually false and its real test concerns its predictive power. In the words of Friedman:

> The ultimate goal of a positive science is the development of theory or "hypothesis" that yields valid and meaningful (i.e., not truistic) predictions about phenomena (...), (p. 4).

Moreover,

> it is frequently convenient to present such a hypothesis by stating that the phenomena it is desired to predict behave in the world of observation as if they occurred in a hypothetical and highly simplified world containing only the forces that the hypothesis asserts to be important (p. 26).

Rustichini points out subjective expected utility as an "illuminating example of this method" (p. 202). Nonetheless, he acknowledges that a unified theory of choice does not still exist (a deeper account can be found *e.g.* in Starmer, 2000, and 1992) and that neuroeconomics could provide such a framework.

Indeed, Camerer (2006) states that "the importance of making good predictions is precisely the reason to explore alternative assumptions grounded in psychological and neuroscientific facts. The hope is that models based on those alternative assumptions will explain anomalies and make interesting new predictions" (p. 2). At this point, a distinction has to be made between the aim of neuroeconomic research and the scope for which applied models can be derived from it.

Concerning the former, Rustichini shows by analogy that the aim of neuroeconomics aligns itself with the research project of the early classics and of the Scottish enlightenment - *i.e.* to provide a unified theory of human behavior (p. 203). He then analyzes the similarities between feature of sympathy and of mirror neurons. Human sympathy, as described by Smith in the *Theory of Moral Sentiments* (1790 in Rustichini, 2005), is defined as the human ability to reproduce our feeling as if we were in someone else's situation. Sympathy is related to an event - not to the emotional state a person is actually into - and it usually applies to a negative situation. Smith addresses the question of how a society made by fundamentally selfish human beings can provide a stable social arrangement. In Smith's eyes, sympathy was the cause of an orderly working of the society, and an innate feature of human nature (p. 207). Nowadays, neuroscientific research has pointed out how the function of mirror neurons resembles sympathy. Mirror neurons provide an internally generated representation of the action performed by another individual or her/his emotional state and a neuronal response to it that leads not only to a facilitated understanding of the action, or emotion, itself, but also to the activation of the same brain areas in charge of reproducing that action, or emotion. As Rustichini says, thanks to Neuroscience, sympathy has now "a basis in the way the brain works" (p.210). This evidence is just an example of the complexity of our information processing system. Being an elaborate, affective state, sympathy, so Rustichini, requires a theory of information processing, which is not naïve and can account for complex, nonlinear interactions.

However and concerning the scope of application of neuroeconomic models, we will see later on that several obstacles hinder in their realization. Before that, we take a glimpse into the major outcomes of neuroeconomic research.

2.2.2 Insights from Neuroeconomics

Based upon a collection of insights from neuroscientific research, psychologic theory and related clinical records, Camerer *et al.* (2005) advocate a "radical approach", according to which neuroscience is expected to provide foundations for an interdisciplinary theory of choice (pp. 10, 14 and 55). They put forward a "Two-Dimensional Theoretical Framework" (p. 15), which hinges upon the interaction between controlled/automatic processes on the one side, and cognitive/affective ones on the other.

Behavior described by standard economic models can be mapped as a result of controlled and cognitive processes only, when referenced to this framework (see quadrant 1, table 1, p. 16). Camerer *et al.* maintain that cognition alone is not sufficient in order to determine an action and that, in order "to influence behavior, the cognitive system *must* operate via the affective system" (p. 18, emphasis added), which intrinsically implies positive/negative valence attributes

to behavioral options. In facts, "most behavior results from interaction of all four quadrants" (p. 19). According to this framework, affect is said to be primary - *i.e.*, the faster affective response occurs even before deliberative thinking can take place, via parallelism of different neural circuits. Object perception comes from our sensory system (quadrant 3) and from stored information in our brain (*e.g.* personal history, hunger, "reward value" of that object; quadrant 4). These are sufficient elements for an unconscious, automatic action, which is consistent with our preferences. At this point, conscious process may occur and modify the response. At the end of the process, the chosen action depends upon the level of intensity of the affective stimulus, although the interaction between cognitive and affective is still an object of research. Low affective impulse result in an "advisory" emotional input for decision. An intermediate impulse may reveal incongruence between conscious and affective inputs - and allow for a conscious correction - while a high affective stimulus could even hinder thoughtful deliberation (p. 30).

The more cognitive, controlled process (quadrant 1) tends to make sense of actions in a consistent way and formulate explanations of these actions, even when they have been executed automatically. This may have two interpretations.

On the one hand, this is what happens as learning - for instance - takes place from a neuroscientific point of view. When facing a new problem, cognitive deliberation requires high mental effort. As experience is gathered, the brain tends to specialize neural response to some areas, limits its activity and shifts the activation of the learned response to the automatic and faster affective process. Decision making is therefore said to take the form of "pattern matching", rather than a cost-benefit analysis (p. 25). On top of that, Camerer *et al.* points out that beliefs update is not a linear process and takes place only when new information leads to re-categorization. From an opposite point of view, this insight of learning is consistent with the interpretation of an experimental result by Thaler and Kahneman, who argue that "learning takes place when there is useful, *immediate* feedback" and when the feedback response can be easily and unambiguously interpreted (Thaler, 2016, p. 1584; emphasis added).

On the other hand, quadrant-1 backward sense-making can be "spurious" (p. 31) - *i.e.* it may mislead us to an erroneous, conscious interpretation of our intuition, or even action. In facts, people suffer cognitive biases, self-deceptions and self-manipulation. For instance, a common behavioral pattern toward a goal implies often over-evaluation of small steps taken, as if the greater goal would have been already reached (*e.g.* gym subscription, book purchase and knowledge). Other examples reported are over estimations of entrepreneurial success and doctors' asserted impartiality concerning pharmacological prescriptions, although they receive gifts from pharmaceutical industries (p. 38).

- Preferences

An even deeper implication for economic theory may come from the understanding of homeostasis - *i.e.* the process by which the body attempts to guarantee survival and reproduction (Camerer *et al.*, 2005, p. 27). Under the lens of homeostasis, preferences can be interpreted as information signals of the body, which reinforces/suppresses stimuli (pleasure/pain) by positive/negative feedback loops. This implies not only that the static preference assumption of standard economic theory may be inadequate, but also that a theory of choice cannot build upon assumptions concerning preferences, when they are indeed an output of the body itself. For instance, the same authors (2004) provide an account of this impasse, by considering two individuals, Al and Naucia, which refuse peanuts at a reasonable price, showing a common disutility in economic terms:

> Al turned down the peanuts because he is allergic: consuming peanuts causes a prickly rash, shortens his breath, and could even be fatal. Naucia turned down the peanuts because she ate a huge bag of peanuts at a circus years ago, and subsequently got nauseous from eating too much candy at the same time. Since then, her gustatory system associates peanuts with illness and she refuses them at reasonable prices.
>
> While Al and Naucia both revealed an identical disutility, a neurally detailed account tells us more. Al has an inelastic demand for peanuts - you can't pay him enough to eat them! - while Naucia would try a fistful for the right price. Their tastes will also change over time differently: Al's allergy will not be cured by repeated consumption, while Naucia's distaste might be easily changed if she tried peanuts once and didn't get sick (p. 563).

Naucia's reaction to peanuts is also an example of how preference, as well as the ability to self-control, seems to be state contingent. The degree of time preference changes with respect of the domain of application, which uses different brain circuits. Different kinds of time preference show correlations with certain actions, which can be ascribed to personality traits.

Indeed, neuroscientific evidence suggests that motivation for taking an action is not always connected to its hedonic consequences. Experiments on rats and studies of human drug addiction[12] show that decision making is composed of two different systems: liking and wanting. As for rats, it could be possible to separate them in human beings as well - *i.e.* to motivate actions that give no further pleasure. This implies that we could not always infer what people like from what they buy, as the Revealed Preference Theory assumes - the Weak Axiom of Revealed

[12]Ref.s in Camerer *et al.* (2005), p. 13.

Preferences logically fails. This represents a critical insight that may invalidate the logic behind constrained utility maximization theory, where quantity bought is directly dependent on a hedonistic utility function.

Moreover, neuroscience findings raise questions about usefulness of economists' tools as risk aversion, time preference and altruism (p. 31). Human information processing suggests that intelligence and rationality are highly domain specific. Ability in a task is linked to the compatibility with – and development of – neural processes created for similar tasks. For instance, mentalizing[13] is such a task (p. 33). Logical-deductive reasoning, as Bayesian updating in Bayesian-Nash equilibrium models, does not replicate the same logic.

The role of money poses another fundamental challenge. While standard economic theory assumes an indirect utility of money, neuroscientific evidence suggests that money may have instead a direct utility (primary reinforcer) as well. However, it seems that neuroscience is not advanced enough in this respect, for money utility can also be stimulated by reinforcements from goods that we can buy with it - in accordance with standard theory. Furthermore, the experience of gaining money may provide direct pleasure, which implies a dislike by expenses and could explain evidence of preference for prepayments/renting instead of buying (p. 35).

- Intertemporal Choice and Incentives

On the basis of these insights, Camerer *et al.* claim that neuroeconomists should think about economic decisions in a comprehensive way, such as to allow integration of brain circuity and neuroscientific evidence.

An example of this is the understanding of intertemporal choice, which also uses both affective and conscious systems. Affective system is myopic by construction, since it has been developed in order to guarantee survival and reproduction. Human capacity to discount is due to the development of the lateral prefrontal cortex and the posterior parietal cortex, which are cognitive regions. Less delayed choices see a mayor activity in the first, while discounting delayed rewards is associated with the second, cognitive circuit.

This functional interpretation is not consistent with economists' common understanding of time preference and incentives, which predicts that people will behave according to standard theory, when faced with the right combination of (pecuniary) incentives.

[13] *I.e.* to create second order beliefs and anticipate expected responses.

This view has been mostly advocated by Becker and Stigler (1977):

> We have partly translated "unstable tastes" into variables in the household production functions for commodities. The great advantage, however, of relying only on changes in the arguments entering household production functions is that all changes in behavior are explained by changes in prices and incomes, precisely the variables that organize and give power to economic analysis. Addiction, advertising, etc. affect not tastes with the endless degrees of freedom they provide, but prices and incomes, and are subject therefore to the constraints imposed by the theorem on negatively inclined demand curves, and other results (p. 89).

Camerer *et al.* (2005) maintain that this is indeed not the case. Just factors that can strengthen or weaken the affective/cognitive system can have indeed an effect on time preferences. This implies a significantly reduced role of changes in price or income. Determinants of impatience can be divided into cognitive (cognitive load, prior exercise of self-control, drugs/alcohol abuse and environmental variables as stress and sleep deprivation) and affective (drug craving and sexual arousal, which produce greater discount for money).

Generally, people care about delayed consequences of their actions (*e.g.*, becoming fat by overeating) only when there is "deliberative affect" – *i.e.* when they can have an immediate, affective reaction to the visualization of the consequence (*e.g.*, imaging a fat self on the beach; example in Camerer *et al.*, 2005, p. 41).

Following neuroscientific insights, the same authors claim that the concept of time preference should be discarded, in favor of a better understanding of the two-system process that underlies impulsive/delayed action. In facts, people make myopic choices when influenced by powerful emotions. Therefore, they claim, the focus of research should be moved to understand what kind of situation make individuals impulsive and what fosters/hinders self-control (p. 41).

Moreover, Foxall (2008) analyzes integrations of the cognitive/affective Two-System Framework with exponential or hyperbolic discounting hypotheses. He claims that no clear conclusion concerning a function for time preference can be sustained neither by behavioral experimental evidence, nor by fMRI investigation (p. 376).

- Risk and Uncertainty

Risk and uncertainty can also be explained in terms of the Two-Systems Framework. In facts, they are evaluated both, consciously (estimating its "objective" level, or guessing an "appropriate" response) and emotionally (fear, phobias).

Neuroscience shows that fear reactions lie mostly outside consciousness. However, the conscious process can suppressed moderate fear responses in the amygdala, via stronger cortex impulses, when the two systems collaborate. Anyway, it seems that fear can be conditioned, but not extinct. Once learned, fear reaction seems to be permanently stored in our brain. Moreover, different degrees of fear can be linked to risk (higher) and to uncertainty (lower) and activate different areas of the brain (Camerer *et al.*, 2005, p. 44).

Concerning risk, there are systematic differences between explicit and implicit (choice) judgement of risk. This phenomenon can also be explained by the fact that implicit judgements have a higher grade of automation and may even not require the interplay with the cognitive process. This may be a consistent explanation for a lottery preference between two lotteries having the same probability and expected value (*e.g.*, the preference between 10% probability to win an amount and 90% probability to lose it). Other experimental phenomena can find a neuroscientific explanation, as incoherent probability reporting and the so called "conjunction fallacy" – where a higher probability is assigned to $A \cap B$ than A or B alone.

- Games

When considering game interaction, neuroscience offers other relevant insights. There is a consensus about the specialization of the Brodmann 10 area in understanding other person's state, how s/he may respond to our actions (second order belief), and processing of cooperative behavioral responses. Researches show indeed that people cooperating more show a greater activation of the Brodmann 10 area in cooperation games and associate faces of cooperative players with positive emotions.

As second order beliefs are required in games, neuroscience points out that they are usually not free from emotional influence. Particularly significant is the tendency to observe a certain acceptance range for ultimatum games, which contradicts Rational Choice Theory (RCT). Unfair offers are processed by different neural circuits involved in finding a balance between the willingness to accept a positive amount and the sorrow of being treated in an *unfair* way.

Moreover, Camerer *et al.* provide reference that hormones, like oxytocin, play a determinant role in trust games, when a player is being trusted in the first place. In cooperation games, alteration of hormonal equilibrium, as a result of lack of sleep, may also result in lower cooperative behavior.

Furthermore, they claim that actual player's equilibrium strategy is more similar to a "state-of-mind" equilibrium driven by neural feedbacks concerning second order beliefs, rather than a game theoretical, backward induced one. Experimental evidence shows that people have problems in encoding more than two or three steps of backward induction. Reinforcement as result of gain/loss takes place al-

most automatically, whether a more deliberative process is in charge of controlling for possible rewards coming from other available options. Most important, human behavior implies complex reasoning and symbolic interpretation. Also in this respect, RCT models are inadequate.

2.2.3 Neuroeconomics and Modeling of Consumer Choice

As we have seen so far, neuroscience can provide the understanding needed in order to pursue a more functional approach to human behavior modeling. On this base, it could be possible to, if not explain, at least describe human behavior in a way more consistent with other disciplines like biology, psychology and neuroscience.

A research program, which faces the ongoing challenge to create "an economic model of the brain" – made of nonlinear interactions between stylized neural systems – and, at the same time, provide predictions – which are consistent with neuroscientific evidence about brain functioning – can be the base upon which empirical deviations can be analyzed and a theory *enhancements* can develop.

However, neuroscience alone will not be sufficient to complete this task. Werbik and Benetka (2016 in Valsiner, 2017) point out that still nowadays neuronal dynamics cannot be empirically determined, for fMRI scans take place at 50-100 times slower speed (p. 40). Moreover, they argue that neuroscience is factually unable to solve some discrepancies between brain functioning and theory of the mind. Valsiner (*ibidem*) recalls that psychological phenomena as the mind or the free will are indeed emergent phenomena of all parts of the brain, and they cannot be inferred by the sole analysis of them (p. 4).

Concerning Choice Theory, Fumagalli (2011) critically review some argument in favor of a neuroeconomic approach. He claims that economists have some "cogent reasons" to avoid integration of neuroscientific accounts into their models. First of all, simplicity and parsimony of model variables should be preserved, because of tractability reasons: "developing a neurally informed account of the variability that human behaviour exhibits across choice contexts would typically involve significant modeling costs" (p. 621). In accordance with Friedman, tractability should stem from simplicity and accuracy of variable selection, even if model hypothesis are not realistic.

However, Fumagalli concedes that neuroeconomics "can help us improve our understanding of the neurophysiological underpinnings of specific economic decisions", although (quoting Bernheim, 2009, p. 7), "precise algorithmic models of decision making of the sort to which many neuroeconomists aspire would presumably map highly detailed descriptions of environmental and neurobiological conditions into choices" (p. 620).

Such models as formulated by Bernheim are particularly useful in order to

assess whether a theoretical formulation can actually produce an observed behavior and under what circumstances. In this respect, neuroeconomics can inform economics by developing consistent Data-Generating Processes, which are able to replicate real data. Anyway, neuroeconomists will hardly be able to develop models having descriptive properties, if they are not able to agree first upon how an even simplified model of, for instance, the brain functioning should look like, and what results it is able to provide.

Therefore, Fumagalli maintains that most economists are justified in adopting a different methodological approach, for neuroeconomists "have hitherto failed to demonstrate that economists will usually find it convenient to incorporate several neural insights into their models." (p. 633).

Another question that he poses (2016) is "whether integrating findings and modeling tools from disciplines as diverse as economics, psychology and neuroscience into a single unified model is feasible" and if economists can indeed make use of them (pp. 79 and 88).

A further weak point contrary to the adoption of a more rigorous, neuroeconomic approach to decision making modeling concerns the so called "neural utility" (Fumagalli, 2013, p. 330). Neural utility is usually claimed to be measurable in specific brain areas and circuits. However, there is no consensus on what these patterns are, or about the composition of the utility stimulus.

Moreover, brain circuity determining the reward stimulus is made by more than one neurotransmitter. What would the scale of such an impulse be? In this respect, further evidence in the next years could undermine the "common currency hypothesis".

On top of that, Fumagalli points out a "reducibility" problem that arises when neural utility and experienced (psychologically based) utility measurements have to be compared (p. 335).

> My point is not just that the neural underpinnings of some hedonic states are topographically and functionally too complex to be captured by current neuro-physiological investigations. Rather, my main concern is that any claim to have disclosed the neural constituents of individuals' hedonic experiences would be philosophically naïve (p. 337). (...) [D]ifferent accounts of how value-related neural signals are computed and integrated have been proposed, and the available evidence does not enable us to effectively discriminate between them (p. 338).

2.2.4 An Example of Neuroeconomic Model of Consiumer Choice

In *Reward, Emotion and Consumer Choice*, Foxall (2008) starts his analysis by acknowledging that neuroeconomics has failed to provide explanatory, neuroscientific theory of consumer choice. Nonetheless, he outlines how neuroeconomic insights, as reward feedback structure and emotional information, can be incorporated into a conceptual framework of analysis, which is able to provide predictive models. An example of these is the Behavioral Perspective Model (BPM), which is summarized later on.

Foxall claims that neuroeconomics lacks a philosophical framework and intentionally uses unclear terminology. Tanks to his skeptical view over the supposed ability of neuroscientists to measure emotions directly, he advocates intentional behaviourism as an operational solution in order to:

- cut off brain complexity (and avoid the related mereological fallacy[14]),
- focus on features of the *mind* (in order to indicate features that cannot be explained by a neuroscientific account of the brain),
- and the use of intentional terms proper of a personal level (knowledge, desires, and beliefs).

This framework is more proper of psychology but is needed by him in order to operationalize the above-reported insight from neuroscience for consumer-choice research purposes.

As starting point for his analysis, Foxall identifies that two elements are central in the explanation of choice: reward and environmental contingencies. Reward has two specific functions. It stimulates a connection with the object of interest and generates emotional states, which helps in determining continuity of behavior. Environmental contingencies (cues) link reward to a repeated behavior. This is the mechanism underlying drug addiction. The reward system responds not only to the first intake but also, as behavior is repeated, to the cues that predict intake.

This is consistent with the evidence provided by Camerer *et al.* (2005) when discussing monkey reaction to juice. Environmental cues play a more central role, for the brain recognizes them as premonitory of drug incoming.

As determinants of the reward signal strength, Foxall does mention the role of several neurotransmitters as dopamine, glutamate, *etc.* However, he acknowledges how complex a representation of the whole reward system would be. Therefore, he considers a simplified dopaminergic reward system, when it comes to modeling.

[14]Erroneous attribution of role, functions and other features, which belong only at the level of the system itself to its components (Bennet and Hacker, 2003, in Foxall, 2008, p. 380).

Such a choice can be seen in contrast with a more comprehensive approach advocated by Camerer, Loewenstein and Prelec, but sounds appropriate, given that no clear evidence exists about how the reward stimulus is formed in the brain, nor about its unicity.

The dopaminergic system is responsible for the ordering of reward signals and the determination of neuron firing-level, following a sensory cue. This makes a comparison with a baseline level possible.

Furthermore, behavior is closely related to the release of dopamine. In particular, it is related to the capacity of the body to match a selection among alternatives to the relative response in form of reinforcer that each alternative provides (the so called "matching law", p. 375). Foxall uses this matching law in order to map relative frequencies of choice with relative frequency of reinforcement. Moreover, he highlights that reward has also an affective and a motivating component, which allows for the creation of memories and habits, and for a link to emotions.

From a theoretical point of view, Foxall imagines a "continuum" of consumer behavior determined by neuronal firing rates, as a result sensorial inputs, *via* dopamine release. Low levels of dopamine release are linked to hedonic feelings and related to everyday purchase of, for instance, a favorite brand of a product. Intermediate levels of dopamine are associated with the expectation of consumption via signaling (*e.g.* going to the pub, or seeing a syringe, rather than alcohol or drug intake). The higher the dopamine release, the higher the level of addiction and the more wanting and liking are dissociated. Moreover, dopamine level and impulsivity are also highly correlated – low impulsivity in everyday grocery-shopping, high under drug craving.

Nonetheless, impulsive behavior can occur also in the first case, since it depends on *relative* increase in dopamine release with respect to a contingent, expected value. However, reward/punishment patterns also depend on the emotional response at the affective level, as well as on cognitive restrain. Conscious control over this reinforcing feedback is easier to exert in the first case. On the contrary, an addicted person needs a disproportionate reward in order to remunerate an abstinence effort, for drugs lower the dopaminergic reward of other goods as well.

BPM The Behavioural Perspective Models is constructed in such a way as to integrate two feedback channels – an informational reinforcement and a utilitarian one. These reinforcers affect the "consumer situation", which hinges upon consumer behavior setting (stimulus antecedents of choice) and her/his history. The interrelation between history and consumer behavior setting generates discriminative stimuli. These can be reinforced/suppressed by stimuli of the situational setting, and determine an overall stimulus for action. The choice has three types of consequences: utilitarian reinforcement, informational one, and "aversive/punitive

consequences" (p. 382).

According to the combination of high/low utilitarian and informational reinforcement, four classes of consumer behavior are outlined: Maintenance (activities necessary for survival), Accumulation (saving, collecting), Pleasure (entertainment), Accomplishment (status goods). These categories form the entrances of the "contingency matrix" and are linked to the positive/negative feedback effects, surveyed via questionnaires.

Foxall uses Rolls' definition of emotions as "states elicited by instrumental reinforcers" (2000, p. 220). This definition "permits an operational definition of the environmental stimuli that leads to emotions" and allows for a functional classification of an emotion into three categories: arousal, pleasure, and dominance (PAD framework, p. 731). Indications of arousal, A, are assigned to the information system. Reports of pleasure, P, to the utilitarian system and feedback signals of gain/loss of confidence and control are summarized in dominance, D. Pleasure is intended to be a signal for "biologically usefulness", which helps maintaining homeostatic equilibrium. Arousal is mostly linked with competitiveness and impulsivity. Dominance refers to interpersonal control and it is reflected by consumer autonomy or induced conformity.

These emotional categories are linked to the "consumer behavior continuum" - *i.e.* the dopaminergic firing scale (p. 384). This highlights that, as the firing rate increases, reported pleasure and dominance take more negative values, while arousal enters into a positive, self-reinforcing feedback loop. This finding is consistent with the view of dopamine as a motivational reinforcer (wanting), rather than a hedonistic one (liking).

The aim of the BPM is to demonstrate a possible operationalization of neuroeconomic concepts to consumer choice research in a consistent, although extremely simplified way. Foxall argues that the BPM/PAD framework finds a root in neural activity and has empirical support.

2.3 Conclusion

Economists wish their models were able to reproduce more general features of human being as the standard theory allows. We have seen how such a generalization could be enriched by insights of brain functioning.

In this respect, neuroeconomics provides deep understanding that can revolutionize economic theory, as the "two-dimensional" interaction between controlled/automatic processes, and cognitive/affective ones.

However, several strong limitations to this approach still exist. On the practical side, technology available nowadays does not allow for an empirical validation of any dynamic theory of the brain. On a more theoretical side, unsolved issues,

like the concept of irreducibility of neural utility, common brain currency, and utility of money – together with some methodological criticisms thereon – hinder that neuroeconomic insights can be translated into descriptive theories or models, without losing neuroscientific foundations.

Nonetheless, neuroscientific evidence points to the need of a deep rethinking of theories undelying several descriptive devices economists use – such as utility, preferences, time discounting, game theoretical equilibria – and to the reconsideration of a role for emotions.

On this basis, it could be possible to (at least) describe human behavior in a way more consistent with other disciplines like biology, psychology and neuroscience in the form of a research program, which faces the ongoing challenge to create "an economic model of the brain", which is made of nonlinear interactions between stylized neural systems.
In accordance with Camerer (2013), it is not hard to imagine that

> neuroeconomics will gradually instill a sense that biological processes are important components of individual choice, inspire specific examples of how to model those processes formally in an insightful way, show surprising causal effects on choice (which are not sensibly interpreted as effects of prices or information and hence provoke new theory) (p. 448).

Part II

The Making of the Model

Chapter 3

The Making of Version 1 - Equilibrium Markets

3.1 Introduction and Purpose

3.1.1 Purpose

The aim of this first version is to reproduce an economic cycle in a free market environment, where good prices adjust at equilibrium level at each time. In order to set up the simulation, we follow Boero, Morini, Sonnessa and Terna (2015) and make use of the Swarm-Like Agent Protocol in Python (SLAPP)[15].

3.1.2 Setting and Agent Typology

In our economic system, two homogeneous goods are produced and traded by two industries. Firms in industry I produce an investment good, G_I, which is used for the production of a final consumption good, G_C, in industry C.

For the sake of simplicity, we consider workers earning a fixed wage, and assume firms sharing the same Constant-Returns-to-Scale (CRS) production technology – represented by a Net-Output vector (Varian, 1992, p. 2) of the form:

$$[Y \;\; K \;\; L]^T = [1 \;\; -1 \;\; -1]^T$$

where Y represents output, K physical capital, and L labor – all entries are in unit terms.

Each agent acting in the model is either a firm or a person[16]. Agent types

[15] `https://github.com/terna/SLAPP/`

[16] Even though the representation of a "class struggle" has been tempting, we limit agent classes to two, which differ in their ontology – a juridical person and a natural one.

are listed in `agTypeFile.txt` and their corresponding agent class is defined in the respective file `.py`. Classes and types are paired in `agClassFile.txt`.

The number of agents acting is fixed and indexed as follows:

Firms in sector I, $f_I = (1, 2, ..., F_I)$;

Firms in sector C, $f_C = (1, 2, ..., F_C)$;

Persons, $n = (1, 2, ..., N)$.

By looking at a `.txtx` file, we can see that every agent has a five digit ID-number in first position. The first digit refers to the class – 1 for a person, 2 for a firm – while the rest is the agent number. *E.g.*, ID 10020 corresponds to the 20th person.

Each firm is owned by one person only – *i.e.* there is a univocal correspondence between an entrepreneur and a firm. This can be seen in `firm.txtx`[17], which contains the following string:

```
20001@20024 &v=n-10000& &if n-20000<=4:v=1#else:v=2&
```

In this way, SLAPP generates 24 firm IDs and pairs each of them with the ID of a person. We can modulate the number of firms in sector I by changing the value 4 with another integer in range from 1 to 24. The corresponding `.txt` output consists of 24 rows, each containing three numbers. Sector I (or C) is here represented as number 1 (or 2). For instance and considering the first row, we have:

```
20001  10001  1
```

This output can be interpreted as "firm 20001 belongs to entrepreneur 10001 and acts in sector I", while the underlying logic of ID-combination applies to every firm, which has been created at the beginning of the simulation.

The owner ID is then red by the Model and assigned to the parameter space of the respective firm instance *via* the `createTheAgent_Class` function, defined in `mActions.py` (the code is reported later on).

3.2 Process Overview and Scheduling

We can now analyze the simulation process at Observer, Model and agent (AESOP) level.

[17]For a deeper insight, look at §2.3.2. of the SLAPP Reference Handbook.

3.2.1 The Observer level

By opening `observerActions.txt`, we can check the steps performed by the Observer at each cycle. These are:

`collectInitialTimeSeries`, `modelStep`, `collectTimeSeries`, `visualizePlot`, `Npause`, `clock`.

They can all be found in `oActions.py`, but `modelStep` – which activates model tasks and will be analyzed later on.

- `collectInitialTimeSeries` stores the number of each type of agent acting and the unemployment level. Data gathered at this point appear at time zero on the x-axis of the graphic output.
- `modelStep` activates the simulation procedure via `modelSwarm`.
- `collectTimeSeries` manages data frames and stores simulation generated values, as programmed in `observer.py`.
- `visualizePlot` displays a graphical output of the collected time series.
- So formulated, `Npause` has no effect on the simulation. However and by removing the character `N` from `Npause`, it is possible to pause the simulation procedure at the end of each cycle and resume it as soon as we hit the enter key. In this way, we can observe numerical outputs with a greater ease.
- Finally, `clock` updates the time counter at the end of each simulation cycle.

3.2.2 The Model level

At the Model level, two steps are performed:

`reset`, `read_scripts`

- As the name may suggest, the first step resets cycle-specific variables for agents and the `WorldState`, as it can be checked in the function `do0` in `mActions.py`.
- `read_scripts` orders the Model to execute agent actions at the AESOP level, which is outlined in the next subsection.

Here below, we can take a look at the code in `mActions.py`:

```
from Tools import *
from Agent import *
import os

def do0(address):
  if common.cycle!=1:
    askEachAgentInCollection( \
    address.agentList, Agent.setNewCycleValues)
    address.worldState.setNewCycleValues()

def do1(address):
  pass

def createTheAgent(self,line,num,agType):
  if len(line.split())==1:
    anAgent = Agent(num, self.worldState, \
    random.randint(self.leftX,self.rightX), \
    random.randint(self.bottomY,self.topY), \
    self.leftX,self.rightX,self.bottomY, \
    self.topY,agType=agType)
    self.agentList.append(anAgent)

  else:
    print "Error in file "+agType+".txt"
    os.sys.exit(1)

def createTheAgent_Class(self,line,num,agType,agClass):

  try: exec("from "+agClass+" import *")
  except:
    print "Class", agClass, "not found."
    os.sys.exit(1)

  if len(line.split())==1:
    try:
      exec("anAgent = "+agClass+"(num,"+\
      "random.randint(self.leftX,self.rightX),"+\
      "random.randint(self.bottomY,self.topY),"+\
      "agType=agType)")
      self.agentList.append(anAgent)
```

```
    except:
      print "Argument error creating an instance"+\
      " of class",agClass
      os.sys.exit(1)

  elif len(line.split())==3 and agType=="firm":
    try:
      exec("anAgent = "+agClass+"(num,"+\
      "random.randint(self.leftX,self.rightX),"+\
      "random.randint(self.bottomY,self.topY),"+\
      "agType=agType,"+\
      "owner=int(line.split()[1]),"+\
      "industry=int(line.split()[2])"+")")
      self.agentList.append(anAgent)
    except:
      print "Argument error creating an instance"+\
      " of class",agClass
      os.sys.exit(1)

  else:
    print "Error in file "+agType+".txt"
    os.sys.exit(1)

def otherSubSteps(subStep, address):
  return False
```

3.2.3 The AESOP level

A closer look to the Schedule

Agent actions are listed in `schedule.xls` as follows:

```
#           1
firm        setup
#           1                       100
firm        planProductionC
firm        setCapitalDemandC
firm        planProductionI
firm        setCapitalDemandI
firm        setLaborDemand
firm        fire
WorldState  computationalUse        countLaborSupply
firm        hire
firm        0,1                     workTroubles
firm        produce
person      setDemand
WorldState  computationalUse        setPriceGc
WorldState  computationalUse        setPriceGi
WorldState  computationalUse        reportAggregateValues
person      save
firm        adjustCapitalI
firm        adjustCapitalC
firm        calculateProfitC
firm        calculateProfitI
WorldState  computationalUse        countAgents
firm        fireIfLosses
firm        checkBusinessCondition
person      toEntrepreneur
```

The column on the left identifies a group acting, while the method on the right is an undertaken action. The schedule is set in order to be repeated up to 100 times.

Methods of Version 1

Some methods in the schedule are just functional, others have a deep behavioral insight. In what follows, we will analyze each of them.

Setup When a firm is created, `setup` adjusts some instance's parameters, according to given values in `firm.txtx`. In detail, it exchanges addresses between the

entrepreneur and the corresponding firm instance – *e.g.,* it allows the entrepreneur to receive her/his profit share at a later stage.

```
def setup(self):
  locList=self.agentList[:]
    for anAgent in locList:
          if anAgent.number==self.owner:
                self.owner=anAgent
                anAgent.myFirm = self
```

Plan production C The first behavioral method, `planProductionC`, consists in the determination of a planned production level, φ^p_C, for firms in sector C. For planned production in sector I is based on orders from sector C, firms the latter sector act before those in the former. φ^p_C is determined in a slightly different manner for each of the first three cycles, for we cannot rely on past data for our economy. This approach has been taken from Mazzoli, Morini and Terna (2017, §7.1).

At time one, a value for $\varphi^p_{C,1}$ is computed by considering the ratio of buyers over sellers – *i.e.* persons over firms in sector C – corrected by a factor ρ_C, which is set equal to 0.35 in `parameters.py`.

$$\varphi^p_{C,1} = \rho_C \frac{N}{F_{C,1}}$$

In the second cycle, $\varphi^p_{C,2}$ is returned by time one data for the aggregate demand for consumption good, $AD_{C,1}$ (in value terms), divided by its equilibrium price at time one, $P^*_{C,1}$.

$$\varphi^p_{C,2} = \frac{\frac{AD_{C,1}}{P^*_{C,1}}}{F_{C,2}}$$

From the third cycle onwards, φ^p is given by:

$$\varphi^p_{C,t} = \frac{\frac{AD_{C,t-1}}{P^*_{C,t-2}}}{F_{C,t}}$$

Intuitively, we can imagine firms planning today's production on the basis of yesterday aggregate demand, which is itself based on the equilibrium price of the day before yesterday.

Theoretically, the use of a double-lagged equilibrium price hinges upon a straightforward consideration. Agent's demand is necessarily based on known prices, *cæteris paribus*, and cannot result from the equilibrium price of the same cycle,

which is a function of the aggregate demand itself. However, we are forced to do so in the second cycle, for we cannot infer $P^*_{C,t-2}$ directly and time-one equilibrium price represents its closest guess.

```
def planProductionC(self):
  if self.industry!=2:
    return
  numberOfPotentialBuyers = common.nPersons
  #print common.nPersons
  numberOfFirmsInSameSector = common.nFirmsGc
  #print common.nFirmsGc
  if common.cycle==1:
    self.plannedProduction = (common.rhoC*\
    numberOfPotentialBuyers) /\
    numberOfFirmsInSameSector
  elif common.cycle==2:
    self.plannedProduction = (common.demand_Gc_lag1t/\
    common.price_Gc_lag1t) / numberOfFirmsInSameSector
  else:
    self.plannedProduction = (common.demand_Gc_lag1t/\
    common.price_Gc_lag2t) / numberOfFirmsInSameSector
```

Set capital demand C Firms in sector C define then their demand of investment good, G_I, via `setCapitalDemandC`. Concerning production capacity, we assume that *new* firms do have machinery in order to produce the planned amount.

Physical capital is assumed to wear out at a constant rate, ρ_I, which is defined in `parameters.py`. A numerical value for ρ_I is set by considering a depreciation rate equal to 5% and a cost of capital of three per unit. Hence, we have $\rho_I = 0.15$.

Capital in need of substitution, $K^p_{obsolete}$, is calculated as a ρ_I fraction of machinery actually used. This implies that, when capital required by planned production, K^p, does not exceed installed capital, K, planned worn-out capital will be calculated as:

$$K^p_{obsolete} = \rho_I K^p$$

Otherwise, we will have

$$K^p_{obsolete} = \rho_I K$$

In the latter case, the excess of capital required, $K^p - K > 0$, is placed on the investment good market, together with $K^p_{obsolete}$.

Jointly considered, each firm in sector C will place a demand for investment good equal to:

$$D_{Gi} = (K^p - K) + K^p_{obsolete} \qquad if \;\; K^p - K > 0$$

and

$$D_{Gi} = K^p_{obsolete} \qquad if \;\; K^p - K \leqslant 0$$

This method is used by firms in both sectors. However, notice that $K^p_{obsolete}$ – *i.e.* `plannedObsoleteK` – for firms in sector I is defined later on in `planProductionI`.

```
def setCapitalDemandC(self):
  if self.industry!=2:
    return
  if common.cycle==1 or self.profitList==[]:
    self.K = self.plannedProduction
  self.K_needed = self.plannedProduction
  delta_K = self.K_needed - self.K
  if delta_K > 0:
    self.plannedObsoleteK = common.rhoI*self.K
    self.demand_Gi = delta_K + self.plannedObsoleteK
  else:
    self.plannedObsoleteK = common.rhoI*self.K_needed
    self.demand_Gi = self.plannedObsoleteK
  common.demand_Gi+=self.demand_Gi
```

Plan production I At this point, firms in sector I plan their production. Each firm in industry I expects an equal share of orders from sector C. Given that firms producing G_C have already placed their demand for G_I, `expectedOrders` can be computed as a share of aggregate demand for good I from sector C:

$$expectedOrders = \frac{AD^C_I}{F_I}$$

where AD^C_I is the aggregate demand for good I coming from firms in sector C, and F_I is the number of firms in sector I.

Given physical capital deterioration at rate ρ_I, firms in sector I need to account for the amount of worn out capital in order to maintain their production capability. In doing so, worn out capital is calculated as

$$K^p_{obsolete} = \frac{\rho_I}{1 - \rho_I} * expectedOrders$$

The planned production a at each cycle, φ_I^p, is thus defined as:

$$\varphi_I^p = expectedOrders + K_{obsolete}^p = \frac{1}{1-\rho_I}\frac{AD_I^C}{F_I}$$

```
def planProductionI(self):
  if self.industry!=1:
    return
  numberOfFirmsInSameSector = common.nFirmsGi
  common.demand_Gi = sorted([common.demand_Gi, \
  common.maxVal])[0]
  expectedOrders = (common.demand_Gi / \
  numberOfFirmsInSameSector)
  self.plannedObsoleteK = common.rhoI/(1-common.rhoI)*\
  expectedOrders
  self.plannedProduction = expectedOrders + \
  self.plannedObsoleteK
```

Set capital demand I Except for the determination of `plannedObsoleteK` – which we have just seen above, firms in sector I determine their capital demand in the same manner as we have seen for firms in sector C. However, this takes place for firms in sector I at a different time in the schedule. The reason why is simple: their demand for G_I must not alter the `common.demand_Gi` value, before every other firm in sector I has determined its production level, which is based thereupon.

```
def setCapitalDemandI(self):
  if self.industry!=1:
    return
  if common.cycle==1 or self.profitList==[]:
    self.K = self.plannedProduction
  self.K_needed = self.plannedProduction
  delta_K = self.K_needed - self.K
  if delta_K > 0:
    self.demand_Gi = delta_K + self.plannedObsoleteK
  else:
    self.demand_Gi = self.plannedObsoleteK
  common.demand_Gi+=self.demand_Gi
```

Set labor demand Each worker represents a labor unit. Firm's labor demand, in unit, is a function of physical capital used. The relation between two units

depends on the technology adopted. Given our *net-output* vector [18], we have a simple 1:1 relation between labor unit and physical capital, and between output and the latter as well.

Labor needed by a firm in order to produce φ_C^p is:

$$L^p = \lceil \min[K,\ K^p] \rceil$$

Therefore, labor demand is simply

$$D_L = L^p - L \qquad\qquad if\ \ L^p - L > 0$$

and

$$D_L = 0 \qquad\qquad if\ \ L^p - L \leqslant 0$$

The corresponding method is `setLaborDemand`:

```
def setLaborDemand(self):
  L_needed = ceil(min(self.K_needed, self.K))
  self.delta_L = L_needed - self.L
  if self.delta_L > 0:
    demand_L = self.delta_L
  else:
    demand_L = 0.
  common.demand_L += demand_L
```

Hire / Fire Firms now act on the labor market and adjust their labor force. Layoff takes place first, in order to allow a faster re-employment of workers by other firms within the same cycle. No particular criterion for layoff or employment is set. Workers in excess are randomly selected and new ones are hired on the basis of a "first-come-first-hired" principle.

```
def fire(self):
  if self.delta_L>=0:
    return
  random.shuffle(self.workerList)
  toBeFired = int(min(-self.delta_L,len(self.workerList)))
  for i in range(toBeFired):
    self.workerList[0].myFirm = None
    self.workerList.remove(self.workerList[0])
    self.L -= 1
```

[18] See page 51

```
def hire(self):
  if self.delta_L<=0:
    return
  locList = self.agentList[:]
  random.shuffle(locList)
  for anAgent in locList:
    if self.delta_L<=0:
      break
    elif anAgent.agType=="person" and anAgent.myFirm==None:
      anAgent.myFirm = self
      self.workerList.append(anAgent)
      self.delta_L -= 1
      self.L += 1
```

WorldState – Count labor supply Between these two methods, the `WorldState` measures labor supply, before hiring takes place.

```
def countLaborSupply(self):
  modelList=common.modelAddress.agentList[:]
  common.supply_L=len([ag for ag in modelList \
  if ag.agType=="person" and ag.myFirm==None])
```

Work troubles[19] With this method, we introduce a source of uncertainty in the determination of output, which can be considered as some kind of machine failure or human mistake. So far we simply assume a percentage reduction, ψ, randomly drawn from a uniform distribution bounded between zero (`psiMin`) and one (`psiMax`) in `common`. We can module the probability of a firm incurring `workTroubles`, by changing the related value set equal to 0.1 in `schedule.xls`.

```
def workTroubles(self):
  self.psiShock=random.uniform(common.psiMin,common.psiMax)
```

Produce Once labor force and physical capital available are known, production takes place. The actual production level, φ, depends on the smallest input available. For two inputs and the over-mentioned net-output vector, we have a Leontief production function:

$$\varphi = \min[K^{suitable}, L]$$

[19]This method has been taken from The Oligopoly project. Credit goes to authors Mazzoli, Morini and Terna.

where capital suitable for production, $K^{suitable}$ is:

$$K^{suitable} = K \qquad if \;\; K^p \geqslant K$$

and

$$K^{suitable} = K^p \qquad if \;\; K^p < K$$

Therefore, capital *actually* used for production, κ, is:

$$\kappa = K \qquad if \;\; K \leqslant K^p \text{ and } K \leqslant L$$

or

$$\kappa = K^p \qquad if \;\; K^p < K \text{ and } K^p \leqslant L$$

or

$$\kappa = L \qquad if \;\; L < K^p \text{ and } L < K$$

Considering `workTroubles`, the share of production, which can be sold on the market, becomes $\varphi(1-\psi)$.

Nonetheless, worn-out capital, $\kappa_{obsolete}$, is calculated in function of the quantity actually produced, as

$$\kappa_{obsolete} = \rho_I \kappa = \rho_I K - \rho_I (K - \varphi)$$

and it is then subtracted from the stock of firm's physical capital, K.[20]

```
def produce(self):
  if self.K < self.K_needed:
    K = self.K
  else:
    K = self.K_needed
  self.Y = min(K, self.L)

  #phisical capital obsolescence
  self.obsoleteCapital = common.rhoI*self.K - \
  common.rhoI*(self.K - self.Y)

  #correction for work troubles
  Y = self.Y
  Y *= (1 - self.psyShock)
```

[20] When $\kappa = K$, $\varphi = K \rightarrow K - \varphi = 0$ and $\kappa_{obsolete} = \rho_I K$. If φ is limited by either K^p or L, $\kappa = \varphi < K$ and so $\kappa_{obsolete}$ is the difference between $\rho_I K$ and capital saved by producing less than $\varphi = K$, *i.e.* $\rho_I(K - \varphi)$.

```
  if self.industry == 2:
    self.Gc = Y
    common.Gc += self.Gc
  else:
    self.Gi = Y
    common.Gi += self.Gi
  self.K -= self.obsoleteCapital
```

Set demand We turn now our attention to `person` agents and let them place a demand of consumption good, D_C, as a function of their income, Υ. As shown here below, income is determined in two slightly different ways.

Economically *active* agents earn a wage, W and may enjoy time $t-1$ profit, Π_{t-1}, if they are entrepreneurs and profit has been positive in the last cycle:

$$\Upsilon_t = W_t + \Pi_{t-1} \qquad if \;\; \Pi_{t-1} > 0$$

In doing so, we consider the following: an entrepreneur facing losses may still spend up to the wage earned, as long as her/his firm does not run out of business - for which a condition is set later on in `checkBusinessCondition`.

So far, W is fixed and set equal to 1.0 in `common.w` for both employers and employees, as reported in `parameters.py`. Differently, unemployed agents are provided with a `socialWelfareCompensation`, SWC, equal to 0.3 as a source of income.

$$\Upsilon_t = SWC$$

Demand of person n is hence calculated as a share δ_n of income:

$$D_{C,n} = \delta_n \Upsilon_n$$

where we may consider three parametrization for δ_n:

$$\delta_1 = 0.8 \qquad \text{if person } n \text{ is an entrepreneur}$$

$$\delta_2 = 0.8 \qquad \text{if person } n \text{ is an employee}$$

$$\delta_3 = 1 \qquad \text{if person } n \text{ is unemployed}$$

In doing so, we assume that unemployed agents spend all their income, while others may save up to 20% of it.

```
def setDemand(self):
  #income
  if self.myFirm!=None:
```

```
    self.income += common.w
  else:
    self.income += common.SWC
  #set demand
  if self.income > common.w:
    self.demand_Gc = common.delta1*self.income
  elif self.income == common.w:
    self.demand_Gc = common.delta2*self.income
  else:
    self.demand_Gc = common.delta3*self.income
  common.demand_Gc += self.demand_Gc
```

Within the text three methods, we focus on the `WorldState`, which is an instance of the `WorldState` class that performs aggregate calculations and manages data intertemporally.

WorldState – Set price Gc As a first example, the `WorldState` calculates the equilibrium price for both, consumption and investment good.

In the first case, the aggregate demand is expressed in value terms. Therefore, the equilibrium price is given by the aggregate demand at time t, $AD_{C,t}$, over the actual aggregate production, $A\varphi_{C,t}$:

$$P^*_{C,t} = \frac{AD_{C,t}}{A\varphi_{C,t}}$$

where, dropping time notation:

$$AD_C = \sum_{n=1}^{N} D_{C,n}$$

and

$$A\varphi_C = \sum_{f_C=1}^{F_C} \varphi_{C,f_C}$$

In case no production has taken place, the price at time $t-1$ is registered.

```
def setPriceGc(self):
  common.demand_Gc=sorted([common.demand_Gc, \
  common.maxVal])[0]
  if common.Gc!=0:
    price_Gc = common.demand_Gc / common.Gc
  common.price_Gc = sorted([price_Gc, common.maxVal])[0]
```

WorldState – Set price Gi Contrary to the consumption good case, the demand of investment good is expressed in units, not in value. Therefore, we have first to retrieve the aggregate demand in value terms by multiplying its time-t counterpart in unit by the price at which it has been formulated – *i.e.*, the price of G_I at time t-1, $P^*_{I,t-1}$:

$$AD_{I,t} = P^*_{I,t-1} \sum_{f=1}^{F} D_{I,f,t}$$

The equilibrium price of the investment good market is therefore:

$$P^*_{I,t} = \frac{AD_{I,t}}{A\varphi_{I,t}}$$

In case no G_I has been produced, the last known price is maintained.

```
def setPriceGi(self):
  if common.Gi!=0:
    price_Gi = common.demand_Gi*price_Gi_lag1t/common.Gi
    common.price_Gi = sorted([price_Gi, common.maxVal])[0]
  #copy for data storing
  common.productionGi=common.Gi
```

WorldState – Report aggregate values The method `reportAggregateValues` has the only function to print aggregate values, as demand for labor, consumption and investment good, as well as prices and production levels, if a reference is needed.

```
def reportAggregateValues(self):
  if self.verbose:
    print "Aggregate demand Gc: ", common.demand_Gc
    print "Aggregate demand Gi: ", common.demand_Gi
    print "Aggregate demand L: ", common.demand_L
    print "Aggregate production Gc: ", common.Gc
    print "Aggregate production Gi: ", common.productionGi
    print "Aggregate supply L: ", common.supply_L
    print "Price Gc: ", common.price_Gc
    print "Price Gi: ", common.price_Gi
```

Save Within a clearing good market, the equilibrium price defines the share of quantity bought by each individual. For persons place a demand for G_C directly in value, they cannot overshoot this amount – as price increases, it is simply the quantity bought that is reduced. Savings are therefore simply the difference between income and the demand for G_C. However and clearly, if no consumption good has been produced, savings equal income.

```
def save(self):
  if common.Gc > 0:
    savings = self.income - self.demand_Gc
  else:
    savings = self.income
  self.credit += savings
```

Adjust capital I/C After determination of the investment good price, firms allocate G_I, in order to replace worn-out physical capital. Firms in sector I act first, so that their production capacity is maintained. Due to this reason, the method enters the schedule twice. Except for agent selection, the two methods are identical.

Firms collect as much investment good from its aggregate stock, as to serve their demand for G_I in unit.

Note that the ordered amount of capital for substitution, $K^p_{obsolete}$, may differ from the actual worn-out one, $\kappa_{obsolete}$. However and since production can be corrected only downwards with respect to its planned level – *e.g.*, as a result of a shortage in labor supply – $K^p_{obsolete}$ is always sufficient to cover actual worn-out capital. If demand of G_I is fully (partially) met, $K_{obsolete}$ is fully (partially) replaced. We call the substituted amount K^s.

Here we report the code for `adjustCapitalI`. To firms in sector C, a similar procedure applies.

```
def adjustCapitalI(self):
  if self.industry!=1:
    return
  #not needed, just for clarity: ##
  if common.Gi == 0:              #
    self.K_substituted = 0.       #
  ###            ###            ###
  elif common.Gi >= self.demand_Gi:
    self.K_substituted = self.demand_Gi
```

```
    common.Gi -= self.demand_Gi
    self.demand_Gi = 0.
  else:
    self.K_substituted = common.Gi
    self.demand_Gi -= self.K_substituted
    common.Gi = 0.
  self.K += self.K_substituted
```

Calculate profit C/I Profit for firms in sector C is calculated on the basis of the following profit function:

$$\Pi_{f_C} = P_C^* \varphi_{f_C} - WL_{f_C} - rP_I^* \kappa_{f_C} - P_I^* K_{f_C}^s$$

Profit for firms in I is given by:

$$\Pi_{f_I} = P_I^* \varphi_{f_I} - WL_{f_I} - rP_I^* \kappa_{f_I} - P_I^* K_{f_I}^s$$

where we consider φ_{f_C} (or φ_{f_I}) as production sold – that is $\varphi(1-\psi)$ – and we assume a cost of capital, r equal to 0.1, which is applied to the *value* of physical capital used[21].

If the amount of capital substituted has been higher than worn-out capital, the profit function becomes:

$$\Pi_{f_C} = P_C^* \varphi_{f_C} - WL_{f_C} - rP_I^* \kappa_{f_C} - P_I^* \kappa_{obsolete,f_C}$$

and profit for firms in I is given by:

$$\Pi_{f_I} = P_I^* \varphi_{f_I} - WL_{f_I} - rP_I^* \kappa_{f_I} - P_I^* \kappa_{obsolete,f_I}$$

Profit components are – respectively – revenues, cost of labor, remuneration of physical capital, and cost of substituted one. If positive, profit at time t is transferred to the entrepreneur and has hence an effect on its demand a time t+1.

```
def calculateProfitC(self):
  if self.industry==1:
    return
  #cost of labor
  cost_L = common.w*self.L
  #cost of capital
  #note: capital actually used equals quantity produced
```

[21] For simplicity we assume the same value for new and installed units of capital.

```
  cost_K = common.r*common.price_Gi*self.Y
  #cost for investment good
  if self.K_substituted>self.obsoleteCapital:
    cost_I  = common.price_Gi*self.obsoleteCapital
  else:
    cost_I  = common.price_Gi*self.K_substituted
  #total cost
  cost = cost_L + cost_K + cost_I
  #revenue
  if self.Gc == 0:
    revenue = 0.
  else:
    revenue = common.price_Gc*self.Gc
  #profit
  profit = revenue - cost
  profit = sorted([common.minVal, profit, common.maxVal])[1]
  if profit > 0:
    self.owner.income += profit
  self.profitList.append(profit)
  common.profitGc += profit
```

WorldState – Count agents Agent populations are counted at this point, before bankruptcies may take place or new firms be created. In this way, graphics return the actual number of active agent in each cycle.

```
def countAgents(self):
  modelList=common.modelAddress.agentList[:]
  nFirmsGc=0
  nFirmsGi=0
  nUnemployed=0

  for ag in modelList:
    if ag.agType=="firm":
      if ag.industry==1:
        nFirmsGi+=1
      else:
        nFirmsGc+=1
    if ag.agType=="person":
      if ag.myFirm==None:
        nUnemployed+=1
```

```
  common.nFirms = nFirmsGc + nFirmsGi
  common.nFirmsGc = nFirmsGc
  common.nFirmsGi = nFirmsGi
  common.nEntrepreneurs = common.nFirms
  common.nEmployees = common.nPersons - nUnemployed \
  - common.nEntrepreneurs
  common.nUnemployed = nUnemployed
```

Fire if losses As losses are registered, it would sound reasonable that a firm cuts its labor force, if the employment level is not sustainable. This method selects a random employee and fires her/him, as profit turns negative.

```
def fireIfLosses(self):
  if self.profitList[-1] <= common.firingThreshold and \
  self.L != 1:
    self.delta_L = -1
    self.fire()
```

Check business condition If a firm registers negative profit for a sequential number of years, it goes bankrupt. This threshold, `yearsOfNegativeProfit`, is set equal to four in `parameters.py`.

```
def checkBusinessCondition(self):
  if len(self.profitList)>=common.yearsOfNegativeProfit:
    n=0
    for a in range (1, common.yearsOfNegativeProfit + 1):
      if self.profitList[-a]<0:
        n+=1
    if n == common.yearsOfNegativeProfit:
      if self.verbose:
        print "firm ", self.number, ": Bankrupt!"
      self.delta_L = -len(self.workerList)
      self.fire()
      self.owner.myFirm=None
      if self in common.modelAddress.agentList:
        common.modelAddress.agentList.remove(self)
```

To entrepreneur With this method we allow employees to set up their own business. In doing so, we assume that this happens with a given probability,

`probabilityTBE`, which is now set equal to 0.1 in `parameters.py`. Moreover, we require our agents to possess a minimum amount of credit, `creditRequirementTBE`, equal to 0.4 and set in the same location.

If these two conditions are met, the acting agent quits her/his actual job and sets up a new firm. The sector selection takes places randomly, but it can be linked to the previous sector of employment as well.

As for firms at the beginning of the simulation, we assume no set-up cost.

```
def toEntrepreneur(self):
  if self.myFirm==None or self==self.myFirm.owner:
    return
  if random.random() <= common.probabilityTBE and \
  self.credit > common.creditRequirementTBE:
    #quit job
    self.myFirm.workerList.remove(self)
    self.myFirm.L-=1
    #prepare a new firm
    highestNumber = self.checkHighestNumber("firm")
    number = highestNumber + 1
    agType = "firm"
    owner = self.number
    industry = random.randint(1,2)
    #alternative:
    #industry=self.myFirm.industry
    #sum up details in "line" string
    line=b'%(a)s %(b)d %(c)d'\
    %{b'a': '#', b'b': owner, b'c': industry}
    #print line
    #print number
    #create the new firm
    createTheAgent_Class(common.modelAddress,line,number,\
    "firm","Firm")
    self.agentList=common.modelAddress.agentList[:]
    locList=self.agentList[:]
    for anAgent in locList:
      if anAgent.number==number:
        anAgent.agentList=self.agentList[:]
        anAgent.setup()

def checkHighestNumber(self, agType):
```

```
  num=0
  locList=common.modelAddress.agentList[:]
  for anAgent in locList:
    if anAgent.agType==agType:
      if anAgent.number > num:
        num = anAgent.number
  return num
```

Set new cycle values Any variable, which is functional for a cycle, can be reset at the beginning of the next cycle, if listed in this method. It is common to all classes. For instance, `WorldState` updates variables intertemporally by making use of it, and firms reset the production shock ψ and the agents' list. For instance, we report here `setNewCycleValues` from `WorldState`.

```
# WorldState
def setNewCycleValues(self):
  common.demand_Gc_lag1t=common.demand_Gc
  common.demand_Gc=0.
  common.demand_Gi=0.
  common.demand_L=0
  common.Gc=0.
  common.Gi=0.
  common.price_Gc_lag2t=common.price_Gc_lag1t
  common.price_Gc_lag1t=common.price_Gc
  common.price_Gi_lag1t=common.price_Gi
  common.profitGc=0.
  common.profitGi=0.
  common.supply_L=0
```

Concerning firms and persons, `setNewCycleValues` resets at this point the random shock on production, `psyShock`, for the former kind of agent, and the income variable for the latter one.

```
# firm
def setNewCycleValues(self):
  self.psyShock = 0.
  self.agentList=common.modelAddress.agentList[:]

# person
def setNewCycleValues(self):
```

```
  self.income=0.
  self.agentList=common.modelAddress.agentList[:]
```

3.2.4 Variable wage

At this point we introduce a new wage formation mechanism for version 1.20.

WorldState – Set wage The wage is formed as a weighted average of two components. The fist one depends on the average price change at $t-1$. It is calculated by simple averaging first-price differences, and weighted by a small 1% coefficient (weight1). The second one is an autoregressive process of the wage itself at one lag (AR(1)), weighted by a coefficient of 0.99 (weight2).

The method `setWage` is added to the shedule right below `countLaborSupply`:

```
(...)
firm        fire
WorldState  computationalUse  countLaborSupply
WorldState  computationalUse  setWage
firm        hire
(...)
```

The method is the following.

```
def setWage(self):
  if common.cycle!=1 or (common.cycle!=1 and common.demand_L!=0):
    common.w=0.01*((common.price_Gc_lag1t - common.price_Gc_lag2t) + \
    (common.price_Gi_lag1t - common.price_Gi_lag2t))/2. \
    + 0.99*common.w
```

Moreover, to the method `setNewCycleValues`, the following line is added between lagged price of G_I and G_C.

```
(...)
common.price_Gc_lag1t=common.price_Gc
common.price_Gi_lag2t=common.price_Gi_lag1t
common.price_Gi_lag1t=common.price_Gi
(...)
```

Chapter 4

The Making of Version 2 - Decentralized Markets

4.1 Introduction and Purpose

4.1.1 Purpose

Complete information about a real economy is hardly available and may be costly. In this second version, we introduce two sources of information asymmetry and, consequently, allow for disequilibrium behavior.

First, we assume that agents have a limited knowledge of other counterparts acting in the economy and, second, we limit the extend to which agents can share new information with peers.

Contrary to version one, agents may now set a different price/wage with respect to the equilibrium one and revise it according to actual market conditions.

In chapter 6, we will then (i) assess the effect of information propagation on prices, wages, and, generally, on aggregate dynamics, and (ii) compare these results with those of version one.

4.1.2 Agent Features

Agents are endowed with a network of peers, which is limited in its extension, and with some behavioral rules that are applied while trading or seeking/offering employment.

Concerning the first, agents gather knowledge of market conditions (both, participants and prices) by acting into the market. For instance, firms plan their production according to the number of buyers and sellers, which they *know*. An employee earns the wage payed by her/his employer, which may differ from the equilibrium wage in the labor market.

Concerning the second, agents revise their price expectation according to whether they success in placing/gathering their supply/demand in a way, which resembles the Hahn adjustment process we have seen at page 28. Moreover, they can set a reservation wage with respect to information concerning both, the wage level and the unemployment rate, gathered *via* their network.

4.2 Process Overview and Scheduling

In what follows, we focus on main changes with respect to version one. Although in the previous chapter we have started our analysis by looking at the Observer, we turn now our attention to Model's actions first, since steps performed by the Observer in version two remain substantially unchanged.

4.2.1 The Model level

At the Model level, the `do0` function in `mActions.py` allows now for a first-cycle assignment of agent addresses, which is executed by persons and firms at the AESOP level within the `setNewCycleValues` method.

Here below, we can look at the new `do0` function:

```
def do0(address):
  askEachAgentInCollection(address.agentList, \
  Agent.setNewCycleValues)
  if common.cycle!=1:
    address.worldState.setNewCycleValues()
```

We can notice a call to agent's `setNewCycleValues`. Via this method, an assignment procedure is then activated through `lookForAgent`.

```
# person
def setNewCycleValues(self):
  if common.cycle==1:
    self.agentList=[self]
    self.lookForAgents()
    self.setUnemploymentThreshold()
  else:
    self.removeAgents()
  self.income=0.
  self.priceList=[]
  self.numberOfAgents=len(common.modelAddress.agentList)
```

The methods `lookForAgents`, `setUnemploymentThreshold` and `removeAgents` are common to both firm and person agents and can be found in `agent.py`. As we can see, the first two take place at the first cycle. Another important detail is the `agentList` reset, which maintains in itself just the acting agent's address by default. In addition to these three methods, some cycle-related variables are listed for reset – here, `income`, `priceList` and the number of agents acting, `numberOfAgents`. The respective method in `firm.py` maintains similar features as the one reported above, although the former is more complicated than the latter in order to allow for different industrial sectors and firm entry/exit. For any reference, it is reported at the end of this chapter.

The agent selection procedure activated by `lookForAgents()` is reported here below:

```
def lookForAgents(self):
  modelList=common.modelAddress.agentList[:]
  agentList=self.agentList[:]
  random.shuffle(modelList)
  newContacts=[]
  for anAgent in modelList:
    if anAgent not in agentList:
      newContacts.append(anAgent)
      if len(newContacts)==common.maxNewContacts:
        break
  agentList.extend(newContacts)
  self.agentList=agentList[:]
```

Each agent extracts from the Model list a randomly selected subset of addresses, which is arbitrary large. Its maximum size, `maxNewContacts`, can be modified in `parameters.py`.

At the first cycle, agents set a unemployment threshold, according to which they determine whether the *perceived* unemployment rate is *high* or *low*. This is done by `setUnemploymentThreshold`.

```
def setUnemploymentThreshold(self):
  if bool(random.randint(0,1)):
    self.uRateThreshold=common.uRateThreshold + \
    (common.uRateXi*random.random())
  else:
    self.uRateThreshold=common.uRateThreshold - \
    (common.uRateXi*random.random())
```

Each agent determines his/her threshold value, `self.uRateThreshold`, on the basis of a reference parameter, `common.uRateThreshold`, and a noise component, ξ, (`uRateXi`). `uRateThreshold` and `uRateXi` are `common` to all agents. They are set respectively equal to 0.2 and 0.1 in `parameters.py`. Therefore, an agent's unemployment-rate threshold may vary between 0.3 and 0.1.

After the first cycle, each agent's contact network is cleared from inactive instances via `removeAgents`:

```
def removeAgents(self):
  modelList=common.modelAddress.agentList[:]
  agentList=self.agentList[:]
  for anAgent in agentList:
    if anAgent not in modelList:
      agentList.remove(anAgent)
  self.agentList=agentList[:]
```

4.2.2 The AESOP level

Macro and the trading process in the schedule

At this point, we introduce a new element in the schedule: a macro. Macros are generally used in order to group a specific time lapse, and subdivide it into several agent tasks[22]. In our case, macros `laborMarket`, `tradeGc` and `tradeGi` have been added to the schedule, which contains the following entries:

[22] A deeper account of macros can be found at §2.2.3.2 of the SLAPP Reference Handbook.

```
#           1
firm        setup
#           1                       100
firm        planProductionC
firm        setCapitalDemandC
firm        planProductionI
firm        setCapitalDemandI
firm        setLaborDemand
macro       laborMarket
WorldState  computationalUse        collectWages
firm        0,1                     workTroubles
firm        produce
person      setDemand
macro       tradeGc
macro       tradeGi
WorldState  computationalUse        collectPrices_Gc
WorldState  computationalUse        collectPrices_Gi
WorldState  computationalUse        collectSales
WorldState  computationalUse        reportAggregateValues
person      save
firm        adjustCapital
firm        calculateProfit
WorldState  computationalUse        countAgents
firm        fireIfLosses
firm        checkBusinessCondition
person      toEntrepreneur
```

If we take a look at the first macro sheet, `laborMarket`, we can notice some methods, like `hire` and `fire`, which we already know from version one. However, the labor market functioning comprehends now some further steps, which we will review later on:

```
#           1                       100                Comment:
firm        fire
WorldState  computationalUse        countLaborSupply
all         checkUnemploymentRate
person      checkAverageWage
person      formWageExpectation
all         setupForLaborMarket                         Iteration:
firm        hire                                                 1
all         reviseWage
firm        hire                                                 2
all         reviseWage
(...)
```

Methods `hire` and `reviseWage` form an employment round. The simulation is set by default in order to allow for fifteen rounds. However, this number can be arbitrarily modified by adding or removing iterations from the corresponding `.xls` sheet.

By opening the `tradeGc` macro sheet in `schedule.xls`, these items are displayed:

```
#     1                 100  Comment:
all   setupForTradeGc        Iteration:
firm  tradeGc                         1
all   revisePriceGc
firm  tradeGc                         2
all   revisePriceGc
(...)
```

Here, a trade round is formed by methods `tradeGc` and `revisePriceGc`, and it is repeated fifteen times as well.

The trading process in each good market maintains the same structure. In macro `tradeGi`, trade rounds are composed by methods `tradeGi` and `revisePriceGi`, and iterations can be modified in the same way.

Methods of these three macro are proper of version two and we will examine each of them in detail. Before that and by following the schedule, we pose our attention to changes in version one methods, which have been needed in order to allow for a decentralized market structure.

Methods of version 2

Generally, methods of version one differ from their counterpart in version two in two respects: the kind of agent list used in a survey and the determination of some macro-level information, such as the actual number of firms acting in each cycle.

Concerning the first, we refer to the `modelList` whenever a survey of *all* agents acting in the simulation is needed for an *auxiliary* purpose. The method `setup` in `firm.py` is an instance of this. There, all agents must be asked in order to find a firm's owner address.

Conversely, an `agentList` is used when an agent surveys peers in order to gather some information about the state of the economy, which is no longer provided by the `common` module.

Here below, the methods of version two are reported. If a change with respect of version one is small, the respective method will be just partially shown.

Setup Firms entering the simulation apply the following procedure:

```
def setup(self):
  modelList=common.modelAddress.agentList[:]
  for anAgent in modelList:
    if anAgent.number==self.owner:
      #set owner
      self.owner=anAgent
      #set own prices
      self.setInitialWage()
      self.setUnemploymentThreshold()
      self.setInitialPrices()
      #change myFirm
      anAgent.myFirm = self
```

where `setInitialWage` and `setInitialPrices` determine an initial wage level and initial good prices. `setUnemploymentThreshold` is called in `setup` because of firm entry.

```
def setInitialWage(self):
  if common.cycle == 1:
    self.w=common.w
    self.owner.w=common.w
  else:
    self.w=self.owner.w
```

After the first cycle, wage determination becomes endogenous. If created later on, firms cannot rely on the initial `common.w` value anymore. As a simplifying assumption, we can think of a firm owner setting the same wage for her/his employees, as the one for which s/he used to work for.

```
def setInitialPrices(self):
  if common.cycle == 1:
    self.price_Gi = random.gauss(common.price_Gi, \
    common.price_Gi_stDv)
    if self.industry==2:
      self.price_Gc = random.gauss(common.price_Gc, \
      common.price_Gc_stDv)
  else:
    self.checkPriceGiFromNetwork()
    if self.industry==2:
      self.checkPriceGcFromNetwork()
```

For the first cycle only, good prices are set close to initial equilibrium ones, P_C^* and P_I^*, observed in version one. An average value for each price and its standard deviation have been inferred by considering data generated by version one within a limited number of cycles[23], from which we gather the following values:

Time	Eq. price, P_C^*	Mean, $\bar{P}_C^*$	St. Dev., $\sigma_{\bar{P}_C^*}$
1	1.57142857	1.64104471	0.05761365
2	1.70695176		
3	1.59773121		
4	1.68806730		
Time	Eq. price, P_I^*	Mean, $\bar{P}_I^*$	St. Dev., $\sigma_{\bar{P}_I^*}$
1	1.53019765	1.83323101	0.23709310
2	1.67294589		
3	2.06489025		
4	2.06489025		

Mean values and their standard deviation are stored in the `common` module, where `common.price_Gc` $= \bar{P}_C^*$, and `common.price_Gc_stDv` $= \sigma_{\bar{P}_C^*}$.

[23]Reported values has been taken from version 1.19 (seed: 2, cycles: 4, prob.(workTroubles): 0.1)).

In order to allow for some price variation at the first cycle, it can be assumed that agent n's prices , $P_{C,n}$ and $P_{C,n}$, comes from:

$$\left.\begin{array}{rcl} P_{C,n} & \sim & \mathcal{N}(\bar{P}^*_C, \sigma^2_{\bar{P}^*_C}) \\ \\ P_{I,n} & \sim & \mathcal{N}(\bar{P}^*_I, \sigma^2_{\bar{P}^*_I}) \end{array}\right\} \qquad \text{if} \quad \text{time } t = 1$$

However and if a firm is set up later on, prices are determined by surveying its network, `agentList`.

```
def checkPriceGcFromNetwork(self):
  agentList=self.agentList[:]
  locList=[]
  for anAgent in self.agentList:
    if anAgent.agType=="firm" and anAgent!=self and \
    anAgent.industry==2:
      locList.append(anAgent.askPrice_Gc)
  price_Gc = sum(locList)/(sorted([len(locList),1])[1])
  if price_Gc==0:
    self.price_Gc = self.owner.price_Gc
  else:
    self.price_Gc = price_Gc

def checkPriceGiFromNetwork(self):
  agentList=self.agentList[:]
  locList=[]
  for anAgent in self.agentList:
    if anAgent.agType=="firm" and anAgent!=self:
      locList.append(anAgent.price_Gi)
  price_Gi = sum(locList)/(sorted([len(locList),1])[1])
  if price_Gi==0:
    self.price_Gi = random.uniform(1., 4.)
  else:
    self.price_Gi = price_Gi
```

In particular, a new firm, f, sets the average price from its network, $\bar{P}^{network}_C$. If this information is not available – *e.g.* there are no firms selling G_C in the network,

a value for P_C is taken from owner's experience as a buyer.

$$P_{C,f} = \begin{cases} \bar{P}^{network}_{C,t-1} = \dfrac{\sum_{f^{nw}=1}^{F_C^{network}} P_{C,f^{nw}}}{F_C^{network}} & \text{if} \quad \bar{P}^{network}_{C,t-1} \neq 0,\ t > 1 \\ \\ P^{owner}_{C,t-1} & \text{if} \quad \bar{P}^{network}_{C,t-1} = 0,\ t > 1 \end{cases}$$

where $F_C^{network}$ is the total number of firms in within the network.

Concerning P_I, a network average-price is calculated in the same manner, but surveying *all* firms in agent's network. However and if no information on P_I becomes available from the network (a rather unlikely event), the acting firm must make a more extreme guess. This is modeled by drawing a value for P_I form:

$$P_{C,f} \sim U(1,4)$$

Plan production C We focus here on the determination of a planned production level, φ^p_C. Capital- and labor-demand formulations remain unchanged with respect to what reported in version one, and can be omitted.

The planned production of G_C is calculated by considering information from competing firms and consumers, which are *known* to the acting firm.

At time one, firms in sector C plan their production as:

$$\varphi^p_C = \rho_C \frac{N^{network}}{F_C^{network}} \qquad \text{if} \quad t = 1$$

where $N^{network}$ and $F_C^{network}$ are represented by `numberOfPotentialBuyers` and `numberOfFirmsInSameSector`, respectively.

At any other time, planned production is computed as:

$$\varphi^p_C = \frac{D_{C,t-1} F^{network}_{C,t-1}}{F^{network}_{C,t}} \qquad \text{if} \quad t > 1$$

An exception is made for firms established after time one, for they do not have information of *their* previous demand. Hence, new firms guess time $t-1$ demand for G_C, in value terms, by surveying persons in their network about past expenditure on it:

$$\varphi^p_{C,f^{new}} = \frac{\frac{D^{network}_{C,t-1}}{P_{C,f^{new}}}}{F^{network}_{C,t}} \qquad \text{if} \quad t > 1$$

where $D^{network}_{C,t-1}$ is represented by `demandInValueFromNetwork_lag1t` and it is defined as follows:

$$D^{network}_{C,t-1} = \sum_{n^{nw}}^{N^{network}} D_{C,n^{nw},t-1}$$

The number of firms in sector C at $t-1$ is `numberOfFirmsInSameSector_lag1t` and it is defined in `setNewCycleValues`.

```
def planProductionC(self):
  if self.industry!=2:
    return
  buyersAndDemandFromNetwork=self.countBuyersAndDemandGc()
  #print numberOfPotentialBuyers
  self.numberOfFirmsInSameSector = \
  self.countFirmsInSameSector()
  #print numberOfFirmsInSameSector
  if common.cycle==1:
    numberOfPotentialBuyers = buyersAndDemandFromNetwork[0]
    self.plannedProduction = (common.rhoC * \
    numberOfPotentialBuyers) /\
    self.numberOfFirmsInSameSector
  elif self.profitList==[]:
    demandInValueFromNetwork_lag1t = \
    buyersAndDemandFromNetwork[1]
    self.plannedProduction = ( \
    demandInValueFromNetwork_lag1t/self.price_Gc) /\
    self.numberOfFirmsInSameSector
  else:
    self.plannedProduction = (self.demand_Gc_lag1t * \
    self.numberOfFirmsInSameSector_lag1t)/\
    self.numberOfFirmsInSameSector
```

Numerical values for `numberOfPotentialBuyers`, `numberOfFirmsInSameSector` and `demandInValueFromNetwork_lag1t` are returned by the following methods:

```
def countFirmsInSameSector(self):
  agentList=self.agentList[:]
  n=len([anAgent for anAgent in agentList \
  if anAgent.agType=="firm"  \
  and anAgent.industry==self.industry])
  #print "Firm #", self.number, "Firms in same sector: ", n
  return n

def countBuyersAndDemandGc(self):
  agentList=self.agentList[:]
```

```
  n = 0
  demandInValueFromNetwork_lag1t = 0.
  if self.industry==1:
    for anAgent in agentList:
      if anAgent.agType=="firm" and \
      anAgent.industry!=self.industry:
        n+=1
  if self.industry==2:
    for anAgent in agentList:
      if anAgent.agType!="firm":
        demandInValueFromNetwork_lag1t += \
        anAgent.expenditure
        n+=1
  return n, demandInValueFromNetwork_lag1t
```

As the name suggests,`countFirmsInSameSector` assesses how many firms within the same sector are active in a network, while `countBuyersAndDemandGc` returns the number of firms in sector C (of persons), if the acting agent is a firm in sector I (in sector C). In the latter case, also persons' demand is summed up an stored in `demandInValueFromNetwork_lag1t`.

Plan production I Firms in sector I consider network information in order to determine the amount of expected orders from sector C. Hence, each firm in I, f_I, guesses its demand:

$$expectedOrders_{f_I} = \frac{D_I^{F_C^{network}}}{F_I^{network}}$$

where $F_C^{network}$ and $F_I^{network}$ represent the number of firms in sector I and C, which are within f_I's network.

```
def planProductionI(self):
  if self.industry!=1:
    return
  numberOfFirmsInSameSector = self.countFirmsInSameSector()
  demand_Gi_FromSectorC = \
  self.calculateDemandGiFromSectorC()
  expectedOrders = (demand_Gi_FromSectorC /\
  numberOfFirmsInSameSector)
  (...)
```

The network demand for good I is calculated by method `calculateDemandGiFromSectorC` as:

$$D_I^{F_C^{network}} = \frac{\sum_{f_C=1}^{F_C^{network}} D_I^{f_C}}{F_I^{network}}$$

where $D_I^{f_C}$ is the demand for good I of firm f_C.

```
def calculateDemandGiFromSectorC(self):
  demand_Gi_FromSectorC=0.
  agentList=self.agentList[:]
  for anAgent in agentList:
    if anAgent.agType=="firm" and anAgent.industry==2:
      demand_Gi_FromSectorC += anAgent.demand_Gi
  demand_Gi_FromSectorC = sorted([demand_Gi_FromSectorC, \
  common.maxVal])[0]
  return demand_Gi_FromSectorC
```

Macro laborMarket Our first macro concerns the labor market and consists of eight methods: `fire`, `countLaborSupply`, `checkUnemploymentRate`, `checkAverageWage`, `formWageExpectation`, `setupForLaborMarket`, `hire`, and `reviseWage`. The first five of them are preliminary to market rounds, but we skip `fire` and `countLaborSupply`, for they remain unchanged.

In what follows, it is assumed that agents may make use of a *perceived* unemployment rate, in order to set their reservation wage.

Moreover, firms consider possible excess of labor demand as well, in order to revise their offered wage.

Workers revise their reservation wage more aggressively, if the spotted unemployment rate is lower than agent's `uRateThreshold`. Conversely, workers get a better understanding of the wage level just by direct participation into the market.

– **Check unemployment rate** Agents guess the unemployment rate at each cycle - but the first one, and before agents enter the labor market. In order to do so, an agent asks each person within its network about her/his employment status. This method is common for person and firms, and it is therefore placed in `Agent.py`.

```
def checkUnemploymentRate(self):
  if common.cycle==1:
    return
  agentList=self.agentList[:]
```

```
  N=U=0.
  for anAgent in agentList:
    if anAgent.agType=="person":
      N+=1
      if anAgent.myFirm==None:
        U+=1
  self.u=U/N
```

– **Check average wage** At this point, persons measure the average wage within their network. Unemployed and workers take the latter group as reference, while entrepreneurs survey themselves. `checkAverageWage` can be found in `Person.py`.

```
def checkAverageWage(self):
  if common.cycle==1:
    self.avWage=None
    return
  #determine average wage level
  cumulWage=N=0.
  agentList=self.agentList[:]
  if self in agentList:
    agentList.remove(self)
  #for unemployed and employees
  if self.myFirm==None or self!=self.myFirm.owner:
    for anAgent in agentList:
      if anAgent.agType=="person" \
      and anAgent.myFirm!=None \
      and anAgent!=anAgent.myFirm.owner:
        cumulWage+=anAgent.w
        N+=1
  #for entrepreneurs
  if self.myFirm!=None and self==self.myFirm.owner:
    for anAgent in agentList:
      if anAgent.agType=="person" \
      and anAgent.myFirm!=None \
      and anAgent==anAgent.myFirm.owner:
        cumulWage+=anAgent.w
        N+=1
  #average wage from network
  if N==0:
```

```
    self.avWage=None
  else:
    self.avWage=cumulWage/N
```

– **Form wage expectation** If agents *consider* unemployment sufficiently low, they review their wage expectation in a more aggressive way.

In particular, we assume that unemployed set a reservation wage which lies between ±30% the average wage.

Employees quit their job, if they find out their pay being at least 20% below average, and set a reservation wage between one and two times the average wage.

Entrepreneurs react to their wage being 40% below average and *set* it directly within 35% below and 100% above the average.

```
def formWageExpectation(self):
  if self.avWage!=None and self.u < self.uRateThreshold:
    if self.myFirm==None:
      self.askW = sorted([self.avWage*random.random()*1.3,\
      self.avWage*0.7, common.maxVal])[1]
    if self.myFirm!=None and self!=self.myFirm.owner:
      if self.w <= self.avWage*.8:
        #quit job
        self.myFirm.workerList.remove(self)
        self.myFirm.L-=1
        self.myFirm=None
        #revise wage
        self.askW = sorted([self.avWage*random.random()*2,\
        self.avWage, common.maxVal])[1]
    if self.myFirm!=None \
    and self==self.myFirm.owner \
    and len(self.myFirm.profitList)!=0:
      if self.w <= self.avWage*.6 \
      and self.myFirm.profitList[-1]>0:
        self.w = sorted([self.avWage*random.random()*2,\
        self.avWage*.75, common.maxVal])[1]
```

– **Setup for labor market** Then, firms and unemployed persons set a boolean value in order to signal, respectively, whether they have just been hired or they have no open position anymore. As firms did in `setup`, each person at

the beginning of the simulation sets her/his ask wage equal to the initial `common` value, W.

```
# firm
def setupForLaborMarket(self):
  self.justSatisfiedLaborDemand=False

# person
def setupForLaborMarket(self):
  self.justHired=False
  if common.cycle==1:
    self.askW=common.w
```

– **Hire** At this point, labor market rounds are launched. In each round, firm agents survey their network and hire workers whenever labor demand is still positive and applicant's asked wage, `askW`, is lower or equal to the offered one.

```
def hire(self):
  if self.delta_L<=0:
    return
  agentList = self.agentList[:]
  random.shuffle(agentList)
  for anAgent in agentList:
    if self.delta_L<=0:
      self.justSatisfiedLaborDemand=True
      break
    elif anAgent.agType == "person" and anAgent.myFirm==None\
    and self.w>=anAgent.askW:
      anAgent.justHired=True
      anAgent.w = self.w
      anAgent.myFirm = self
      (...)
```

– **Revise wage** At the end of each round, agent's reservation wage is revised. this happens in two different ways for each agent class.

```
# person
def reviseWage(self):
  if self.justHired:
    self.askW = self.w + .1
    self.askW = sorted([self.askW, common.maxVal])[0]
```

```
    self.justHired=False
  elif self.myFirm==None and (self.askW - .1) >=0:
    self.askW -=.1
    if len(self.agentList)!=self.numberOfAgents:
      self.lookForAgents()

# firm
def reviseWage(self):
  if common.cycle==1:
    if self.justSatisfiedLaborDemand:
      if (self.w - .1) >=0:
        self.w -=.1
      self.justSatisfiedLaborDemand=False
    elif self.delta_L>0:
      self.w +=.1
      self.w = sorted([self.w, common.maxVal])[0]
      if len(self.agentList)!=self.numberOfAgents:
        self.lookForAgents()
  else:
    if self.justSatisfiedLaborDemand:
      if self.u>=self.uRateThreshold and (self.w - .1)>=0:
        self.w -=.1
      self.justSatisfiedLaborDemand=False
    elif self.delta_L>0:
      if self.u<self.uRateThreshold:
        self.w +=.1
        self.w = sorted([self.w, common.maxVal])[0]
      if len(self.agentList)!=self.numberOfAgents:
        self.lookForAgents()
```

If a person is still unemployed, s/he will lower her/his asked wage of a fixed amount, equal to 0.1. If instead s/he has just been hired, s/he equates her/his expected wage to the actual one, and revise the former upwards of 0.1 for future opportunities.

Concerning the other class, we can think of firms offering a lower wage, when unemployment level is *perceived high*, and they can easily satisfy labor demand. On the contrary, a higher wage is offered when unemployment is rather *low* and there has been some labor demand, which was not satisfied.

WorldState – Collect wages As soon after the labor market process is terminated, the WorldState acquires and stores information about the overall wage

level via `collectWages` in `WorldState.py`.

```
def collectWages(self):
  modelList=common.modelAddress.agentList[:]
  wageList=[]
  for anAgent in modelList:
    if anAgent.agType=="person" and anAgent.myFirm!=None:
      wageList.append(anAgent.w)
  n=len(wageList)
  if n==0:
    common.w = common.w_lag1t
    common.stDvW = 0.
  else:
    wageArray = array(wageList)
    common.w=mean(wageArray)
    common.stDvW=std(wageArray)
```

In case no hiring has taken place, previous-time average wage is stored and displayed, while standard deviation is set equal to zero.

Unchanged methods: work troubles, produce As stated previously, some methods do not need changes. This is the case for `workTroubles` and `produce`, which will be hence omitted.

Set demand On the contrary, method `setDemand` displays deep changes. Recall that, in version one, person's demand for G_C was placed directly in value terms, and the WorldState acted like a Walrasian Auctioneer, by setting the market clearing price. In version two, we lack this mechanism and agents set both, demand and price of a good, by themselves.

Regarding the first, we can restate that, in version one, a person n's demand for G_C consisted in a fraction δ of her/his income, Υ_n. Following the same line of reasoning, the respective demanded quantity at time one can be defined as:

$$D_{C,n}^{unit} = \frac{D_{C,n}}{P_{C,n}} = \frac{\delta \Upsilon_n}{P_{C,n}}$$

where we assume that person n's price of G_C, $P_{C,n}$, comes from:

$$P_{C,n} \sim \mathcal{N}(\bar{P}_C^*, \sigma^2_{\bar{P}_C^*}) \qquad \text{if} \quad \text{time } t = 1$$

and

$$P_{C,n} = P_{C,n,t-1}^{trade} \qquad \text{if} \quad \text{time } t > 1$$

In doing so, we can define $P^{trade}_{C,n,t-1}$ as the reservation price for G_C, which results from the trading procedure at time $t-1$.

```
def setDemand(self):
  if common.cycle==1:
    self.price_Gc = random.gauss(common.price_Gc, \
    common.price_Gc_stDv)
  if self.myFirm!=None:
    self.income += self.w
    if self.income > self.w:
      self.demand_Gc = common.delta1 * self.income / \
      self.price_Gc
    elif self.income == self.w:
      self.demand_Gc = common.delta2 * self.income / \
      self.price_Gc
  else:
    self.income += common.SWC
    self.demand_Gc = common.delta3 * self.income / \
    self.price_Gc
  common.demand_Gc += self.demand_Gc
  common.demand_Gc=sorted([common.demand_Gc, \
  common.maxVal])[0]
```

Macro tradeGc We turn now our attention to the market procedure and examine macros `tradeGc` and `tradeGi`.

– **Setup for trade Gc** Via this auxiliary method, firms make a copy of the production level in order to keep the stock of G_C up to date, while into the trading process, without tampering with the actual stock indicator, `self.Gc`. The boolean variables `justSoldWholeProduction` and `justSoldWholeProduction` will be used later on, in order to revise agent's price for G_C.

```
# firm
def setupForTradeGc(self):
  if self.industry!=2:
    return
  self.GcCopy=self.Gc
  self.justSoldWholeProduction=False

# person
```

```
def setupForTradeGc(self):
  self.justSatisfiedDemand=False
  self.expenditure=0.
```

– **Trade Gc** In each trading round, firms in sector C ask people in their network, whether they demand some consumption good. If ask price and bid one are in range, and the demand can still be at least partly satisfied, the exchange takes place. The traded quantity is accounted as an outflow from firm stock of G_C, as well as from person's demand. As exchange price, the ask price is recorded, and added to both agent's `priceList`. The traded quantity value (`billed`) is added to firm's revenues and accounted as buyer's expenditure. When person's demand reaches zero, the boolean variable `justSatisfiedDemand` is set to `True`. The same happens to `justSoldWholeProduction`, when firm's stock of G_C is depleted.

```
def tradeGc(self):
  if self.industry!=2 or self.GcCopy==0:
    return
  agentList=self.agentList[:]
  agentList=[anAgent for anAgent in agentList \
  if anAgent.agType=="person"]
  random.shuffle(agentList)
  for anAgent in agentList:
    if self.GcCopy !=0 and anAgent.demand_Gc !=0 \
    and anAgent.price_Gc >= self.price_Gc:
      if self.GcCopy >= anAgent.demand_Gc:
        self.GcCopy -= anAgent.demand_Gc
        billed = anAgent.demand_Gc * self.price_Gc
        anAgent.demand_Gc = 0.
        anAgent.justSatisfiedDemand=True
      else:
        anAgent.demand_Gc -= self.GcCopy
        billed = self.GcCopy * self.price_Gc
        self.GcCopy = 0.
      self.revenue += billed
      anAgent.expenditure += billed
      self.priceList_Gc.append(self.price_Gc)
      anAgent.priceList.append(self.price_Gc)
      if self.GcCopy==0:
        self.justSoldWholeProduction=True
        return
```

– **Revise price Gc** Soon after a trading round, agents acting revise their price.

If there is still some quantity to be sold, seller's ask price is decreased of a fixed, small component (0.1) and seller's `agentList` is enlarged via the method `lookForAgents`.

Conversely, seller's ask price is revised upward of the same small amount only if s/he has *just* placed all her/his supply on the market – *i.e* within the same trade round. In this case and after price increase, `justSoldWholeProduction` is set again to `False`, so that the ask price is not increased at each further trade round – we can think of this seller exiting the market.

On the same line of reasoning, a buyer's bid price is increased at each trade round, until her/his residual demand is zero, or if there are funds available – *i.e* if agent's demand in value doesn't overshoot her/his residual income. On the contrary, buyer's bid price is decreased of 0.1, when her/his demand reaches zero, and only within that trade round.

```
# firm
def revisePriceGc(self):
  if self.industry!=2:
    return
  if self.justSoldWholeProduction:
    self.price_Gc+=.1
    self.price_Gc=sorted([self.price_Gc, common.maxVal])[0]
    self.justSoldWholeProduction=False
  elif self.GcCopy!=0:
    if (self.price_Gc - .1) >= 0:
      self.price_Gc-=.1
    if len(self.agentList)!=self.numberOfAgents:
      self.lookForAgents()

# person
def revisePriceGc(self):
  if self.justSatisfiedDemand:
    if (self.price_Gc - .1) >= 0:
      self.price_Gc-=.1
    self.justSatisfiedDemand=False
  elif self.demand_Gc!=0:
    if self.demand_Gc*(self.price_Gc + .1)<= \
    (self.income - self.expenditure):
      self.price_Gc+=.1
```

```
      self.price_Gc=sorted([self.price_Gc, \
      common.maxVal])[0]
    if len(self.agentList)!=self.numberOfAgents:
      self.lookForAgents()
```

Macro tradeGi The trade procedure for G_I is very similar to the one we have already seen for G_C. However, we should now notice that a firm of sector I can be either a seller or a buyer. The latter is the case when a firm cannot supply enough G_I in order to replace its obsolete capital (because of `workTroubles`, for instance).

– **Setup for trade Gi** For the reason stated above, firms in sector I remove their demand for G_I from the stock, before entering the market. Hence, they just trade the remaining G_I produced.

```
def setupForTradeGi(self):
  if self.industry==1:
    if self.Gi>=self.demand_Gi:
      self.Gi -= self.demand_Gi
      self.K_substituted += self.demand_Gi
      self.demand_Gi=0.
    else:
      self.demand_Gi -= self.Gi
      self.K_substituted += self.Gi
      self.Gi=0.
    self.GiCopy = self.Gi
    self.justSoldWholeProduction=False
  else:
    self.justSatisfiedDemand=False
```

– **Trade Gi** The `tradeGi` method recalls `tradeGc` in its structure. However, account has been taken for the case in which a same firm in I enters the `agentList` as a buyer as well. In this case, the acting firm's address is removed from the `agentList`.

```
def tradeGi(self):
  if self.industry!=1 or self.GiCopy==0:
    return
  agentList=self.agentList[:]
  agentList=[anAgent for anAgent in agentList \
```

```
  if anAgent.agType=='firm' and anAgent != self]
  random.shuffle(agentList)
  for anAgent in agentList:
    if self.GiCopy !=0 and anAgent.demand_Gi !=0 \
    and anAgent.price_Gi >= self.price_Gi:
      if self.GiCopy >= anAgent.demand_Gi:
        self.GiCopy -= anAgent.demand_Gi
        billed = anAgent.demand_Gi * self.price_Gi
        anAgent.K_substituted += anAgent.demand_Gi
        anAgent.demand_Gi = 0.
        anAgent.justSatisfiedDemand=True
      else:
        anAgent.demand_Gi -= self.GiCopy
        billed = self.GiCopy * self.price_Gi
        anAgent.K_substituted += self.GiCopy
        self.GiCopy = 0.
      self.revenue += billed
      anAgent.cost_I += billed
      self.priceList_Gi.append(self.price_Gi)
      anAgent.priceList_Gi.append(self.price_Gi)
      if self.GiCopy==0:
        self.justSoldWholeProduction=True
        return
```

– **Revise price Gi** Price revision takes place according to the same logic as for `revisePriceGc`. Buyers raise bid price until their demand is satisfied, and sellers lower their ask price as long as there is still some unsold supply, while enlarging their network in between.

```
def revisePriceGi(self):
  if self.industry==1:
    if self.justSoldWholeProduction:
      self.price_Gi += .1
      self.price_Gi=sorted([self.price_Gi, \
      common.maxVal])[0]
      self.justSoldWholeProduction=False
    elif self.GiCopy!=0:
      if (self.price_Gi - .1) >= 0:
        self.price_Gi -= .1
      self.lookForAgents()
  else:
```

```
    if self.justSatisfiedDemand:
      if (self.price_Gi - .1) >= 0:
        self.price_Gi-=.1
      self.justSatisfiedDemand=False
    elif self.demand_Gi!=0:
      self.price_Gi+=.1
      self.price_Gi=sorted([self.price_Gi, \
      common.maxVal])[0]
      if len(self.agentList)!=self.numberOfAgents:
        self.lookForAgents()
```

WorldState – Collect prices G_C/G_I When the two trading procedures have come to an end, WorldState collects the average values for prices of G_C and G_I, and their respective standard deviation. Here below we report `collectPrices_Gc`. Method `collectPrices_Gi` is identical in its structure, and can be hence omitted.

```
def collectPrices_Gc(self):
  modelList=common.modelAddress.agentList[:]
  priceList_Gc=[]
  for anAgent in modelList:
    if anAgent.agType=="firm" and anAgent.industry==2:
      priceList_Gc.extend(anAgent.priceList_Gc)
  n=len(priceList_Gc)
  if n==0:
    common.price_Gc = common.price_Gc_lag1t
    common.stDvPrice_Gc = 0.
  else:
    priceArray_Gc = array(priceList_Gc)
    common.price_Gc = mean(priceArray_Gc)
    common.stDvPrice_Gc = std(priceArray_Gc)
```

WorldState – Collect sales Given that equality between production and sales does not hold anymore in version two, the WorldState collects at this point sold quantities as well.

```
def collectSales(self):
  modelList=common.modelAddress.agentList[:]
  for anAgent in modelList:
    if anAgent.agType=="firm" and anAgent.industry==2:
      common.soldGc += (anAgent.Gc - anAgent.GcCopy)
```

```
    if anAgent.agType=="firm" and anAgent.industry==1:
      common.soldGi += (anAgent.Gi - anAgent.GiCopy)
```

WorldState – Report aggregate values With respect to version one, `reportAggregateValues` has been provided with mean price values, their standard deviations and a general overview of trade aggregates.

```
def reportAggregateValues(self):
  if self.verbose:
    print "Aggregate demand Gc: ", common.demand_Gc
    print "Aggregate demand Gi: ", common.demand_Gi
    print "Aggregate demand L: ", common.demand_L
    print "Aggregate production Gc: ", common.Gc
    print "Aggregate production Gi: ", common.Gi
    print "Aggregate sales Gc (unit): ", common.soldGc
    print "Aggregate sales Gi (unit): ", common.soldGi
    print "Aggregate supply L: ", common.supply_L
    print "Mean price Gc: ", common.price_Gc, \
    "StDv. :", common.stDvPrice_Gc
    print "Mean price Gi: ", common.price_Gi, \
    "StDv. :", common.stDvPrice_Gi
```

Save Once the amount purchased is known, persons can update their residual income, by subtracting expenditure. Recall that `self.expenditure` is set equal to zero by `setNewCycleValues` in `person.py` at the beginning of each cycle.

```
def save(self):
  if self.expenditure != 0:
    savings = self.income - self.expenditure
  else:
    savings = self.income
  self.credit += savings
```

Adjust capital Via method `adjustCapital`, firms update their capital stock by adding the acquired amount. As for `expenditure`, also `K_substituted` is reset by `setNewCycleValues` in `firm.py`.

```
def adjustCapital(self):
  self.K += self.K_substituted
```

Calculate profit In version two, profit calculation has been unified, for we do not need agents in I to act fist any longer. All we need is a diversification between sectors, when updating `common.profitGi` and `common.profitGc`.

Now that wages are differentiated, labor cost is determined by summing up workers' wages, plus entrepreneur's one. Used capital is still remunerated at a rate r, but its value depends on the (average) market price for G_I. In case G_I has not been sold in a cycle, agent's reservation price, `price_Gi`, is used.

`cost_L` and `avPrice_Gi`are returned by two auxiliary functions, `determineCostL` and `determineAvPrice_Gi`. Notice that also `self.cost_I` is reset to zero at the end of each simulation cycle via `setNewCycleValues` in `firm.py`.

```
def calculateProfit(self):
  #cost of labor
  cost_L = determineCostL(self.workerList) + self.owner.w
  #cost of capital
  avPrice_Gi=determineAvPrice_Gi(self.priceList_Gi)
  if str(avPrice_Gi)=='nan':
    avPrice_Gi=self.price_Gi
  #note: capital actually used is equal to quantity produced
  cost_K = common.r*avPrice_Gi*self.Y
  #cost for investment good
  if self.K_substituted>self.obsoleteCapital:
    self.cost_I = self.obsoleteCapital*avPrice_Gi
  #total cost
  cost = cost_L + cost_K + self.cost_I
  #profit
  profit = self.revenue - cost
  profit = sorted([common.minVal, profit, common.maxVal])[1]
  if profit > 0:
    self.owner.income += profit
  self.profitList.append(profit)
  if self.industry==2:
    common.profitGc += profit
  else:
    common.profitGi += profit
```

Unchanged methods Methods `WorldState countAgents` and `fireIfLosses` remain unchanged.

Check business condition The decentralized network structure imposes a change in this method. In order to keep agent addresses up to date, we iterate over a copy of `modelList` – taking care that the acting agent herself/himself in it – and update agent addresses. Just by removing *every* reference to an agent's address from agent- and model lists we can indeed exclude such an agent from any further step in the simulation procedure.

```
(...)
self.owner.myFirm=None
modelList=common.modelAddress.agentList[:]
if self in modelList:
  modelList.remove(self)
for anAgent in modelList:
  if self in anAgent.agentList:
    anAgent.agentList.remove(self)
if self in common.modelAddress.agentList:
  common.modelAddress.agentList.remove(self)
```

To entrepreneur The opposite is obviously true. As a new agent enters the simulation, his/her address is automatically added by SLAPP to the `modelList`. Since in version two an agent's `agentList` is by default empty, the owner of a new firm passes her/his contacts to it.

```
(...)
createTheAgent_Class(common.modelAddress,line,number,"firm","Firm")
modelList=common.modelAddress.agentList[:]
for anAgent in modelList:
  if anAgent.number==number:
    self.agentList.append(anAgent)
    anAgent.agentList=self.agentList[:]
    anAgent.setup()
```

Set new cycle values Methods for WorldState and Firm agents:

```
#WorldState
def setNewCycleValues(self):
  common.demand_Gc=0.
  common.demand_Gi=0.
  common.demand_L=0
  common.Gc=0.
```

```
  common.Gi=0.
  common.price_Gc_lag1t = common.price_Gc
  common.price_Gi_lag1t = common.price_Gi
  common.profitGc=0.
  common.profitGi=0.
  common.soldGc=0.
  common.soldGi=0.
  common.supply_L=0
  common.w_lag1t = common.w

#Firm
def setNewCycleValues(self):
  if common.cycle==1:
    self.agentList = [self]
    self.lookForAgents()
  else:
    self.removeAgents()
    if self.industry==2:
      if self.profitList==[]:
        self.Gc = 0.
        self.GcCopy = 0.
        self.numberOfFirmsInSameSector = 0
      self.demand_Gc_lag1t=self.Gc-self.GcCopy
      self.numberOfFirmsInSameSector_lag1t = \
      self.numberOfFirmsInSameSector
    if self.industry==1:
      if self.profitList==[]:
        pass
  if self.industry==2:
    self.priceList_Gc=[]
  self.cost_I = 0.
  self.K_substituted = 0.
  self.priceList_Gi=[]
  self.psiShock = 0.
  self.revenue = 0.
  self.numberOfAgents=len(common.modelAddress.agentList)
```

Part III

Model Dynamics

Chapter 5

Dynamics and Comparison

5.1 Introduction

Social scientists commonly define three levels of analysis of a social system. Namely, a micro-, a meso- and a macro-level.

In chapters 3 and 4, we have seen how agents singularly behave (micro-level). In the first part of this chapter, we place ourselves at the meso level, and in the second one, at the macro-level.

Lacking a clearer definition, we interpret as *meso* that level of analysis, which let us focus on connections between the other two.

However, such "connections" are neither univocally defined, nor univocally analyzed in scientific literature. Indeed, their definition is critical in identifying both, the object of analysis and, consequently, the relative discipline. Concerning the first, we could think of them as, for instance – and not mutually-exclusive:

- Interconnection of agents;
- Institutions and agents' behavior;
- Stock/flow structure of a system;
- Empirical regularities.

To each of these interpretations, a method of analysis follows:

- Social Network Analysis / Sociology;
- Institutional research / Behavioral Economics / Anthropology;
- Engineering / System Dynamics;
- Statistics / Econometrics.

In the following section, we outline the underlying systemic structure of the model, and describe dynamics resulting from agent interaction thereupon.

In section 6.3, we will then link these dynamics to macro-level phenomena.

5.2 Meso Level – A CLD Representation

First, we look at agent processes in isolation and, by making use of a Causal-Loop Diagram (CLD) representation, we point to dynamic implications. Then we will put them together, in order to assess system-level dynamics.

Production

From time two onwards, firms plan their production by dividing previous-time aggregate demanded quantity of G_C by the number of firms in sector C. Planned production, φ_C^p, is therefore positively related to agents' $AD_{C,t-1}$ in value, negatively on both, $P_{C,t-2}$ and $F_{C,t-1}$. Figure 6.1 shows this simple relation in CLD form, using information arrows with positive or negative polarities and a delay sign (double line). For our simulation model is set within a discrete-time setting, each delay sign corresponds to one cycle lag. (*E.g.*, with respect to φ_C^p, AD_C is one time lagged, while P_C is double lagged).

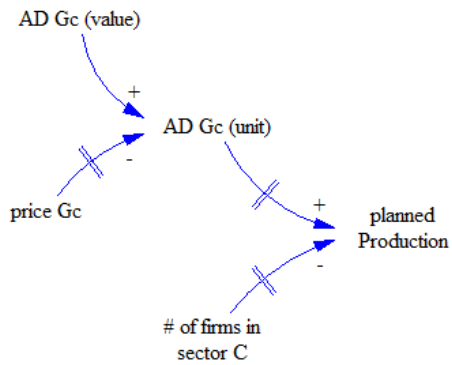

Fig. 6.1: planned production G_C.

Together with the technological input-output relation, φ_C^p determines the amount of capital needed, K^p. Its difference with respect to physical capital stock, K, positively affects the demand of investment good to firms in sector I.

We can think of a firm, f, entering the market at time $t > 1$. At the beginning, its production capacity is sufficient to produce the planned amount. If AD_C has risen (or F_C declined) at time t , f will place a demand for investment good to sector I one period later, $t + 1$, in order to close the output gap. At time $t + 2$, demanded quantity of G_I is delivered and, *Cæteris paribus*, ΔK turns to zero. At this point, no "direct" investment takes place, until a further increase of AD_C is registered. This dynamic is represented by a negative feedback loop in figure 6.2, where a dashed arrow symbolizes this discontinuity. As long as $K^p > K$, this negative feedback loop remains active.

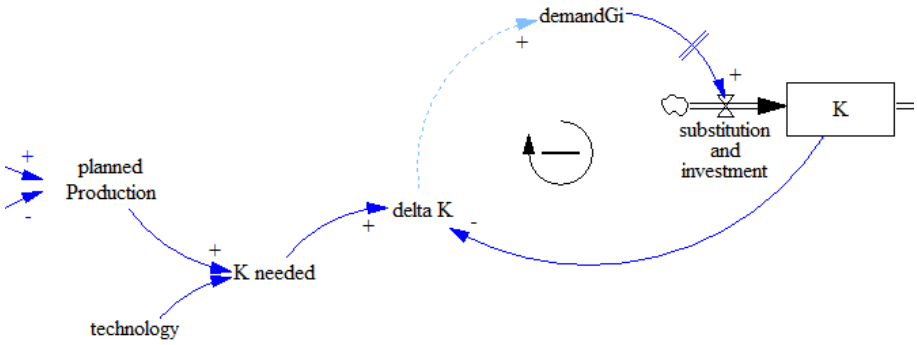

Fig. 6.2: ΔK and capital demand.

A second set of feedback loops enters into play *via* physical capital substitution (fig. 6.3). When producing at full capacity, the higher the capital stock, the higher the worn-out capital amount. At the same time, firms take this outflow into account and increase demand of G_I by the same amount. Below full capacity, the same role is played by K^p. These two feedback loops balance each other out and keep the capital stock at a constant level, provided that supply of G_I occurs seamless. If this is not the case, K depletes as production continues. At constant φ_C^p, capital demand is kept higher than the substitution amount by K^p until a source of G_I is found.

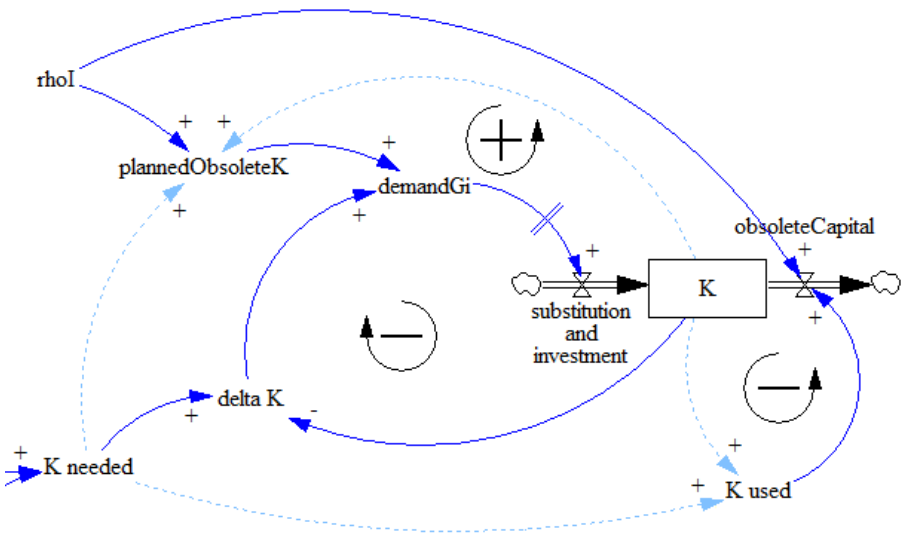

Fig. 6.3: physical capital demand and substitution.

Looking at labor, we have a similar dynamic mechanism. Suitable capital for production and technological constraint defines labor needed, L^p. Whenever

$\Delta L > 0$, a firm hires new workers. Their number tends toward the desired one, ΔL decreases, until it reaches zero. On the contrary, dismissal takes place with a negative ΔL. As then number of employees declines, ΔL increases toward zero and halts.

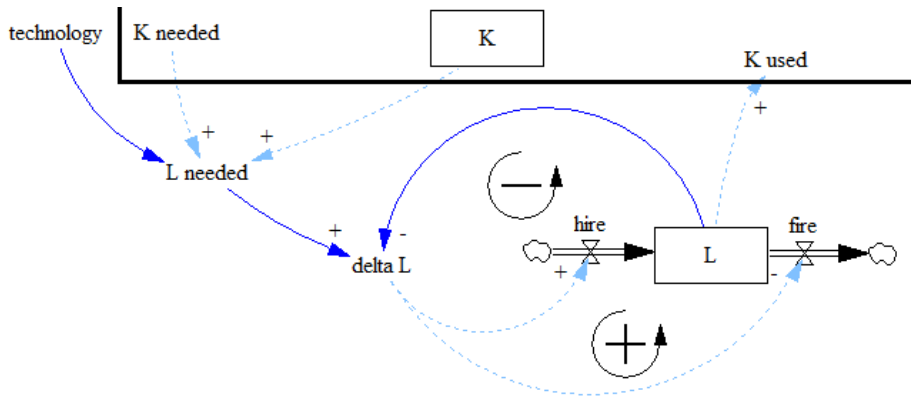

Fig. 6.4: labor adjustment.

Finally, production takes place on the basis of κ and L, closing the production process.

In sector I, the same dynamics take place. The only difference lies in the determination of φ_I. Here we have a second component, $K^p_{obsolete}$, which is directly added to the planned production. Given that $0 < \rho_I < 1$, the related geometric series converges to a finite number and this feedback loops dies out.

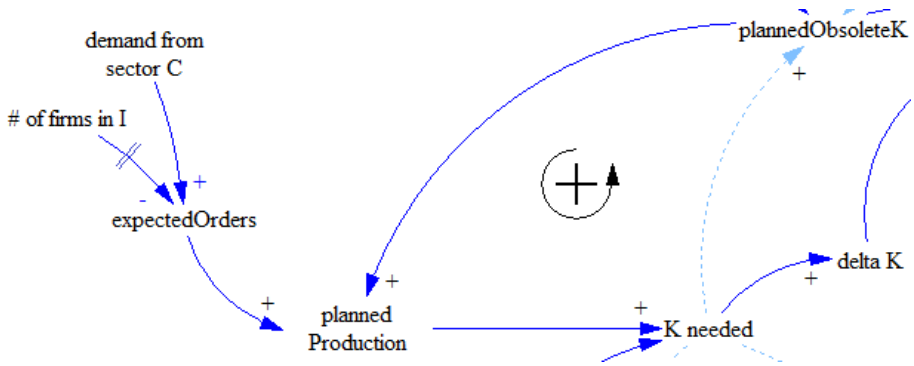

Fig. 6.5: planned production G_I.

Demand G_C

Concerning person agents' demand, we do not have feedback loops in version one. Demands takes place statically, according to our parametrization. The corresponding CLD representation is the following:

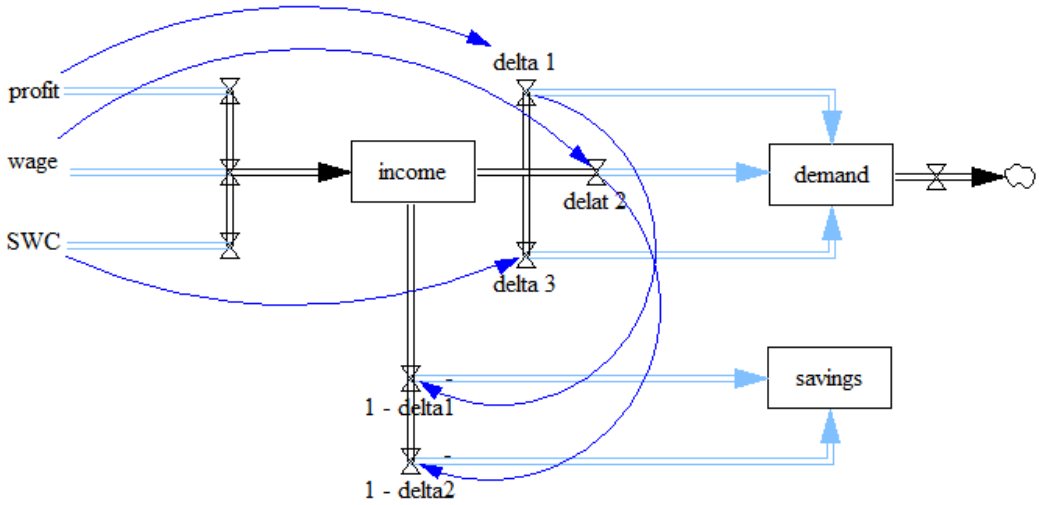

Fig. 6.6: demand G_C.

Set prices G_C, G_I

As mentioned in chapter 4, the WorldState sets prices so that they negatively depend on $A\varphi$ and positively on AD in value terms:

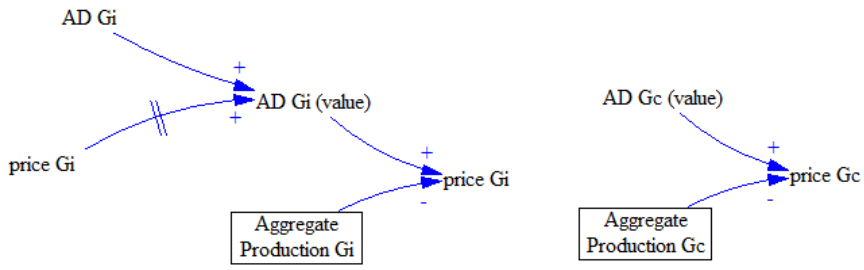

Fig. 6.7: set prices G_C and G_I.

Adjust capital C, I

Here an example of G_I substitution:

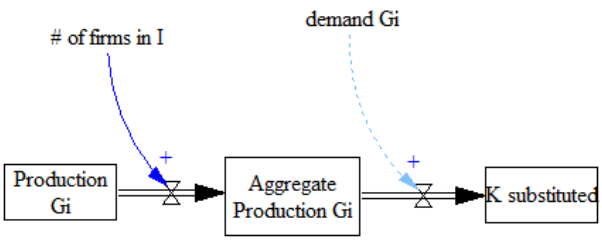

Fig. 6.8: adjust capital G_I.

Good I produced is aggregated and each firm subtracts its capital demand.

Calculate profit G_C

Just looking at the CLD representation, we can notice a negative feedback loop, which is related to the method `fireIfLosses`. A small number of employees are dismissed as profit turns negative. This reduces the cost of labor, and "positively" affect profit. The problem is that this relation does not holds *cæteris paribus*, for production is consequently reduced as well. Therefore, this feedback loop may be misleading, especially when small variations in sales make profit turn negative. Nonetheless, it is appropriate during downturns, when demand stays negative for some cycles. In this case, profit moves toward zero form below, as labor cost is cut.

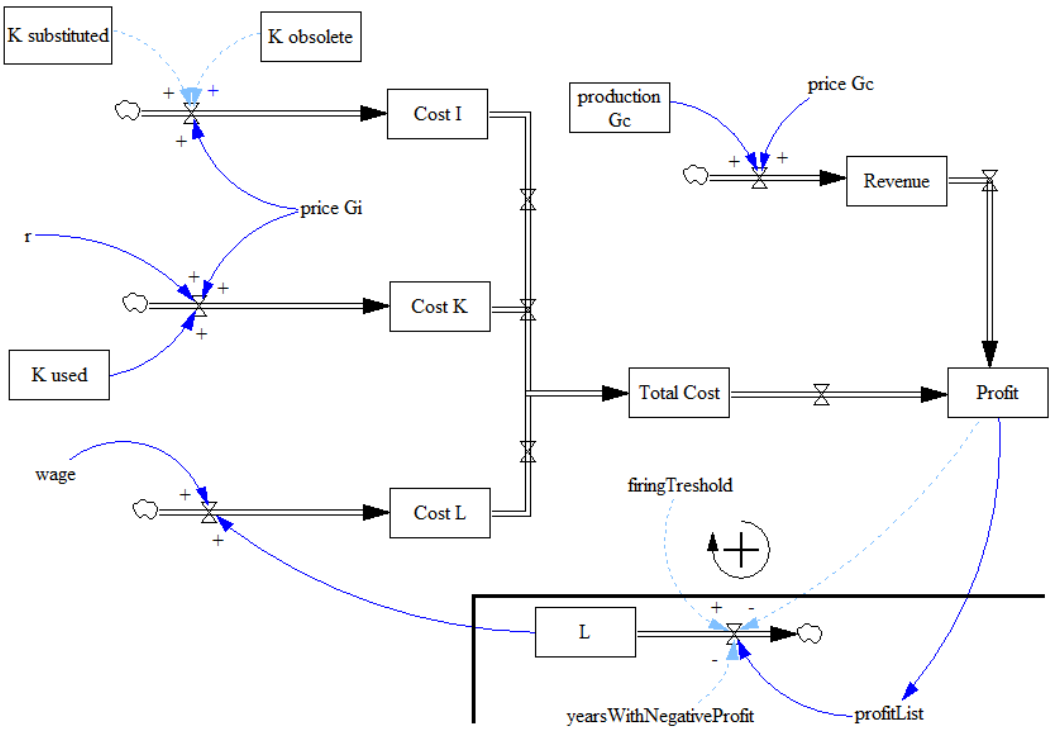

Fig. 6.9: calculate profit G_C.

Calculate profit G_I

In sector I, G_I is a production factor and an output as well. If considered together with `setPriceGi`, we can notice a double implication of quantity of G_I produced on profit. As $\varphi_{I,t}$ is increased at time t, the equilibrium price, $P^*_{I,t}$ declines, and with it the cost of K^s. However, the effect on profit is still undefined,

for it depends on how much revenue falls as well, as a result of price fall, and of how much cost rises, due to increased production.

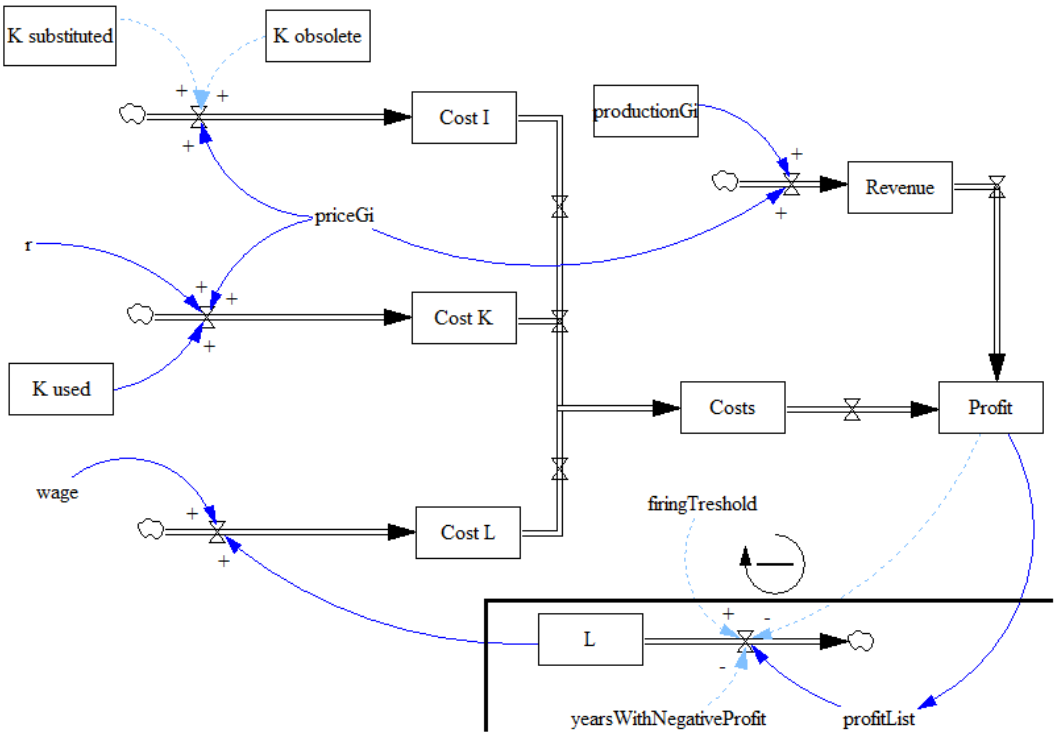

Fig. 6.10: calculate profit G_I.

Pitfalls of the systemic overview

By putting together all these sub-systems, we can appreciate a messy-at-first-look representation as the one in fig. 6.11.

This overview shows some trivial and non-trivial implications, and it is particularly helpful in analyzing the correlation table of macro-level time series. Moreover, we can notice that the whole system, so defined, relies upon few exogenous variables: population parameters and the interest rate. We well see later on that especially the former are essential in determining the evolution of the system in time.

However, CLD representation becomes burdensome and unclear, as the model boundaries are expanded. What has been gained in terms of understandability is lost into what is called in the jargon a "spaghetti" model.

On top of this, most of these causal relations are undefined in their outcome, for many relationships are non-linear or discontinuous, and the system is generally over-identified.

Therefore, we try now to move from the meso to the macro level, by analyzing a simulation run.

5.3 From Meso to Macro – version 1

In this section, we look first at version one with fixed wage and then compare the results with the variable-wage version.

5.3.1 Fixed wage

Graphic analysis

We launch a simulation of version 1.19 with 24 firms (4 in sector I, the rest in sector C) and 144 person agents. The simulation is set to run for 12 cycles. The random-number generator is initialized with seed number 2 and method `workTroubles` has been switched off.

Each simulation generates five graphical output. The first is a general overview. The second represents agent populations. The other three concern markets for labor, and both goods, G_C and G_I.

Here below we report them in full, in order to give a clearer interpretation to generated time series. After the first, general overview, a closeup on profit is taken. Recall that at time zero, parametrization is reported – cycles start from index 1.

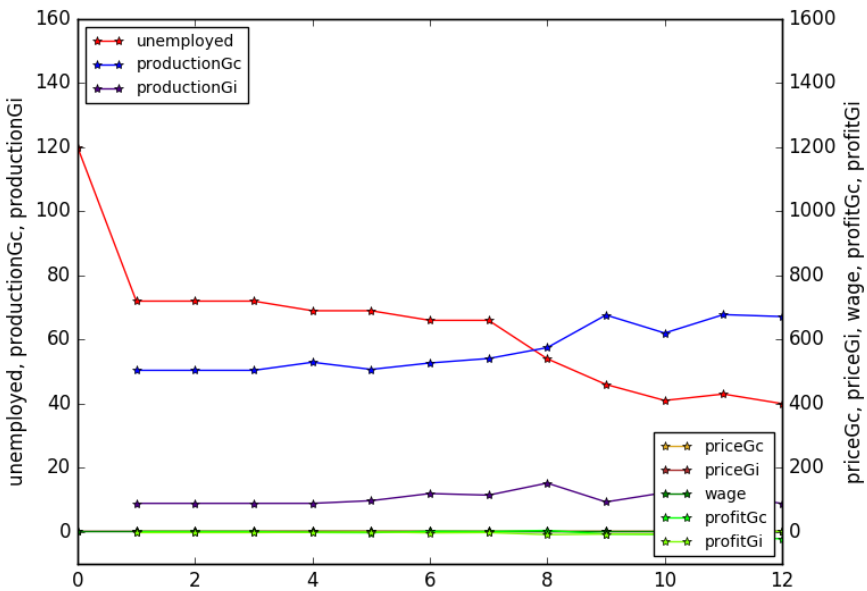

Fig. 6.12: A first run of version 1.19 – fixed wage.

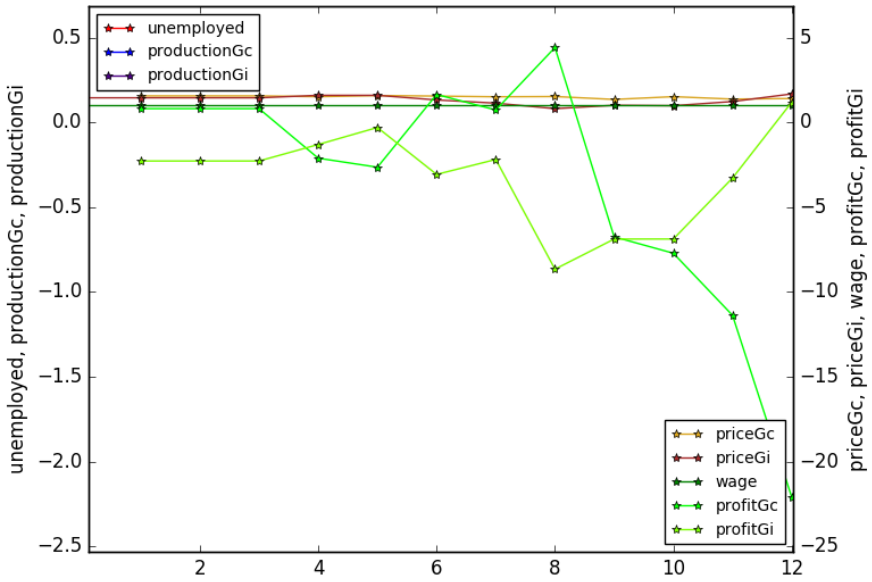

Fig. 6.13: A closer look at profit.

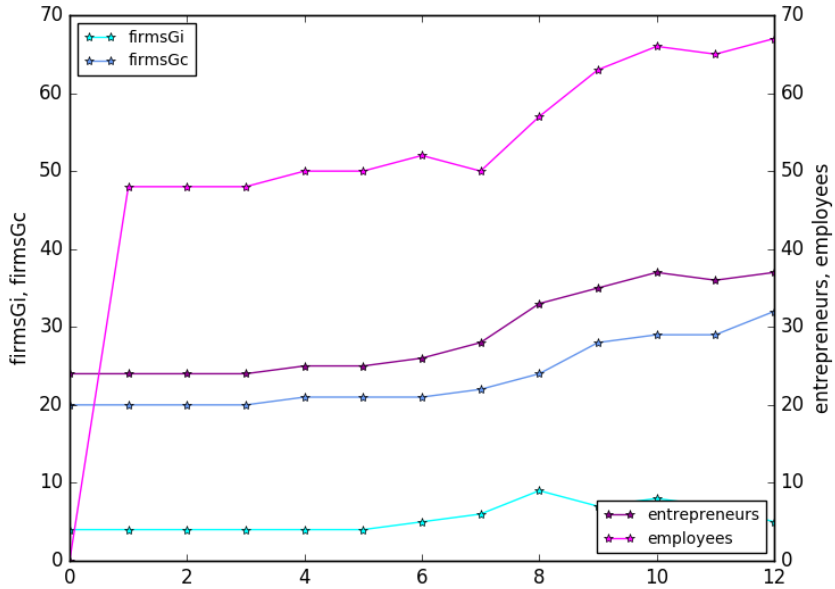

Fig. 6.14: populations.

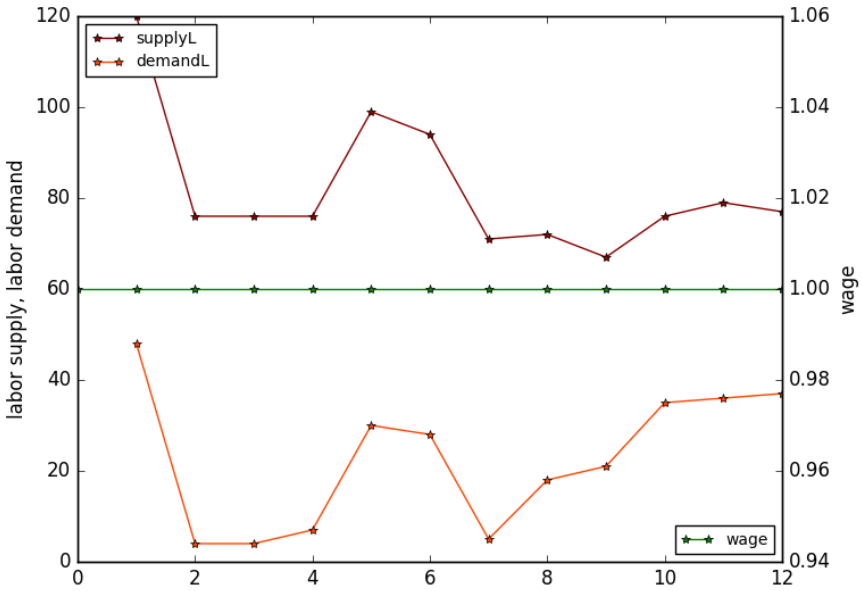

Fig. 6.15: labor market – fixed wage.

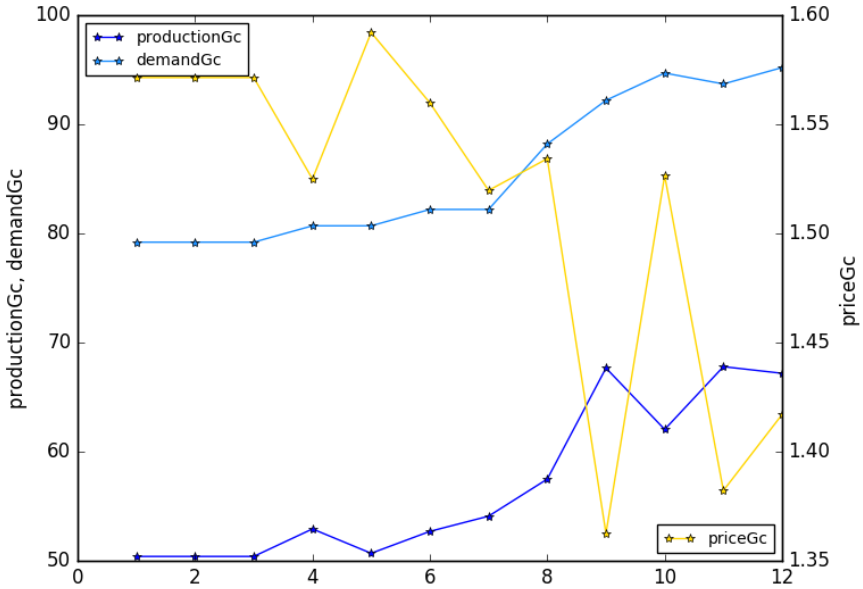

Fig. 6.16: consumption good market.

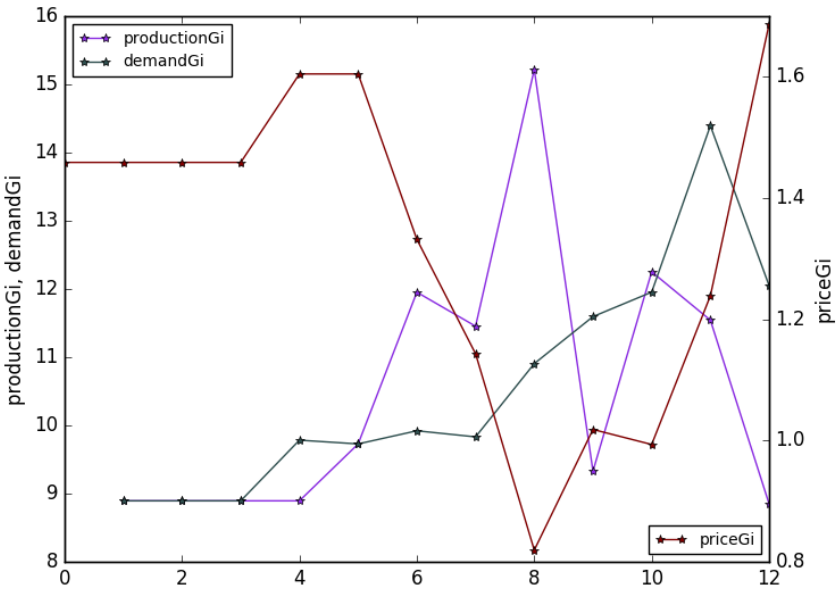

Fig. 6.17: investment good market.

We can notice first how flat the first three cycles are. Firms population remains stable until time $t = 4$. Indeed, firms in sector C make (slightly) positive profit in the first three cycles, but then their profit oscillates until cycle 9 and remain negative thereafter.

As firms in C make positive profit, their entrepreneurs increase demand for G_C one period after. Aggregate demand for good C is therefore pushed upwards and, with it, production of G_C. Firms in C place investment orders. Unemployment decreases.

Looking at the labor market, we can see that labor demand stays positive and, from the second cycle onwards, shows a fluctuating, but increasing trend.

As workers are hired, demand of G_C rises even more.

At time $t = 4$, the number of firms in C rises. By referring at page 109, and comparing numerical values, we can conclude that φ_C^p also rose, given that the increase in AD_C is larger than the number of firms entering the market for G_C – and P_C^* has been substantially constant a time $t = 2$.

Looking at the investment good market, we can notice a substantial increase in demand, as firms enter sector C at time $t = 4$. P_I^* consequently increases at time $t = 4$, and $t = 5$. Profit of firms in sector I moves toward zero from below.

While firms in sector I adapt their production capacity and deliver higher quantities of investment good, new firms enter the same sector between $t = 5$ and $t = 8$. Firm population in C increases less rapidly in the same period. This results

in a plunge of P_I^*, and, consequently, in a reverse, declining trend of Π_I.

The lower profit in sector I, the less firms therein, from time $t = 9$ onwards.

Back to sector C, we can notice double effect on AD_C. On the one hand, low profit in sector I decreased labor demand from time $t = 5$ to $t = 7$, and partially reduced AD_C. On the other hand, this effect on AD_C has been offset by a low P_I^*, which reduced cost in sector C. Consequently, Π_C turned into positive areas from time $t = 6$ to $t = 8$. All in all, AD_C increased.

At this point, firm population in C keeps increasing, pushing input demands, employment and AD_C upwards. φ_C increases relatively more than AD_C, and determines a plunge of P_C^* at $t = 9$. As AD_C stabilizes itself, φ_C and P_C^* offset one against the other.

On the G_I market, a low number of producing firms and a rising AD_I from sector C push P_I^* upwards and Π_I toward positive values from time $t = 8$ on. Profit in C turns negative, which contributes to stabilization of AD_C.

Correlation table

When looking at correlations, the correlation table captures several model implications outlined in CLDs. Some instances thereof are the positive correlation between aggregate production in a sectors and demand of the related good.

With respect to fig. 6.7, aggregate production and price in the same sector are negatively correlated. On the contrary, we find a negative relation between price and aggregate demand in both sectors, which contradicts CLD representation.

The number of firms in a sector is negatively correlated with profit and positively with $A\varphi$ therein. This sounds interesting, given that firm entry/exit is not programmed to be linked to profitability of a sector.

Nonetheless, we can explain this relation intuitively. As the number of employees increases, there is a higher probability that a new firm is established. Firms then share the aggregate demand in that sector. As each firm share decreases, profit turn negative. As time goes by, the number of firm decreases because of the "no-more-than-four-years-with-negative-profit" rule. Then, production shares increase again, and profits turn positive.

By the same token, a high demand for a good sustains firm population in that sector. This is captured by the high correlation between the two.

The negative relation between profit and $A\varphi$ in one sector represents another counterintuitive implication at first. However, this becomes understandable, if we look at the positive correlation between profit and prices, and it is, however, in line with the relation between firm population and profits that we have seen above.

Finally, we can notice a positive link between the two ADs. This is explained by model structure, given that demand of G_I from sector C is augmented by "direct" investment, when firms in C face a particularly high demand.

	employees	unemployed	firmsGc	firmsGi	productionGc
employees	1.00	-1.00	0.98	0.66	0.96
unemployed	-1.00	1.00	-0.98	-0.71	-0.96
firmsGc	0.98	-0.98	1.00	0.58	**0.96**
firmsGi	0.66	-0.71	0.58	1.00	0.62
productionGc	0.96	-0.96	**0.96**	0.62	1.00
productionGi	0.27	-0.32	0.17	**0.81**	0.17
priceGc	-0.79	0.79	-0.82	-0.44	**-0.93**
priceGi	-0.35	0.41	-0.25	-0.90	-0.34
profitGc	-0.79	0.75	**-0.86**	-0.09	**-0.78**
profitGi	-0.32	0.36	-0.19	**-0.83**	-0.28
demandGc	1.00	-1.00	0.98	0.71	**0.96**
demandGi	0.91	-0.91	0.88	0.65	0.91
demandL	0.47	-0.45	0.45	0.15	0.38
supplyL	-0.40	0.43	-0.41	-0.48	-0.46

Table 5.1: correlation table 1/3 – fixed wage.

	productionGi	priceGc	priceGi	profitGc	profitGi
productionGi	1.00	0.02	-0.78	0.27	**-0.69**
priceGc	0.02	1.00	0.23	**0.70**	0.16
priceGi	**-0.78**	0.23	1.00	-0.27	**0.94**
profitGc	0.27	0.70	-0.27	1.00	-0.32
profitGi	-0.69	0.16	0.94	-0.32	1.00
demandGc	0.32	**-0.79**	-0.41	-0.75	-0.36
demandGi	**0.34**	-0.81	**-0.34**	-0.69	-0.26
demandL	0.06	-0.23	0.05	-0.46	0.02
supplyL	-0.22	0.47	0.41	0.20	0.34

Table 5.2: correlation table 2/3 – fixed wage.

	demandGc	demandGi	demandL	supplyL
demandGc	1.00	0.91	0.45	-0.43
demandGi	**0.91**	1.00	0.44	-0.36
demandL	0.45	0.44	1.00	0.62
supplyL	-0.43	-0.36	0.62	1.00

Table 5.3: correlation table 3/3 – fixed wage.

5.3.2 Variable wage

We consider now version 1.20, which allows for a variable wage. On this basis, all workers are equally payed, as in the previous version.

Wage formation

The wage is formed as a weighted average of two components. The fist one depends on the average price change at $t-1$. It is calculated by simple averaging first-price differences, and weighted by a small 1% coefficient (weight1). The second one is an autoregressive component of the wage itself at one lag (AR(1)), weighted by a coefficient of 0.99 (weight2).

In this sway, we can model a persistent wage that is positively correlated with the overall price change. Given that weight2 falls between zero and one, the AR component drives the wage slightly below its lagged value.

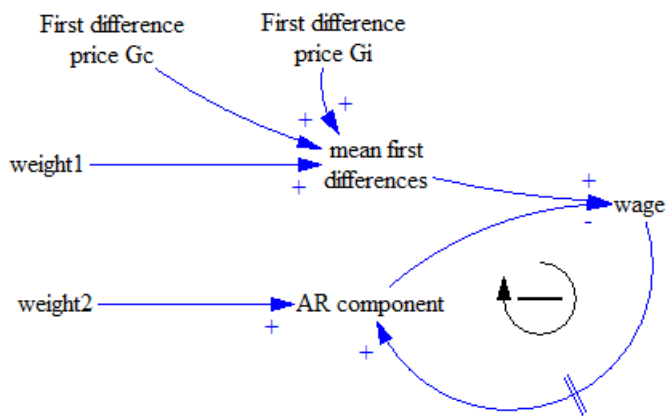

Fig. 6.18: wage formation.

Graphic analysis

We analyze now the same simulation setting as at page 112 with a variable wage, as specified here above.

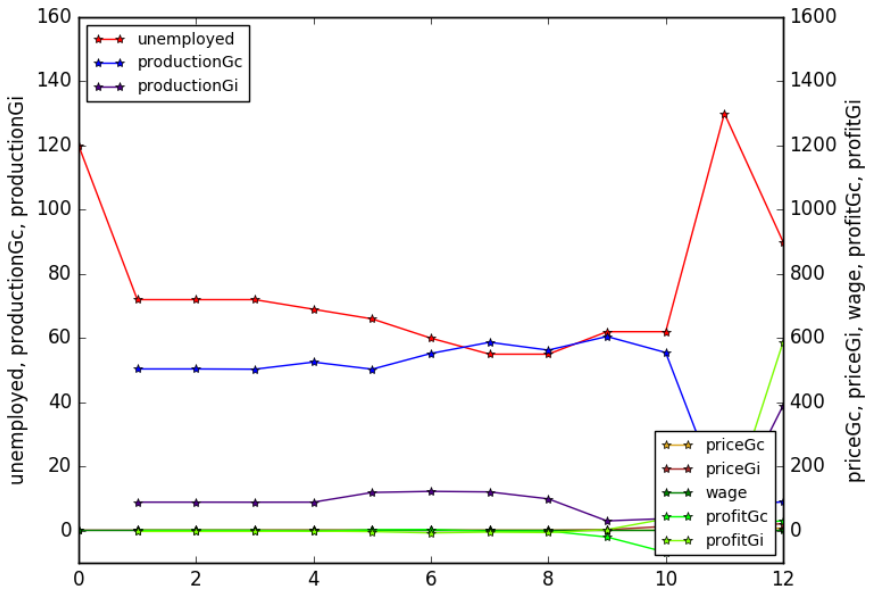

Fig. 6.19: Version 1.20 – variable wage.

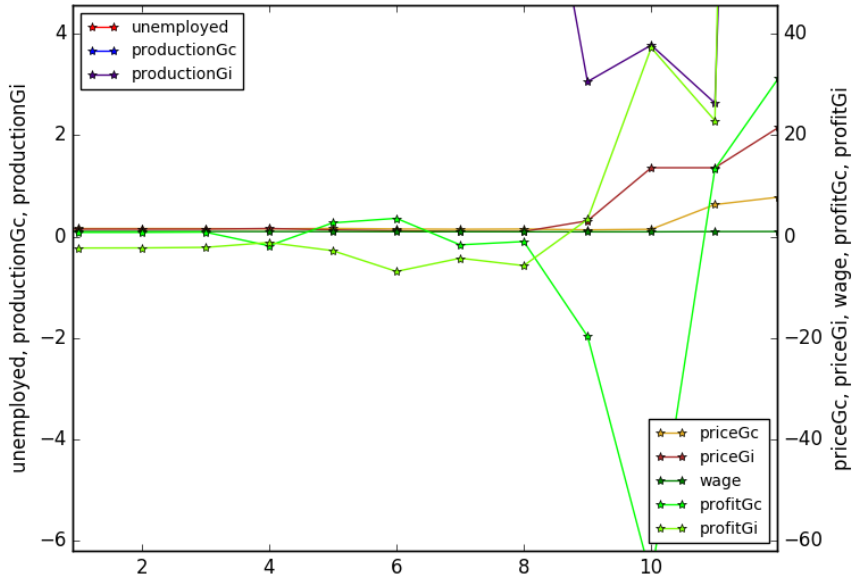

Fig. 6.20: A closer look at profit.

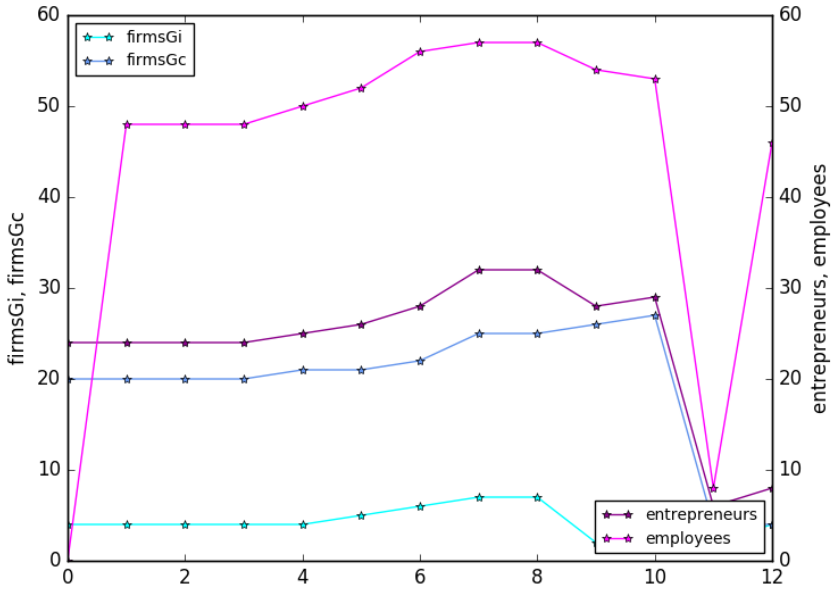

Fig. 6.21: populations.

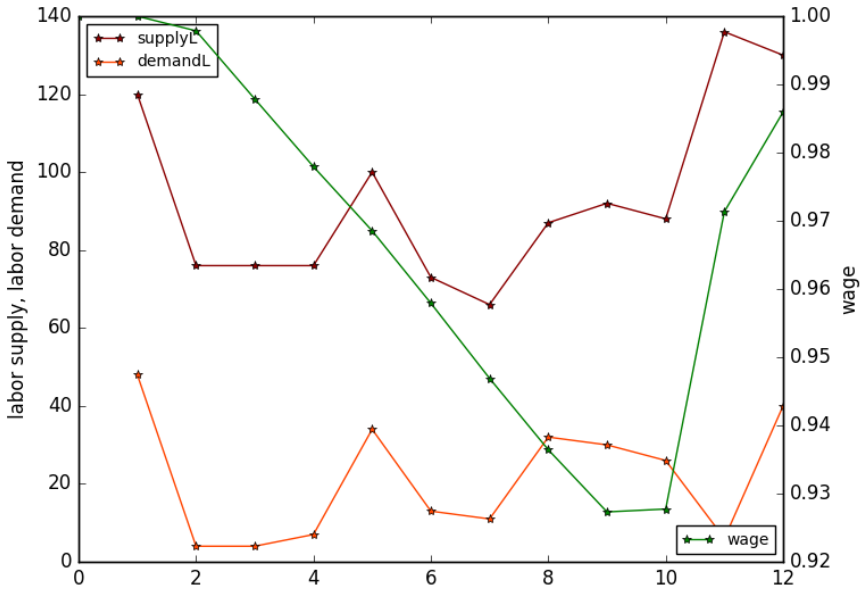

Fig. 6.22: labor market – variable wage.

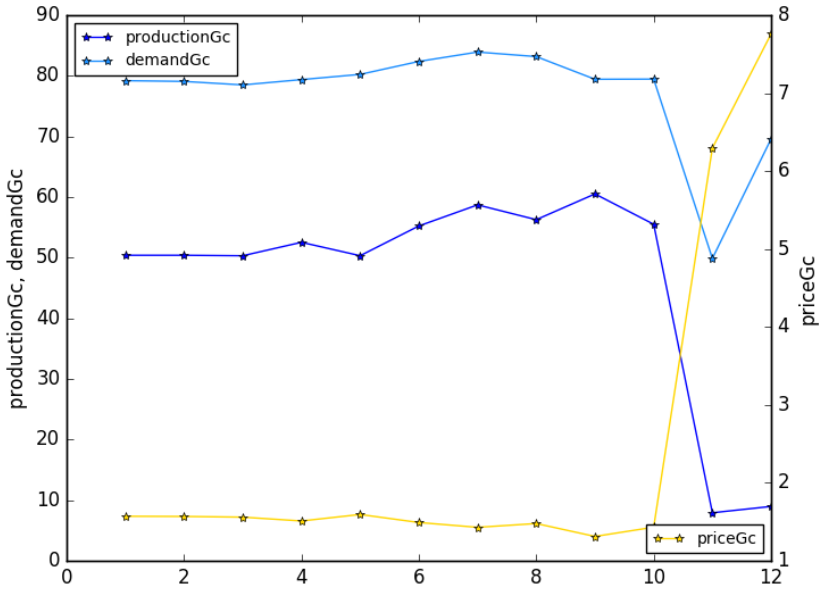

Fig. 6.23: consumption good market.

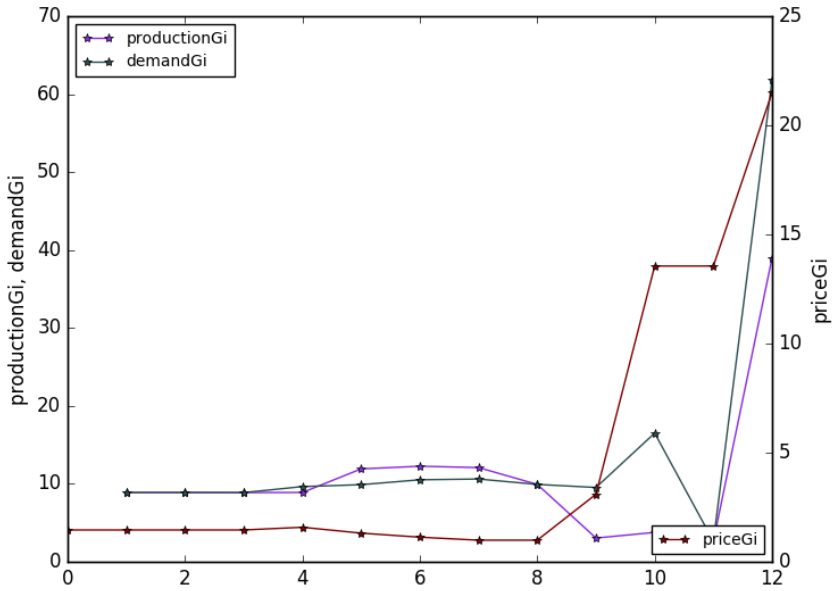

Fig. 6.24: investment good market.

A focus on prices is added here below. In order to make a comparison with the previous version, the y-axis has been reshaped.

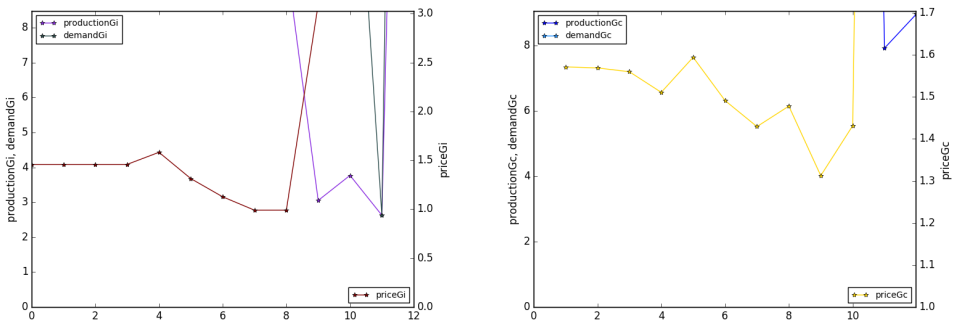

Fig. 6.25: focus on prices.

In comparison with version 1.19, we can notice a decrease of P_C^* already at time $t = 3$. Although P_I^* remains constant until time $t = 3$, we can retrace wage decrease to the wage formation mechanism: the wage is pushed down by both, average price decrease – driven by P_C^* – and the AR component. Wage decreases of about 1% until time $t = 9$, thanks to opposite price changes within the two sectors.

Consequently, income is reduced, but firm entrance after time $t = 4$ reverses this effect, by pushing employment upwards.

As employment and firm population increase, AD_C goes up as well. However, firm population increases relatively more. Therefore, market share of firms in C shrinks, while φ_C^p must have risen in absolute terms.

Indeed $A\varphi_C$ increases up to time $t = 9$. This explains the positive gap between $A\varphi_I$ and AD_I. *I.e.*, firms in I increased production capacity from time $t = 5$ until $t = 7$. Their profit are in facts negative in the same time period.

Consequently, many firms in I went bankrupt at time $t = 8$, and $A\varphi_I$ plunges at time $t = 9$, while we face a constant AD_I. As a result, P_I^* increases soon after, and profit in sector C sinks even more.

As some firms in I go bankrupt, unemployment rises slightly at time $t = 9$ and remains constant at $t = 10$, due to firm entrance in C.

Overall, AD_C shrinks. As firm in C have realized it, labor demand decreases even more, while labor supply increases.

Given that Π_C has been already negative at time $t = 6$ and $t = 7$, many firms in C go bankrupt between time $t = 10$ and $t = 11$. Consequently, $A\varphi_C$ drops and unemployment rises dramatically at time $t = 11$, pushing AD_C downwards. For $A\varphi_C$ decrease more in relative terms, P_C^* rockets.

The few remaining firms in C end up sharing a relatively high demand of C, which fosters them to place labor and capital demand anew. Therefore, P_I^* increases again after time 11, and firms in sector I enjoy even higher profit.

In comparison with the fixed-wage case, we can notice that fluctuations are of a higher magnitude.

Price fluctuations are transferred to wages, which affect AD_C, $A\varphi_C$ and capital investment. This result in a fluctuation-amplifying mechanism, which endangers firm-population survival in longer time simulations.

Correlation table

By comparing correlations with those calculated for version 1.19, we can generally see how key relationships have been preserved.

Correlation between $A\varphi_C$ and F_C, as well as that between the former and AD_C are very high. $A\varphi_C$ and P_C^* are still highly and negatively related, as well as Π_C and $A\varphi_C$, or F_C and Π_C. Positive relationships with $A\varphi_I$ are still shown for F_I and AD_I, even though by a different magnitude.

On the contrary, some other relationships show opposite sign or no correlation at all. The former case concerns AD_I and P_I^*, for instance. The latter case regards $A\varphi_I$ and AD_C, which are here practically not correlated. $A\varphi_I$ and $A\varphi_C$ are now negatively related, while they shown a positive correlation before. AD_I and Π_C are also reversed in correlation sign, which is now in accordance with the positive relation between Π_C and P_C^*.

Concerning the wage, we find a negative correlation with AD_C, even though we would expect it positive by model construction. This is probably linked to the scenario described above in the last cycles of the simulation, where AD_C decreased consistently because of bankruptcies, while the wage has risen due to high increase in prices. Indeed, we find a positive correlation between the wage and P_C^*, albeit no correlation with respect to P_I^* is shown. Generally, a high persistence is captured by wage correlation with its own lag.

Wage regression

If we focus on the relation between wage, its one-time lagged value and first differences in prices, we can analyze the OLS results at page 126, where the wage mechanism has been inferred from generated data.

Even though autocorrelation should be taken into account, we can still look at OLS coefficients for an indicative purpose. Indeed, coefficients for price difference lie around the *actual* 0.01 weight, while the relation between wage and its lagged value (if we consider constant prices) is 0.9915, which is even closer to the 99% weight as price-difference coefficients are.

	employees	unemployed	firmsGc	firmsGi	productionGc
employees	1.00	-0.97	0.77	0.51	0.78
unemployed	-0.97	1.00	-0.89	-0.52	-0.90
firmsGc	0.77	-0.89	1.00	0.28	**0.98**
firmsGi	0.51	-0.52	0.28	1.00	0.34
productionGc	0.78	-0.90	0.98	0.34	1.00
productionGi	0.15	0.07	-0.51	**0.28**	-0.49
priceGc	-0.66	0.80	-0.95	-0.28	**-0.98**
priceGi	-0.46	0.60	-0.69	-0.49	-0.79
wage (t)	-0.30	0.39	-0.52	-0.03	-0.39
profitGc	-0.31	0.42	**-0.67**	0.35	**-0.55**
profitGi	-0.09	0.31	-0.65	-0.10	-0.68
demandGc	0.97	-0.99	0.85	0.54	**0.88**
demandGi	0.10	0.12	-0.50	-0.02	-0.53
demandL	0.27	-0.18	0.01	0.00	-0.04
supplyL	-0.67	0.76	-0.77	-0.45	-0.81
wage (t-1)	0.28	-0.20	-0.01	0.32	0.13

Table 5.4: correlation table 1/3 - variable wage.

	productionGi	priceGc	priceGi	wage (t)	profitGc
productionGi	1.00	0.61	0.50	0.33	0.58
priceGc	**0.61**	1.00	0.85	0.28	0.54
priceGi	**0.50**	0.85	1.00	-0.01	0.05
wage (t)	0.33	0.28	-0.01	1.00	0.61
profitGc	0.58	0.54	0.05	0.61	1.00
profitGi	0.91	0.79	0.79	0.22	0.42
demandGc	**-0.02**	-0.80	-0.64	**-0.24**	-0.33
demandGi	**0.93**	0.66	0.72	0.15	**0.32**
demandL	0.35	0.12	0.22	-0.10	-0.02
supplyL	0.30	0.78	0.67	0.28	0.35
wage (t-1)	0.31	-0.18	-0.40	**0.79**	0.44

Table 5.5: correlation table 2/3 – variable wage.

	profitGi	demandGc	demandGi	demandL	supplyL
profitGi	1.00	-0.29	0.98	0.38	0.52
demandGc	-0.29	1.00	-0.11	0.17	-0.76
demandGi	0.98	-0.11	1.00	0.42	0.39
demandL	0.38	0.17	0.42	1.00	0.51
supplyL	0.52	-0.76	0.39	0.51	1.00
wage (t-1)	0.05	0.34	0.08	-0.35	-0.39

Table 5.6: correlation table 3/3 – variable wage.

Dep. Variable:	wage	**R-squared:**	0.928
Model:	OLS	**Adj. R-squared:**	0.892
Method:	Least Squares	**F-statistic:**	25.88
No. Observations:	10	**Prob (F-statistic):**	0.000785
Df Residuals:	6	**Log-Likelihood:**	37.194
Df Model:	3	**AIC:**	-66.39
		BIC:	-65.18

	coef	**std err**	**t**	**P>|t|**	**[0.025**	**0.975]**
Intercept	-0.0607	0.129	-0.470	0.655	-0.377	0.255
D_priceGc_1L	0.0075	0.002	3.144	0.020	0.002	0.013
D_priceGi_1L	0.0135	0.003	4.946	0.003	0.007	0.020
wage_1L	1.0522	0.134	7.873	0.000	0.725	1.379

Omnibus:	10.043	**Durbin-Watson:**	3.007
Prob(Omnibus):	0.007	**Jarque-Bera (JB):**	4.223
Skew:	-1.205	**Prob(JB):**	0.121
Kurtosis:	5.081	**Cond. No.**	125.

Table 5.7: wage – OLS regression results.

5.4 Version 2 – decentralized markets

As described in chapter 4, agents can revise reservation prices and wage in version 2.

Comparison with version 1 will be just partially possible. In facts, outcomes of the trade processes are not only determined by agents' behavioral rules – which differ consistently with respect to the price determination mechanism in version one, but also by the order upon which agent interact. Even if we preserve the same agent ordering, repeated trade rounds render this effort vain.

Nonetheless, we will point out some common regularities in the time series generated.

In order to appreciate these dynamics, we compare three simulation runs.

1. At first, we consider a parametrization comparable with version one;

2. A second simulation considers a longer time horizon;

3. Initial populations change in the third run.

5.4.1 Version 2 – First run

We set up our simulation by considering parametrization used at page 112 and run it for 12 cycles.

Graphic analysis

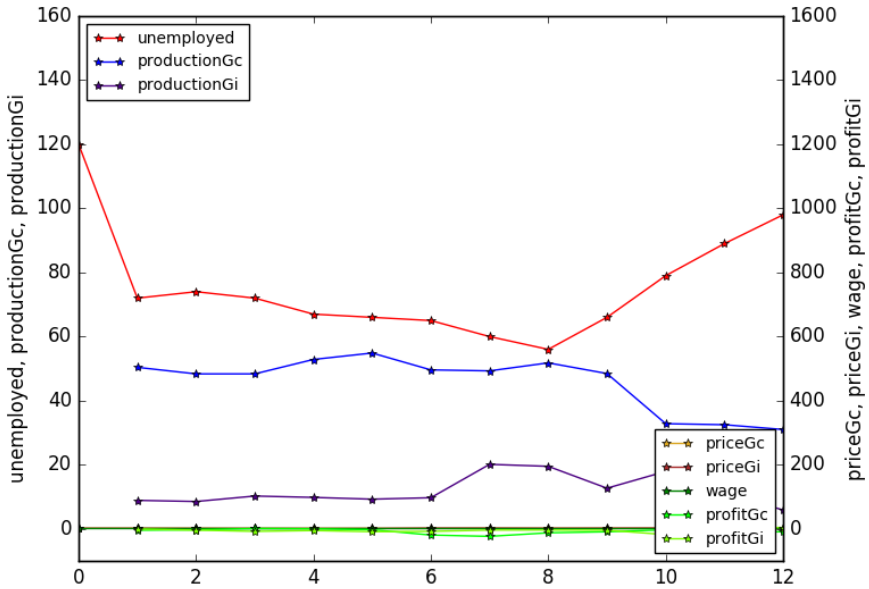

Fig. 6.26: Version 2.09 – decentralized markets.

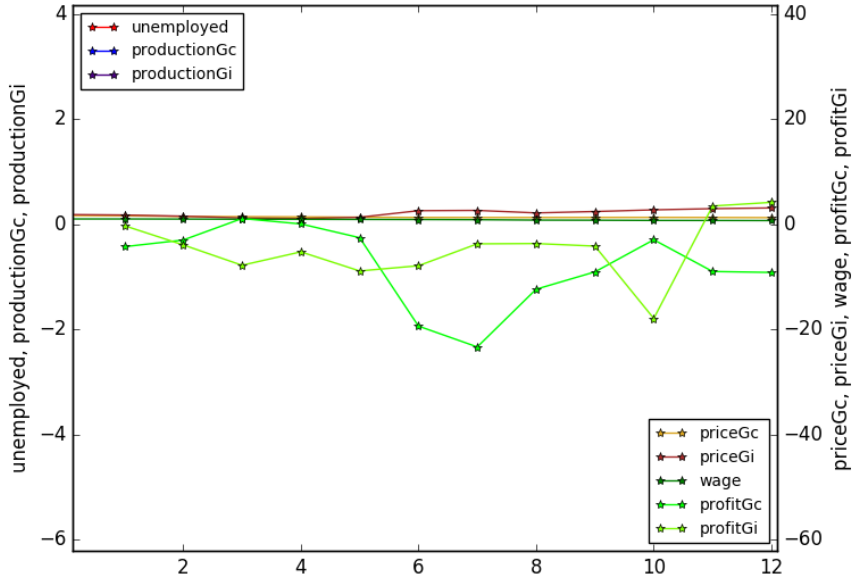

Fig. 6.27: A closer look at profit.

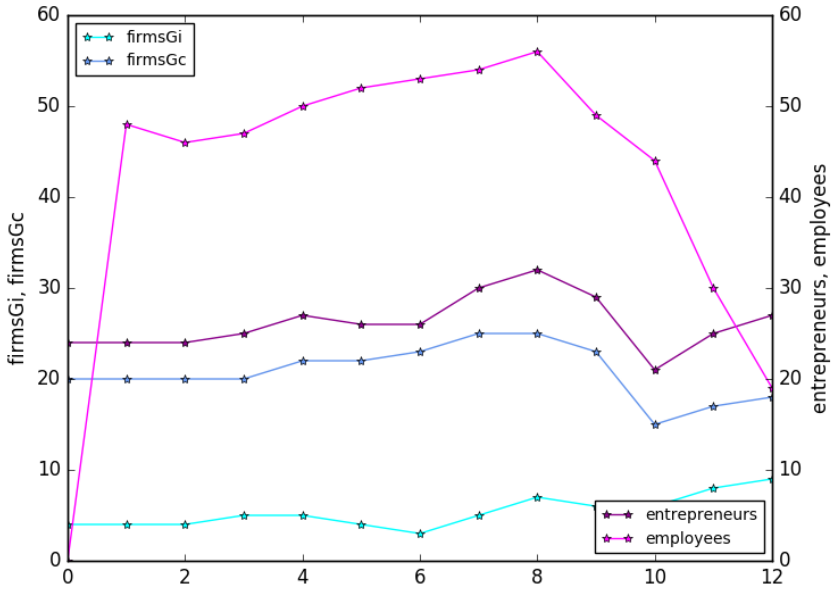

Fig. 6.28: populations.

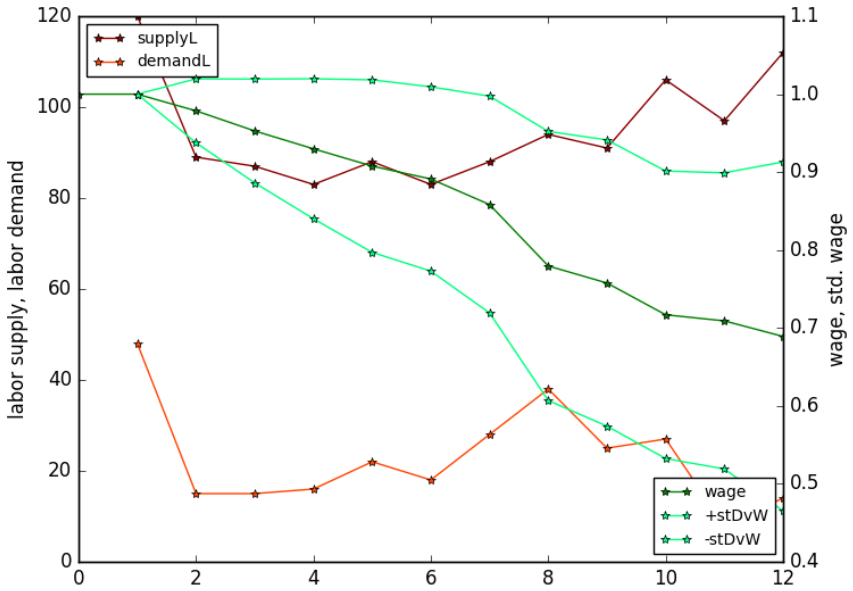

Fig. 6.29: decentralized labor market.

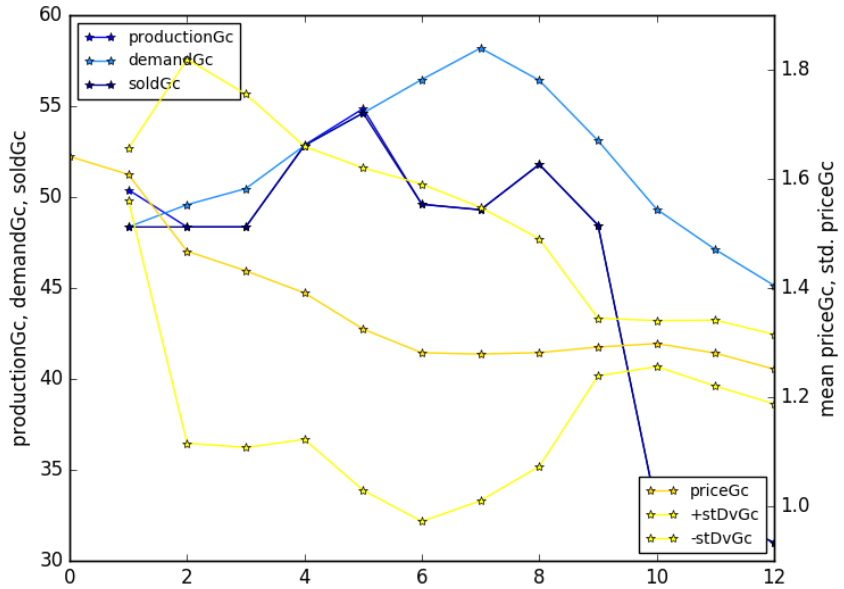

Fig. 6.30: consumption good market.

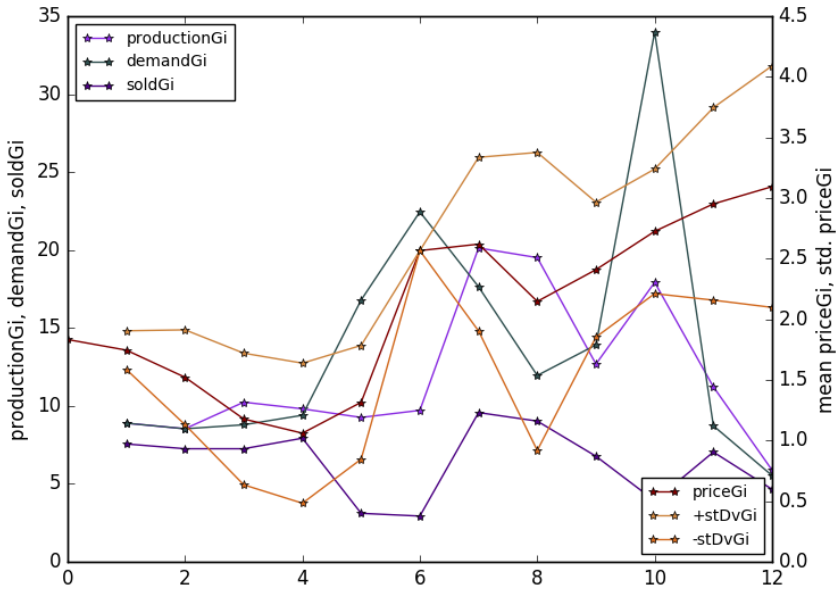

Fig. 6.31: investment good market.

Looking at fig. 6.26, we can already recognize a similar representation as in fig. 6.19. Unemployment follows a slight decrease and rises from time $t = 8$ onwards. $A\varphi_C$ remains now substantially constant and decreases after time 8, as in version 1.20. $A\varphi_I$ increases more at time $t = 7$ and drop at time $t = 9$.

Profits in C remain negative, plunge at time $t = 6$ and recovers afterwards. Π_I moves in the opposite direction and turns positive after time $t = 10$.

Similarities appear in the other graphs as well. Firm population in C generally rises with employment in the first half, while drops significantly in the second one, determining a drastic plunge of the employment level – as in figure 6.21. On the contrary, the number of firms in sector I remains higher in the last cycles.

Labor demand rises on average from time $t = 2$ to $t = 8$ and sinks afterwards. Supply rises exponentially, but reaches a lower peak, while the average wage decreases constantly and does not show any upswing. Wage standard deviation increases as simulation goes on.

Same tendencies are observed in fig. 22, even though the average wage decreases less in magnitude and shows an increase at time $t = 11$ and $t = 12$.

P_C remains in range (1., 2.) and does not increase consistently as production falls, as in fig. 6.23. Demand of C is sensibly lower. Both, $A\varphi_C$ an AD_C, decline, with respect to their initial values. Drop in production and demand appear here less sudden and of a lower magnitude.

Concerning prices of G_I, we see a different trend. A decrease in P_I takes place

	priceGc	priceGi	wage		priceGc	priceGi	wage
count	12.00	12.00	12.00	count	12.00	12.00	12.00
mean	2.42	5.17	0.97	mean	1.35	2.11	0.85
std	2.18	6.95	0.03	std	0.11	0.72	0.11
min	1.31	0.99	0.93	min	1.25	1.06	0.69
25%	1.47	1.27	0.94	25%	1.28	1.47	0.75
50%	1.54	1.46	0.97	50%	1.29	2.28	0.87
75%	1.58	5.71	0.99	75%	1.40	2.65	0.94
max	7.76	21.50	1.00	max	1.61	3.09	1.00

Table 5.8: variable wage (left) and decentralized markets (right).

in the first cycles. Then it increases afterwards – which is exactly the opposite as in fig. 6.25, until time $t = 8$. Prices of G_I are slightly higher than in fig. 6.25, but do not explode as in version 1.20 after time $t = 8$.

Comparing descriptive statistics for prices (table 5.8), we can notice how max. values have driven mean and standard deviation (std) upwards in version 1, while they are not observed in version 2. By considering just the lower 75% of the sample, we can see that price for G_C and wage have been generally higher in version 1, while the contrary holds for prices of G_I. The mean value for wage is lower in version 2, while its standard deviation is higher 2.

Correlation table

Some key featured of the model are captured by the correlation table also in version 2.

As in version 1, $A\varphi_C$ is highly correlated with F_C and AD_C, while $A\varphi_I$ is such with respect to P_I and AD_I.

However, $A\varphi_C$ and P_C show now a positive relationships, while they were strongly negative related in version 1. Indeed, firms increase the price of a small amount, when they have placed all supply. Conversely, hey lower the price if excess of supply is registered. In this case, aggregate demand at time t has been lower than planned, and production at $t+1$ will be decreased, *cteris paribus*. So, as the price is low, production has already been cut, while the contrary holds as well.

Firms in C and Π_C are still negatively related, while Firms in one sector are not correlated with profit in the other sector anymore.

In sector I, $A\varphi_I$ and F_I are almost not correlated anymore. The former maintains a correlation with P_I, but displays a negative one with P_C – which was 0.61 in version 1.

	employees	unemployed	firmsGc	firmsGi	productionGc
employees	1.00	-0.97	0.70	-0.74	0.85
unemployed	-0.97	1.00	-0.83	0.61	-0.86
firmsGc	0.70	-0.83	1.00	-0.36	**0.80**
firmsGi	-0.74	0.61	-0.36	1.00	-0.73
productionGc	0.85	-0.86	0.80	-0.73	1.00
productionGi	0.47	-0.52	0.31	**0.10**	0.05
priceGc	0.21	-0.08	-0.10	-0.51	**0.37**
priceGi	-0.51	0.44	-0.26	0.59	-0.73
wage (t)	0.55	-0.46	0.33	-0.84	0.75
profitGc	-0.15	0.27	-0.51	-0.03	**0.00**
profitGi	-0.53	0.39	0.08	0.47	-0.18
demandGc	0.84	-0.91	0.86	-0.49	**0.71**
demandGi	0.34	-0.23	-0.13	-0.27	-0.12
demandL	0.48	-0.48	0.31	-0.23	0.37
supplyL	-0.52	0.55	-0.54	0.40	-0.52
wage (t-1)	0.66	-0.60	0.47	-0.81	**0.81**

Table 5.9: correlation table 1/3 – decentralized markets.

A positive relationship links now $A\varphi_I$ and AD_C, which is consistent with the model, for firm in C invest when facing particularly high AD_C – in version 1 we had no correlation.

Looking at the wage, the model shows a clear correlation between wage and P_C, as well as between wage and F_C – negative in version 1.

Concerning the lagged wage, it shows now a strong correlation with $A\varphi_C$, as modeled by the relation between φ_C and income. In version 1, the correlation was substantially absent. Moreover, correlation with wage and its lagged value is very high, as well as its relation with P_C. A positive correlation is found between the lagged wage and demand for C, which is consistent with model construction.

On top of this, supply of labor and wage are negatively related, while the wage and labor demand are positively related. This is a particularly interesting, for it relates period of high unemployment with low wages and *vice versa*. Also this latter relation was not spotted from data of version 1, where the respective signs were inverted.

	productionGi	priceGc	priceGi	wage (t)	profitGc
productionGi	1.00	-0.37	0.27	-0.30	-0.44
priceGc	**-0.37**	1.00	-0.64	**0.79**	0.52
priceGi	**0.27**	-0.64	1.00	-0.81	-0.63
wage (t)	-0.30	0.79	-0.81	1.00	0.28
profitGc	-0.44	0.52	-0.63	0.28	1.00
profitGi	-0.38	0.05	0.25	-0.12	-0.21
demandGc	**0.56**	-0.28	-0.17	0.23	-0.54
demandGi	**0.53**	-0.34	0.28	-0.23	-0.21
demandL	0.41	0.39	-0.07	**0.21**	-0.13
supplyL	-0.13	0.29	0.37	**-0.26**	0.14
wage (t-1)	-0.12	**0.77**	-0.85	**0.98**	0.22

Table 5.10: correlation table 2/3 – decentralized markets.

	profitGi	demandGc	demandGi	demandL	supplyL
profitGi	1.00	-0.35	-0.83	-0.11	0.28
demandGc	-0.35	1.00	0.35	0.26	-0.66
demandGi	-0.83	0.35	1.00	0.17	-0.07
demandL	-0.11	0.26	0.17	1.00	0.47
supplyL	0.28	-0.66	-0.07	0.47	1.00
wage (t-1)	-0.30	**0.47**	-0.13	0.01	-0.80

Table 5.11: correlation table 3/3 – decentralized markets.

5.4.2 Version 2 – Second run

By maintaining the same parametrization, we run version 2 for 40 cycles.

Graphic analysis

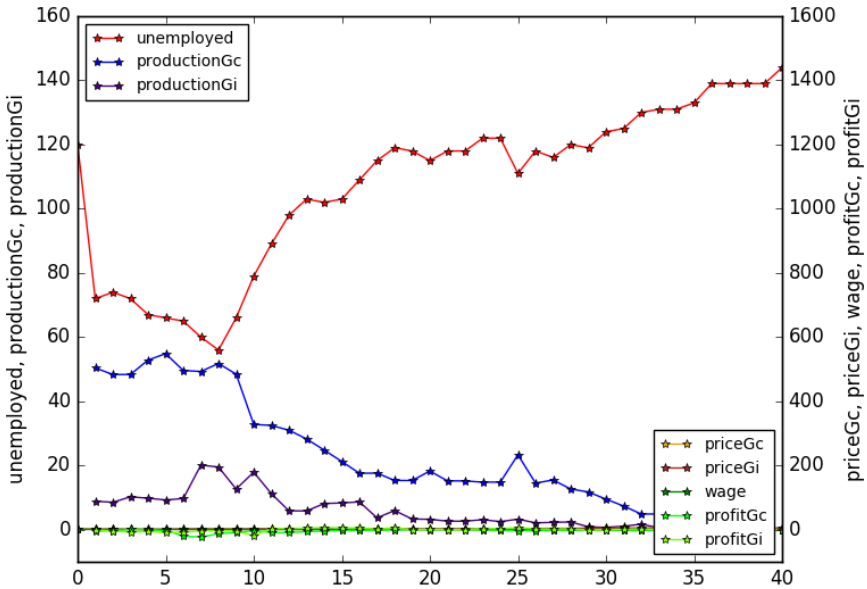

Fig. 6.32: Version 2.09 – decentralized markets.

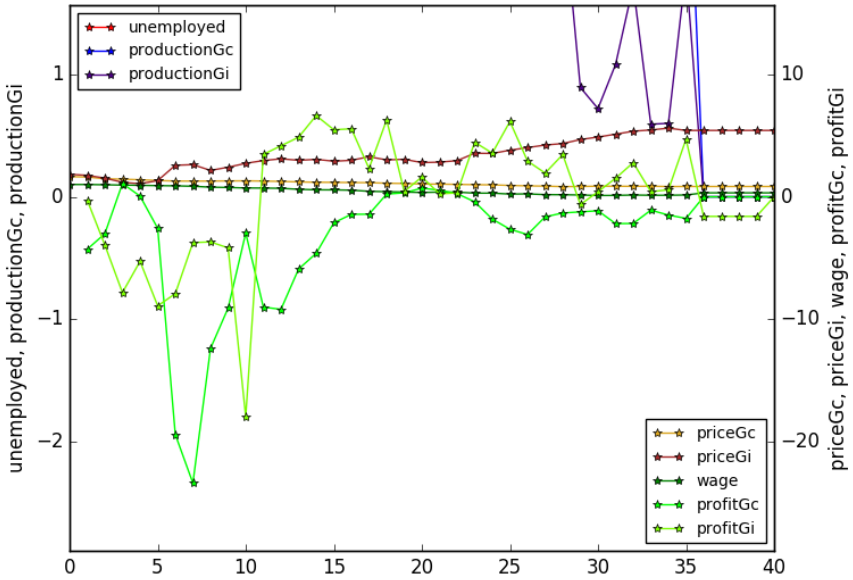

Fig. 6.33: A closer look at profit.

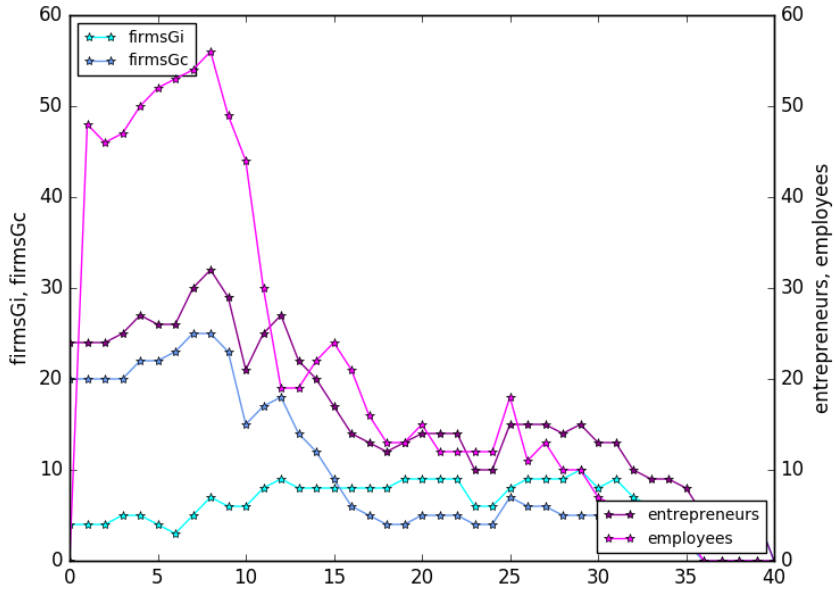

Fig. 6.34: populations.

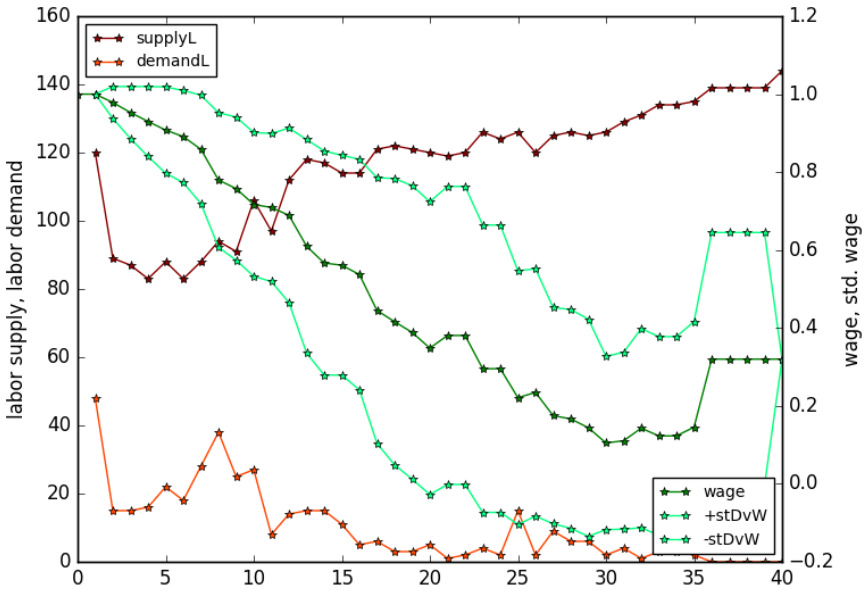

Fig. 6.35: decentralized labor market.

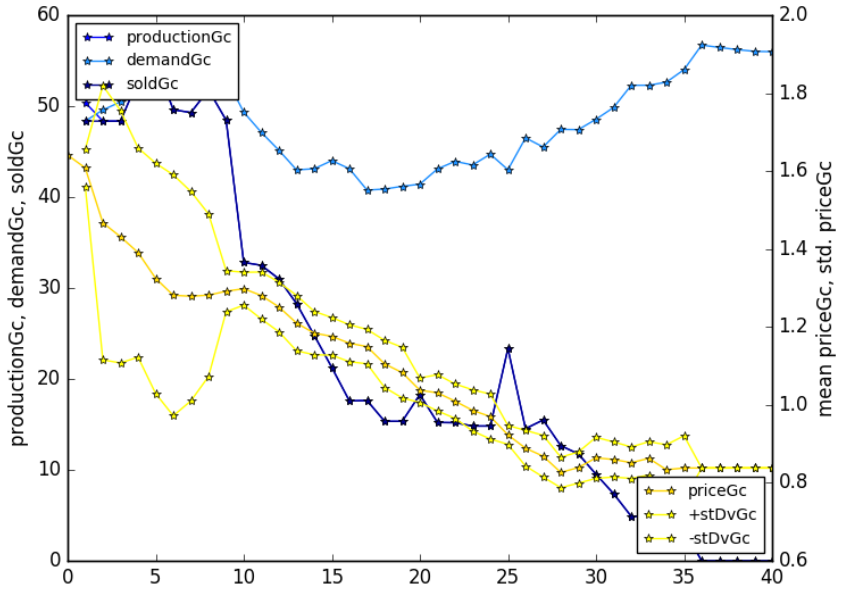

Fig. 6.36: consumption good market.

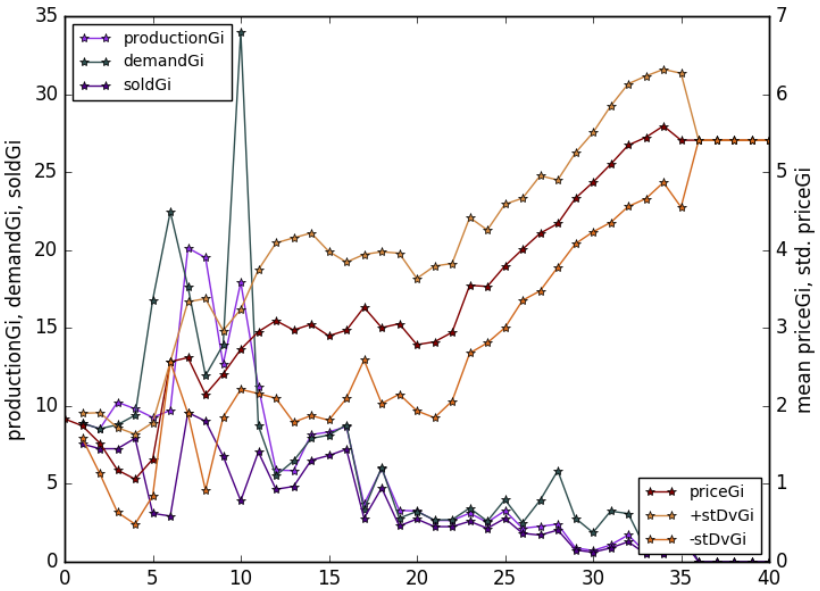

Fig. 6.37: investment good market.

As a longer period of time is considered, our modeled economy shows some tendencies that are not of immediate interpretation at first.

We can see that profit is generally negative in both sector until time $t = 10$. The number of firms in C initially goes up – due to higher employment – and declines after time $t = 8$. The demand for G_I exceeds production and the price level of G_I rises.

Given the high unemployment, the wage level and P_C decline. Within the first 8 cycles, AD_C is sustained by firm entrance, but drops as soon as F_C does. Therefore, firms in C invest in production capacity. In facts, demand for G_I is particularly high until time $t = 11$. In the following 10 cycles, P_I remains substantially stable. φ_C and the wage share a declining trend in this time horizon. Profit in both sectors compensate each other. Notice the high variance of P_C, as AD_C start sloping downwards.

The remaining firms in C face a relatively high demand in terms of both, market share (due to bankruptcies in C) and magnitude (because of a lower number of new firms in C, due to low employment). Unemployment slopes gradually down and the number of firms in both sectors variates less and less. Around time $t = 21$, wages even rise shortly.

Around time 17 to 25, older firms in C have probably already much production capacity installed, that no further investment in G_I is needed. Indeed, production in I is rather low.

AD_C reverses its trend and slopes upward from time $t = 20$ onwards. φ_C increases again at time $t = 25$, together with employment and F_C.

Firms in C place again a higher demand for G_I around time $t = 27 and t = 28$. Consequently, P_I rises. As firms in I enter anew thereafter, Π_I move toward zero. Unemployment continues to rise.

We can speculate that firms entering and exiting sector C just contributes to demand of G_C, by spending wages up to bankruptcy.

5.4.3 Version 2 – Third run

We see now whether changing population parameters lead to a less oscillating

system. We set up our simulation by considering 74 firms (2 in secor I, the rest in C) and 544 person agents. The simulation is set to run for 40 cycles and initialized with seed 2.

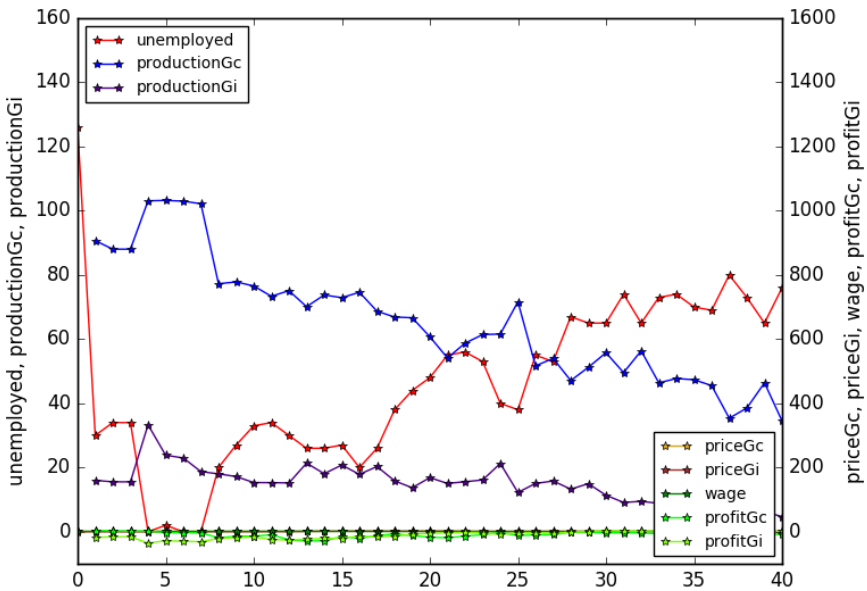

Fig. 6.38: A closer look at profit.

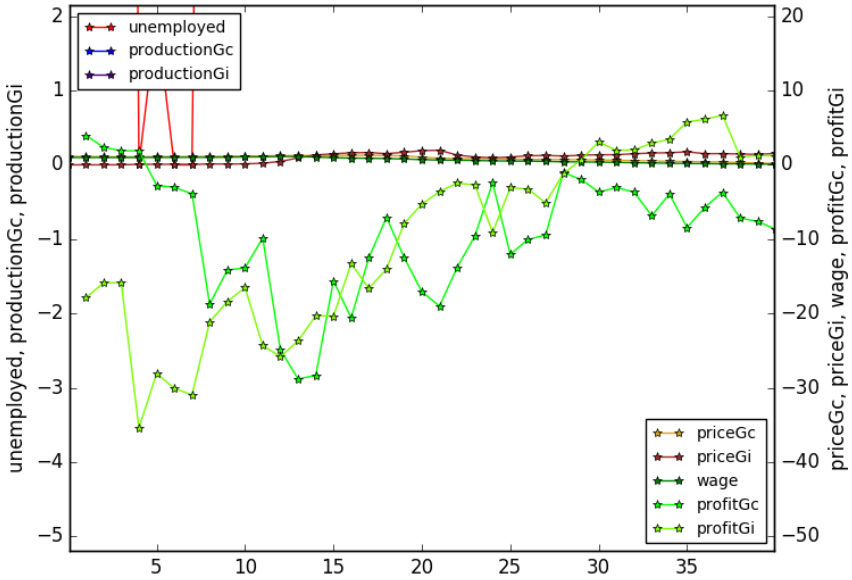

Fig. 6.38: A closer look at profit.

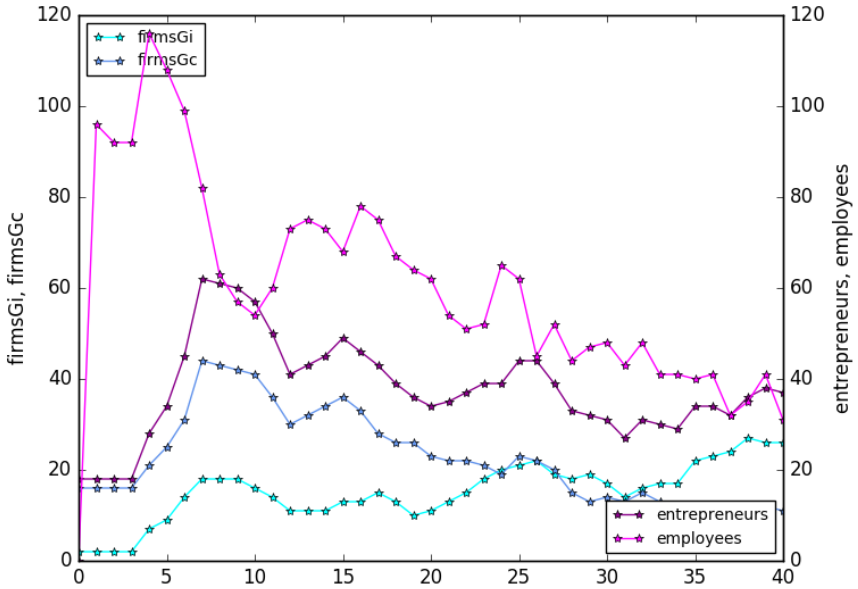

Fig. 6.39: populations.

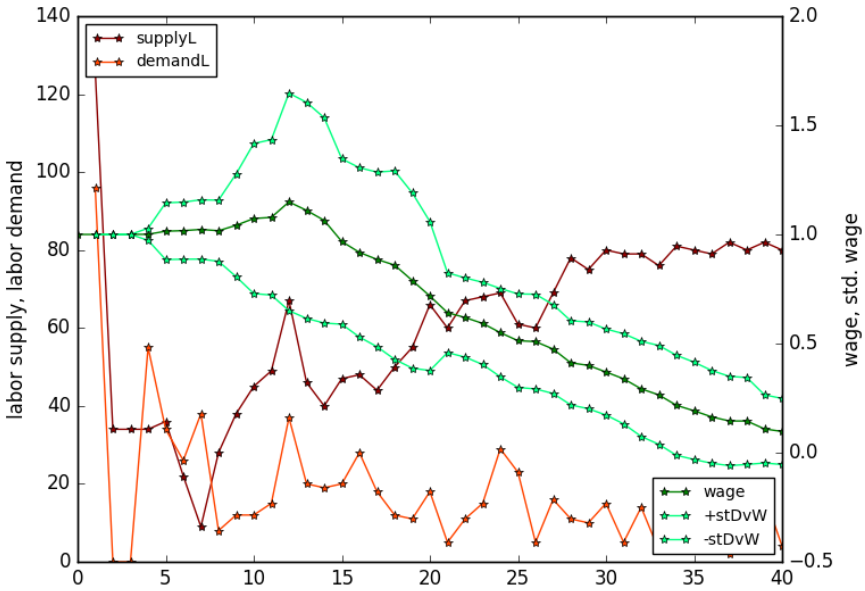

Fig. 6.40: decentralized labor market.

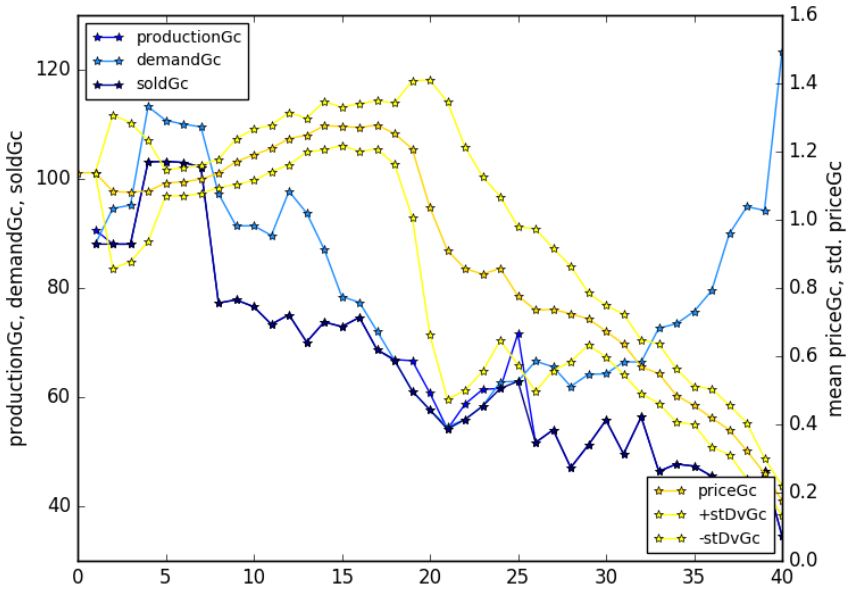

Fig. 6.41: consumption good market.

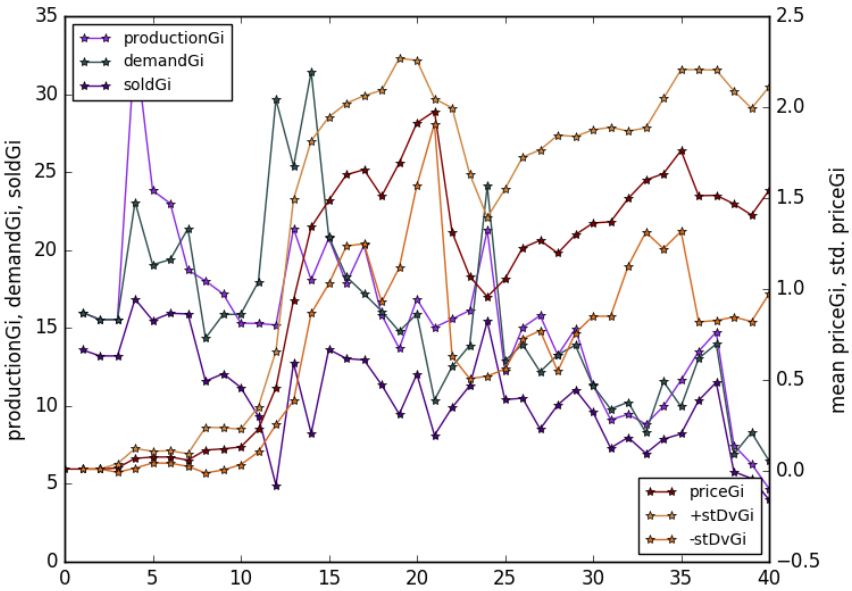

Fig. 6.42: investment good market.

As we see, the simulation produces indeed smoother time series.

In particular, the average wage remains in range 0.7 - 1.2 within the whole time lapse.

Firm populations and employment level generate long-lasting cycles with less fluctuations, with respect to the previous case.

The relation between demanded quantity and production determines price dynamics. P_C increases as demand exceeds production, and falls under excess of supply. As demand increases again, P_C recovers. As we see, the demand / production relation leads the price cycle.

Concerning the investment good market, we see a exponential decrease in price, and a convergence toward a small but positive price. After cycle 27, dynamics explained above alters this tendency.

Nonetheless, profit in sector I are negative during the whole simulation and those in sector C turn negative at about cycle 24.

Conclusion

In this chapter we looked in detail to dynamics of three models: version 1 with fixed wage, with variable wage, and version 2 with completely decentralized markets.

Version 1 with fixed wage offered already some relevant insights about fluctuations. Causal-Loop Diagrams, together with a correlation table, let us trace back generated time series to model implications. In particular, the relation between profit, firm populations, production employment and price dynamics was already clear. The correlation table captured some model features as a positive relation between aggregate demand and production in both sectors and the negative one concerning $A\varphi_C$ and both, P_C^*, and Π_C.

Version 1 with variable wages replicated some of version 2 features as a declining wage and declining profits in sector C. In comparison with the fixed-wage case, fluctuations have been found of a higher magnitude. The transmission channel results in a fluctuation-amplifying mechanism, which endangers firm-population survival in longer time simulations. Concerning correlations, some relationships show opposite sign or no correlation at all, with respect to the previous version. For instance, we find a negative correlation between the wage and AD_C, even though we would have expected it positive by model construction.

The third version considered decentralized markets. We analyzed three runs. The first offered a comparable parametrization with the previous model. We observed not only opposite trends of P_I, but also a more stable series thereof. Price curves were generally smoothed and wage showed a lower standard deviation, which implies smaller fluctuations.

Analyzing correlations, some more intuitive regularities have been observed. For instance, $A\varphi_C$ and P_C have shown a positive relationship, while they were strongly negative related in version 1, as well as AD_C and P_C. In facts, firms lower the price if they cannot sell the whole produced amount on the market. Conversely, they set a higher price if demand is high.

Moreover, we find a countercyclical relation between firm population in one sector and prices in the other, and *vice versa*. In version 1 these relations were not shown.

We then assessed version 2 over a longer time horizon and tried to explain model behavior, which would have otherwise seen counterintuitive. This run has shown some criticality of the model. On the one hand it is due to model features as fixed person population and fixed technology. On the other hand, a better relation between agent populations is needed. Therefore, we have provided a more smoothed graphical outcome by augmenting the number of firms in C and the person/firm ration. Graphical result display some genuine features of a business cycle, although the above-stated limits of model conception keep emerging as time goes by.

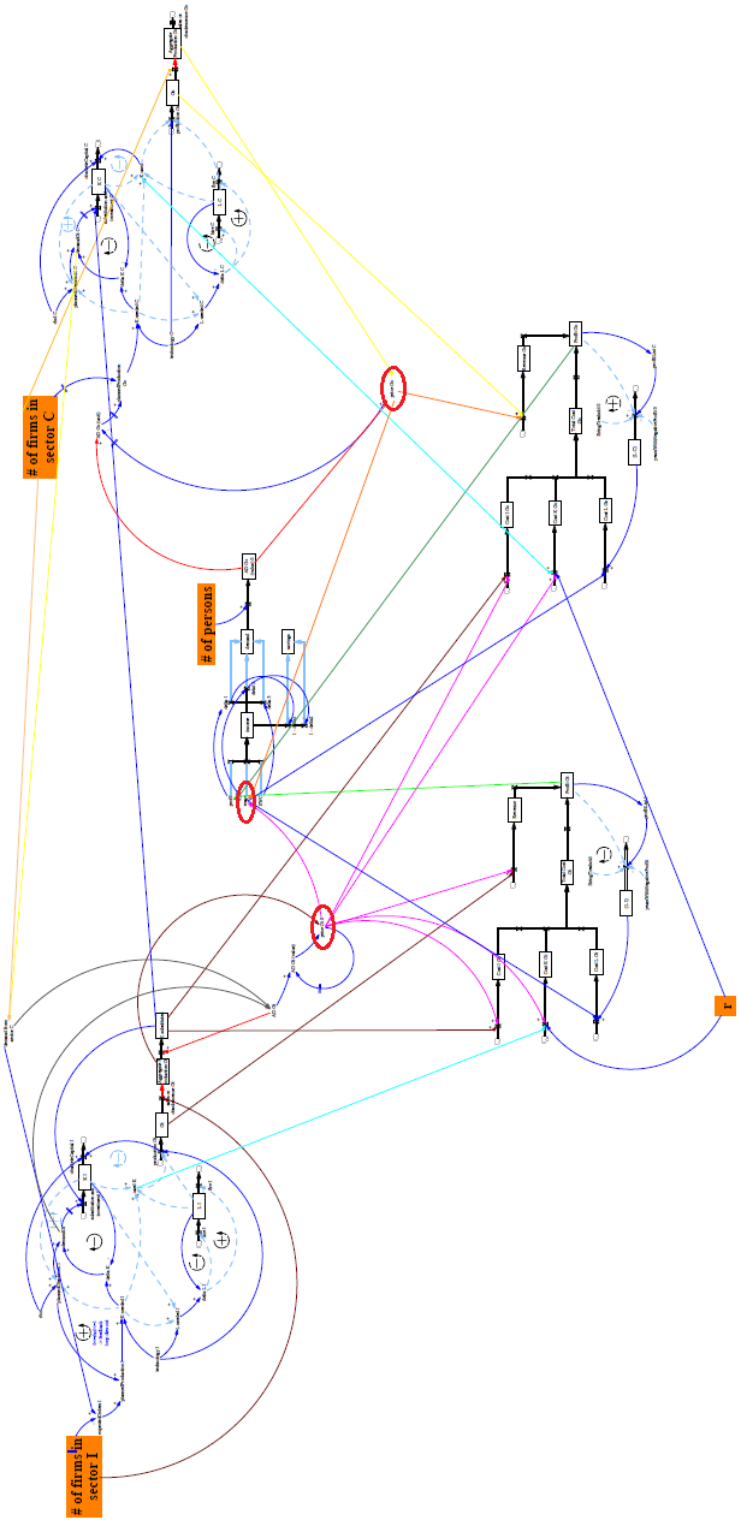

Fig. 6.11: systemic overview – version 1.20.

Chapter 6

Conclusions

At the end of this thesis, two Agent-Based Models of a two-sector economy have been developed. One thereof acts within a disequilibrium setting and displays some intuitive features of a business cycle. Thanks to SLAPP, it has been possible to model agent behavior in a way less constrained by the use of mathematical functions and explore the richness and flexibility of an Agent-Based simulation.

Here below we sum up the core points of previous chapters and conclude.

In chapter one, we traced the evolution of contemporary approaches to DSGE and NNS modeling back to the Marginalist revolution. We highlighted some methodological issues at the basis of these approaches and critically reviewed the literature thereupon. We posed our attention to the role of explanations (and particularly *causal* relations) of human behavior for what concerns Economics, and provided some more comprehensive theoretical concepts for modeling disequilibrium phenomena, by following mainly Fisher (1983) and Hahn (1962).

In chapter two, we pointed at some criticism of human-behavior modeling within R.C.T. and outlined a more general framework by focusing on insights from Neuroeconomics.

Therefrom, we highlighted strong implications for Economics, which undermine some of the building blocks of standard theory.

Neuroeconomics provides indeed a deep understanding of brain functioning that can revolutionize economic theory. An example thereof is the "two-dimensional" interaction between controlled/automatic processes, and cognitive/affective ones. These implications may help Economists to reproduce more general features of human beings.

In facts, neuroscientific evidence points to the need of a deep rethinking of theories underlying several descriptive devices economists use - such as utility,

preferences, time discounting, game theoretical equilibria - and to the reconsideration of a role for emotions.

Nonetheless, we have put forward some practical – as well as theoretical – reasons why Neuroeconomic is still an emerging discipline and many of its implications require further research.

In chapter three, version 1 has been presented. It has been conceived in order to reproduce an economic cycle in a free market environment, where good prices adjust at equilibrium level in each cycle.

By building onto the `SLAPP` architecture, we reviewed the simulation process and analyzed each method at Observer, Model and at the AESOP level. This process structures agent actions upon three markets: a labor market, a consumption-good market, and an investment-good one.

Our economy consisted of heterogeneous agents as person and sole proprietorship firms. The latter share a C.R.S. technology in form of an input-output vector, which is common to all of them. Exit has been conditioned upon a negative-profit requirement, while entry has been restricted to workers with non-negative credit.

Capital has been modeled in form of physical machinery, which wears out at a constant rate, ρ_I. This choice implied modeling a substitution mechanism – based on orders from the consumption-good sector to the investment-good one – as well as a self ordering one – between the latter sector and itself.

According to the literature analyzed in chapter one, agent demand has been subjected to the so called "positive cash assumption" in form of a condition on credit. On the contrary firms have been let free to make debts, as long as the profit condition is satisfied.

Moreover, the economy is subjected to productivity shocks, as well as to shortenings on both supply sides and demand one.

Based on version 1, two models have been developed. A fist one with a common, fixed wage, and a second allowing for a variable wage. Wage variation has been modeled by a highly persistent mechanism made of an AR(1) component and a second one, related to first differences in good prices.

In chapter four, we have inspected a second version, which is characterized by a decentralized market structure.

Version 2 has been also based on more complex agents' behavioral rules and allows for two sources of information asymmetry – number of agents acting, and price levels. Agents interacted by means of a network and shared informations on prices.

The simulation process has been enriched by the uses of *macros* and multiple trade rounds. At each of them, prices are updated according to highly discontin-

uous methods, which differ for each agent class.

We reviewed the price formation mechanisms. Price and wage expectations are set locally, on the basis of incomplete information from network or direct market interaction.

Prices are communicated by firm announcement and a agents act as long as their supply/demand remains positive.

We have seen how wages may be assessed by person agents if their *perceived* unemployment level is *low*.

It has been shown how version 2 is highly scalable and how its parametrization has been adapted in order to fit version 1.

In chapter five we have analyzed dynamic implications of agent behavior and interaction by making use of Causal-Loop Diagrams. As revealed later on, such an approach has proved fruitful in assessing model-generated time series and correlations.

Fixed-wage version 1 has been used as a starting point. As shown, just some model implications have been captured by correlation tables. Generated time series reproduced fluctuations, although inference of transmission channels results particularly difficult, without knowing the model structure. To this aim, correlation table proved even misleading in some respects.

Thereafter, version 1 with variable wage has been analyzed. We have seen as the price-wage transmission channel constituted a fluctuation-amplifying mechanism, which may even endangers firm-population survival in longer time simulations. Concerning correlations, some relationships show opposite sign or no correlation at all, with respect to the previous version.

Version 2 considered decentralized markets. We analyzed three runs with different parametrization and time length. Regarding the fist one, time series replicated some of version 1 variable-wage features. Price curves were generally smoothed and wage standard deviation resulted smaller. Analyzing correlations, some more intuitive regularities have been observed.

Contrary to version 1, we found a countercyclical relation between firm population in one sector and prices in the other, and *vice versa*.

Over a longer time horizon, a more smoothed graphical outcome has been reached by augmenting the number of firms in C and the person/firm ratio. This graphical result displayed some genuine features of a business cycle.

Nonetheless, the model shows some critical features, which require further programming and theoretical rethinking of model architecture. An instance thereof is the technological input-output relation – which is fixed, as simplification, as well as the modulation of F_I self-ordering process and its relation to output designed for sales. This is particularly necessary when self ordering exceeds actual produc-

tion (*e.g.*, when the latter is constrained by some input). In this case, firms in I allocate much of the production to capital accumulation and few further capital is supplied on the market.

We concluded that not only parametrization of agent populations is essential in defining the future path of the economy, but also fixed person population and non-obsolescence of unused (but installed) capital stock represent strong limitations.

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