SIGIL·VNIVERS·AVGVSTAE·TAVRINORVM

ESSAYS ON AGENT-BASED MODELLING:

A METHODOLOGICAL PERSPECTIVE AND TWO APPLICATIONS

Candidate: Eleonora Priori

Supervisor: Professor Roberto Leombruni

Vilfredo Pareto Doctorate in Economics and Complex Systems

XIII CYCLE

Index

Introduction

This thesis focuses on the role of agent-based models (hereafter ABMs) in the broader context of the economic modelling, from both a theoretical viewpoint and an applied one. The work is structured in three subsequent chapters, being all publishable journal articles and representing my research pattern during my Ph.D. period at the Vilfredo Pareto Doctorate in Economics, where I opted for the curriculum in Economics and Complex systems.

Chapter I frames ABM techniques from a methodological perspective, which aims at showing their epistemic value in the economic discipline. The article, which is coauthored with Roberto Leombruni, being also the supervisor of mine, argues in favor of the explanatory nature of ABMs. We sustain that simulating heterogenous populations of agents that act according to plausible behavioral rules, they can capture the complexity characterizing modern economies through an emergentist approach. This provides a way to express causal relations, and then to offer scientific explanations, without a nomological requirement but rather stressing on the study of processes generating social and economic aggregate phenomena.

Chapter II and Chapter III present two ABM applications to knowledge economics: these articles can be placed in the field of the evaluation of public policies, as they both analyze the mechanisms of academic recruitment discussing how different policy scenarios may affect the management of public universities. Since both the articles focus on the role of biases affecting the evaluation process while selecting academic staff, the usage of agent-based modelling techniques is a fortunate choice as they allow to highlight the effects of the interaction between individual behaviors and decisions on aggregate outcomes. Moreover, they provide the opportunity of comparing different scenarios to observe under which conditions these effects change.

In particular, Chapter II represents my single-author paper: here, I develop an ABM where researchers who adhere to different schools of thought, research programs and subjects of studies compete to get promoted to professorship, and two sources of biases disturb such a competition. The first one affects selectors' judgements, who tend to prefer candidates belonging to closer schools of thought; the second one reflects the competitive advantages coming from belonging to majoritarian schools of thought, as they provide more opportunities of publishing and getting citations. I simulate different infrastructural settings to study which of them are more likely to protect pluralism in scientific disciplines, and which ones drive faster to monopolistic drifts.

Two spinoffs were born from this work. The first one is an extended version[1] of the article, which has been published in Italian language for *Sistemi Intelligenti* in 2021 with the contribution of two colleagues, namely Carlo Debernardi and Marco Viola. The second spinoff is the article presented in Chapter III, where a thorough empirical work on data allowed to overcome some of the theoretical limits of the model presented in Chapter II, also providing a reliable validation of the model itself.

The article is coauthored with Silvia Pasqua and Marianna Filandri: we implement an ABM being a scale reproduction of the Italian academia in 2019, and we model different sources of discrimination

---

[1] Debernardi C., Priori E., Viola M. (2021). *Reclutamento accademico: come tutelare il pluralismo epistemico? Un modello di simulazione ad agenti.* Sistemi Intelligenti, 1 (aprile 2021). doi: 10.1422/97367

originating the gender gap in the composition of the academic staff. We simulate several policy scenarios that could be introduced to reduce and even close the gender gap by correcting the discrimination mechanisms and we compare different policy hypotheses: the model also allows to observe which scenarios yield more efficient outcomes.

CHAPTER I

The epistemic value of Agent-Based Modelling.

Simulations as a way to scientific explanations.

Eleonora Priori (University of Turin)

Roberto Leombruni (University of Turin)

Abstract

Agent-based modelling (ABM) techniques are gaining an increasing popularity in the last thirty years and there are many applications of them both in hard and social sciences. In economics, they can reflect the complexity of a modern economy through an emergentist approach and bring that diversity which many scholars call for. However, the debate on their epistemic contribution is still open. We review some old and new accounts of scientific explanations to frame AB simulations into the broader economic modelling literature, arguing in favor of their explanatory nature. Our main contribution suggests that ABMs may provide how-possibly types of explanations being a way to represent causal relations that stresses on processes and aggregation: they adopt a view of these relations akin to the notion of Inus condition, expressing causality without a nomological requirement.

Keywords: agent-based modelling; economic methodology; scientific explanations; Inus condition.

Introduction

In the wake of the financial crisis and the Great Recession, the economic discipline is facing a tough credibility crisis with public opinion. Many scholars and commenters are launching a call for "rethinking economics": they stress on the need of providing new tools to analyze modern complex economic phenomena and a better self-understanding of the discipline. In *Economics Rules* (2015) Rodrik proposes an outstanding critique from within: drawing on the history of the field, he examines when economics falls short and when it works arguing that economic models can be a powerful tool to understand (and improve) the world, but only if economists give up universal theories and commit to getting the context right. This contribution raised much hype and boosted a refreshing debate among the scholars, with many of them stressing the focus on the need of an increasing diversity in the modelling practice. Some authors suggest that different models should be considered as complementary among them rather than competing as they serve different purposes (Grüne-Yanoff and Marchionni, 2018); others that a higher degree of pluralism in economics would enforce the economic modelling explanatory capacity (Aydinonat, 2018; Grabner and Strunk; 2020); still others that more diversity would provide a more adequate self-portrait of the discipline, which economists desperately need (Mäki, 2018). For all these reasons, the debate about the status of economic modelling has been enriched and challenged by the diffusion of new analytical techniques in recent years.

Among these, ABMs stand out as they can reflect the complexity of modern economies. Simulating heterogeneous populations interacting according to plausible behavioral rules, they allow to study emergent phenomena through a "bottom-up" approach (Epstein and Axtell, 1996; Leombruni, Delli Gatti and Gallegati, 2001), which has been defined as that of a "generative" science (Epstein, 1999). Among the reasons for the increasing popularity of ABM techniques there is the variety of applications that they can cover, both in the hard and in the social sciences. As long as the latter are concerned, we have examples in sociology (*e.g.* Kohler and Gumerman, 2000; Macy and Willer, 2002; L. An, 2012), in psychology (*e.g.* Abrahamson and Wilensky, 2005; Smith and Conrey, 2007), in criminology (*e.g.* Birks D. and Elffers H., 2014) and, of course, in economics (see Tesfatsion, 2003 and Arthur, 2015 for an introduction). Their early developments date back to the late 1940s, when Von Neumann designed a theoretical machine capable of reproduction from which he later invented the model of computation of the so-called cellular automata. Their first applications in economics appeared in the early 1970s, but it was in the 1990s that they experienced a notable expansion with many scholars (*e.g.* Epstein, Axtell, Gilbert and Terna) diffusing their usage and study. Then, in the 2000s, they established definitively themselves in the social sciences, and in particular in economics[2] (*e.g.* see Matsue-shi, Terano, 2002; Hamill and Gilbert 2015; Delli Gatti *et al.* 2018).

---

[2] In economics, in turn they have been applied to a huge array of different fields. Just to provide some examples, simulations have been used to analyze financial markets (*e.g.* Bischi *et al.*, 2006; Chiarella *et al.*, 2003), innovation dynamics (*e.g.* Roventini and Fagiolo, 2010), macroeconomics (*e.g.* Stiglitz *et al.*, 2016; Terna *et al.* ,2019), resources management (*e.g.* Gilbert, 2016), game theory (*e.g.* Adami, 2016), policy making (*e.g.* Terna and Fontana 2015).

This paper aims at exploring and justifying their usage to explain economic phenomena, as to assess their epistemic value. To do so, we first define what an ABM is, showing its constitutive elements and relevant features. Then we provide some considerations from ABM practitioners to discuss a sort-of self-assessment of its methodological status (*cf.* § 1). After this, we address a more specific question, *i.e.*, whether and how ABMs are a way to provide scientific explanations. Indeed, simulations have a role in social sciences in the so-called "context of discovery", as a tool to explore new ideas and hypotheses, and they serve as a tool to build forecasts in complicated settings where the micro-behaviors play an essential role contributing to the formation of aggregate results. In which sense, and how soundly, are they also a form of explanation of social phenomena? To address this question we extend our scope to the broader literature on economic methodology comparing old and new assessments of what an explanation is in the case of social sciences (*cf.* § 2). We move away from the most traditional view of scientific explanation (*i.e.* the so-called Deductive-Nomological one, that entails "law-like" statements to express causation links), and focus on the role of counterfactuals to achieve how-possible types of explanations, showing that a common tenet in the debate within ABM practitioners and in the reviewed methodological literature is a view of scientific explanation which expresses causation without a nomological requirement. Our main contribution is to show that ABMs are a way to represent causal relations adopting a view of them akin to the clarification of the concept proposed by Mackie (1962), who first introduced the notion of Inus condition (*i.e.* an Insufficient but Non-redundant part of an Unnecessary but Sufficient condition), stressing on the study of processes generating social and economic aggregate phenomena (*cf.* § 3). We claim that their epistemic value rests on the ability of providing how-possible explanations following this path.

1. *Agent-based models from the point of view of agent-based modelers*

The first aim of this work is to define what agent-based models are, showing their main features and the purposes they may serve, particularly within the economic field. In this section we first discuss these questions and then we offer a picture of how agent-based modelers look at the AB methodology, convinced that these cues will help us shed light on its epistemic value.

According to a generally accepted definition, ABMs are a class of computational models that simulate behaviors and interactions of autonomous agents (both as individual and collective entities) within a certain *ecology*, with a view to assessing their effects on the system as a whole. These models generate the system's dynamics by calculating the dynamics of the system's constituent elements and aggregating these into the system dynamics (Grüne-Yanoff and Weirich, 2010): through the simulation computational tool, some agents interact according to plausible behavioral rules that combine their features, and such behaviors and interactions determine output scenarios.

Delli Gatti *et al.* (2018) recall the bottom-up approach establishing the agent-based methodology and sketch their basic features. Its basic unit is the agent, which, in economics, can be anything from individuals to social groups – like families, firms, or more complicated organizations. Furthermore, an agent can also be made up of other agents: in this case, it has to be perceived as a unit from the outside and to act and interact with the environment and with other agents. According to this requirement, also the environment can be modeled in terms of agents: if not, it may be considered just as a set of variables characterizing the system. The micro-level frames the behaviors of these heterogeneous agents: these are “captured by simple, often empirically based heuristics”, which allow for adaptive and learning rules. Aggregate variables are calculated as summations or averages across the agents’ population. Then, some statistical regularities that cannot be inferred from the primitives of individuals emerge at the macro-level due to interaction and nonlinearities. One of the main goals of ABMs is to analyze the effects of interaction, which plays a twofold role in models. By one side, as Shalizi (2006) suggests, agents are “a persistent thing which has some state we find worth representing, and which interacts with other agents, mutually modifying each other’s states”. By the other one, it is the very way in which the agents interact that determines the collective trajectories of the system. Then, ABMs allow us to study how changes in individual variables affect the aggregate behavior of a system. In a sense, we can say that agents’ individual behaviors provide a micro-foundation of the system’s aggregate behavior, but actually there is something more. To put it with the words that Anderson (1972) used in a well-known essay that launched complexity studies, “more is different” since at each new level of complexity entirely new properties appear, and quantitative differences turn into qualitative ones. Such a property, named emergence, displays a key role in defining complex systems since it enlightens their self-organization, that is the aptitude of a system of sustaining patterns without being controlled by a central or an external element (Ladyman *et al.*, 2013). As Delli Gatti *et al.* (2018) point out, “the self-organization of the macroeconomy can be represented by a statistical equilibrium in which the aggregate spontaneous order is compatible with individual disequilibrium”. As they state, in an ABM applied to the macroeconomy, a crisis is none other than a phenomenon emerging spontaneously at the macro-level from the complex interactions of heterogeneous agents at the micro-level.

As already mentioned, ABMs have been widely applied in different fields as useful tools in the context of the discovery. However, where to place the AB class of models in the economic-methodological debate is still an open question, and many authors proposed epistemic and practical justification for their usage. Here, we propose some considerations from AB practitioners, to explore their role in the so-called context of explanation, convinced that this may clarify their epistemic value. According to Terna (1998), ABMs should be placed “beyond methodological individualism” precisely by the virtue of unfolding aggregate emerging behaviors. Fontana (1999) points out that although the starting point of an agent-based model is the individual, the emergent collective structures, such as institutions, have feedback effects on the agent population, altering the behavior of individuals, a claim that is more tuned with holistic formulations. Epstein (1999) proposes simulations as a “new kind of science” arguing in favor of their explanatory nature. To do so he introduces the notion of generative explanation, in which macroscopic *explananda* emerge in populations of heterogeneous software individuals (agents) interacting locally under plausible behavioral rules. The choice of the “generative” term introduced by Epstein was inspired by Chomsky’s (1965) early usage in linguistics: syntactic theory seeks minimal rule systems that are sufficient to generate the structures of interest, grammatical constructions among them; analogously, the generated structures of interest that we look for are, of course, social. Under this view, to explain a social phenomenon then is to be able to reproduce it with a simulation, and the *motto* of a generative scientist is "If you didn't grow it, you didn't explain its emergence". More specifically, Epstein argues that agent-based models provide computational demonstrations that a given micro-specification is sufficient to generate a macro-structure of interest, and this demonstration is a necessary condition for explanation itself.

This view places AB simulations far distant from a deductive reasoning approach: even if we can deduce the proposition expressing that observation from other – more general – propositions because for every computation there is a logical deduction, not all deductive arguments have the constructive character of agent-based modeling. Axelrod (2006) agrees that simulations do not perfectly match with a traditional view of deduction since they work by combining deductive techniques (starting with sets of explicit assumptions) with data that they generate, which can be analyzed inductively. Leombruni and Richiardi (2005) discuss the reasons why mainstream economists are sceptical about AB modelling focusing on two criticisms that are usually posed: the absence of generality; and the difficulty of estimation of simulation models. They show why both of these criticisms fail, presenting among the advantages of ABMs the richer specification they can support, which allows for the description of complex phenomena, placing ABMs as useful tools in the context of explanation.

It is already Kirman (1992) denouncing the inadequacy of the "representative individual" to analyze modern economies: he proposes to consider agents' heterogeneity by developing "a paradigm in which individuals operate in a limited subset of the economy, are diverse both in their characteristics and the activities that they pursue, and interact directly with each other". Analogously, Ackerman (2002) suggests that economic theory should be enriched with a new model of consumer choice, nonlinear analyses of social interactions, and recognition of the central role of institutional and social constraints. More recently, Dosi and Roventini (2019) claim that the economy should be considered as a complex evolving system — *i.e.* as an ecology populated by heterogenous agents —, whose far-from-equilibrium interactions continuously change the structure of the system, and where macroeconomic phenomena such as crisis and growth emerge from these interactions. A similar position is expressed by Chorafakis (2020), who stresses the focus on the metaphysical principle of emergence as a foundational premise in a progressive economics research programme, stating that it is indispensable for understanding complex economic systems and for explaining related economic phenomena. Being able to capture the complexity of economic phenomena and to represent their emergent properties, ABMs are a natural candidate for this.

Then, what the ability to simulate a system provides is a laboratory where to explore its features, which – from a methodological point of view – means that simulations are playing a role in the so-called context of discovery. This role shall consist precisely of the capability of enlightening new properties emerging and processes generating them. This has been already stressed explicitly by Axtell (2000), who argued that simulations can shed light on the solution structure of the models and illustrates their dynamical properties whenever mathematical models can be written down but cannot be completely solved.

2. *Old, very old and new views of scientific explanations*

This section discusses the role of modelling in explaining economic phenomena, comparing different views of scientific explanations that emerged in the philosophy of science. We focus on the broader category of economic models, aiming at understanding where to place ABMs into this general framework as to catch the specificity providing them their epistemic value.

Hempel's logical positivism sums up what has been for a long time the "received view" of scientific explanations (Bouman and Davis, 2010). Under this view, a scientific explanation of a phenomenon consists in its reduction to a general law. This is the so-called Deductive-Nomological (DN) or "covering-law" view of a scientific explanation[3], according to which the core of a scientific endeavor is the discovery of new laws and the building of new theorems. According to the Stanford Encyclopedia of Philosophy, for the *explanans* — *i.e.* the elements adduced to account for a phenomenon — to successfully explain the *explanandum* — *i.e.* the phenomenon to be explained — some conditions are required: a) the explanandum must follow as a logical consequence of the explanans, given for true the sentences constituting the explanandum (being the "deductive" component); b) the explanans must include at least one "law of nature", being it an essential premise in the derivation of the explanandum (representing the "nomological" — or "lawful" — component). However, today the DN view of scientific explanation is far from being the "received view" in the philosophy of science literature: first because the stress should not be on general laws, but on processes and on aggregation; and, secondly, because the epistemic value of economic theories does not rest on their theorem formulations.

Looking pretty back in time, we can find in Hayek an interesting definition of what economic research means: economics has to do with the unwanted effects of individual actions on aggregate behavior. This definition leads to a completely different view of scientific explanation, and according to Hayek economics methodology has to be clearly distinguished from that of hard sciences like physics. About the latter, he quotes Popper saying that the direction of the explanatory path is from the "known to the unknown": given a known phenomenon, the task of the scientist is to discover the unknown law by which it can be deduced, and this way fully explained (or "covered"). Actually, this helps us frame the complex nature of social and economic phenomena, suggesting how their explanatory patterns should be explored beyond the paradigm of the covering-law. As Koppl *et al.* (2014) point out by comparing social sciences with biology, their evolutionary dynamics are "creative" since they leave some room for patterns laying out from a deterministic system. "[T]hey are, in a sense, derivative: they consist of deductions derived from combinations of known laws of physics, and do not, strictly speaking, state distinct laws of their own but elaborate the laws of physics into explanatory patterns appropriate to the peculiar kind of phenomena to which they

---

[3] Deductive-Nomological explanations are "deductive arguments whose conclusion is the explanandum sentence E, and whose premiss-set, the explanans, consists of general laws and of other statements which make assertions about particular facts" (Hempel 1966, p. 51).

refer" (Hayek 1955, 6–7). Hayek's main point is that a reliable (scientific) explanation of the regularities — the unwanted effects of individuals' actions — that emerge at the macro level rests on "whether we have selected the appropriate hypotheses from our store of accepted statements and have combined them in the right manner" (Hayek 1955, 7). The stress then is not on general laws: it is on market processes and on aggregation. The reason for which the familiar knowledge we have on individuals' behaviors ends up in unknown macro-outcomes rests on the complexity of economic systems (Hayek 1964). Needless to say, there is a clear resemblance between Hayek's derivative view of explanation in social sciences and Epstein's generative one. Considering also his stress on complexity, as Vriend (2002) puts it, Hayek may even be viewed as an agent-based computational economist avant-la-lettre.

Also the fact that the added value of economic theories rests on their theorem formulation is a simplistic conclusion: Salmon (1989) flagpole's shadow example is truly effective in illustrating this. In his example, one can derive the length of the shadow cast by a flagpole from the height of the pole and the angle of the sun above the horizon and formalize such a relation through theorem building. This derivation meets the Deductive-Nomological criteria and seems explanatory, but actually it does not provide any information on the causal linkage between the flagpole and its shadow. As Salmon puts it, "a flagpole of a certain height causes a shadow of a given length and thereby explains the length of the shadow", but by contrast, "the shadow does not cause the flagpole and consequently cannot explain its height". This point is discussed in Sugden (2000), who claims that economic models can be seen as a conjunction of two elements: an uninterpreted formal system within which logical deductions can be made, and a story which gives some kind of interpretation of that formal system. According to this idea, he emphasizes the need of finding "credible words", being able to fill the gap between the model world and the real world. The Sugden's insight is that models are not internally consistent sets of uninterpreted theorems, neither they are simplified or abstracted or exaggerated descriptions of the real world: they describe credible counterfactual worlds, and this credibility gives us some warrant for making inductive inferences from model to real world. Morgan (2001) proposes a similar idea, arguing that stories are not simply devices of persuasion; rather, they form an integral part of the identity of a model. Without the narrative elements setting of the story told with the model, we would not be able to apply model-structures directly onto the facts of the economic world, nor demonstrate outcomes about the hypothetical world represented in the model. Few years before, Morgan and Morrison (1999) suggested that models should be considered as mediators between theory and real-world phenomena, *i.e.* as instruments of investigation. This has twofold value in depicting the role of models in explaining: by one side it deepens how models relate with the real world by providing its representations with similarity features; by the other one, it clarifies how models relate among them in the knowledge formation process. Grüne-Yanoff (2008) specifies that minimal economic models are not similar to the real world, do not resemble some of its features, and do not adhere to accepted regularities; however — he argues — one can still learn something from them if their construction and analysis affects one's confidence in hypotheses about the world, recalling the notion of credibility. This standing point allows us to think of models not as theories, but as representations of them, where the compact set of the assumptions, upon which a model is built on, combine among them, shaping one of the possible realizations of the model as an output. According to this view, models are mixed instruments: in fact, the model-based storytelling reckons on relationships between elements of the models that are covered by the economic theories and incorporate the logic of whatever mathematics they are expressed in, but the modeler has to make sensible choices to make these stories meaningful, allowing them to provide scientific explanations. To tell a story by means of a formal model expressed as a general law is a matter of convenience, but the model should not hide the processes it is meant to represent.

However, the connections between explanations, causality and models are still today a hot topic of the methodological and epistemic debate. As Verrault-Julien (2019a) points out, the notion of causality as a requirement to achieve scientific explanations has recently come under severe attack, and a new account of understanding grounded on the notion of non-causal explanations has emerged. The so-called "explanation paradox" conceived by Reiss (2012) is a crucial tool to frame this account. Reiss proposes the following trilemma: i) economic models are false; ii) economic models are nevertheless explanatory; iii) only true accounts explain. He argues each of the three sentences, and states that the paradox is genuine and likely to stay, sustaining that we should think about how models explain in ways different from the usual causal and unificationist paradigms. This has raised a lively debate that gathered contributions from the scholars in the discipline: some of these contributions are collected in the "Symposium on the Explanation paradox" (2013), and they usually solve the trilemma by rejecting one or more of its hypotheses. Grüne-Yanoff (2013) argues that some economic models might be true, and that many economic models are not intended for providing how-actually explanations, but rather how-possibly explanations. Also, Mäki (2013) rejects the first proposition of the paradox and fussy criticizes Reiss: he first attacks the notion of falsehood as misrepresentation, and then analyzes the differences between falsehood, idealization and unrealisticness. He proposes a functional decomposition account, considering how this is related with truth. Mäki focuses on his view of isolation by idealization and, as also Grüne-Yanoff does, he states that models can provide functional explanations. Analogously, Rol (2013) asserts that the claim that models are false is itself false and offers a deeper look on the meaning of truth. He distinguishes abstract truth from counterfactual truth, arguing that counterfactual reasoning is one of two ways to drive science. Since it allows us to infer some what-if reasoning on how things would be like if conditions were different, this induces scientists to describe the world in terms of law-like representations. However, they can do that only after abstract reasoning has heuristically enlightened some aspects of the phenomena they observe, conjecturing causal links between a very limited number of its variables, and neglecting other ones. Instead, Hausman (2013) identifies the conditions under which the explanation paradox survives, *i.e.* only if economic models "succeed in explaining even though they are not approximately true, fail to identify the causes of what they purport to explain, and misdescribe the mechanism by which the causes lead to the effects to be explained". He argues that all economic models contain some falsehoods, but they fail in being explanatory only when their results structurally rely on these falsehoods: under this view, there is no reason to believe that models that do not describe causes and mechanisms are nevertheless explanatory. Sugden (2013) enters the debate by recalling his notion of "credible worlds" to show how fictional accounts can explain, setting similarity as the fundamental explanatory concept in his account of models, and arguing that there is nothing more to scientific explanation than finding similarities between models and real-world phenomena. We share the view that fictional accounts that counterfactual models produce may work as allegorical tools: as Rol (2013) argues "fairy tales are false, they are fictions. But the fairy tale of Pinocchio teaches me that lying does not pay. I may be convinced by the message of the fairy tale, although still I am unconvinced that my nose can grow like Pinocchio's".

Anyhow, one may agree or not with the arguments of the "explanation paradox", but we cannot ignore the conclusions it carries out, and the increasing attention that non-causal explanations are gaining in the philosophy of science is a fact. Lange (2012) exploits the Salmon flagpole's shadow example to claim that distinctively mathematical explanations are non-causal, and then can supply a kind of understanding that causal explanations cannot because they show the explanandum to be more necessary than ordinary causal laws could render it.

Interestingly enough, Reutlinger (2016) suggests that there is a monist theory of causal and non-causal explanations, that is the counterfactual theory of scientific explanations (hereafter CTE). He quotes the Euler's solution to the notable mathematical problem of Seven Bridges of Königsberg, which is widely recognized as a powerful example of non-causal explanation since it employs graph theory, to show that also non-causal explanations serve a why-question. In fact, the Euler's solution satisfies all the three conditions that a CTE imposes on the relation between explanans and explanandum: *i.e.* i) the veridicality condition, ii) the implication condition, and iii) the dependency condition. In this way, Reutlinger shows that both causal and non-causal explanations are explanatory by the virtue of revealing counterfactual dependencies between explanans and explanandum: this clarifies that also in non-causal explanations the focus is on these dependencies.

One of the main merits of the CTE is that of highlighting how-possibly explanations (hereafter HPEs). It is again Reutlinger *et al*. (2017) that point out that the CTE may be seen as how-actually explanations, and that this account may be extended to the weaker case of the HPEs. These refer to causes that could make the effect to be explained happen, and so differ from how-actually explanations, which identify what actually engendered the phenomenon. There is a vast and flourishing literature about the epistemic import of HPEs in the philosophy of science (*e.g.* see among the others: Dray, 1968; Brandon, 1990; Lipton, 2004; Bokulich, 2014; Aydinonat, 2018), and this shares many contact points with the Peirce's notion of "inference to the best explanation" (Sober, 2003). Today, according to Grüne-Yanoff and Verrault-Julien (2021), there is a large consensus around the idea that the epistemic value of models lies in providing how-possibly explanations rather than offering actual explanations of phenomena. They point out that since these provide *possible* explanations, they often show the causes of a phenomenon. Their suggestion is that a criterion should be selected to distinguish between "objective" and "epistemic" HPEs, and identify which ones are "just-so stories" expressing a false possibility claim. In another recent work, Verrault-Julien (2019b) clarifies that HPEs may apply when there is a lack in the empirical support to establish a claim of actuality, but there is enough for a possibility claim. Then, he exposes that the characterization making plain what is for a model to provide a HPE is the one which supplies evidence for propositions of the form '(p because q)'. In this view, knowing the general form of HPEs and how these relate to models allows us to assess the contribution of certain models: "some models provide reasons to believe the explanans is possible, others the explanandum, or they may even provide evidence about their impossibility".

Therefore, HPEs fit both into the conceptual framework of causal and non-causal explanations, and, applying a mechanism analogous to that working in the CTE, they do so by enlightening the dependencies between explanans and explanandum.

After reviewing the evolution of the notion of scientific explanations over the last century, we sum up here some beliefs on where economic modelling is today in the philosophy of science: i) the epistemic import of economic modelling rests on unfolding processes and aggregation, rather than general laws ii) models are mixed tools mediating between theory and real-world phenomenon, and they do so describing *credible* counterfactual worlds that allow us to make inductive inferences from models to real world iii) both causal and non-causal explanations are explanatory by the virtue of revealing counterfactual dependencies between explanans and explanandum; iv) the epistemic value of models lies in providing how-possibly explanations rather than how-actually ones.

3. *How do ABMs provide explanations? Expressing causation without a nomological requirement*

What we have presented in the previous section does not pertain to the specific methodological status of agent-based models, having rather to do with economic models as a broader category. We have widely discussed different notions of scientific explanation emerged over time and their relationship with economic modelling, and we have drawn some criteria to establish what confers epistemic import to an economic model. In this section we present how agent-based models fit into a modern account of scientific explanation, showing the path through which they provide these.

As we learnt, the deductive-nomological approach is no more the “received view” of scientific explanation in the economic methodology because the stress should not be on general laws or theorem formulation, but rather on processes and aggregation. Counterfactuality, instead, has assumed a great relevance in stating the epistemic value of economic models. Sugden (2000) already identifies the crucial role of counterfactuals – which under his view must be “credible” – to achieve compelling explanations for economic phenomena. To do so he brings two models as examples: the Akerlof’s market for “lemon” (1970) and the Schelling's Checkerboard model (1971). While the former represents a paradigmatic application of the deductive-nomological account of scientific explanation, the latter is widely recognized as a predecessor of agent-based models (*e.g.* Epstein and Axtell, 1996; Aydinonat, 2007), and may be used to show the way through which ABMs can provide scientific explanations. In this model, clearly distinctive patterns of spatial segregation (*e.g.* ghettos) emerge even if individuals display only weakly segregationist behaviors. Aydinonat and Ylikoski (2014) refer to this arguing that theoretical models can be better understood in the context of a menu of possible explanations: they distinguish between causal scenarios and causal mechanism schemes to focus on the role of the HPEs in the evaluation of explanatory hypotheses. Their conclusion is that the epistemic value of this kind of theoretical models lies in the aptitude to show causal mechanism schemes improving our explanatory understanding even if they do not describe the actual cause of a particular phenomenon. Then, our claim is that agent-based models fit smoothly in this conceptual framework: it is not a case that the Checkerboard model, although implemented on a checkerboard with dimes and pennies, is unanimously recognized as one of the first ABMs.

Therefore, we argue that, among the different views of scientific explanations that we discussed before, AB simulations match with that of causal scientific explanations since the story that an ABM is telling is an explanation of a phenomenon as far as it is talking about its *causes*. Nonetheless, the causal pattern they enlighten cannot be reconducted to that of the covering law presented in the DN model because as Axelrod (2005) notes, simulations, like deduction, "start with a set of explicit assumptions. But unlike deduction, do not prove theorems". The generalization of their results into a general law conflicts with the impossibility of spanning numerically the domain of all relevant variables and parameters of any non-trivial simulation. At the same time, they do not even adhere to a non-causal view of scientific explanation as the Euler's solution to the problem of Seven Bridges (which is itself provided with a theorem formulation) because, as the Checkerboard shows, ABMs display causation mechanism schemes while simulating the processes taking place. In a sense, we can say that agent-based models provide us with just anecdotic evidence, which is collected in a casual or informal manner and relies, heavily or entirely, on direct testimony. As Moore and Stilgoe (2009) points out, since anecdotes and anecdotic evidence are clearly individual, they drive to reconstruction in terms of ''subjective'' rather ''objective'' modes of thought. However, when simulations display a certain degree of statistical regularity observed over a large number of experiments, it may be the case to consider as relevant the results coming from anecdotic evidence. As Epstein (1999) noted, with almost a note of frustration, "No one would fault a 'theoremless' laboratory biologist for claiming to understand population dynamics in beetles when he reports a regularity observed over a large number of experiments. But when agent-based modelers show such results — indeed, far more robust ones — there's a demand for equations and proofs". So, the merit of anecdotic evidence in simulations is that of shedding light on the mechanisms generating output scenarios, following causal patterns which go beyond the traditional covering-law approach – that often cannot offer scientific explanations for social phenomena.

Grüne-Yanoff (2009) sketches a tough criticism about this point: in his opinion, a causal explanation should tell the "whole" causal (hi)story of an event to be complete, and therefore ABMs can only provide partial explanations, which he calls "functional explanations" and are epistemically second class. Elsenbroich (2012)'s reply is that the partial nature of explanations in ABMs is not unique to ABMs, being rather an intrinsic feature of the social sciences. Her argument refers to the notion of causal explanations for complex systems introduced by Machamer *et al*. (2000): according to this, the ontology of causality as regularities makes capturing causal processes in complex systems impossible, and an ontology that involves entities and activities is proposed. Under this view the Grüne-Yanoff's functional explanation is not a second-class one at all, but a causal explanation in an ontology that sees causality as more than mere regularity. Furthermore, Jackson (2002) already states that economists should attribute greater relevance to explicit functional explanation methods since they display several attractive features, such as "a pluralistic attitude to causality, an awareness of stratification and emergence, and a compatibility with a realistic perspective" – being all key ingredients of ABM techniques.

One point that we have stated is that in economics it is not deductions per se what we need, while stories about how social processes develop and macro phenomena are generated. While looking for these stories, we have observed that complex economic phenomena usually arise because of a plurality of causes, and that economic models should be judged as epistemically worthy when they are able to reflect such a pluralistic attitude to causality, which provide us with a better understanding of the phenomena to be explained. Now, our main contribution suggests that AB simulations are explanatory by the virtue of unfolding the causes bringing about the phenomena to be explained, expressing causality without a nomological requirement: we state that they do so by identifying the so-called Inus condition(s) for an event to occur.

Mackie (1962) proposes a view of causality which does not require law-like statements. He considers the case of a fire in a building, which a short circuit is recognized as the cause of. In general, a short circuit cannot be considered a necessary condition for a fire, since many other factors can start it. Neither can it be considered a sufficient one, since it can happen, say, far from flammable materials. How should we interpret, then, the proposition "The fire has been caused by a short circuit?". Mackie suggests the following explication: first, even if a short circuit is not a sufficient condition for a fire, it comes with a set S of events that, as a whole, is a sufficient (even if not necessary) condition for a fire. Second, the short circuit is an essential element (a necessary one) of the set S, meaning that, without it, the set S will no more be a sufficient condition for a fire. With a sort of… short circuit of words, he defines a cause as an Insufficient but Non-redundant condition, to an Unnecessary but Sufficient condition for an effect to happen; in a word, an Inus condition. Actually, what Mackie does with the Unnecessary clause is stressing that effects have typically a plurality of causes, meaning that a certain effect can be brought about by a number of distinct clusters of factors. According to this view each cluster is sufficient to bring about the effect, but none of them is necessary.

Among the various attempts of operational definitions of the "Regularity View of Causality", the Inus condition stands out because it does not require universal quantifiers in stating that a hypothesized cause generated an explanandum. In a sense, we could label this definition as a "lawless" view of causality, since it provides explanations of phenomena in terms of potentiality: *i.e.* they are law-less because the starting set of conditions does not imply mandatorily the occurrence of the output phenomenon, but while observing it we find that starting set of conditions existing and we look for the link explaining why the former yields the latter. Inus conditions are not lawlike even if they could look so, because they miss the compulsory nature of the causal relation between input conditions and output scenario. Therefore, Mackie's Inus condition account is not an alternative way to explanation in terms of law, but rather an account of the relationship between input and output occurrences stressing the role of causation links in terms of (most-likely) explanations. In a word, we move the stress from a *law-chasing* approach to a *cause-chasing* one. Already Riegelman (1979) resumes the notion of *contributory cause* to refer to a factor that is one among several co-occurrent causes for a specific effect. This is strictly related with the definition of sufficiency and necessity in logic: a contributory cause is said to be not sufficient for the specific event to occur, because it is by definition accompanied by the other causes; but there is no implication either that it is necessary, even if it also may be so. Under this view, ABMs can be used to formalize causal relations, and indeed, looking for the contributory causes generating racial segregation in the Shelling's model, we can say that both racism and a mild preference for neighbors of the same ethnicity are Inus conditions for it.

All of this has much in common with the notion of HPE. As Davis (2018) frames well, agent-based modelling and generative explanations involve how-possibly types of explanation since a HPE "answers a conjectural *what-if* question, and so emphasizes the exploration of a subject matter rather than demonstrating that certain relationships must characterize that subject matter". What an Inus condition does is not to prove something, but is rather to provide a plausible HPE for an effect, by illuminating the causes bringing about it. Focusing on the sufficiency and necessity of these causes allows one to evaluate both the relations binding the different contributory factors and those between them and the effect(s) that they engender. Determining whether a cause displays the features of an Inus condition permits to identify a HPE for the effect to be explained. In this scheme, ABMs come out as a powerful tool since they can show these explanatory causal patterns without framing them into general laws, but rather stressing on processes and aggregation. Clearly, borrowing the terminology of Grüne-Yanoff and Verrault-Julien (2021), this does not guarantee that the HPE that an agent-based model provides is "objective" and not merely "epistemic"; but there is no methodology ensuring *a priori* this. Rather, it is the way in which a model is set up, the tuning of its assumptions, the mechanisms on which it relies guaranteeing that a HPE, and the related Inus condition(s) originating it, are epistemically well-founded. However, AB simulations give us the opportunity to observe the path through which an explanation is formulated: entering its causal mechanisms and recognizing how they work brings something to the understanding of how a HPE arises.

It is worth noting that this very notion of causality shares much of Hayek's "derivative" and Epstein's "generative" views of scientific explanation. In both cases, the need was that of selecting the appropriate hypotheses about the micro-units and combining them obtaining a given (unwanted) result. That is, telling a credible story in which the result is generated, or, in other words, proposing a how-possibly explanation for that result looking at the Inus condition(s) bringing it about. So, we can say that the epistemic virtue of an ABM rests on its capability of providing scientific explanations, expressing causality without a nomological requirement, but rather stressing on processes and aggregation.

Concluding remarks

In this paper we have discussed the role of agent-based modelling techniques in providing scientific explanations for complex economic phenomena, arguing that they are not only useful as a tool in the context of discovery, but should also be considered a sound methodology on their own.

After a close look into the definition and the main features of an ABM, we have reviewed some considerations from ABM practitioners to provide an insight of where they place their methodology in the epistemic debate. Then, we have explored different views of scientific explanations that emerged over time, achieving that the epistemic import of economic modelling rests on the ability of highlighting processes and aggregations rather than providing general laws. We have stressed the role of counterfactuals as a tool allowing us to make inductive inferences from models to real world in the framework of the how-possibile type of explanations. We then discussed why "law-like" statements are neither necessary for an explanation, resorting to the clarification of causality in terms of Inus conditions proposed by John L. Mackie (1962): in a motto, you do not need theorems to state causal relations. Rather, we need to identify which is the set of conditions being able to trigger a certain phenomenon stressing on the process generating it. We have concluded that the ABMs specificity is that of providing how-possible explanations for economic phenomena by expressing causal relations without a nomological requirement but stressing on aggregation and processes which they simulate, and that their epistemic value rests on this.

Agent-based techniques can tell credible stories stating "law-less" causal relations. In this, we share the view that they are, more than a new kind of science, an alternative way of investigating social phenomena adopting the very same methodological criteria and inference patterns that social phenomena require, that is that of a how-possible type of explanation.

Bibliography

Abrahamson D., Wilensky U. (2005). Piaget? Vygotsky? I'm Game! - Agent-Based Modeling for Psychology Research. *Paper presented at the annual meeting of the Jean Piaget Society*, Vancouver 1-3 June.

Ackerman F. (2002). Still dead after all these years: interpreting the failure of general equilibrium theory. *Journal of Economic Methodology*, 9:2, 119-139, doi:10.1080/13501780210137083

An L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*, Vol. 229, 25-36, doi:10.1016/j.ecolmodel.2011.07.010

Anderson P.W. (1972). More is different. Science, New Series, Volume 177, Issue 4047, 393-396, doi:10.1126/science.177.4047.393

Arthur B.W. (2015). *Complexity and the Economy.* Oxford University Press*:* Oxford.

Axelrod R. (2006). Advancing the art of simulation in the social sciences. In *Handbook of Research on Nature Inspired Computing for Economy and Management*, J. Rennard, Ed., Hersey, PA: Idea Group.

Axtell, R. (2000). Why agents? On the varied motivations for agent computing in the social sciences. *The Brookings Institution, Center on Social and Economic Dynamics*, 22 p. (CSED Working Paper, n.. 17), Washington.

Aydinonat N.E. (2007). Models, conjectures and exploration: an analysis of Schelling's checkerboard model of residential segregation. *Journal of Economic Methodology*, 14:4, 429-454, doi: 10.1080/13501780701718680

Aydinonat N.E. (2018). The diversity of models as a means to better explanations in economics. *Journal of Economic Methodology*, 25:3, 237-251, doi:10.1080/1350178X.2018.1488478

Aydinonat N.E., Köksal E. (2019). Explanatory value in context: the curious case of Hotelling's location model. *The European Journal of the History of Economic Thought,* 26:5, 879-910, doi:10.1080/09672567.2019.1626460

Birks D., Elffers H. (2014). Agent-Based Assessments of Criminological Theory. In: Bruinsma G., Weisburd D. (eds) *Encyclopedia of Criminology and Criminal Justice.* Springer, New York, NY. https://doi.org/10.1007/978-1-4614-5690-2_687

Bokulich, A. (2014). How the tiger bush got its stripes: "How possibly" vs. "How actually" model explanations. *The Monist*, 97(3), 321–338. doi:10.5840/monist201497321

Brandon, R. (1990). *Adaptation and Environment.* Princeton: Princeton University Press.

Boumans M., Davis J.B. (2010) *Economic methodology: understanding economics as science.* Palgrave Macmillan.

Chorafakis G. (2020). Emergence versus neoclassical reductions in economics. *Journal of Economic Methodology*, 27:3, 240-262, doi:10.1080/1350178X.2020.1727549

Davis J.B. (2018). Agent-Based Modeling's Open Methodology Approach: Simulation, Reflexivity, and Abduction. 509-529 *Oeconomia*, 8-4, 509-529 doi:10.4000/oeconomia.4402

Delli Gatti D., Fagiolo G., Gallegati M., Richiardi M., Russo A. (2018). *Agent-based Models in Economics: A Toolkit.* Cambridge Press University.

Dosi G., Roventini A. (2019). More is different...and complex! The case for agent-based macroeconomics. *Journal of Evolutionary Economics*, 29 1–37, doi:10.1007/s00191-019-00609-y

Dray W.H. (1968). On explaining How-possibly. *The Monist*, 52(3), 390–407. doi:10.5840/monist196852339

Elsenbroich C. (2012). Explanation in Agent-Based Modelling: Functions, Causality or Mechanisms?. *Journal of Artificial Societies and Social Simulation*, 15, (3) 1, doi: 10.18564/jasss.1958

Epstein J.M., Axtell R. (1996). *Growing Artificial Societies – Social Science from the Bottom Up.* MIT Press, Cambridge (MA)

Epstein J.M. (1999). Agent based models and generative social science. *Complexity,* Vol. 4, No. 5. doi:10.1002/(SICI)1099-0526(199905/06)4:5<41::AID-CPLX9>3.0.CO;2-F

Fontana M. (1999). Market and Institutions, an agent-based computational economic model. *Phd Dissertation, Doctoral Programme in European Economic Studies* (XI cycle).

Gräbner C., Strunk B. (2020). Pluralism in economics: its critiques and their lessons. *Journal of Economic Methodology*, 27:4, 311-329, doi:10.1080/1350178X.2020.1824076ù

Grüne-Yanoff T. (2008). Learning from Minimal Economic Models. *Erkenn*, 70:81-99 doi:10.1007/s 10670-008-9 138-6

Grüne-Yanoff T. (2009). The explanatory potential of artificial societies. Synthese, 69, 539–55, doi:10.1007/s11229-008-9429-0

Grüne-Yanoff T., Weirich P. (2010). The Philosophy and Epistemology of Simulation: A Review. *Simulation & Gaming* 41(1) 20–50, doi:10.1177/1046878109353470

Grüne-Yanoff T. (2013). Genuineness resolved: a reply to Reiss' purported paradox. *Journal of Economic Methodology*, 20:3, 255-261, doi:10.1080/1350178X.2013.828866

Grüne-Yanoff T., Marchionni C. (2018). Modeling model selection in model pluralism. *Journal of Economic Methodology,* 25:3, 265-275, doi:10.1080/1350178X.2018.1488572

Grüne-Yanoff T., Verreault-Julien P. (2021). How-possibly explanations in economics: anything goes?. *Journal of Economic Methodology*, doi:10.1080/1350178X.2020.1868779

Hamill L., Gilbert N. (2015). *Agent-Based Modelling in Economics.* John Wiley & Sons Inc.

Hausman D.M. (2013). Paradox postponed. *Journal of Economic Methodology*, 20:3, 250-254, doi:10.1080/1350178X.2013.828868

Hayek F.A. (1955). Degrees of explanation. *The British Journal for the Philosophy of Science,* vol. 6, No. 23, 209-225, https://www.jstor.org/stable/685677

Hayek F.A. (1964). The theory of complex phenomena. In *Studies in philosophy, politics and economics*. Routledge & Kegan Paul, London.

Jackson W.A. (2002) Functional explanation in economics: a qualified defence. *Journal of Economic Methodology*, 9:2, 169-189, doi:10.1080/13501780110078981

Kirman A.P. (1992). Whom or What Does the Representative Individual Represent?. *Journal of Economic Perspectives*, Volume 6, Number 2, 117–13, doi:10.1257/jep.6.2.117

Kohler T.A., Gumerman G.J. (2000). *Dynamics in Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes.* New York, NY: Oxford University Press.

Koppl R., Kauffman S.A., Felin T., Longo G. (2014). Economics for a creative world. *Journal of Institutional Economics*, 11(01):1-31, doi:10.1017/S1744137414000150

Ladyman J., Lambert J., Wiesner K. (2013). What is a complex system?. *European Journal of Philosophy of Science*, 3, 33–67, doi:10.1007/s13194-012-0056-8

Lange M. (2012). What Makes a Scientific Explanation Distinctively Mathematical? *Brit. J. Phil. Sci.*, 64, 485–511, doi:10.1093/bjps/axs012

Leombruni R., Delli Gatti D., Gallegati M. (2001). Growing theories from the "Bottom Up". A simple entry-exit model.

Leombruni R, Richiardi M. (2005). Why are economists sceptical about agent-based simulations? *Physica A*, 355, 103–109, doi:10.1016/j.physa.2005.02.072

Lipton, P. (2004). *Inference to the best explanation* (2nd ed). Routledge.

Machamer P., Darden L., Craver C.F., (2000). Thinking about mechanisms. *Philosophy of Science*, 67:1-25, doi:10.1086/392759

Macy M.W., Willer R. (2002). From Factors to Actors: Computational Sociology and Agent-Based Modeling. *Annual Review of Sociology*, Vol. 28:143-166, doi:10.1146/annurev.soc.28.110601.141117

Mackie J.L. (1962). Causes and conditions. In E. Sosa and M. Tooley, editors, *Causation*. Oxford University Press: Oxford.

Mäki U. (2013). On a paradox of truth, or how not to obscure the issue of whether explanatory models can be true. *Journal of Economic Methodology*, 20:3, 268-279, doi: 10.1080/1350178X.2013.828869

Mäki U. (2018). Rights and wrongs of economic modelling: refining Rodrik. *Journal of Economic Methodology*, 25:3, 218-236, doi: 10.1080/1350178X.2018.1488475

Matsue-Shi, Terano T., Kurumatani K., Namatame A. (2002). *Agent-Based Approaches in Economic and Social Complex Systems.* Ios Pr Inc.

Moore A., Stilgoe J. (2009). Experts and Anecdotes: The Role of ''Anecdotal Evidence'' in Public Scientific Controversies. *Science, Technoogy and Human Value*, Vol. 34 issue 5, 654-677, doi:10.1177/0162243908329382

Morgan M.S., Morrison M. (1999). *Models as mediators.* Cambridge University Press, Cambridge.

Morgan M.S. (2001) Models, stories and the economic world. *Journal of Economic Methodology,* 8:3, 361-384, doi:10.1080/13501780110078972

Reiss J. (2012). The explanation paradox. *Journal of Economic Methodology*, 19:1, 43-62, doi:10.1080/1350178X.2012.66106

Reutlinger A. (2016). Is There A Monist Theory of Causal and Non-Causal Explanations? The Counterfactual Theory of Scientific Explanation. *Philosophy of Science* 83 (5):733-745, doi:10.1086/687859

Reutlinger A. (2017). Explanation beyond causation? New directions in the philosophy of scientific explanation. *Philosophy Compass*, 12:e12395, doi:10.1111/phc3.12395

Riegelman R. (1979). Contributory cause: Unnecessary and insufficient. *Postgraduate Medicine*, 66:2, 177-179, doi:10.1080/00325481.1979.11715231

Rodrik D. (2018). *Economics Rules: Why Economics Works, When It Fails, and How To Tell The Difference.* Oxford University Press.

Rol M. (2013). Reply to Julian Reiss. *Journal of Economic Methodology*, 20:3, 244-249, doi:10.1080/1350178X.2013.828870

Salmon W.C. (1989). Four decades of scientific explanation. *Minnesota Studies in the Philosophy of Science*, 13:3-219, https://hdl.handle.net/11299/185698

Shalizi C.R. (2006). Methods and techniques of complex systems science: an overview. In *Complex systems science in biomedicine* (pp. 33–114). Berlin: Springer.

Smith E.R., Conrey F.R. (2007). Agent-Based Modeling: A New Approach for Theory Building in Social Psychology. *Personality and Social Psychology Review*, 11: 87, doi:10.1177/1088868306294789

Sober E. (2003). Two uses of unification. In: Stadler F. (eds) *The Vienna Circle and Logical Empiricism*. Vienna Circle Institute Yearbook, vol 10. Springer, Dordrecht. doi:10.1007/0-306-48214-2_17

Stanford Encyclopedia of Philosophy, "Scientific explanation". Retrieved on April 4th, 2021, from https://plato.stanford.edu/entries/scientific-explanation/

Sugden R. (2000). Credible worlds: the status of theoretical models in economics. *Journal of Economic Methodology*, 7:1, 1-31, doi:10.1080/135017800362220

Sugden R. (2013). How fictional accounts can explain. *Journal of Economic Methodology*, 20:3, 237-243, doi:10.1080/1350178X.2013.828872

Terna P. (1998). Creare mondi artificiali: una nota su Sugarscape e due commenti. *Sistemi Intelligenti*, 10(3), doi:10.1422/3493

Tesfatsion L. (2003). Agent-based computational economics: Modeling economies as complex adaptive systems, *Information Sciences* 149(4):262-268, doi:10.1016/S0020-0255(02)00280-3

Verrault-Julien P. (2019a). Understanding does not depend on (causal) explanation. *European Journal for Philosophy of Science*, 9: 18, doi:10.1007/s13194-018-0240-6

Verrault-Julien P. (2019b). How could models possibly provide how-possibly explanations?. *Studies in History and Philosophy of Science*, 73, 22-33, doi:10.1016/j.shpsa.2018.06.008

Vriend N.J. (2002). Was Hayek an ACE?. *Southern Economic Journal,* Vol. 68, No. 4, pp. 811-840, doi:10.2307/1061494

Ylikoski P., Aydinonat N.E. (2014). Understanding with theoretical models. *Journal of Economic Methodology*, 21:1, 19-36, doi: 10.1080/1350178X.2014.886470

CHAPTER II

Protecting pluralism of scientific disciplines from biases in the academic recruiting process. An agent-based simulation.

Eleonora Priori (University of Turin)

Abstract

Academic recruitment is subject to several biases connected with the school of thought, research program or subject of studies which researchers adhere to. One of these reflects the so-called researcher's narcissism, according to which evaluators tend to judge more benevolently candidates belonging to closer schools of thought: I name it an epistemic bias. A second source of bias is that belonging to majoritarian schools of thought provides some advantages in terms of bibliometric indexes as it implies higher possibilities of publishing and getting citations, and then to achieve careers' advancements: I refer to the latter as a bibliometric bias. To represent how these biases affect academic careers I build an agent-based model where researchers compete to get promoted. I simulate different infrastructural settings to study which of them are more likely to protect pluralism in scientific disciplines, and which ones drive faster to the extinction of minoritarian schools of thought in favor of monopolistic ones. Main results show that: i) the epistemic bias increases the speed of the process, whereas the bibliometric bias affects its acceleration, having a greater impact in the long term; ii) higher turnover rates reduce the risk of monopolistic drifts; iii) the system is more sensitive to different turnover rates rather than to different arrangements in the recruiting methods.

Keywords: knowledge economics; economic methodology; agent-based model; sociology of science

Academic recruitment aims at choosing the "best" candidate among several ones, or so it should do in theory: in practice there is a widespread feeling that this does not happen. This feeling, at least in Italy, turns into many cases of journalistic scandals and scientific publications,[4] suggesting how intellectual and professional evaluations may be often set aside in favor of nepotistic considerations. However, even if nepotistic cases certainly exist, this discontentment may depend on a disagreement about the criteria to choose *who* is the best. Several factors affect the choice of assigning a certain position, and they contribute to this in different measures: for instance, the teaching experience, the quality of the training, the reference letters, the scientific relevancy, a list of publications certifying the ability of producing quality research.

Let me focus on the latter: how should one measure the quality of scientific publications? Answering this question is hard due to the elusive and complex nature of the notion of *quality*. According to Baccini (2010:40), one can distinguish among three dimensions of quality in a research product: i) the internal quality; ii) the impact among the scientific community; iii) its impact outside academia. In Italy, despite the international recommendations,[5] bibliometrics, which measures a research's impact typically through citations, is increasingly used as an *objective* indicator for the quality of research, if not that of researchers themselves. An example of this is the institution of threshold-values for some sectors (hence named "bibliometric sectors") is the National Scientific Qualification – which is the requirement introduced in 2010 with the Law n. 240 to verify the suitability of a researcher to run in the competitions for a tenured position. To support such a practice, Ancaiani *et al.* (2015) stated that qualitative judgements expressed by some reviewers during the Evaluation of the Quality of the Research in 2004-2010 have displayed a high concordance with those obtained through bibliometric indicators among a sample of 9000 papers. However, Baccini and De Nicolao (2016) disputed the analysis method used, and hence the results. Furthermore, it has recently been shown that the unusual increment in the scientific impact of Italian researchers starting from 2010 may reasonably come from researchers' strategic behaviors, that would have biased the indicators by using self-citations and "citation clubs" to pimp compatriots' results (Baccini, De Nicolao and Petrovich, 2019).

However, shortcomes in the evaluation do not pertain just to "quantitative" measurements, as the bibliometric ones, but also to the "qualitative" ones, depending on the peers' judgement.[6] A

---

[4] *E.g.* see Perotti (2008) and Pivato's (2015) "*j'accuse*".

[5] See *e.g.* the San Francisco Declaration of Research Assessment (https://sfdora.org/) and the Leiden Manifesto for Research Metrics (Hicks *et al.*, 2015).

[6] The distinction between quantitative and qualitative is less clear than it might appear immediately. Quantitative evaluations on a bibliometric basis are based on the count of publications and citations present in the journals contained in a certain database, and this may be intended just as the aggregation of a set of qualitative choices made by the referees and editors of those journals. On the other hand, it is not possible to exclude that sometimes certain evaluations that would be qualitative are themselves based on quantitative criteria such as the number of citations, in addition to or instead of reading the articles or books in question (especially when the high number of items to evaluate makes reading difficult).

flourishing literature shows how different biases perturb peer review processes (Lee *et al*., 2013). Some of these come from sociological factors such as gender (*e.g.* De Paola e Scoppa, 2015; Filandri and Pasqua, 2019; but also *cf.* Squazzoni *et al*., 2020) or the prestige of the researcher's affiliation. Furthermore, these factors tend to combine each other (De Cruz, 2018). However, epistemic biases are crucial in determining evaluation procedures. This work focuses on one of them: that presented by Gillies (2014) under the name of "researcher's narcissism". According to this, "an individual researcher believing quite strongly that his or her approach to research in the field is the best one, and most likely to produce good results, while the other approaches are less good and less likely to produce any good results" will tend to evaluate more benevolently those articles, research projects, etc. fitted to that approach, and less benevolently the ones coming from who belongs to a rival school of thought. Here, I refer to rival schools of thought as different research groups adhering to different methodologies and/or doctrines, but displaying at least overlapping explanatory areas – *i.e.* groups competing to explain the same set of phenomena (Viola, 2017:58).

The available evidence certifies the influence of such a bias in the evaluation processes (*e.g.* look at Mahoney 1977; Travis and Collins 1991; and more recently Javdani and Chang 2019; for an optimistic viewpoint stating the irrelevance of such a bias, look at Buonaccorsi 2016). However, given the toughness in traducing such a bias in an observable indicator, there is no estimation of its effects available. While acting to favor majority schools of thought, it may exacerbate their over-representation damaging the heterodox ones, which risk ending choking.

Many discussions on research evaluations focus on the evaluation on national scale (Whitley, 2007), probably because the funds allocation depend on them (Hicks, 2012). However, some kind of "evaluation" is exerted whenever you need to distribute some resources. In the social structure of modern science, these resources range from research funds to the opportunity of publishing in a journal, to job (and power) positions. Merton (1968) says that the incentives structure in modern sciences is influenced by what he calls the *Matthew effect*: those enjoying greater prestige will tend more easily to accumulate more rather than those having less. Reasonably, such an advantage does not pertain only to prestige, but it also applies to other kinds of resources: *e.g.*, those cumulating more research funds in the universities usually get a more benefited position to produce more articles, which will help them in getting more extra-funds in the future, such as in winning the tenure of a professorship. So, the presence of a bias as the one suggested by Gillies may propagate through a multiplier effect in different moments of the resource allocation process, implying a further thinning of pluralism.

Among all these activities of resource allocation, recruitment holds a crucial position. Indeed, in many academic systems there is a rigid division between the tenured staff and the non-tenured one (typically composed by post-doc researchers). In Italy, this distinction may be summed up as the one between (full and associate) professors and researchers (including all the precarious profiles, such as those holding a research grant). The former ones (and their corresponding in foreign systems) are in charge of almost all the activities of *gatekeeping* (Hoenig 2015), *i.e.* they make decisions about every kind of resource allocation.

Academic recruitment does not depend only on the choices of single selectors: these face up to a system of laws and regulations. This work aims at exploring *if* and *how* different institutional settings may impact positively or negatively the schools of thought pluralism within a given scientific discipline, exacerbating or mitigating the biases that may lead to monopolistic situations.

According to the starting point of this work, protecting a certain degree of pluralism is a value in itself. However, such an assumption fits also into some "prudent monism" positions: *i.e.*, one can think that the scientific community must ultimately come to converge on a single school of thought, and yet admit a transition period in which the newborn schools of thought can show their eventual epistemic merits (Zollman 2010; *cf.* § 2).

Indeed, radical pluralists are eager to delay the suffocation of minority schools, but it is also in the interest of all the scientific community to ensure that, if the latter converges on the adoption of a unique school of thought, this happens because of epistemically founded considerations, and in any case allowing the minority schools to express their potential. In other words, this work aims at answering at the following question: *i.e.*, how to minimize the acceleration due to institutional and non-epistemic mechanisms?

A definitive answer would inevitably require some work based on empirical data, that are not available up to date. Furthermore, the collection itself of these depends on the formulation of a theoretical framework within which elusive concepts such as those of *school of thought* or *epistemic bias* are embedded. Also because of this, this work aims at proposing a model to clarify the problematic points and providing a key to interpret the dynamics at stake.

So, in the following sections of this article I propose an agent-based model aimed at outlining the dynamics of Italian academic recruitment over the last ten years with a certain level of fidelity. Focusing on the Italian context is interesting enough as in the last decade the introduction of the NSQ has deeply impacted the methods of recruiting staff, and, at the same time, the reduction in research funding has narrowed the contestable space between researchers, potentially exacerbating the conflict between rival schools of thought.

1. *Using agent-based simulations to study how scientific research works*

I build an agent-based model (ABM) as they allow, assuming some starting conditions and a set of rules determining how the latter interact, to simulate the *output scenarios* that different contexts yield. In ABMs, the presence of mutually heterogeneous agents that develop non-linear interactions gives rise to a complex system, whose emerging behaviors at a collective level cannot be reduced to the sum of individual behaviors. In fact, in these multi-agent systems, the aggregate dynamics at a system level comes from the decision-making heuristics of individual agents, as well as from the interactions between the different behavior rules they follow.

The usage of an agent-based simulation allows one to develop a concept-driven model through which to explore a complex system such as that of academic recruitment. Indeed, while dealing with a complex system, one cannot look for punctual solutions, but rather for output scenarios taking shape under certain hypotheses. The individual choices driving researchers' and professors' behaviors and their interactions determine aggregate trajectories for the academic system, and ABM techniques display all the key features to represent such dynamics.

There is a huge literature of ABMs representing structural dynamics of scientific research (look at Payette 2012 for an enjoyable review). Among the more successful models on the topic, the work of Weisberg and Muldoon (2009) raised much interest. There, each scientific sector is represented as a three-dimensional epistemic landscape, where agents, moving at each time from one approach (represented by a quadrant) to a neighboring one, identify the most promising approaches (*i.e.* climb the higher quadrants). These agents have only two pieces of information available: the height of the quadrants around them, and the traces left by the agents previously passed through those quadrants. Compared to these traces, the authors play with agents moved by opposite heuristics: in the absence of a higher quadrant immediately adjacent, traditionalist agents (followers) will prefer to move in a quadrant already explored, while mavericks will prefer to venture into an unknown quadrant. The authors conclude that a population of nonconformists will be quicker in climbing the peaks than a population of traditionalists; but adding even a few nonconformists to a population of traditionalists greatly increases the speed of exploration.

Another key model in this debate is that of Zollman (2010), studying how the dynamics of reaching consensus in the scientific community varies while the strength of individual scientists' beliefs and their degree of interconnection change. His counter-intuitive conclusion is that a community with many ties and little polarization risks converging quickly to consensus towards an incorrect thesis.

The article "The Natural Selection of Bad Science" (Smaldino and McElreath, 2016) has raised even more hype. The authors attribute the reproducibility crisis that has worried science so much in recent years (*cf.* Romero, 2019) to a system of incentives and selection of publications that exerts some “selective pressures” as it rewards the quantity of studies conducted by laboratories to the detriment of their robustness. Simulations concerning the peer review mechanism (reviewed by Feliciani *et al*. 2019) are less known but still instructive. Moreover, the model of Balietti, Mäs and Helbing (2015), which is inspired to the Kuhnian framework of the establishment of a paradigm as a prerequisite for progress, explores the possible causal relationships between minor/major disciplinary fragmentation in alternative schools of thought and speed/scarcity of progress – explicitly contrasting the human and social sciences with the physical and natural ones.

However, while interpreting these models, it is useful to recall the warning of Martini and Fernández Pinto (2017): in the absence of a rigorous empirical calibration sensitive to the context – which is missing in almost all the models present in the literature according to the authors – simulations results should not be interpreted as predictions, and it is dangerous to derive from them immediate policy advice.

This does not mean that the models, even after validation, are of no use. Taking up Epstein (2008), models do not necessarily have to serve to elaborate a prediction (and this is not the objective of this work): rather they can perform several different functions in the context of scientific research. One of the most fascinating ones has to do with the possibility of comparing different scenarios in terms of the effects that the variation of a parameter exerts on a given system.

The present model aims at exploring the possible consequences that mechanisms such as that of the researcher's narcissism described by Gillies exert on the researchers’ recruitment.

2. *The model*

I model the potential effects of two types of bias that can alter recruiting choices. A first type of bias, the *epistemic bias*, directly alters the evaluation of those who examine the candidates, causing them to favor (ceteris paribus) those who belong to their school of thought despite those who adhere to rival schools. A second type of bias, the *bibliometric bias*, acts instead upstream, and refers to those scientific sectors where the bibliometric criteria of research impact are used as evaluation tools. The insight behind this second bias is that the membership in a majority school of thought, which has privileged access to many journals, offers greater opportunities to publish articles and/or receive citations; opportunities that are likely to contract and expand in proportion to the numerosity of that school.

So, the simulated ecology is that of a scientific community, which for simplicity is assumed to be a closed system; *i.e.*, it is assumed that training (which underlies the generation of new researchers) and recruitment (yielding their career advancements) can only take place within the community object of the model.

The model reckons on two categories of agents. The first one is *professors*, representing all the holders of a permanent position. They can be drawn to be part of the committees judging during the competitions for tenured-positions or for the NSQ; and retire once they reach 70 years of age. Once that some of them retire (at the end of each cycle), a given number of new permanent positions is opened: this corresponds to the number of retiring agents weighed by a turnover factor.

The second class of agents is *researchers*, representing all those who hold fixed-term positions: they contribute to fill the permanent positions left open by retirement – thus becoming professors. New researchers enter the system every year. The working duration of these agents is set at 12 years (corresponding to the maximum number of the years that a researcher can cumulate in Italy by law before getting a tenure-tracked position); all those who fail to obtain a tenure, or the stabilization of their position, are removed from the model during this time.

To formalize the competition between researchers, I provide them with a *curriculum*. This consists in a number increasing every year by a random value, possibly weighed through the bibliometric bias. The role of the curriculum is to represent the scientific prestige (for instance in terms of publications and citations) that researchers gain during their careers. Since the aims at analyzing the institutional structures and not the individual paths of researchers, I do not to design the dynamics through which the latter unfolds.

Both professors and researchers belong to a *school of thought*, which is assigned to them at 'birth' and is unchangeable. The distribution among the schools of thought of the new researchers generated each year follows the share of professors belonging to each of them. In each situation of researchers' evaluation – both in the case of competitions for tenured positions and of a session to assign NSQ – a panel of professors randomly drawn is formed (3 for the competitions, 5 for the NSQ).

Subsequently, each professor P member of a committee expresses an evaluation E of candidate R in these terms:

$$E(P,R) = CV * (1 + EB) * N$$

Where CV represents the curriculum of a researcher R, EB the epistemic bias – greater than zero if the researcher belongs to the same school of thought as the selector –, and N a noise (a random number in a neighborhood of 1 whose amplitude is adjustable by model parameters).

The bibliometric bias, which turns into an increase in researchers' curriculum weighted by the influence of their school of thought, represents the greater ease of publishing and/or receiving citations for those who belong to a dominant research tradition. When this parameter takes values greater than 0, the increase in the curriculum of each researcher from year *t* to year *t + 1* formally becomes:

$$CV(t+1) = CV(t) + G * (1 + BB * S / T)$$

Where G is a random number extracted from a normal distribution (with mean 5 and standard deviation 1.66), BB is the value of the bibliometric bias, S is the number of scholars – both researchers and professors – belonging to the same school of thought, and T stands for their total number.

Each simulation is divided into cycles, each of which corresponds to one year. At each cycle the following events happen:

1. Increase of the age of all agents.
2. Removal from the model of researchers who have not been promoted to professorship for 12 years.
3. Increase of the curriculum of each researcher in activity.
4. Retirement of professors.
5. Generation of new researchers.
6. [For models involving NSQ] Extraction of the NSQ evaluating committee (5 members).
7. [For models invovling NSQ] The committee examines researchers who are not in possession of the NSQ and possibly assign it to them.
8. Draw of committees (3 members) and opening of the competitions for tenured positions.

<table>
<tr><td rowspan="4">RESEARCHERS</td><td>Contracts duration</td><td>12 years</td></tr>
<tr><td>Accumulate curriculum</td><td>CV(t+1) = CV(t) + G * (1 + BB * S / T)</td></tr>
<tr><td colspan="2">If the bibliometric bias is active, they have an advantage in belonging to majority schools of thought</td></tr>
<tr><td colspan="2">If the NSQ is on, they compete to get the NSQ</td></tr>
</table>

	Compete for tenured positions	
PROFESSORS	Retirement	70 years old
	They are randomly drawn to act as panelists in competitions for tenured positions and in sessions to assign the NSQ.	
	Evaluate researchers	$E(P,R) = CV * (1 + BE) * N$
	If the epistemic bias is active, they favor researchers belonging to their school of thought	

Table 1: dynamic behavior of the agents in the model.

4. Results

Results show the evolution of the system in 100 cycles, observing average values across 1,000 replications of the simulation to test the robustness of the model. The model is designed along the lines of the Italian university recruitment system: for this reason, in defining the parametric space to be explored, I focus on three alternative scenarios inspired by the different recruitment methods taking place in Italy over the last decade.

- Direct competitions for tenured positions: researchers can directly access to them, the NSQ is not required.
- NSQ, 4 opinions: to access the competitions for tenured positions, the NSQ is required. To obtain it researchers have to receive a positive opinion from at least 4 of the 5 members of the panel.
- NSQ, 3 opinions: to access the competitions for tenured positions, the NSQ is required. To obtain it researchers have to receive a positive opinion from at least 3 of the 5 members of the panel.

To explore how a disparity between schools emerge in the model ceteris paribus, I assume: a) the existence of only two schools of thought; b) that at the beginning of each simulation the two schools of thought display the same number of adherents – where in the real scenarios the starting situation is often already polarized, making the speed of the process even more relevant. The simulation could easily be extended to case studies with more than the two starting schools of thought. However, I have focused this study on a hypothetical scenario as simplified as possible to observe how, even under initial conditions defined in the most equitable way possible, the intrinsic mechanisms on which the recruitment system rests structurally lead to the abuse of one school of thought on the other (or others) in the long run.

Given the finite size of the system, the long-term dynamics of the model (for t → ∞) would converge towards uniformity even if both biases were set at zero. However, as previously pointed out, my focus is on the speed of the process taking place, since a too rapid convergence – and determined by institutional factors – would not allow all the schools of thought involved to show their epistemic merits.

The first relevant feature is the *path dependence* of the time series, becoming even more prominent in the presence of one or both biases. Even the slightest advantage of one school of thought over the other(s) is going to increase as time goes on and it is sufficient in most cases to make the school dominant in the long run: this validates the hypothesis of the *Matthew effect* described by Merton (1968).

In Figures 1and 2 I present the role of the two implemented biases.[7] Comparing them one can observe the cumulative nature of the bibliometric bias, whose impact is even greater than that of the epistemic bias – even if also the latter assumes relatively high values.

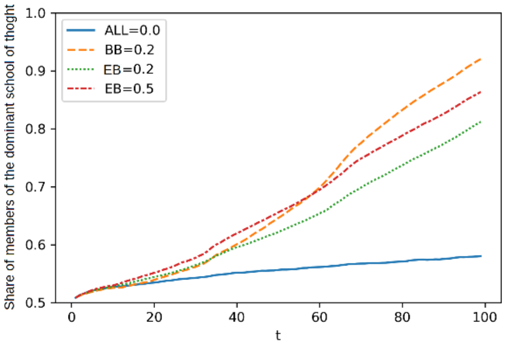


Figure 1: share of majority school members out of total. Average trend of the time series for different bias values. Recruitment=direct competitions, turnover = 1

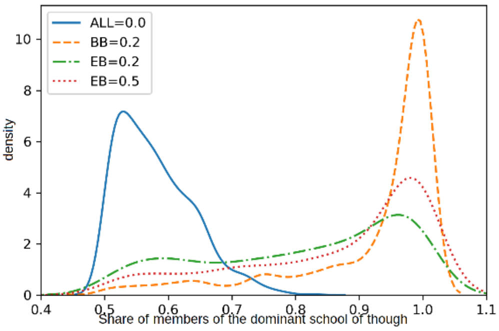


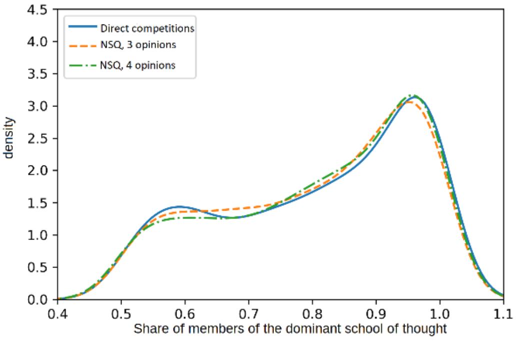
Figure 2: share of majority school members out of total. Comparison of time series distributions under different bias values. Recruitment=direct competitions, turnover = 1

As mentioned above, one of the objectives of this work is to identify the differences between various institutional settings. From the viewpoint of pluralism, the NSQ is more restrictive than direct

---

[7] Figs. 2--5 are comparisons of distributions made with the kernel density estimation (KDE) technique. This choice allows greater ease of visualization of the data when comparing different distributions when comparing different distributions. It should be noted that the extension of the distributions on share values of the majority school members below 0.5 and above 1 is an artifice introduced by the visualization technique used. Furthermore, although at a first glance it may not be evident, probability density values greater than 1 are consistent: the area underlying the function represented is in fact normalized to 1. Each simulated scenario consists of the aggregation of 1000 simulations with the same set of initial parameters.

competitions, since it introduces a further evaluation step. The request for more positive opinions and the raising of the *threshold* help speed up the process. However – as can be seen in Figures 3 and 4 – this difference is small. Probably calibrating the model parameters on empirical data might show a larger gap between the various systems.



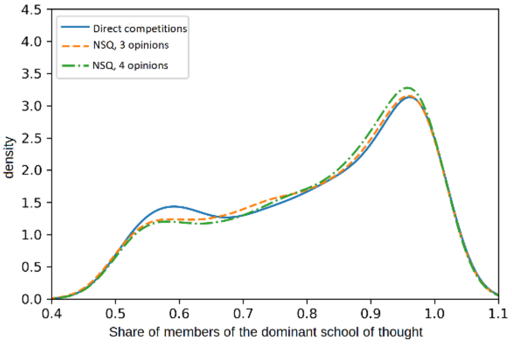


Figure 3: share of majority school members out of total. Comparison of time series distributions at time t = 100 under different recruitment systems. Turnover = 1, NSQ Threshold = 40, Epistemic Bias = 0.2, Bibliometric Bias = 0.0

Figure 4: share of majority school members out of total. Comparison of time series distributions at time t = 100 under different recruitment systems. Turnover = 1, NSQ Threshold = 60, Epistemic Bias = 0.2, Bibliometric Bias = 0.0

On the other hand, turnover is a key parameter. Figure 5 highlights the huge impact of an insufficient recruitment on the demographics of minority schools of thought. Furthermore, it should also be considered that these simulations were carried out with the same epistemic bias, while it is reasonable to think that the awareness of a regime of scarce resources determines the exacerbation of this bias. If this were the case, the influence of a negative turnover – however significant – would even be underestimated in the model.

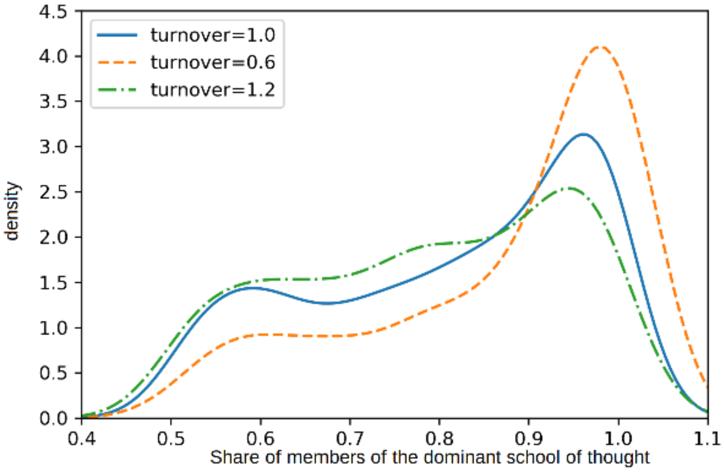


Figure 5: share of majority school members out of total. Comparison between distributions of the time series at time t = 100 for different turnover values. Recruitment = *concorso*, Epistemic Bias = 0.2, Bibliometric Bias = 0.0

Conclusions and further developments

In this article, after showing the rationale of the research request (§1) and motivating the choice to simulate it through an ABM (§2), I present a model simulating how the interaction between different sources of biases and certain institutional arrangements favors the suffocation of non-majority schools of thought within a discipline in different spans of time (§3). The simulations inspired by the Italian context suggest that: i) where the epistemic bias increases the speed of the process, the bibliometric bias increases its acceleration, causing a greater impact in the long term; ii) under ceteris paribus conditions, a higher turnover is more safeguarding of the pluralism between schools of thought; iii) reductions in turnover have a greater impact on pluralism than different recruiting methods.

This work can contribute to policy-making processes according to heuristic dynamics. Indeed, it provides a "tool for thinking" (Hoad and Watts, 2012) allowing the mechanisms involved to be made explicit, while structuring the collection of empirical data calibrating the model. For instance, the hypothesis that a low turnover amplifies the bias by significantly accelerating the extinction of minority schools could be verified with a careful check of the recruitment dynamics occurring in some disciplines during the decade 2008-2018, characterized by low turnover rates.

Although the model was designed to explore issues related to the pluralism of schools of thought, the same architecture could be applied to investigate other aspects of recruitment dynamics. A further research question could concern the emerging scenarios in the presence of the possible segmentation of a school of thought, observing how the benefits deriving from biases would be distributed among the different sub-schools. It would also be possible to simulate, for example, the competition between disciplines or sub-disciplines that depend on the same resources for recruitment: in this case the epistemic bias should rather be intended as a “disciplinary bias”. Furthermore, with little effort, the model could be adapted to analyze sociological biases such as gender or ethnicity, for which empirical literature is already available, and this would allow its calibration. Then there is the possibility of modeling hybrid scenarios, simulating and studying the interaction between social and epistemic variables.

Bibliography

Ancaiani, A., Anfossi, A. F., Barbara, A., Benedetto, S., Blasi, B., Carletti, V., Cicero, T., Ciolfi, A., Costa, F., Colizza, G., Costantini, M., di Cristina, F., Ferrara, A., Lacatena R.M., Malgarini, M., Mazzotta, I., Nappi C.A., Romagnosi, S., Sileoni, S. (2015). Evaluating scientific research in Italy: The 2004–10 research evaluation exercise. Research Evaluation. 24(3), pp. 242-255.

Azoulay, P., Fons-Rosen, C., Graff Zivin, J.S. (2019). Does science advance one funeral at a time?. American Economic Review, 109(8), pp. 2889-2920.

Baccini, A. (2010). Valutare la ricerca scientifica: uso e abuso degli indicatori bibliometrici. Bologna: Il Mulino.

Baccini, A., De Nicolao, G. (2016). Do they agree? Bibliometric evaluation versus informed peer review in the Italian research assessment exercise. Scientometrics, 108(3), pp. 1651-1671.

Baccini, A., De Nicolao, G., Petrovich, E. (2019). Citation gaming induced by bibliometric evaluation: A country-level comparative analysis. PLoS ONE, 14(9): e0221212. doi:10.1371/journal.pone.0221212.

Balietti, S., Mäs, M., & Helbing, D. (2015). On disciplinary fragmentation and scientific progress. PloS one, 10(3).

Bonaccorsi, A. (2015). La valutazione possibile. Teoria e pratica nel mondo della ricerca. Bologna: Il Mulino.

De Cruz, H. (2018). Prestige Bias: An Obstacle to a Just Academic Philosophy. Ergo, an Open Access Journal of Philosophy, 5.

De Paola, M., Scoppa, V. (2015). Gender discrimination and evaluators' gender: evidence from Italian academia. Economica, 82(325), pp. 162-188.

Epstein, J. M. (2008). Why Model?. JASSS - Journal of Artificial Societies and Social Simulation, 11(4), 12.

Feliciani, T., Luo, J., Ma, L., Lucas, P., Squazzoni, F., Marušić, A., & Shankar, K. (2019). A scoping review of simulation models of peer review. Scientometrics, 121(1), 555-594.

Filandri, M., Pasqua, S. (2019). Gender discrimination in academic careers in Italy. WP n. 21/19 Dipartimento di Economia e Statistica Cognetti de Martiis, Università degli Studi di Torino.

URL=https://www.est.unito.it/do/home.pl/Download?doc=/allegati/wp2019dip/wp_21_2019.pdf

Gillies, D. (2014). Selecting applications for funding: why random choice is better than peer review. RT. A Journal on research policy and evaluation, 2(1).

Hicks, D. (2012). Performance-based university research funding systems. Research policy, 41(2), pp. 251-261.

Hicks, D., Wouters, P., Waltman, L., De Rijcke, S., Rafols, I. (2015). Bibliometrics: the Leiden Manifesto for research metrics. Nature News, 520(7548), p. 429.

Hoad, K., Watts, C. (2012). Are we there yet? Simulation modellers on what needs to be done to involve agent-based simulation in practical decision making. Journal of Simulation 6, pp. 67–70.

Hoenig, B. (2015). Gatekeepers in Social Science. The International Encyclopedia of the Social & Behavioral Sciences. 2nd edition, Vol. 9. Oxford: Pergamon.

Javdani, M., Chang, H-J. (2019). Who Said or What Said? Estimating Ideological Bias in Views Among Economists. doi: 10.2139/ssrn.3356309

Lee, C.J., Sugimoto, C.R., Zhang, G., Cronin, B. (2013). Bias in peer review. Journal of the American Society for Information Science and Technology, 64(1), pp. 2-17.

Lotka, A.J. (1926). "The frequency distribution of scientific productivity". Journal of the Washington Academy of Sciences, 16 (1926), pp. 317-323.

Mahoney, M.J. (1977). Publication prejudices: An experimental study of confirmatory bias in the peer review system. Cognitive therapy and research, 1(2), pp. 161-175.

Martini, C., & Fernández Pinto, M. (2017). Modeling the social organization of science. European Journal for Philosophy of Science, 7(2), pp. 221-238.

Merton, R.K. (1968). The Matthew effect in science: The reward and communication systems of science are considered. Science, 159(3810), pp. 56-63.

Payette N. (2012). Agent-Based Models of Science. In Scharnhorst A., Börner K., van den Besselaar P. (Eds.) Models of Science Dynamics. Understanding Complex Systems. Berlin-Heidelberg: Springer.

Perotti, R. (2008). L’università truccata. Torino: Einaudi.

Planck, M. (1950). Scientific autobiography and other papers. American Journal of Physics, 18, pp. 117-117.

Pivato, S. (2015). Al limite della docenza. Roma: Donzelli.

Smaldino, P. E., & McElreath, R. (2016). The natural selection of bad science. Royal Society open science, 3(9), 160384.

Squazzoni, F., Bravo, G., Dondio, P., Farjam, M., Marusic, A., Menhami, B., Willis, M., Birukou, A., & Grimaldo, F. (2020). No evidence of any systematic bias against manuscripts by women in the peer review process of 145 scholarly journals. https://doi.org/10.31235/osf.io/gh4rv

Travis, G.D.L., Collins, H.M. (1991). New light on old boys: Cognitive and institutional particularism in the peer review system. Science, Technology, & Human Values, 16(3), pp. 322-341.

Viola, M. (2015). Some remarks on the division of cognitive labor. RT. A Journal on Research Policy and Evaluation, 3, pp. 1-14.

Viola, M. (2017). Evaluation of Research (ers) and its Threat to Epistemic Pluralisms. European Journal of Analytic Philosophy, 13(2), pp. 55-78.

Wang, Q., Sandström, U. (2015). Defining the role of cognitive distance in the peer review process with an explorative study of a grant scheme in infection biology. Research Evaluation, 24(3), pp. 271-281.

Weisberg, M., & Muldoon, R. (2009). Epistemic landscapes and the division of cognitive labor. Philosophy of science, 76(2), pp. 225-252.

Whitley, R. (2007). Changing governance of the public sciences. In Whitley, R., Gläser, J. (a cura di), The Changing Governance of the Sciences. The Advent of Research Evaluation Systems. Dordrecht: Springer, pp. 3-27.

Zollman, K. J. (2010). The epistemic benefit of transient diversity. Erkenntnis, 72(1), pp. 17-35.

CHAPTER III

Breaking through the glass ceiling in academia.

An agent-based model simulating policies to close the gender gap.

Eleonora Priori (University of Turin)

Marianna Filandri (University of Turin)

Silvia Pasqua (University of Turin)

Abstract

Gender discrimination in academia is still far from being solved. The persistent gender gap in the different rungs of the academic ladder and the "leaky pipeline" phenomenon, *i.e.* the progressive lower proportion of women as they advance in academic careers, are well-known facts in all OECD countries: the recent debate focuses on the policies that can be adopted to increase the gender balance in the university systems. We build an agent-based model to study how the gender composition of a virtual academia, that is a scale reproduction of the Italian academia, might evolve in one hundred years. We simulate recruitment and promotions of the academic staff by considering the discrimination mechanisms producing the gender gap and we test the effectiveness of different policies aimed at closing it. Results show that, despite the rhetoric of meritocracy, even if female researchers had the same scientific productivity as their male colleagues the gender gap will not close even in the long run. To reach more gender equality, but also higher efficiency in the recruitment and promotion, universities should implement a set of policies acting on the different mechanisms causing discrimination. These include maternity bonuses in the evaluation of the CVs of female candidates to promotions, rules for a more gender balanced composition of the evaluating committees, and gender quotas in the promotions to full professorship positions. However, our simulations show that that it is only by guaranteeing a more gender balanced recruitment that gender gap will close in a reasonable time.

Keywords: academic careers; knowledge economics; gender discrimination; agent-based model.

Introduction

Gender equality is recognised as a key element in public institutions that should guarantee access and equal opportunities of career advancement to men and women. However, women still represent a minority of professors in OEDC countries' universities even if the number of female graduate students overtook those of male ones (OECD, 2016). In particular, women are a small minority in the highest academic rungs, *i.e.* among full professors, heads of department, deans and rectors. This is the so-called "leaky pipeline" phenomenon, that describes the progressive disappearance of women as we move upwards in the academic ladder. Some progress has been done, but only in the lowest levels of the academic career.

The reasons for the under-representation of women in the highest levels of the academia have been widely investigated in the literature and the main explanations are related to the lower productivity of female researchers with respect to their male colleagues, (being the result of their family responsibilities), to their smaller professional networking, to the worse evaluation of their research, to their higher reluctancy to compete for promotions, to more teaching and service activities done. These are often the consequences of the universities being 'gendered organizations' in which norms and practices are based on a stereotyped vision of male and female workers (Dubois-Shaik and Fusulier, 2019). However, female researchers also suffer discrimination as women in the same scientific sector with the same seniority and scientific productivity than male researchers are less likely to be recruited and promoted (Ginter and Kahn, 2004; De Paola and Scoppa, 2015; De Paola *et al*., 2018, Filandri and Pasqua 2021).

Introducing gender equality policies, therefore, has not only equal opportunity aims, but can improve the efficiency of the recruitment and promotion system in the universities. Moreover, gender equality is also needed to guarantee heterogeneous and non-gendered approaches to research and teaching and to promote gender roles especially in those disciplines (mainly STEM) in which female students are still a minority. Universities and research institutes where women do not have the same opportunities as men are also proven to be characterised by a worse climate: people are less effective, and this has negative consequences on the whole organisation and not only on women's productivity (Tindal and Hamil, 2004; Casad *et al*., 2020). Awareness of these issues has led the European Union to encourage universities and research funding organizations to develop gender equity plans (GEPs) to overcome gender imbalance in the academic institutions (Council of the European Union, 2015; Clavero and Galligan, 2020).

The debate about the most effective policies to reach gender balance in academia is still open. Beside mentoring, supporting women in their research and networking activities, promoting a more equal distribution of teaching and administrative tasks between men and women in the universities, gender quotas in funder and selection committees have been proposed, but the results of having more women in the committees are not conclusive (Zinovyeva and Bagues, 2011; Vernos, 2012; De Paola and Scoppa, 2015; Bauges *et al*., 2017; Checchi *et al*., 2019; Bennouri *et al*., 2020).

Our paper contributes to the existing literature on policies for gender equality by simulating an agent-based model that considers the complex nature of gender discrimination and shows the possible effects of different polices aimed at reducing the gender gap in academia. Based on administrative data, we replicate in our model the structure of the Italian academia and we observe the evolution of the gender composition over a period of one-hundred years with and without these policies. The Italian case can be considered as representative of a common situation as Italy is in line with the other European countries in terms of gender composition in the universities (European Commission, 2019): in 2019 less than 25% of full professors and only 6 out of 84 rectors were women, while among associate professors and tenure track assistant professors the percentages increase to 39% and 42% respectively (data MUR, 2019).

With our simulations we aim at answering to four main research questions:

1) given that in the Italian academia the recruitment of assistant professors over the last years has been more gender balanced, can we expect this turning into a more balanced gender composition also among full professors in the subsequent years?

2) is there, and how relevant is gender discrimination in the promotion of associate professors to full professors (*i.e.* how many men less ‘productive’ than their female colleagues are promoted)?

3) which is the most effective policy (or combination of policies) to reduce gender gap in the Italian universities?

4) how long would it take to these policies to close the gender gap in full professor positions?

The paper is organized as follows. In Section 1 we present and discuss the state of the art on gender discrimination in academia and policies to overcome it. Section 2 introduces the institutional context of the Italian university system. In Section 3 we present the method and the data upon which we base our simulations. In Section 4 we show and discuss the results of our simulations. Conclusion follows.

1. *The gender gap in academia*

A flourishing literature investigated the causes of gender gap in academia to identify possible interventions to reduce the bias. One of the most frequent explanations for the difference in the probability of being recruited or promoted between men and women is the difference in their scientific productivity. Because of family responsibilities, female researchers are involved in fewer research projects and networks and therefore they publish fewer papers (Dubois-Shaik and Fusulier, 2019). Moreover, having smaller networks has proven to impact negatively on the probability of being hired and promoted especially in a country like Italy where connections with the selection committees’ members increase the chances of success (Bauges *et al.*, 2015; Checchi *et al.*, 2019). Finally, female professors are often assigned with more teaching and administrative tasks that reduce the time they can devote to research (Coate and Howson, 2014; Babcock *et al*., 2017; Guarino and Borden 2017; Marini and Meschitti, 2018).

However, despite the rhetoric of meritocracy typical of academic institutions, also studies in which scientific productivity is controlled for show that gender discrimination persists, and women are less likely to be recruited and promoted (De Paola and Scoppa, 2015; Marini and Meschitti, 2018; Filandri and Pasqua, 2021). This discrimination is particularly high for the promotion to full professorship: female associate professors are 17 percentage points less likely to be promoted than their male colleagues with the same level of scientific productivity, being 8 percentage points the corresponding gender difference in the promotion of assistant professors to associate positions (Filandri and Pasqua, 2021).

Psychological traits and attitudes, which often come as consequences of cultural and educational conditioning, could also matter. On the one hand, over-commitment and strain are stronger for female researchers than for male ones, resulting in higher work stress and intention to leave academia of female postdocs (Dorenkamp and Weiß, 2017). On the other hand, women are often characterized by less competitive traits and lower attitudes to bargaining for promotion and wage increase (Bertrand, 2011), probably as a result of being in an environment that discourages them to act as their male colleagues do. This can explain why less women apply for the positions in the highest rungs of the academia (Howe-Walsh and Turnball, 2016; De Paola *et al*., 2017; Pautasso, 2015; Doherty and Manfredi, 2006; Chesterman and Smith, 2006).

Mentoring is considered an important tool to support women professional development in university that has been a male environment for centuries. Previous literature shows that mentoring had positive effects on the mentees, but it is still not clear if it helps institutions to become more gender-equal and diversity-oriented (Meschitti and Lawton Smith, 2017). In fact, several scholars have emphasized the importance for organizations to fix their own structures and cultures, instead of aiming at 'fix the women' (*e.g.* Voorspoels, 2018).

Among the possible policies that have been suggested to tackle the gender gap in the universities there is the increase in the number of women in the selection committees. Men and women might have different preferences and might evaluate differently CVs of researchers that focus on different topics (Gillies, 2014; Debernardi *et al*., 2021) or might evaluate differently different dimensions of the candidates' CVs. Men and women, in fact, tend to do research in different subfields and evaluators tend to overrate the importance of their own research topics and approaches (Gillies, 2014; Burges *et al*., 2017). Therefore, the presence of women in the selection committees could lead to outcomes that are less gender biased than those of all-male committees. The Code of Conduct for the Recruitment of Researchers adopted by the European Commission in 2005 sets some general principles that employers and funders should follow when recruiting researchers. Recommendations to ensure diversified career paths are several: they range from not taking into account only the number of publications in the selection process, to guaranteeing that career breaks due to maternity or other care needs are not penalizing for women, up to the introduction of more gender-balance rules in the committees that evaluate career advancements.

The analyses on the effect of having more women in the selection committees, however, did not lead to conclusive results. For the Italian academia, De Paola and Scoppa (2015) found that, controlling for scientific productivity, female candidates are less likely to be promoted by all-male committees and their probability increases with mixed-sex commissions while Bauges *et al*. (2017) show that having a woman in the selection committee makes male evaluators even harsher towards female candidates, with an overall negative effect on the chances of success for them. Vernos (2012) found no effect of the share of women in the evaluation panels for the success rate of female scientist that applied for an ERC grant. Opposite results have been found by Zinovyeva and Bagues (2011) for competitions to full professorship in Spain where the presence of at least one woman in the committee makes men and women equally likely to succeed. In a different context, Bennouri *et al.* (2020) found that gender quotas in the boards of directors do not affect the likelihood of appointing a female CEO.

In other domains, gender quotas on outcomes of selections have been introduced. Gender quotas in the boards of directors of listed companies as well as in electoral competitions are the most popular examples. Gender quotas policies are considered dangerous in academic contexts because they might imperil a system in which merit guarantees the highest quality in research and teaching. However, Bennouri *et al.* (2020) show that the introduction of mandatory gender quotas in the boards of directors improved firms' performance indicators. In the academia, the current merit system seems to have favoured men since the definition of merit itself is often a gendered concept that reflects social values and constructs favouring men over women (Van den Brink and Benschop, 2012). As a consequence, women's chances of being recruited and promoted are lower to those of their male colleagues with the same scientific productivity. For these reasons actions are urgently needed to reach more gender balance in academia in a reasonable time span (Wallon *et al.*, 2015).

In our agent-based model we simulate how different policies, including gender quotas on promotions to full professorship, could act to reduce and even close the gender gap in the university system.

2. *The Italian academia: recruitment and promotions*

Simulating the effect of different policies in an academia that is the scale reproduction of Italian university is particularly interesting for several reasons. Firstly, in Italy gender discrimination is still a newsworthy fact, and the university system is characterised by a strong gender imbalance especially in the highest rungs. Furthermore, the recent reforms in recruitment and the budget cuts suffered by the Italian university over the last ten years did not contribute to reduce the gender imbalance.

In the Italian academic system there are different hierarchical levels: full professors, associate professors, assistant professors with permanent contracts, temporary assistant professors that can be either tenure-track or non-tenured and postdoctoral researchers. As the effect of a recent reform (Law no. 240/2010 better known as Gelmini's reform), assistant professors are only hired with temporary contract and therefore the position of permanent assistant professor no longer exists. Therefore, all permanent assistant professors currently employed in the universities have been recruited before 2010. As far as temporary assistant professors, the reform distinguish between non-tenured positions (known as assistant professors Type-A) and tenure-track positions (Type-B). Type-A assistant professors are similar to postdoctoral researchers[8], and we will not consider this position in our simulations.

Every year the Ministry of University defines the amount of resources that each university can use to recruit and promote. These resources are defined in terms of "Punti Organico Ministeriali" (hereafter POMs), that correspond to an authorisation by the Ministry to allocate resources for personnel. The rationale of this mechanism is to keep under control the personnel expenses at single university level (Rossi, 2015). There is a correspondence between POMs and budget costs, as one POM is equivalent to around 100,000 euros per year. For this reason, each professor position has a different cost in terms of POMs: a full professor corresponds to 1 POM, an associate professor to 0.7 POM and a tenure-track temporary assistant professor to 0.5 POM (Table 1)[9].

POM	Temporary assistant professor	Permanent assistant professor	Associate professor	Full professor
Cost of recruitment	0.5	0.5	0.7	1
Cost of promotion to	-	-	0.2	0.3

Table 1: cost in terms of POMs of each position of Italian professors

Given the total amount of POMs received from the Ministry, each university decides how to spend them (specifically they choose whether to recruit or to promote) with no obligation for universities to substitute the professors who retire. Therefore, recruitment and promotions compete for the same resources. Moreover, periodically the Ministry also decides to invest extra resources for recruitment

---

[8] They have a contract lasting three years, renewable for another two.

[9] Non-tenure assistant professors do not cost POMs and Type-A positions can be opened by each university according to their budget.

(these are called *piani straordinari, i.e.* supplementary plans, that usually take the form of more resources for the recruitment of tenure track assistant professors).

Recruitment of tenure track assistant professors is done in each university with open competitions. For the associate professorship and full professorship, a two-step mechanism has been introduced by the Gelmini's reform in 2010. The first step is the National Scientific Qualification (NSQ): assistant professors who want to be promoted associate professors and associate professors who aspire to become full professors apply for the qualification, that is granted by national committees (one for each scientific disciplinary sector). The National Scientific Qualification has been introduced to limit local favouritism (Nieddu and Pandolfi, 2018; Sala and Bosisio, 2017; Abramo *et al.* 2015) and to improve the quality of research and teaching in the Italian university system.

Temporary assistant professors Type-B holding the NSQ obtain a tenure as associate professors when their temporary contracts expire. This promotion is done with a simplified procedure and is nearly automatic. Those who do not get the qualification (actually a minority not relevant for statistical purposes) exit the system at the end of their three-years contract. Permanent assistant professors and associate professors holding the NSQ participate to competitions for associate professor and full professor positions respectively. These positions are decided and opened by each university.

In our simulation model we reproduce the university system, conceiving it as it was a single university in which, at the begging of each year, resources for recruitment and promotion are set in terms of POMs. The total number of POMs depends on the one hand on retirements and on the other on extra resources for recruitment defined at the Ministry level. We simulate the academic composition of the four tenured and tenure track positions of professor. We do not consider the promotions of permanent assistant professors to associate professors as this figure, as already mentioned, is going to disappear in the next years. We also do not consider Type-A non-tenure assistant professors as the opening of such positions do not cost POMs to the universities. Therefore, hereafter when we refer to temporary assistant professors, we will mean tenure-tracked assistant professors.

3. *Methods and data*

3.1. The methodological choice: why an agent-based model?

In our study we use an agent-based model (ABM). ABMs are computational models simulating actions and interactions of heterogeneous and autonomous agents. Their aim is to observe the aggregate effects that agents produce on the system they act into. They allow to state some initial conditions, to define a set of rules depicting how agents behave and interact, and to observe how relevant dynamic evolves over time and the emerging scenarios that are the results of those dynamics (Eason *et al.*, 2007). ABMs can be used to understand how different causes interact to produce an observed outcome (Geanakoplos *et al.*, 2012; Grow and van Bavel, 2015), to evaluate policy measures and to formulate recommendations (Dawida and Neugart, 2011; Dosi *et al.* , 2018).

As showed in the literature, several causes can lead to the under-representation of women in the full professor positions and, in this respect, several policies can be adopted.

With our model[10] we observe the evolution of the gender gap dynamics in a time of one-hundred years. First, we set an initial scenario that is the exact scale reproduction of the Italian academia in the year 2019 in terms of gender and hierarchical composition (based on administrative data of the Ministry of University). Then, we simulate the evolution of our virtual academia by assuming the personnel strategies of the University, its recruiting and promoting mechanisms, and the gender discrimination that can arise in these mechanisms. Finally, we introduce some policy hypotheses which aim at offsetting different forms of gender discrimination occurring in the academia, and we observe the outcomes, *i.e.* the dimension and the gender composition of each hierarchical level in the academia after one-hundred years.

3.2. Overview of the computational model: the starting setting

To define the initial setting of the model, we create a population of 1,000 agents, where each agent belongs to one of the breeds, *i.e.* the classes to which each agent may belong to, listed in Table 2 and reflecting the size and the gender composition[11] of the four rungs of the academic career.

	MALES (%)	FEMALES (%)	TOTAL
TEMPORARY ASSISTANT PROFESSORS	49 (58.4%)	35 (42.6%)	84
PERMANENT ASSISTANT PROFESSORS	106 (50.5%)	104 (49.5%)	210
ASSOCIATE PROFESSORS	265 (60.8%)	172 (39.2%)	437
FULL PROFESSORS	202 (75.2%)	67 (24.8%)	269
TOTAL	623	377	1000

Table 2: The starting population of our simulation

---

[10] To simulate our model we use the specific-ABM software NetLogo 61.1.

[11] The present work focuses on the under-representation of women in the academia, then the discrimination of other gender orientations is not treated here. Furthermore, Ministerial data report gender using the binary classification.

Beside *gender*, each agent is characterized by two variables: *age*, and *productivity*. As far as age is concerned, the variable is assigned to the agents in the model following the actual distribution observed in MUR data (2015-2019). Table 3 summarizes the types, the average values and the variances of the age distribution[12] of our simulated population from which age values are extracted. The age of each agent increases by 1 at each subsequent year of the simulation and when agents get 70 they retire and are removed from the model.

	distribution	μ	σ
TEMPORARY ASS. PROFESSORS	random-normal	39	9.4
PERMANENT ASS. PROFESSORS	random-normal	50	8.5
ASSOCIATE PROFESSORS	random-normal	52	6.2
FULL PROFESSORS	random-gamma	59	5

Table 3: The age distribution of the simulated population for each academic rung

At time zero each agent is endowed with an initial *productivity*, which is a number taking a positive random value extracted from a normal distribution having μ=37.5 and σ=21.9 for males and μ=34.8 and σ=20.4 for females, following the actual distribution of the Italian academics' scientific productivity in Filandri and Pasqua (2021), where a measure of scientific productivity is built by considering the number of publications, number of citation and H-index of Italian scholars taken data form Elsevier SciVal data. However, as *productivity* is a dynamic variable evolving over time, we attribute to the agents an annual increase in their *productivity* that corresponds to a positive value extracted from a random-normal distribution with μ=2% and σ=2% according to Elsevier SciVal data (2019). Furthermore, we consider that women having children show, on average, a slowdown in the increase of their *productivity*. To take this into account, we took the Istat maternity rate of women in childbearing age and we plug it in the model. Then, we attribute a lower increase in *productivity* (μ=1.4% and σ=2%) to women for five years after childbirth, being this the pre-school age. Table 4 summarizes how agents' *productivity* evolves over time.

---

[12] In the random extractions a cap of 70 years of age is set for all the agents, as this is the maximum retirement age.

	MALES	FEMALES
Productivity at time zero	μ=37.5 σ=21.9	μ=34.8 σ=20.4
Annual increase of *productivity*	μ=2% σ=2%	μ=2% σ=2%
Annual increase in *productivity* for women in the five years after childbirth	----	μ=1.4% σ=2%

Table 4: Dynamics of agents' *productivity* over time

In their career advancements, agents are evaluated according to their *curriculum* in which not only scientific productivity, but also teaching experience and contribution to administrative tasks within the university are taken into account. Therefore, we construct our variable *curriculum* summing the normalised values of *age* and *productivity*: as a result, in the final value of the *curriculum* age and productivity weights respectively about 1/3 and 2/3.

3.3. *Overview of the computational model: dynamics*

In our simulation we reproduce the retirement of the agents and the mechanism of the POMs that defines the resources available for hiring and promoting. The retirement is based on the age of agents, which is set at 70, the maximum retirement age by law. For example, when a full professor retires, one POM becomes available in the next year. We also assume that all tenure track assistant professors become associate professor after three years, *i.e.* that all obtain the NSQ.

Furthermore, we assume that the resources made available by retirements are integrated with some extra-resources, being annually 15% of the POMs from retirements. This value reflects the so-called "supplementary plans" (see Section 2) that, over the last ten years, the Ministry of University approved every two years and that distributed extra-resources corresponding to about 30% of the POMs available from retirements.

The flowchart in Figure 1 summarizes the mechanism of POMs generation and use: retirements generate resources and these are used for recruitment and promotions.

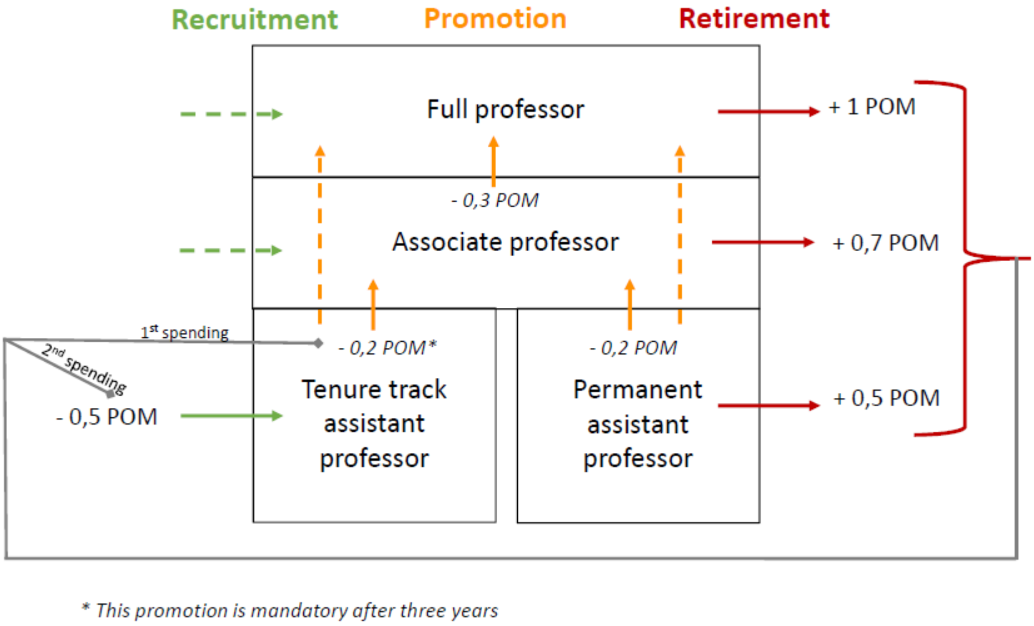


Figure 1: Flowchart of the generation and use of POMs in the University system

Given the resources available, *i.e.* the total amount of POMs, the Universities choose how to spend them. This choice is not neutral as recruiting means to keep or even to increase the dimension of the academic staff and boosting the services that a university can offer, while promoting those who are already in tenured positions means to keep constant or even decrease (if all POMs available are used for promotions) the number of professors in the university. These choices depend on the decisions taken at each university level and different university can adopt different personnel policies. In our model we assume a standard resources' allocation agenda that reflects the prevalent strategy adopted in the Italian universities after the 2010 reform:

1. all *temporary assistant professors* who are in their third year of contract are promoted *associate professors* at the cost of 0.2 POMs;
2. if POMs are left, these are used to recruit new *temporary assistant professors* at the cost of 0.5 POMs to substitute professors who retired. In the model they are spawned as new agents. We assume that the maximum number of new *temporary assistant professors* spawned into the model corresponds to the number of agents retiring in the year. It may happen to observe some years in which few professors retire. In these cases, the available resources may not cover the cost of all new assistant professors needed to replace retired professors and therefore we progressively reduce the number of new *temporary assistant professors* recruited until the university can afford their cost;
3. after the previous two steps, if some resources are still available, these are used to promote associate professors to full professors at the cost of 0.3 POMs.

If some resources not sufficient to hire or to promote professors are left, these are set away and reinvested in the next year.

3.4. Overview of the model: the origin of gender gap

Going back to the resources allocation agenda we defined above, it is possible to show whether and how the gender gap originates at each step of the resource allocation agenda:

1. as all the *temporary assistant professors* at the end of their third year of contract are promoted to associate professorship positions, their gender distribution reflects that of *temporary assistant professors* at the third year of contract;

2. when new *temporary assistant professors* are spawned into the model, we follow the actual gender distribution of temporary assistant professors (MUR data, average 2015-2019), *i.e.* 42% are females and 58% are males, considering some random fluctuations in the range of ±2%;

3. promotion to full professorship positions follows a more sophisticate mechanism since it involves a selection process where gender bias may arise. First, when associate professors apply for the full professorship positions, their *curriculum* (as defined in Section 3.2) must exceed a certain threshold: this reflects the condition of having the NSQ to be promoted. However, a previous literature stated, women are more reluctant to apply for promotion than men, and therefore the threshold is set 10% higher for females reflecting their lower probability of applying and hence to obtain the NSQ (Pautasso 2015; De Paola *et al.* 2017; Filandri and Pasqua, 2021). Finally, a well-established literature emphasizes that evaluation processes are subjected to the principle of homophily: evaluators tend to judge more benevolently candidates who display some common features with them. Gillies (2014) and Debernardi *et al.* (2021) discuss this bias in terms of research interests, whereas Bauges *et al.* (2017) and Checchi *et al.* (2019) show that similar results apply to the gender bias: while expressing an evaluation, men will tend to judge more benevolently male candidates, and so do women with female candidates. To model this mechanism, in our model we assume that a candidate i receives an evaluation EV from the committees j being a function of both his/her *curriculum* CV and of a gender-bias B, plus a white noise ε, expressing some random fluctuations in the range ±10%. Therefore:

   $$EV_i^j = CV_i + B_i^j + \varepsilon$$

   The gender-bias B can take a positive or a negative value depending on both the candidate gender and the gender composition of the evaluating committee, according to the homophily principle. The values of the bias B are randomly extracted in the ranges reported in Table 3 to reproduce a stronger or weaker bias that depends on the gender composition of the committee.

GENDER COMPOSITION OF THE COMMITTEE	*Male candidate*	*Female candidate*
Three males and no females	between 0 and +30 points	between 0 and -30 points
Two males and one female	between 0 and +15 points	between -5 and +5 points
One male and two females	between -5 and +5 points	between 0 and +15 points
No males and three females	between 0 and -30 point	between 0 and +30 points

Table 5: Values of the bias *B* according to the gender composition of the committee and the gender of the candidate

Furthermore, we assume that the members of the evaluating committees are randomly chosen from the population of full professors, and, therefore, it is much more likely to have male rather than female members in the committees. Then, as long as the homophily principle holds, the more males are in the committees, the stronger is the bias against female candidates. These model's parameters have been calibrated to replicate MUR data on promotions for the period 2014-19 (see Annex 1).

3.5. Introducing gender policies

Once we have defined the baseline of our virtual academia and its functioning dynamics, we simulate some scenarios in which we introduce different policies aimed at reducing gender discrimination, and we observe if they would be effective in closing the gender gap. The policies we consider are:

i. the introduction of a maternity bonus in the evaluation for promotion to full professorship to compensate for the slowdown in the growth of *productivity* in the five years after each childbirth. The bonus is calculated as the difference between the average *productivities* of all the agents from one year to the next;

ii. a minimum threshold of at least one woman in each committee for promotion to full professor to contrast the gender bias in the evaluating process;

iii. the introduction of 40% gender quotas in promotions to full professorship, *i.e.* none of the two gender can exceed the threshold of 60% of the new positions for full professor created every year.

We compare the effects of these policies by simulating the introduction of one policy a time (*Scenario 3, 4* and *5)* and then we combine all policies (*Scenario 6)* to observe whether and how long it would take to close the gap in the academic population in the different scenarios. Finally, we simulate the effects of introducing gender policies also in the recruitment of assistant professors assuming an annual increase of 0.5% in the share of females on new entrants until a perfect the gender- balance is achieved (*Scenario 7*). However, before discussing the effects of the policies, we simulate our model by assuming that males and females are characterized by the same distribution of *productivity* to see whether the unbalanced composition of the academic staff is simply the result of a meritocratic system that always promotes the most productive individuals (*Scenario 2)*. Table 6 summarizes all the scenarios we simulate.

Scenario 1	No policy
Scenario 2	Males and females are assigned with the same *productivity* distribution
Scenario 3	Introduction of the maternity bonus
Scenario 4	Introduction of the minimum threshold of at least one woman in the evaluating committees for promotion
Scenario 5	Introduction of a 40% gender quota for promotion to full professorship positions
Scenario 6	Introduction of the previous three policies combined
Scenario 7	Introduction of the three policies combined and an increasingly more balanced entrance of new assistant professors

Table 6: Simulated scenarios

Results

In this section we present the results of the simulations of the scenarios listed above and we discuss the effectiveness of the policy interventions that we consider. We run 1,000 replications for each scenario to test the robustness of our results and we show for the variables of interest the average values (and 95% confidence intervals) across the 1,000 replications over a period of one hundred years to observe how the gender composition of our virtual academia evolves.

We first observe the evolution of the composition of our virtual academia by hierarchical positions in the long run. Figure 2 shows the trend for each rung regardless of the gender composition. These trends are common to all the scenarios, as the policies that we consider do not impact on the distribution of the staff over the different hierarchical levels but they only affect its gender composition.

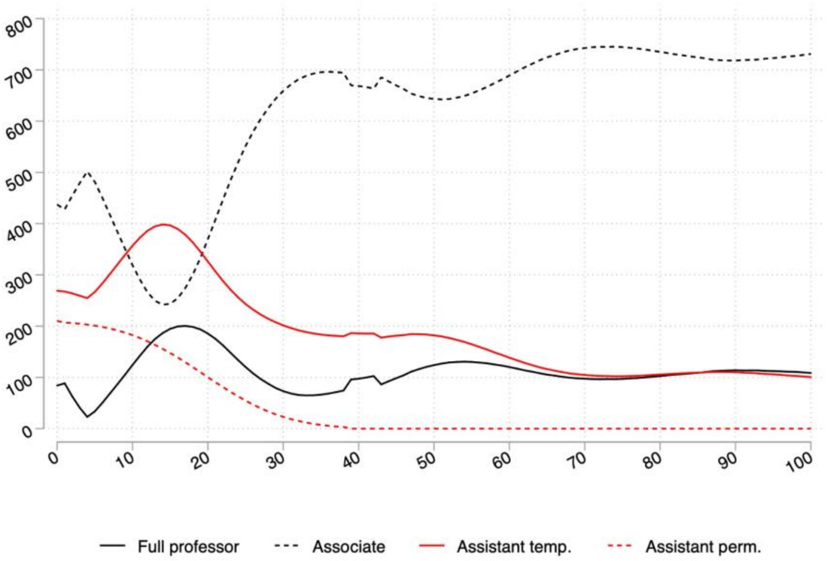


Figure 2: Trend of the academic staff by hierarchical level

In Figure 2 we see that, as expected, the number of *permanent assistant professors* decreases until they disappear after 37 years, as their contract type has been abolished in 2010 and there are no new permanent assistant professors recruited in the system. *Temporary assistant professors* display a trend that reflects the trend of retirements as a new temporary assistant professor is spawned in the model for each agent that achieves the retirement age. Therefore, the increase in the number of *temporary assistant professors* in the very first cycles (years) depends on the relative high average age of the agents present in the system, which reflects actual data. In the medium run the number of *temporary assistant professors* decreases until it stabilizes when the average age of the simulated population becomes lower. *Associate professors* experience a symmetric decrease in the first phase of the simulation, because as long as *permanent assistant professors* are still present in the model, they continue to retire generating enough resources to allow the former to access to full professorship.

When *permanent assistant professors* expire, the number of *associate professors* displays a significant increase, whereas the number of *full professors* suffers a drastic decrease over time. These two phenomena should be read as complementary, as the decrease in the latter is due to the limited amount of resources that do not allow to open a larger number of positions for full professor enlarging the size of the associate professor rung because career advancements become slower.

Since we are interested in the gender composition of each rung, we compute the percentage of female associate and full professors over a period of 100 years in the different scenarios listed above. We do not show the gender composition neither of *permanent assistant professors* as it changes slightly depending on the age distribution of our agents (*i.e.* on those retiring in a certain year) nor of *temporary assistant professors* as this is a constant input data in our model in all scenarios (42% of women with random fluctuations of ±2%) but in *Scenario 7*. In Figure 3 (A and B) we show the share of female among *associate* and *full professors* (with the 95% confidence interval) in the different scenarios.

Scenario 1 shows the simulated evolution of the university system under the assumption of no policy intervention to reduce the gender gap. In the first 15 years we observe a significant reduction in the gender gap among the *associate professors* due to the starting decrease in their number that we discussed above. As in this phase there are more resources available, more of them are promoted to full professorship and the share of females among *associate professors* increases because under the conditions of *Scenario 1* males are more likely to be promoted and to become *full professors*, enlarging the share of female *associate professors*. Symmetrically, we observe an initial contraction in the share of females among *full professors*, as well as its boost in the following years that comes from a lower number of positions for full professorship opened, which favours a slightly more balanced outcome. After the first 15 cycles the total number of full professors present a slight decrease, to get stable about after 50 years in the simulations: in this phase the share of females keeps stable with some kind of long-wave fluctuations. However, after one hundred years females represent only the 25% of the *full professors'* population meaning that there is no possibility of closing or even significantly reducing the gender gap without interventions in the system.

In *Scenario 2*, we assume the same distribution of *productivity* for male and female professors. Our results show that the gender gap is not the result of applying objective merit criteria (*i.e.* those with better *curriculum* are promoted first, regardless their gender), but depends on the gender bias affecting the evaluation dynamics. In fact, *Scenario 2* points out that, even if males and female professors had the same productivity distribution, the latter would be penalized because of a) the slowdown in their scientific production during the childrearing periods, and b) the bias occurring in the committees for promotions. In fact, even if the gender gap among *full professors* is slightly reduced with respect to *Scenario 1*, with women being slightly above 30% in the long run, it is still far from being closed, demonstrating the persistence of the bias, and its discriminatory character.

Then, we show the effects of introducing the three policies described above one at a time. In *Scenario 3* we show the effects of a maternity bonus compensating for the slowdown in the *productivity* growth after the birth of each child, *Scenario 4* considers the effects of setting a minimum threshold of one woman (out of three) in the promotion committees, whereas *Scenario 5* shows the results of introducing 40% gender quotas in the promotions to full professorship positions. As the graphs in Figure 3 show, none of the three policies alone is effective in closing the gender gap: the upper bound of the confidence intervals of the share of women do not reach the value of 50% even in the long run neither among *associate professors* nor among *full professors*. However, if we look at the confidence interval, the share of female *full professors* achieves the 40% threshold in all the three scenarios considered, whereas women among *associate professors* is well above this threshold. Therefore, by introducing one policy at a time more gender balanced composition of the academia is achieved, but only in 51 years in the case of *Scenario 3*, in 92 years in the case of *Scenario 5*, whereas it would take only 19 years under the assumptions of *Scenario 4*, revealing that having a more gender balanced composition in the promotion committees would be the most effective policy in reducing the gender gap in the highest ladder of the academic career.

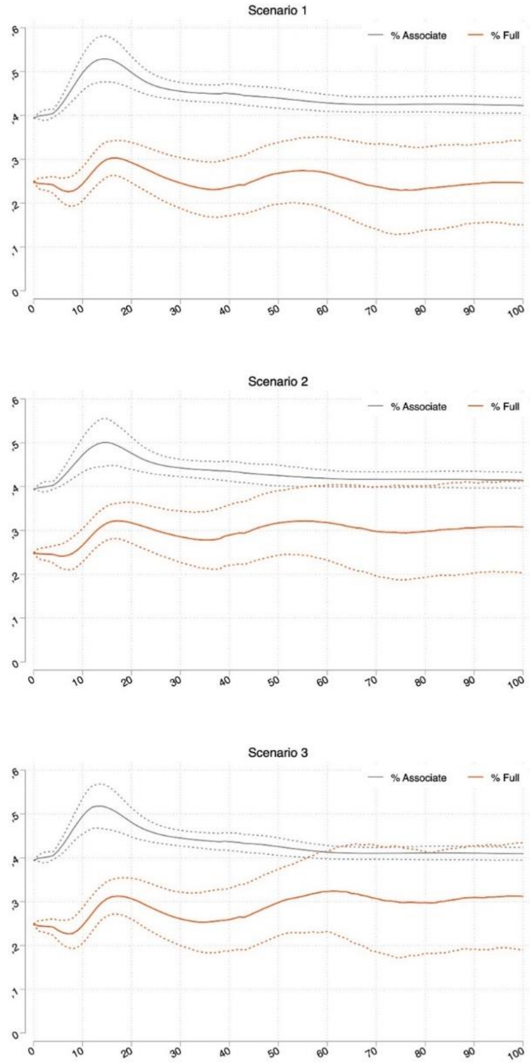
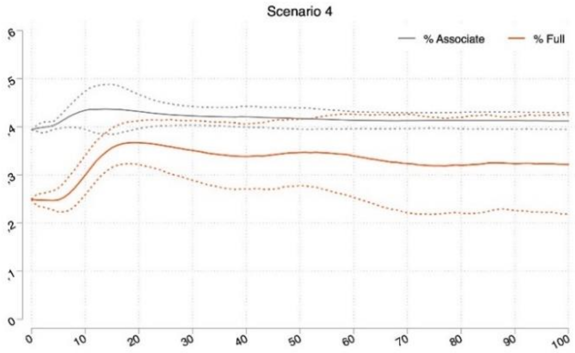
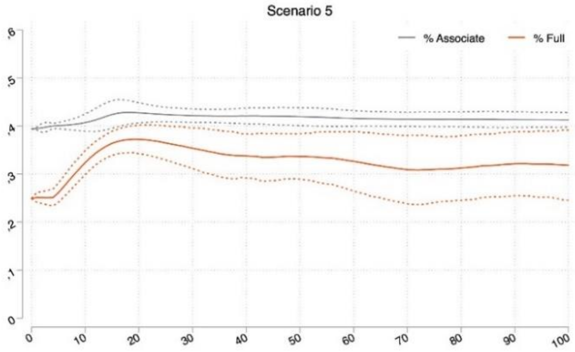
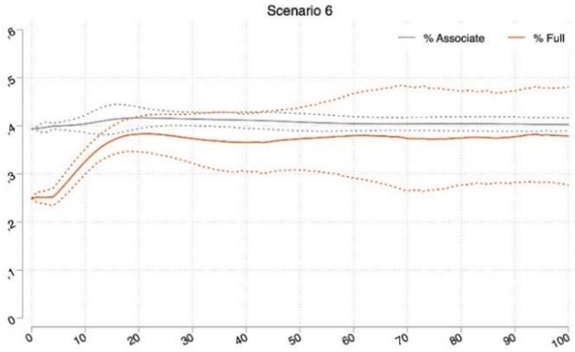


Figure 3A: Share of females for *associate* and *full professors* in the simulations' outcome of all the scenarios (average values across 1,000 replications - 95% confidence interval)







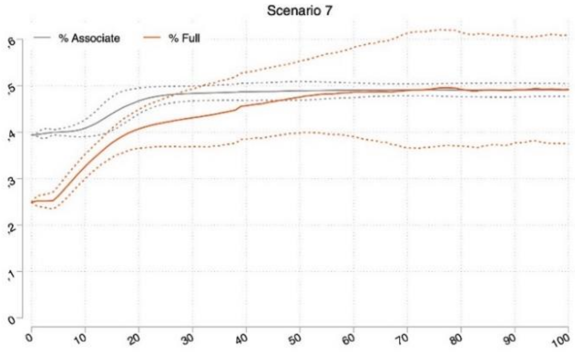


Figure 3B: Share of females for *associate* and *full professors* in the simulations' outcome of all the scenarios (average values across 1,000 replications - 95% confidence interval)

The situation is much better in *Scenario 6*, in which all the three policies discussed above are introduced simultaneously. In this case, the upper bound of the confidence intervals for *full professors* achieves a 50% share of female in 70 years, whereas it would be above 40% already after 16 years, showing that introducing a mix of different policies would be crucial to reduce the gender gap as this would act in contrasting the different sources of discrimination. Even more interestingly, *Scenario 7* shows that it would be possible to achieve more gender equity and to achieve it faster only by extending the policies that we applied for the tenured staff also to the recruitment of new assistant professors. In fact, if we assume an annual increase of 0,5% in the share of females among new *temporary assistant professors* until a perfectly balanced (50-50%) entrance is reached (being this the same increasing trend that we register by introducing our set of policies on the tenured population in *Scenario 6*) the upper bound of the confidence intervals for *full professors* would achieve a value of 40% in the share of women in 14 years, and, even more surprisingly, a 50% share is reached in only 27 years. In other words, by introducing the three policies to the whole academic population would make it possible to close the gender gap in less than 30 years.

Table 7 summarizes how long would it take in each scenario to reduce the gender gap significantly (*i.e.* to achieve a 40% share of women among *full professors*) and to close it (*i.e.* to achieve the 50%).

	Years to achieve the 40% share	Years to completely close the gender gap (*i. e.* to achieve the 50% share)
Scenario 1	target not achieved	target not achieved
Scenario 2	60	target not achieved
Scenario 3	51	target not achieved
Scenario 4	19	target not achieved
Scenario 5	92	target not achieved
Scenario 6	16	70
Scenario 7	14	27

Table 7: Speed of the policies in achieving the target in all the scenarios

Clearly, these results also depend on the amount of resources we have assumed universities can invest in recruiting and promotions, as well as on the resources allocation agenda that we have imposed to the model. Increasing the number of positions for full professorship under the policy conditions that we considered could possibly help to achieve quicker a more gender balanced academia, but it could not be affordable for reasons of sustainability of the system under the constraint of the available resources. We should combine an increase in the available resources with a different allocation scheme to obtain a more balanced outcome in shorter times.

The results presented so far show which set of policies should be implemented to improve or even to reach gender equity in the academia. However, our model allows also to measure the degree of discrimination, and, even if not specifically thought for this purpose, to consider when the latter drives to inefficiency. To measure discrimination, we compare the CV score of the male candidate winning a competition with that of the female candidate with the highest CV score applying for the same position but not winning the position. Whenever the latter score is higher than the former, our indicator records a gender discrimination penalizing a female candidate. Symmetrically, we consider as discrimination against men the case in which a female candidate winning the competition has a CV score lower than the non-winning male with the highest CV score.

Figure 4 shows the trend of such a discrimination rate, *i.e.* the share of competitions which are not won by the most productive individual, over time and across the different scenarios, distinguishing between discrimination against women and discrimination against men, both being an inefficient sub-optimal outcome of the system dynamic. We can observe how the policies implemented contribute to reduce the overall inefficiency of the system. The discrimination rate reaches peaks of 30% of competitions not rewarding the most productive individual in the first scenarios (where no policy is implemented), whereas the peak is reduced at 25% when we introduce all the policies in *Scenario 7*. As far as the long-run trend is concerned, the rate of inefficiency progressively decreases to 8% in *Scenario 1* up to its minimum value of 6% in *Scenario 7* when policies against discrimination are introduced. This reduction in the overall inefficiency of the system may appear not so outstanding, even if still significant. However, interestingly, we observe a shift in the discrimination phenomenon: whereas in *Scenario 1*, *Scenario 2* and *Scenario 3* discrimination episodes systematically affect women, from *Scenario 4* onwards there is a change in the gender distribution of discrimination episodes with a more balanced distribution between males and females. This happens because the corrective mechanisms that we propose are not thought to eliminate inefficiency, which is the result of an evaluation process that involves subjective homophilic judgements. The policy intervention we simulate can smooth the systematic discrimination against women, and our simulations show that they are effective in achieving this target, as the discrimination episodes are equally distributed among men and women in the last scenarios. However, they are unable to completely eliminate inefficiency. A further discussion is needed to identify recruitment and promotion mechanisms that allow to counteract the effects of homophile, being gender-blind competitions (as in Goldin and Rouse, 2000) not possible in the academic context.

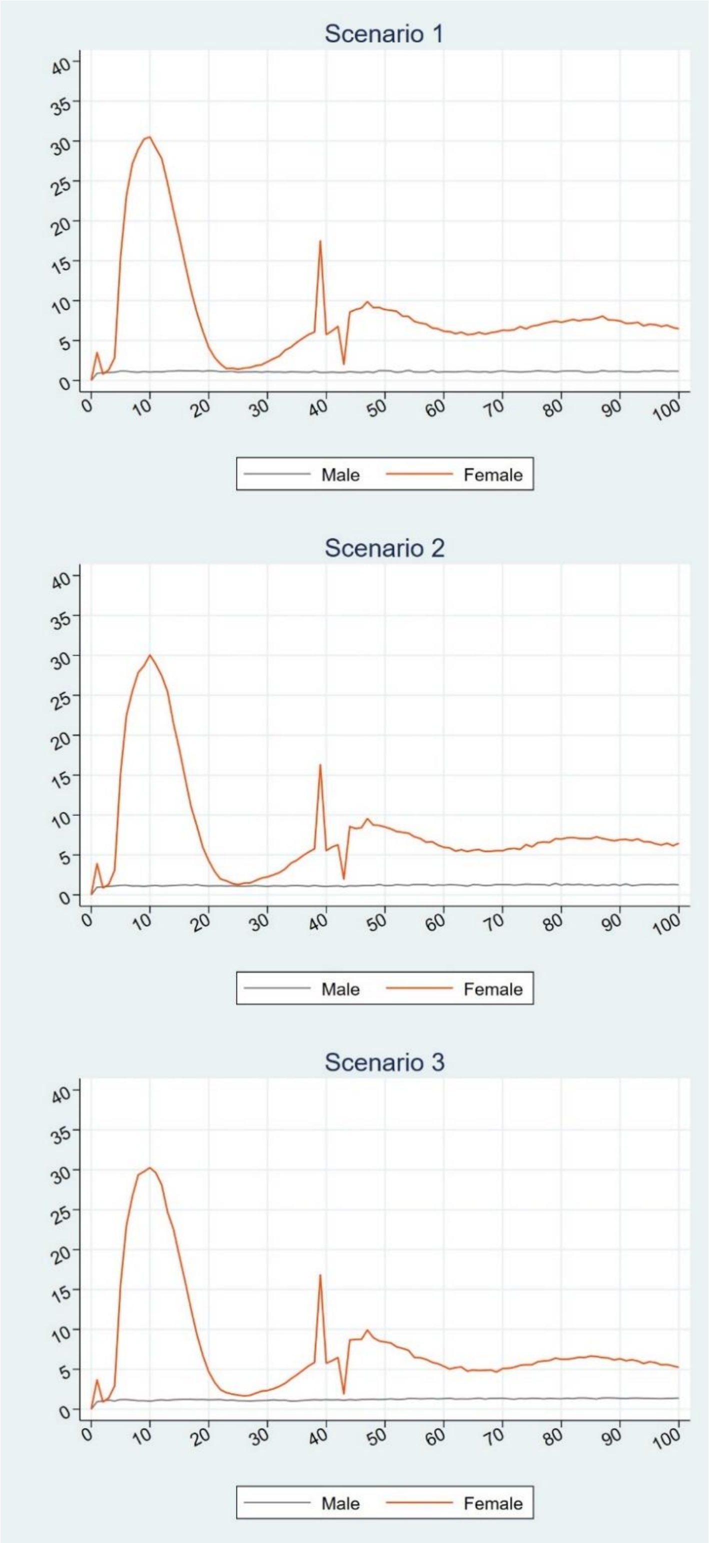


Figure 4A: discrimination rates against males and females in the simulations' outcome of all the scenarios (average values across 1,000 replications).

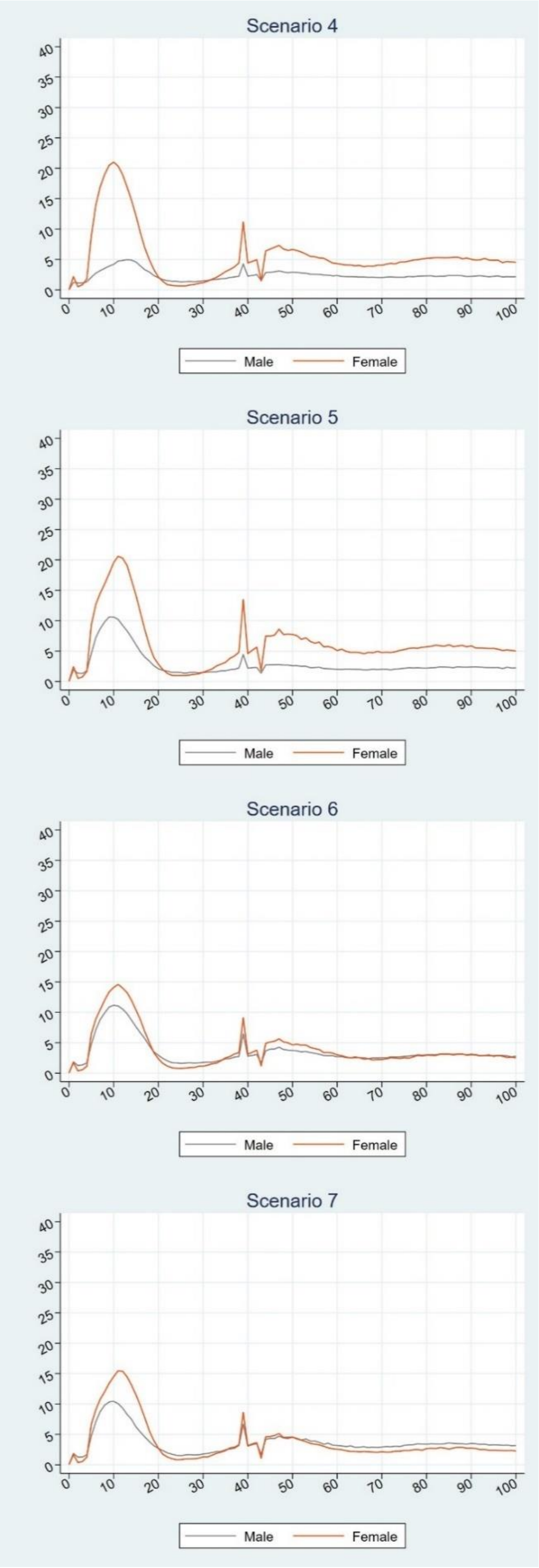


Figure 4B: discrimination rates against males and females in the simulations' outcome of all the scenarios (average values across 1,000 replications).

Conclusions

We present an agent-based model simulating gender discrimination dynamics giving rise to the gender gap in a virtual academia that is the scale reproduction of the Italian one to study how these may evolve over a period of one hundred years under the different policy scenarios. Our results show that if current conditions (*i.e.* with the average trends of the last five years) are kept constant in the long run women will remain under-represented in all the levels composing the academic staff, with a dramatic situation especially among full professors where the share of women will remain below 30% despite the more gender balanced entrance of new *assistant professors* in the system.

We then estimated the impact of introducing different policies to reduce the gender gap aimed at correcting the mechanisms producing discrimination phenomena. Specifically, we analysed the impact of policies compensating for the women loss of productivity during the childrearing years, ruling the gender composition of the evaluating committees, and introducing gender quotas. Results show that the introduction of these polices can partially mitigate the gender discrimination phenomenon. However, given the complex nature yielding the gender gap, it is only by combining a set of policies that contrast the different sources of discrimination that it would be possible to achieve the target of reducing, and even closing, the gender gap in a reasonable lapse of time. Furthermore, this would be much effective intervening on both recruitment and promotion of the academic staff. We also show that the policies considered are able to reduce only slightly the overall inefficiency of the system, but they modify the distribution of discriminating episodes against men and women, eliminating the systematic negative effect on women' careers.

ANNEX 1

Calibration of the gender bias in the evaluating committees

Tuning the gender bias that arises during the evaluation has been one of the more challenging tasks in designing our model. Even if the so-called *homophily principle* affecting the evaluating processes is a widely recognised phenomenon in the literature (Bauges *et al.*, 2017 and Checchi *et al.*, 2019) turning it into well-defined mathematical operations and identifying the extent to which develop it in the model required a rigorous calibration work, that we explain more in the details in the present annex.

As we mentioned, we assume that during the competitions to promotion to full professorship positions each candidate *i* receives an evaluation *EV* from the committee *j*, and that this evaluation is a function both the curricula *CV* of the candidate and of a gender-bias *B* (plus a white noise *ε*, expressing some random fluctuations in the range ±10%), then:

$$EV_i^j = CV_i + B_i^j + \varepsilon$$

where the *CVs* of the candidates depend on both their *age* (Table 3) and *productivity* distribution (Table 4) as described in Section 3.2 and the bias *B* takes values in the ranges reported in Table 5.

To calibrate the parameters used in our model, we build a second model isolating the gender-bias arising in the promotion committees and we plug in it a starting scenario corresponding to the actual data of the Italian academia in the year 2014 (MUR data): then, we test the robustness of the mechanism we assume in the model by comparing the results performed by running the simulation of the model with actual data observed over the period 2014-2019.

To this purpose, we consider only the *associate* and *full professors*' population, providing them with the same characteristics that we attributed to the agents of our main model, and assuming that for each retiring agent a new *associate professor* is spawned in the model. Our virtual academia in 2014 follows the gender composition reported in Table A1.

	Males	Females
ASSOCIATE PROFESSORS	97	120
FULL PROFESSORS	200	54

Table A1: Gender composition of associate and full professors in a scale reproduction of Italian academia in 2014

Furthermore, we consider a number of competitions for promotions to full professorship opened in the period 2015-19 that are a scale reproduction of the actual number of positions opened in this period in the Italian universities. Once that the model is set up, we perform the simulation and compare the simulated results with the actual data collected in those years. Results of the comparison show that, under the current calibration of the parameters that generate the gender bias mechanism, the simulation of the model is able to reproduce actual data and, therefore, the values of the parameter we use are correctly calibrated.

Bibliography

Babcock L., Recalde M. P., Vesterlund L., and Weingart L. (2017), Gender differences in accepting and receiving requests for tasks with low promotability, *American Economic Review*, vol. 107(3), p. 714–747.

Bagues M., Sylos-Labini M. and Zinovyeva N. (2017), Does the Gender Composition of Scientific Committees Matter?, *American Economic Review*, vol. 107(4), p. 1207-1238

Bagues M., Sylos-Labini M. and Zinovyeva N. (2019), Connections in scientific committees and applicants' self-selection: Evidence from a natural randomized experiment, *Labour Economics*, vol. 58, p. 81-97

Bennouri M., De Amicis C. and Falconieri S. (2020), Welcome on board: A note on gender quotas regulation in Europe, *Economics Letters*, Vol. 190

Bertrand M. (2011), New perspectives on gender, in O. Ashenfelter and D. Card (eds), Handbook of Labor Economics, Vol. 4B, Amsterdam: North-Holland

Bianco M. L. (2000), Effetti della riforma dei concorsi universitari su carriere accademiche e dinamiche di genere, *Polis* Vol. 16(3), p. 417–444

Casad B.J., Franks J.E., Garasky C.E., Kittleman M.M., Roesler A.C., Hall D.Y., Petzel Z.W. (2020) Gender inequality in academia: Problems and solutions for women faculty in STEM, *Journal of Neuroscience Research*, vol. 99, p. 13-23

Checchi, D., Cicognani, S. and Kulic, N. (2019) 'Gender Quotas or Girls' Networks? Evidence from an Italian Research Selection', *Work, Employment and Society*, vol. 33(3), p. 462-482

Chesterman C. and Ross Smith A. (2006), Not tokens: reaching a "critical mass" of senior women managers, *Employee Relations*, vol. 28(6), p. 540-552

Clavero S. and Galligan Y. (2020), Analysing gender and institutional change in academia: evaluating the utility of feminist institutionalist approaches, *Journal of Higher Education Policy and Management*, DOI: 10.1080/1360080X.2020.1733736, online first.

Coate K. and Howson C. K. (2014), Indicators of esteem: Gender and prestige in academic work, *British Journal of Sociology of Education*, p. 1–19

Council of the European Union (2015), Advancing gender equality in the European research area: Council conclusions. 14846/15 (http://data.consilium.europa.eu/doc/document/ST-14846-2015-INIT/en/pdf)

Dawida H. and Neugart M. (2011), Agent-based Models for Economic Policy Design, *Eastern Economic Journal*, vol. 37, p.44–50

De Paola M. and Scoppa V. (2015), Gender Discrimination and Evaluators' Gender: Evidence from Italian Academia, *Economica*, vol. 82(325), p. 162-188

De Paola M., Ponzo M. and Scoppa V. (2017), Gender differences in the propensity to apply for promotion: evidence from the Italian Scientific Qualification, *Oxford Economic Papers*, vol. 69(5), p. 986-1009

Doherty L. and Manfredi S. (2006), Women's progression to senior positions in English universities, *Employee Relations*, vol. 28(6), p. 553-572

Dorenkamp I. and Weiß E. (2018), What makes them leave? A path model of postdocs' intentions to leave academia, *Higher Education*, vol. 75, p. 747-767

Dosi G., Pereira M.C., Roventini A. and Virgillito M.E. (2018), The effects of labour market reforms upon unemployment and income inequalities: an agent-based model, *Socio-Economic Review*, vol. 16(4), p. 687–720

Dubois-Shaikand F. and Fusulier B. (2015),'Academic careers and gender inequality: Leaky pipeline and interrelated phenomena in seven European countries, WP GARCIA (Gendering Academia and Research: combating Career Instability and Asymmetries), n. 5, Univeristy of Trento

Eason R., Rosenberger R., Kokalis T., Selinger E. and Grim P. (2007), What kind of science is simulation?, *Journal of Experimental & Theoretical Artificial Intelligence*, vol. 19(1), p. 19-28

European Commission (2019), She Figures 2018, Brussels: Directorate-General for Research and Innovation

Filandri M. and Pasqua S. (2021), Being good isn't good enough': gender discrimination in Italian academia, *Studies in Higher Education*, vol. 46(8), p. 1533-1551

Gillies D. (2014), Selecting applications for funding: why random choice is better than peer review, *RT. A Journal on research policy and evaluation*, vol. 2(1).

Ginther D.K. and Kahn S. (2004), Women in Economics: Moving Up or Falling Off the Academic Career Ladder?, *Journal of Economic Perspectives*, vol. 8(3), p. 193-214

Goldin, C. and Rouse C. (2000), Orchestrating Impartiality: The Impact of "Blind" Auditions on Female Musicians. *American Economic Review*, 90 (4): 715-741.

Guarino C. M. and Borden V. M. (2017), Faculty service loads and gender: Are women taking care of the academic family?, *Research in Higher Education*, vol. 58(6), p. 672–694.

Grow A. and Van Bavel J. (2015), Assortative Mating and the Reversal of Gender Inequality in Education in Europe: An Agent-Based Model, *PLoS ONE*, vol. 10(6), p. 1-24

Howe-Walsh L. and Turnbull S. (2016), Barriers to women leaders in academia: tales from science and technology, *Studies in Higher Education*, vol. 41(3), p. 415-428

Leombruni R. and Priori E. (2020), The methodological status of agent-based modelling. Simulations as a way to causal explanations, mimeo

Marini G. and Meschitti V. (2018), The trench warfare of gender discrimination: evidence from academic promotions to full professor in Italy, *Scientometrics*, vol. 115(2), p. 989-1006

OECD (2016), Education at a Glance 2016: OECD Indicators, OECD Publishing

Pautasso M. (2015), The Italian University Habilitation and the Challenge of Increasing the Representation of Women in Academia, *Challenges*, vol. 6, p. 26-41

Tindall T. and Hamil B. (2004). Gender disparity in science education: the causes, consequences, and solutions, *Education*, vol. 125, 282–295

van den Brink M. and Benschop Y. (2012), Slaying the Seven-Headed Dragon: The Quest for Gender Change in Academia, *Gender, Work & Organization*, vol. 19(1), p. 71-92

Vernos I. (2013), Quotas are questionable, *Nature*, vol. 495, p. 39

Voorspoels J. (2018), Beyond controversy: gender-quota implementation in academic decision-making bodies, Antwerpen: Antwerpen University

Wallon G., Bendiscioli S. and Garfinkel M. S. (2015), Exploring Quotas in Academia, EMBO, https://www.embo.org/documents/science_policy/exploring_quotas.