AGENT-BASED MODELS AND METHODOLOGICAL INDIVIDUALISM: ARE THEY FUNDAMENTALLY LINKED?

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RÉSUMÉ. – Cet article étudie la littérature sur le bien-fondé du lien entre les modèles à base d'agents artificiels et l'individualisme méthodologique. L'argument défendu est que ces analyses reposent sur une définition spécifique de l'individualisme méthodologique rendant ainsi les conclusions dépendantes de la définition retenue. L'article propose alors de considérer les modèles à base d'agents artificiels et l'individualisme méthodologique comme des « instruments génériques », à savoir des dispositifs ayant des propriétés transversales à des problèmes explicatifs, à des domaines d'étude et à des disciplines hétérogènes. De ce point de vue, les modèles à base d'agents artificiels et l'individualisme méthodologique semblent partager des principes élémentaires qui sont indépendants des entités et des niveaux d'analyse propres à un objet d'étude particulier. En ce sens, cet article soutient finalement que les modèles à base d'agents artificiels et l'individualisme méthodologique sont intrinsèquement liés.

MOTS-CLÉS. – Simulation informatique ; Modèles à base d'agents artificiels ; Individualisme méthodologique ; Individualisme méthodologique fort ; Individualisme méthodologique faible ; Instruments génériques.

ABSTRACT. – The article discusses recent scholarship on whether or not the association between agent-based computational models and methodological individualism is justified. It is argued that these analyses are problematic because they start with a specific understanding of methodological individualism, which makes their conclusion contingent on the chosen view of what this perspective either is or is not. To overcome this problem, the paper proposes to think of both agent-based models and methodological individualism as "generic instruments," i.e. devices with properties that are transversal to explanatory problems, fields, and disciplines. Within this framework, it appears that agent-based models and methodological individualism share some basic principles irrespective of the entities and levels of analysis involved by the explanatory problem under examination. In this sense, this study claims, they are essentially linked.

KEYWORDS. – Computer Simulation; Agent-Based Models; Methodological Individualism; Strong Methodological Individualism; Weak Methodological Individualism; Generic Instruments.

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Agent-based computational models (hereafter, ABMs; or, ABM for agent-based model/modeling) are stylized representations of set of entities that, given certain contextual constraints, interact over time according to given behavioral rules, thus creating, usually through feedback loops across different levels of analysis, outcomes and trends that were not present at the outset of the simulated process. ABMs are computational models in the sense that they are solved by the execution of a computer program that translates algorithmically the hypothesized entities' rules, interactions and constraints (for an introduction, see: Wilensky & Rand, 2015).

Over the last twenty years or so, this type of computer simulation has been applied across a variety of disciplines to topics as diverse as cancer growth (Norton *et al.*, 2019), blood circulation (Bora *et al.*, 2019), animal behaviors (Tang & Bennet, 2010), disease diffusion (Ajelli *et al.*, 2010), city changes (Hosseinali, Alesheikh & Nourian, 2013), traffic jams (Barthélemy & Carletti, 2017), pedestrian movements (Kerridge, Hine & Wigan, 2001), ancient civilization dynamics (Heckbert, 2013), crime (Malleson, 2012), fertility decisions (Gonzales-Bailon & Murphy, 2013), mating behaviors (Billari *et al.*, 2007), tax evasion (Hokamp *et al.*, 2018), financial trends (Lux & Marchesi, 1999), social inequalities (Manzo, 2013), the diffusion of innovations (Manzo *et al.*, 2018) or opinion dynamics (Flache *et al.*, 2017), to name only a few topics. Originally dominated by over-simplistic models, the field is becoming aware of the importance of ABMs that seek more systematic connections with existing sociological theories and empirical data (compare, for instance, the studies reviewed in Macy & Willer [2002] with those discussed in Bianchi & Squazzoni [2015]).

The proliferation of ABMs was paralleled by meta-analyses on their potential and limitations. Some debates concerned highly technical issues such as the tools for the implementation of ABMs (Railsback *et al.*, 2017), the ways they can be studied (Thiele *et al.*, 2014) or how an ABM can be calibrated and/or validated empirically (Smith & Burow, 2018); the attempt to build shared research guidelines is also a recurrent line of reflection (Müller *et al.*, 2014). Other debates focused on the epistemological status of ABMs. In particular, epidemiologists started to investigate whether an ABM can produce causal knowledge (Marshall & Galea, 2014) whereas

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philosophers of social science questioned its explanatory potential (Elsenbroich, 2012). Recently, a new stream of discussion, involving both practitioners and philosophers of social science, appeared and added a new question to the debates on offer: is there an inescapable connection between ABMs and methodological individualism (MI, hereafter) (see, in order of publication: Marchionni & Ylikoski [2013]; Bulle & Phan [2017]; Di Iorio & Chen [2019]; and, Zahle & Kincaid [2020])? In the present article, I focus on this specific debate. My aim is to propose a new way of framing the question of whether or not ABM can/should be seen as the ideal tool to study formally theoretical explanatory models conceived in MI terms.

My argument stems from the observation that existing analyses of the connection between ABMs and MI are all premised on specific interpretations of what MI is. By "specific," I refer here to definitions of MI that are given in terms of types of entities that can legitimately enter an explanatory model, in order for the model to remain within the realm of MI. That current analyses endorse this starting point is certainly not surprising. As documented by Lars Udehn, the entire history of MI across authors and disciplines can indeed be thought of as a slow evolution from "strong" to "weak" versions of MI, where the distinction essentially refers to the proportion of collective and institutional (*versus* individual) variables, entities and properties that are accepted within the explanation (see, in particular, Udehn [2001: 347]; see also Udehn [2002: 499, 502]).

Although understandable, the problem with starting from a specific interpretation of MI is that, given the variety of definitions of MI on offer, the analysis of the link between ABMs and MI is transformed into a "battle" over the "right" understanding of MI (this is what I will call the "definition battle"). As right here essentially means deciding what entities can be legitimately introduced within an explanation inspired by MI, this battle in turn triggers a more subtle dispute about why this or that type of entities are legitimate or not and should have a primary explanatory role, a dispute that ultimately shifts to the ontological level (I will refer to this as the "ontological battle"). Thus, within this argumentative framework, the answer that one can offer to the question of whether or not ABM can/should be seen as an implementation of MI will only continue to be controversial.

To overcome these problems, I suggest reversing the way existing analyses approach the connection between ABM and MI. Rather than basing the investigation on a specific definition of MI, thus implicitly going from MI to ABMs, I suggest starting with ABM by identifying the generic properties of this method. By

"generic" properties, I refer to properties that are not defined in connection with any particular type of entities that a given ABM may be able to represent. My inspiration here is taken from the concept of "generic instruments," a concept that sociologists of science created to describe those material devices that are conceived in such a way that their functioning can be reshaped again and again as a function of the specific requirements of a given context of application (see Joerges & Shinn [2001: 9]; Joerges & Shinn [2002: 208, 212, 217, 244]; Shinn [2007]; Shinn [2008]). ABM's generic properties thus tell us only the type of problems the method is best suited for. The main proposal of the paper then is to move from ABM to MI in order to apply this understanding of "genericity" to MI and formulate the working hypothesis that ABM's generic properties are compatible with principles that partisans of MI may also support.

To defend this view, the paper goes through the following steps. I first retrace the way the connection between ABMs and MI was established. Secondly, I offer an overview of the arguments defended by those authors who have systematically addressed the question of whether or not the connection between ABMs and MI is inevitable. Third, I show that these investigations share two common problems that are likely to make the answer to the focal question continuously controversial. Finally, I formulate my own view on the connection between ABMs and MI, and explain in what sense ABMs and MI share generic properties that make them intrinsically associated.

The origin of the link between ABM and MI

In the following comment, Macy and Flache formulate a typical statement on the intimate association that computational sociologists tend nowadays to establish between ABM and MI:

> We begin, in section 11.1, by introducing ABC [agent-based computational] modeling as a computational implementation of "methodological individualism," the search for the micro-foundations of social life in the actions of intentional agents […] the agent-based approach replaces a single integrated model of the population with a population of models, each corresponding to an autonomous decision maker. This reflects the core methodological-individualist interest in the emergence of population dynamics out of local interaction. Although methodological individualism is older by many decades, ABM modeling can be characterized as its fullest formal representation (Macy & Flache, 2009: 246, 248; emphasis added).

The link between ABMs and MI here is motivated by identifying MI with the quest for actor-centered explanations of macroscopic patterns and ABM as the methodological tool used to study micro-based explanatory models. The origin of this association between MI, micro-foundation, and ABMs has a specific history. It is related to a well-defined technical problem—i.e. the so-called "transformation problem"—with which MI has struggled for decades. Making this history explicit helps to see that the way current analyses of the connection between ABMs and MI frames the problems, i.e. with specific definitions of MI in mind, in fact results from a longstanding, but particular, line of reasoning. Being aware of this peculiar context is a preliminary step to argue, as I will do, that the link between ABM and MI can in fact be established on more general bases (see below, section: A new perspective on the connection between ABM and MI).

From the transformation problem to ABMs

Within the history of MI, Coleman is usually associated with the so-called Coleman's boat (see, in particular, Coleman [1987]). In Udehn's terminology, the diagram visually illustrates a "weak" form of MI where macroscopic outcomes are seen as the result of concatenations of dynamic loops between structures and actions—as opposed to "strong" forms of MI where structural conditions, possibly pre-existing and out of the control of actors, are excluded from the focus of the analysis (Udehn, 2001: 292-306). Whilst, as clearly suggested by Raub and Voss (2017), Coleman should be credited with popularizing this non-reductionist form of MI more than for having invented it—strictly equivalent formulations can be found in Boudon (1986: 30), for instance, or, even earlier, among Dutch sociologists who in fact coined the term "structural individualism" (see, for instance, Wippler [1978: 143])—, it seems fair to say that Coleman discussed the main problem posed by the rigorous implementation of this form of MI more explicitly than others.

Since his highly quoted article on the theory of action, Coleman (1986: 1320-1321) indeed emphasized that the most difficult theoretical problem for action-oriented sociologists is "[…] the means by which purposive actions of individuals combine to produce a social outcome […]." Coleman called this problem the "micro-to-macro problem" but he acknowledged that, in Europe, the expression of "problem of transformation" was often in use (see Wippler & Lindenberg [1987]). When discussing his diagram, Coleman then translated this general statement into a claim about which step of the explanation should require the highest attention

(Coleman, 1987: 155). For him, this is the third one, "[…] for it is the third which moves back up from the individual level to the societal level." Coleman's chapter in fact is entirely devoted to showing how many strands of the sociological literature have developed explanations that fail fully to elaborate on the specific ways individual actions combine to produce a given social outcome. The failure, Coleman notes, consists in assuming that "simple aggregation" is enough to account for the micro-to-macro transition (Coleman, 1987: 157). The interdependence between actions is the missing element. Some years later, in the *Foundations of Social Theory*, he re-iterated the point and noted that most of economic theory, too, eludes the micro-to-macro transition by relying on the metaphor of the "representative agent" (Coleman, 1990: 10).

Interestingly, the same critique simultaneously appeared in economics where Kirman forcefully argued that this metaphor "is not simply an analytical convenience […] but is both unjustified and leads to conclusions which are usually misleading and often wrong" (Kirman, 1992: 117). The reason is that the "representative agent" is a "fiction" (*ibid.*, p. 125) that gives economists the impression of having solid micro-foundations while in fact the specific ways actors' heterogeneity is transformed into complex macro-outcomes —like economic cycles or price dynamics—, through interdependent behaviors, is simply ignored (*ibid.*, p. 132, 134).[1] It should be noted that, although without using the name, methodological individualism in sociology, too, can adopt this simplification. Boudon, for instance, defines "individualistic" statements as "[…] statements explaining why the ideal-typical individuals to relevant categories behave the way they did" (Boudon, 1998: 176). Only to consider "typical" individuals of a given category amounts to accepting that heterogeneity between individuals within the category can be ignored without consequences: the behavior of one actor is assumed to be sufficient to deduce the aggregate behavior of the whole. In contemporary advanced game theory, the construction of (a limited number of) "types" of players is indeed the standard way to account for actors' potential heterogeneity in strategic behavior (see, for instance, Fehr & Gintis [2007]).

To go back to Coleman, the interesting point of his analysis is that he formulated a precise hypothesis to explain why sociologists and economists have been obliged for so long to adopt such simpli-

1. This is the complete definition Kirman provides of the "representative agent" approach: "[…] macroeconomic models […] typically [they] assume that the choices of all the diverse agents in one sector—consumers for example—can be considered as the choices of one 'representative' standard utility maximizing individual whose choices coincide with the aggregate choices of the heterogeneous individuals" (Kirman, 1992: 117).

fying assumptions to handle interdependence and heterogeneity. According to him, the responsible is the "[…] little development of methods for characterizing systemic action resulting from the interdependent actions of members of the system" (Coleman, 1986: 1316). The absence of appropriate quantitative tools would have impeded formal analysis of theoretical models that include action interdependence (and heterogeneity), thus allowing sociologists to do only half of the job (Coleman, 1987: 157), and, on the other hand, as technique tends to feedback into ways of thinking (on this general mechanism, see Abbott, 1988; Abbott, 1990), not having a method suited for interdependence and heterogeneity, may have slowed down advanced theoretical elaboration along these lines.

To my argument, what now matters is that, around 2000, ABMs entered the social sciences precisely as the methodological solution to study macroscopic patterns and trends from the bottom-up through the algorithmical implementation of hypotheses on the heterogeneous behaviors of heterogeneous interdependent actors.

In one of the founding manifestos of the field, Joshua Epstein claimed: "Artificial society modeling allows us to 'grow' social structures *in silico* demonstrating that certain sets of microspecifications are sufficient to generate the macrophenomena of interest" (Epstein, 2007: 8). In a call for a stronger link between economics and ABMs, Farmer and Foley, after re-iterating the critique of the "representative agent" and the mathematical toolkit requiring such a simplification, stated: "[…] There is a better way: agent-based models. […] Done right, the agent-based method can provide an unprecedented understanding of the emergent properties of interacting parts in complex circumstances where intuition fails" (Farmer & Foley, 2009: 685, 686). In sociology, Macy and others explicitly recognize that one of the virtues of ABMs is that they "[…] have repeatedly demonstrated how the emergence of macro-social patterns out of micro-social interactions is not always a matter of simple aggregation" (Macy *et al.*, 2011: 252).

The connection between ABMs and MI was established through this path. MI fundamentally requires explaining macroscopic patterns as resulting from the combination of individual actions. The various ways in which individuals' actions may be interdependent, and how this interferes with various forms of actors' heterogeneity, however, make it difficult to study theoretical models in the absence of methods being able to treat both elements formally. ABMs were seen as the technique that could be used to face this challenge.

Thus, almost naturally, a long list of statements explicitly conceiving ABMs as a "formal implementation of methodological individualism" (*ibid.*) has appeared over the last few decades (see, in chronological order, O'Sullivan & Haklay [2000: 1413-1414]; Sawyer [2004: 263]; Manzo [2007: 5]; Neuman [2008]; Macy & Flache [2009: 246]; Wan [2011: 188]). These statements are not all based on exactly the same understanding of MI; nor do all authors see the link between ABMs and MI in a positive way. But even those—like O'Sullivan and Haklay (2000: 1413-1414), and Sawyer (2004: 263)—who consider that framing ABMs as a tool for MI may restrict ABMs potentialities do not contest that ABM has a privileged connection with MI in that it allows this perspective to implement its quest for the micro-foundations of social regularities.

Partisans and critics of the link between ABM and MI

Over the last few decades, the claimed link between ABMs and MI has been investigated in a systematic way by Marchionni and Ylikoski (2013), Bulle and Phan (2017), Di Iorio and Chen (2019), and Zahle and Kincaid (2020). These analyses reached opposing conclusions. Whilst Marchionni and Ylikoski (2013) argued that the link in fact is neither necessary nor desirable (and as did Zahle & Kincaid [2020]), Bulle and Phan (2017) concluded that this connection is necessary and fruitful (as did Di Iorio & Chen [2019]). In this section, I scrutinize the arguments put forward by each contribution; although briefly (and in footnotes), I also point to particular problems raised by each line of reasoning. The problems that, in my view, are common to the four articles, which constitute the focus of my critical analysis, will instead be discussed in the next section.

Marchionni and Ylikoski initiated the debate with the aim of demonstrating that ABM "[…] should not be conflated with the doctrine of methodological individualism" (Marchionni & Ylikoski, 2013: 324). To defend this thesis, they start from two premises. On the one hand, they conceive of a mechanistic explanation within an ABM as amounting to identifying the model's assumptions that at the same time are sociologically interpretable and produce a difference in the outcome that is of interest when they are systematically manipulated (*ibid.*, p. 328). On the other hand, they define MI as the principle according to which "Social phenomena can only be explained (or they are best explained) by accounts that only refer to individuals, their properties and their interactions" (*ibid.*, p. 332). On this basis, Marchionni and Ylikoski inspect a published ABM on

opinion diffusion and argue that the variables that are systematically manipulated in fact refer to "structural" properties—i.e. "properties that are attributed to larger scale entities than individuals or if they are attributed to individuals, they presuppose some larger scale entities" (*ibid*., p. 334). Thus, Marchionni and Ylikoski conclude that as some of the variables to which ABM modeler attributes explanatory value are "structural," the association between ABM and methodological individualism is unsound and should be broken (*ibid*., p. 335).[2]

In response to Marchionni and Ylikoski, Bulle and Phan (2017: 404, proposition I) elaborate a different line of reasoning. They accept that in principle there is no inherent connection between ABMs and MI but argue that, in practice, this connection is needed to maximize ABMs' capacity to deliver mechanism-based explanations. Bulle and Phan, too, premise their argument on a specific definition of MI. In particular, they see MI as the "generic approach in the social sciences" according to which "[…] forces in action in society are governed by the subjective meaning of the reasons for individual actions," and claim that "[…] For methodological individualism, social/relational structures have an explanatory or causal role in the representation of generative mechanisms only insofar as they affect the subjective meaning of/the reasons for individual actions by the contextual properties they define" (*ibid*., p. 332). As to ABMs, Bulle and Phan also formulate an important premise. They correctly remark that an ABM intrinsically is nothing more than a symbolic system, which, "[…] from the point of view of the phenomenal world […] 'speaks' of nothing" (*ibid*., p. 387). That is why, Phan and Bulle continue, any ABM needs an interpretative framework that assigns specific meanings to the entities, properties, and connections postulated by the model. The authors regard MI as the required interpretative framework because of its emphasis on

2. In my view, Marchionni and Ylikoski's conclusion raises three specific problems. First of all, they start with a definition of MI that excludes by construction the potential explanatory role of contextual and structural factors. Whilst many contemporary philosophers of social sciences may accept this definition as a "philosophical commonplace" (in Ylikoski's own words, private correspondence), it should also be admitted that MI has received other, and more inclusive, interpretations during its long history, and that premising an argument on this or that definition is not neutral for the conclusion. Second, the selected definition of MI regards the interactions among actors as a legitimate explanatory variable. It is then unclear why properties concerning these interactions and their structure are exclusively considered "structural" and lead an ABM including them to go beyond MI. Finally, Marchionni and Ylikoski do not consider the possibility that, when ABM modelers systematically manipulate structural variables, they are in fact exploring the conditions under which the postulated actor-centered mechanism is able to trigger the expected consequences. In this case, structural properties should not be regarded as "crucial explanatory variables" but simply as scope conditions. And structural variables as conditions for the explanation seem a less strong violation of the proposed view of MI than if structural variables were "the" explanation.

actors' rationality. They consider indeed that actors' rationality has the property of being "trans-situational," a property that Bulle and Phan in turn see as the necessary feature that the entities represented by a given ABM must possess in order to make the mechanisms postulated by the model generalizable (*ibid*., p. 399, 402, 404, proposition E).[3]

Di Iorio and Chen have recently pursued the debate through a different line of reasoning (Di Iorio & Chen, 2019). They directly attack one of the premises of Marchionni and Ylikoski's argument, namely their understanding of MI. According to Di Iorio and Chen, "Marchionni and Ylikoski agree with the dominant interpretation of MI in terms of reductionism […]," an interpretation that "[…] is misleading and *philologically incorrect* […]" (*ibid*., p. 2; emphasis added). Di Iorio and Chen thus deliver a synthetic study of MI over the long run and argue that a non-atomistic variant of MI exists that "[…] conceives of society in an emergentist and systemic way and the agent as being influenced by many structural and socio-cultural factors that limit his/her freedom" (*ibid*., p. 6). Within this understanding of MI, the authors continue, "non-individual agents" are also admitted provided one can imagine shared decision procedures that justify the attribution of choices and actions to the collective actors (*ibid*., p. 15). When, Di Iorio and Chen conclude, it will be accepted that "the widespread interpretation of MI in terms of reductionism is historically incorrect and must be rejected," then it will become obvious that the presence and the manipulation of structural properties simply means that ABMs "[…] must be regarded as explanations in terms of non-reductionist MI" (*ibid*., p. 17).[4]

3. By stressing the conceptual emptiness of ABM, Bulle and Phan make a potentially highly consequential point (I will come back to it in the section: the A new perspective on the connection between ABM and MI). However, their emphasis on actors' rationality, and in particular on the supposedly "trans-situational" nature of this rationality, makes the entire argument questionable. The concept of "trans-situationality" is implicitly defined in terms of "invariance" but it is unclear in what sense and on which basis the authors claim that "rationality" is "invariant." Theoretically, Boudon explicitly insisted on the fact that actors' reasons can be "context-free" as well as "context-dependent" (Boudon, 2014); empirically, it has repeatedly shown that actors' rationality tends to change across decision contexts (Gigerenzer & Gaissmaier, 2011) and frames (Della-Vigna, 2009). It is also unclear why "trans-situationality," and, consequently, generalizability, should be seen as a necessary condition for good mechanistic explanations. One may indeed defend the opposite claim, as Kroneberg did in a recent and provocative article (Kroneberg, 2019).

4. To those who are familiar with careful historical analyses of MI—like the monumental *summa* provided by Udehn (2001), Di Iorio and Chen's general line of reasoning is perfectly acceptable. However, their conviction that it is possible to demonstrate that one (or a few) of the existing variants of MI is (are) "philologically" and "historically correct," to take their own words, seems more debatable. Who has the skills to establish the proper variant of MI? What selection of writings should be included within the analysis? Which disciplines should we consider? What periods of time? From a methodo-

However, what seems to be going without saying to Di Iorio and Chen is again challenged by Zahle and Kincaid (2020). Similarly to Marchionni and Ylikoski, they want to demonstrate that "[…] ABMs need not, and sometimes should not, be seen as embodying the methodological individualist program" (*ibid*., p. 1). Again, the argument is premised on a certain definition of MI. According to Zahle and Kincaid, "the key MI claim" is that "explanations should be in terms of individuals" (*ibid*., p. 2). They acknowledge however that this claim has received different interpretations. To some (but they do not give any specific reference), individualistic explanations amount to only considering individuals in isolation. Given this understanding, they argue, many ABMs clearly escape MI because they represent social interactions as well as a non-physical environment (*ibid*., p. 5). To others (Zahle and Kincaid explicitly refer here to Watkins), however, "relations between individuals" are legitimate explanatory elements within an individualistic explanation, a view that would then obviously make ABMs compatible with MI. In some accounts of MI, continue the authors (who refer here to Popper, Agassi, and Jarvie as examples of "institutional" individualists), even institutions (like firms, universities, states or codified laws and social norms, they say) are accepted as legitimate elements defining the context of individuals' actions. Within this view of MI, ABMs can also be seen as a tool for MI because they are able to model institutions (*ibid*., p. 5). If so, is there any element that is out of the acceptable explanatory toolbox of MI while being (possibly) present within ABMs? According to Zahle and Kincaid, these elements are of two types: collective actors (among which they mention "households, firms, nations, banks, central banks, political parties, elites, and governments") and aggregative properties (among which they consider "statistical properties" and "formal network properties"). In both cases, they claim, these elements are often introduced within an ABM not as simple background features defining the context of actions of individual agents but, more fundamentally, as central explanatory variables. To Zahle and Kincaid, this is "unacceptable even to institutional individualists" (*ibid*., p. 6).[5]

logical point of view, the idea of the existence of a correct version of MI seems problematic. It is certainly possible to ascertain that this rather than that interpretation of MI is at work within a specific (set of) piece(s) of research, and that this rather than that version is heuristically more useful for the research purpose at hand. By contrast, to reach a stable consensus, among scholars and across disciplines, once and for all, on what MI really is seems a task doomed to fail.

5. Zahle and Kincaid's analysis has the merit of progressively increasing the inclusiveness of MI definitions and showing how the answer to the question of whether ABMs fall within MI depends on these modifications. However, what they consider as the frontier separating MI from non-MI explanations illustrates the difficulty of this "definitional" approach. On the inclusion of collective actors, indeed, Di Iorio and Chen defend

In sum, contrary to computational modelers who suggested that ABM is a "formal implementation of methodological individualism" (Macy *et al*., 2011: 252), scholars who systematically investigated the claimed link between ABMs and MI reached symmetrically opposed conclusions on the soundness of this link. How can such markedly different answers to the same question be explained? In the next section I discuss two reasons that seems to me at the origin of the disagreement.

Common problems with the current analyses

Existing principled analyses of the supposedly deep link between ABMs and MI can be questioned on this or that point of their specific line of reasoning.[6] However, I would like to suggest that these analyses in fact also have two fundamental limitations in common. These limitations trap the debate in what I propose to label the "definition" and the "ontological" battle, respectively. These problems require a systematic analysis because they are likely to make the debate on the connection between ABMs and MI endless and unproductive. I discuss them in turn.

The "definition battle"

The four articles that I have analyzed share a first general, but fundamental, point: they all premise their analysis of the link between ABMs and MI on a specific understanding of MI. The authors have opposite orientations on the status of the selected definition, however.

The contrast is well illustrated by Marchionni and Ylikoski (2013: 331)—who state that "[…] the debate over the proper definition of methodological individualism is a distraction from the real methodological issues"—and, on the other hand, Di Iorio and Chen (2019: 4)—who claim that "[…] within the frame of philosophical analysis, the problem of the compatibility between MI and ABS cannot be satisfactorily analyzed without considering the debates on the proper definition of MI, i.e. without assuming that the substantial aspects of this problem are relevant." Both perspectives—which I suggest to call respectively "stipulationist" and "realist"—seem problematic.

the opposite interpretation of MI when they overtly claim that "the fact that ABS [agent-based system] methodology sometimes refers to non-individual agents is not a sufficient condition to conclude that ABS is incompatible with MI" (Di Iorio & Chen, 2019: 15).

6. See footnotes [2-5].

Marchionni and Ylikoski implicitly ask the reader to accept their starting definition of MI as a convention that one must stipulate for the sake of the argument and/or in order to be understood within a certain academic circle. This "stipulationist" stance is problematic because the answer to the question of whether or not ABMs and MI are intrinsically connected in fact crucially depends on the starting definition of MI. Thus, why should one regard as convincing the conclusion of an argument that is premised on a definition of MI that sounds acceptable only for a specific audience? Marchionni and Ylikoski's claim could also be read as meaning that any starting definition of MI should only grasp the essential features of this doctrine. This view would be in line with Zahle and Kincaid's starting point according to which "the key MI claim" is that "explanations should be in terms of individuals" (Zahle & Kincaid, 2020: 2).

However, Zahle and Kincaid's paper itself shows that several interpretations exist of what an individualistic definition is so that the proposed definitional strategy raises the problems of knowing if one has considered all the possible interpretations and of establishing which one better corresponds to "the key MI claim." For all these reasons, Di Iorio and Chen's view seems more transparent in that it overtly raises the issue of the definition of MI rather than trying to bypass it. The shortcoming of their approach, however, is the implicit conviction that some interpretations of MI are more correct than others.

Ultimately, the stipulationist view—according to which only the essential features of MI (as seen within a certain audience) matter in discussing whether or not ABMs are individualist—like the "realist" one—according to which it is necessary to establish the proper interpretation of MI—underestimate the difficulty of reaching a consensus on how MI should be interpreted. Detailed historical investigations of MI concluded that "methodological individualism exists in a bewildering number of different versions" (Udehn, 2001: 346). Even a single author—like Popper (see Udhen [2001: ch. 7])—or specific variants of MI—like "rational choice individualism" (*ibid*., ch. 10)—can in fact be received differently. This is not to deny that progresses in understanding what MI is can be made. But this progress may realistically come precisely from accepting the existence of a variety of versions of MI and the absence of a "true version of this doctrine" (Udehn, 2002: 480).

This lesson is highly consequential for the debate on the connection between ABMs and MI. The existing analyses all premise their assessment of whether or not ABM can be seen as an

implementation of MI on a specific understanding of MI without considering the intrinsic difficulty of finding an agreement on how MI should be interpreted. This strategy can only lead to conclusions that are likely to remain controversial: it only suffices to disagree on the chosen definition(s) of MI to be tempted to reject the conclusion on the nature of ABM.

The "ontological battle"

The difficulty of agreeing on the proper definition of MI is reinforced by a second, and deeper, problem. When arguing in favor of or against a given understanding of MI the authors of the articles under examination are in fact discussing what kind of entities can legitimately be inserted within a given theoretical model. This is the defining feature of what I have termed the "specific" interpretation of MI in the introduction. Now, to defend the legitimacy of this or that entity, the authors inevitably end up with developing, more or less explicitly, an argument on the existence of these entities, and, based on this, on their explanatory primacy. Thus, no matter if this is explicitly endorsed or not, the dispute over the proper content of a MI-inspired model, shifts silently and smoothly into an ontological dispute.

Similarly to the definition problem, the authors animating the debate on the link between ABMs and MI display opposite views as to the impact that ontology may have on their conclusions. Marchionni and Ylikoski regard MI as "a thesis about explanation, not about ontology," and claim that ontological arguments are not directly consequential for theses about explanation (Marchionni & Ylikoski, 2013: 332).[7] Di Iorio and Chen challenge this interpretation of MI and claim that the proper understanding of MI—i.e., the non-reductionist variant, in their view—is based on explicit "ontological individualism" (Di Iorio & Chen, 2019: 11).[8]

Explicitly admitting the potential relevance of the ontological level seems a more defensible perspective. A commitment to the disjunction between the explanatory and ontological levels is indeed

7. Zahle and Kincaid think along similar lines when they state that "methodological individualism is a claim about explanations" (Zahle & Kincaid, 2020: 2).

8. Here is Di Iorio and Chen's full statement: "Even regarding this point, the dominant interpretation seems to us to be historically inaccurate. […] Many non-reductionist individualists such as Carl Menger, Max Weber, Georg Simmel (1858-1919), Herbert Spencer (1820-1903), Ludwig von Mises, Friedrich Hayek and Karl Popper argued that MI is based on ontological individualism […] According to ontological individualism, while the word 'individual' does correspond to a real entity, collective nouns such as 'capitalism' or 'society' do not, in the sense that they refer to a collection of individuals and the consequences of their interaction (which must be described in systemic terms)" (Di Iorio & Chen, 2019: 11).

likely to be violated in practice as soon as the argument is pushed farther. Zahle and Kincaid well illustrate this potential inconsistency when, after arguing that ABMs are not limited to individualistic explanations, they ask whether ABMs should be still used *only* to provide individualistic explanations. To challenge one of the possible arguments from the individualist camp in favor of this thesis—namely, that "social phenomena are causally inert"—, they note:

> […] as social properties supervene on individualist properties, the latter supervene on biological properties that, in turn, supervene on chemical properties that supervene on physical properties. […] As a result, individualist properties, qua being supervenient, are causally inert too and MIs must admit that it isn't legitimate to offer individualist (causal) explanations either (Zahle & Kincaid, 2020: 7).

Although the discussion is framed in explanatory terms, the argument ultimately (but implicitly) is based on the assumption that certain entities of the social and physical realm exist and that these entities are organized in a clearly identifiable hierarchy. This is an ontological debate, not an epistemological one. However, when ontology is explicitly taken into account, as in Di Iorio and Chen's approach to MI, problems that are likely to trigger further debates that are difficult to settle also arise. Given the focus of my discussion, let me illustrate this point by evoking one of these debates, namely the *vexata quaestio* of the existence of individuals and of their analytical primacy (for a detailed analysis, see Goldthorpe [2006: ch. 8, 174-183]).

Within MI, the fact that only individual actors exist is usually regarded as something that goes without saying. To express this point, Hedström proposed the following metaphor: "The causal efficacy of actions would be readily seen if we were able to press a pause button that suddenly froze all individuals and prevented them from performing any further actions. All social processes would then come to an immediate halt" (Hedström, 2005: 28). Similarly, Abell claimed: "The substantive point is that the motor energy of individual actions is *necessary* for the creation of any pattern of social causality" (Abell, 2003: 259; emphasis in the original). To those authors, it is obviously that the "energy" has its origin in actors' beliefs and intentions but this does not go at all without saying for scholars of other orientations. Sperber, for instance, formulates this concern as follows: "Individual agency is taken as a primitive in this approach, rather than as a tentative construct that should be unpacked and possibly questioned by psychology and biology" (Sperber,

2011: 64). He remarks that, empirically, "no primary reasons to give pride of place to intentions among the cognitive determinants of behavior;" "attention or memory," he noted, may equally claim a primary role (*ibid.*, p. 71). From a relational (rather than sub-individual) perspective, Padgett and Powell (2012: 2) formulate a similar objection when they remark that, within MI, actors' preferences are not further unpacked.[9]

In sum, as these contrasting statements show, the "definitions" and the "ontological" battles are inevitably related. The defense of interpretations of MI that are specific requires the justification of the legitimacy of the postulated entities, and, to argue in favor of this legitimacy, one is ultimately required to make ontological assumptions explicit, which in turn raises issues that are difficult to ascertain empirically. For these reasons, if the question of the connection between ABMs and MI is addressed by starting with a specific definition of MI, the answer to the question is likely to inherit all the difficulties related to the chosen definition. The assessment of the link between ABM and MI thus remains unstable because it entirely depends on the extent to which an observer agrees on the posited (specific) account of MI.

A new perspective on the connection between ABM and MI

To frame differently the question of the link between ABMs and MI, let me start with the following observation. From a computer programming perspective, an ABM is nothing more than a set of "objects," i.e. computational units defined by certain properties (attributes) and rules of behavior (methods or procedures). According to the bundle of properties and rules defining an object, the latter can be used to model the behavior and interactions of a set of particles, molecules, cells, beliefs, actors, groups (of particles, molecules, etc.), organizations, etc. (see Manzo [2010: 146-147]; Manzo [2014: 440-441]). Within the debate under examination, although using different terms, Marchionni and Ylikoski, Bulle and Phan,

9. Here is Padgett and Powell's full statement: "Most social science proceeds according to the logic of methodological individualism. […] 'Actors' are objects imbued with boundaries, purposes, and choices whose teleological behavior is explained thereby. […] To assume axiomatically that real people are *actors* makes them logically impenetrable to the theories built upon them. No theory can derive its own axioms. The problem is not that the social science concept of actor is not useful. The problem is that the atomic conception of actor precludes investigation into the construction and emergence of the real people and organizations that we refer to by that abstraction" (Padgett & Powell, 2012: 2; emphasis in the original).

and Zahle and Kincaid have all rightly remarked on this aspect when they acknowledged that the interpretation of the entities and the rules on which an ABM is based is not dictated *a priori* by the method itself (Marchionni & Ylikoski, 2013: 335 ; Bulle & Phan, 2017: 387; Zahle & Kincaid, 2020: 6). None of them, however, drew out all the consequences of this important technical observation.

The intrinsic substantive emptiness of an ABM indeed ultimately implies that including or excluding this or that type of entities (and/or relationship between them) from a given account of MI is inconsequential to knowing whether or not ABMs fall within the realm of MI: no matter what choice one makes, it will be always possible to find (or to design) an ABM where the computational objects and their relations represent the entities posited by the selected definition of MI.

This is a fundamental reason for looking at the connection between ABMs and MI from a different perspective. In particular, I propose to take seriously the intimate substantive emptiness of ABM and to look for ABM's generic properties. As anticipated in the introduction, I take here inspiration from the concept of "generic instruments" that sociologists of science and techniques coined to describe electronic or mechanical devices—like micro-processors or ultra-centrifuges (Joerges & Shinn, 2002)—or symbolic tools—like programing languages (see Shinn [2007])—that are based on principles and properties that are malleable, adaptable, and transversal to specific application domains (see Joerges and Shinn [2001: 9]; Shinn [2008]). From this perspective, ABM's generic properties can be defined as those technical features that are independent of the specific type of entities that a given model may want to represent. Once these theoretical lenses are endorsed, the problem of the link between ABM and MI can be addressed, first, by identifying ABM's generic properties, and, then, by assessing the extent to which these properties can also be seen as defining MI irrespectively from the type of entities that are regarded as legitimate within a given understanding of the doctrine. I discuss these problems in turn in the two following sub-sections.

ABM's generic properties

Behind the endlessly diversity of ABMs in terms of macroscopic outcomes, entities, connections, dynamic processes and levels of analysis involved, existing ABMs in fact share fundamental properties that

are independent from the specific content of each model.[10] Among these properties, five of them constantly recur across applications. I propose to call them "level-change" propensity, "recursivity," "fractality," "generalized interdependence," and "heterogeneity." Let me briefly discuss each of them in turn.

By "level-change" propensity, I refer to ABM's flexibility in understanding a given pattern in terms of mechanisms that are conceptualized (by the modeler) as located at a different level of analysis. "Level-change" can concern problems where a macro-pattern needs to be understood in terms of micro-patterns ("upward" level-changes) as well as problems where a micro-pattern is conceived of as being impacted by some macro-patterns ("downward" level-changes). For instance, if one wants to understand the specific location of a pedestrian (low-level) within a given physical space (high-level), an ABM can be used to model the way the structure of the environment (macro-patterns) impacts on the likelihood of the pedestrian being in a given point in the space at some point in time (micro-pattern) (Zheng *et al.*, 2009). What matters is that the modeler thinks that moving from one level to another can generate some explanatory gain—whatever the content of these levels and/or the "direction" of the movement are. "Level-change" propensity should be analytically distinguished from the operation of *micro-reducing* macro-patterns. ABMs are indeed often perceived simply as a tool to demonstrate that macroscopic patterns in fact do not have *sui generis* properties and that it suffices to understand the behaviour of the parts to explain the properties of the whole (see, for instance, Little's distinction between "generativity" and complexity [Little, 2016: ch. 5]). Quite the contrary, an ABM is often built to show how moving up and down across levels, i.e. "level-change" propensity, can help to understand the origin of properties that no low-level entity can possess on its own (for an example in the field of social stratification, see Manzo [2013]).

ABM's "level-change" propensity is not a static feature. Within an ABM, moving up and down across sets of entities conceived of as located at different levels of analysis is an operation that is repeated iteratively. This is what can be called "recursivity," which I regard as the second generic feature of an ABM. Recursivity is a direct consequence of the fact that ABM is a simulation-based method.

10. This astonishing variety could be documented by inspecting literature reviews of ABMs in disciplines as diverse as sociology (Bianchi & Squazzoni, 2015), political science (De Marchi & Page, 2014), demography (Grow & Van Bavel, 2016), psychology (Eberlen *et al.*, 2017), criminology (Birks *et al.*, 2012), epidemiology (Tracy *et al.,* 2018), economics (Neugart & Richiardi, 2018), geography (O'Sullivan, 2008), ecology (Thober *et al.*, 2017), archaeology (Wurzer *et al.*, 2015) or biology (Metzcar *et al.*, 2019).

There is no simulation without computational time elapsing. Concretely this means to iterate a set of rules a certain number of times. The intrinsic dynamic nature of an ABM—see, on this point, Miller and Page (2007: 80, 81, 83, 84)—thus implies that the procedures defining the entities' behaviors trigger a chain of activities, reactions, and updating that constitute the ultimate higher-level outcome of interest through a cascade of loops composed of upward local aggregations and downward effects. As we have seen earlier, the capacity to handle "upward" level-changes was the initial motivation for adopting ABM in sociology, in particular within the MI tradition (see section: The origin of the link between ABM and MI). This should not hide however the fact that, within an ABM, "moving up" is never disconnected from "moving down:" iteratively looping levels over time, i.e. recursivity, is the second deepest generic features of ABM.

The third one is its fractal nature. By this I refer to ABM's capacity to realize "level-change" propensity every time one wants to decompose a given level of analysis into more elementary mechanisms. This property is another consequence of the basic unit on which an ABM is based, i.e. computational objects. Within the object-oriented paradigm, everything can be "objectified." This means that, as soon as a given class of objects is created to represent a given set of entities/properties/activities/connections, another class of objects representing another set of entities/properties/activities/connections that is regarded as internal to the first set can be created to better ground the behavior of the first posited class of objects. For instance, if a given class of objects represents the properties and the activities of a population of actors (still the most frequent use of ABMs in social sciences), the brain functioning of each actor may be modeled by means of another class of objects representing neurons, their properties, activities, and connections; and one can let the two classes of objects depend on, and communicate with, each other. This is done, for instance, when an agent-based model at the actor level is coupled with an agent-based model at the infra-actor level (through the use of artificial neural networks—see, for instance, Hayward [2006]).

The fourth feature that recurs within ABMs across disciplines is the dependence of one entity's state(s) and behavior(s) on other entities' state(s) and behavior(s). This is possible because computational objects can communicate with each other through message passing at the deep level of computer's memory addresses (Hummon & Fararo, 1995). In fact interdependence comes under three different forms that must be distinguished analytically. First,

entity interdependence can be mediated by a global aggregate, namely an outcome derived from the behavior of all entities present in the artificial population that feedbacks into the subsequent behaviors of each entity. Second, entity interdependence can be mediated by a local aggregate, namely an outcome derived from the behavior of all entities to which the focal entity is connected that feedbacks into the subsequent behaviors of the focal entity. Third, when the relevant input for a given entity comes from a single other entity, entity interdependence is purely dyadic. In the latter two cases, the relevant entity's neighborhood can be defined on a spatial and/or relational basis. In any minimally complex ABM, these forms of interdependence combine in various ways. In this sense, I propose to call "generalized" interdependence the fourth generic feature of ABM.

Finally, heterogeneity clearly is a fundamental generic property of this method. ABM's capacity to handle heterogeneous entities again comes from the underlying object-oriented nature of the technique. Objects can be heterogeneous in a variety of ways (Epstein, 2007: ch. XVI, 7). First, objects within the same class, whilst by definition sharing the same properties (and activities), are such that these properties can get different values. Second, objects in different classes by construction possess different types of behavior. Third, by playing with the objects' scheduling, objects can be represented as being heterogeneous in terms of behavioral sequences (i.e. the time at which a given behavior is realized). Finally, as I remarked at the beginning of this section, objects are conceptually "empty," meaning that, by playing with variables, vectors or other data structures, the objects' states can model any attributes of the entities of interest, and, by creating logical and numerical functions over these states, the objects' "methods" can be used to model every activities of these entities. As a consequence, heterogeneity can also take the form of multiple classes of objects representing different types of entities at different levels of analysis, such as organizations and actors (see Ferber *et al.* [2005]).

It should now be clear that "level-change" propensity, "recursivity," "fractality," "generalized interdependence," and "heterogeneity" have a fundamental feature in common: they are not defined with reference to the specific entities, behaviours, connections, and levels of analysis a given model may want to represent. This explains why these properties travel across ABMs in different fields. These properties are "generic" because they are transversal to models representing an infinite variety of specific entities and relationships among them. These five properties can thus be seen as the ingredi-

ents that an explanatory problem should have to justify the use of an ABM irrespective of the specific entities involved by the problem at hand. Could one defensibly argue that MI can be interpreted along similar lines?

ABM's generic properties and MI

The way James Coleman comments on MI in the *Foundations of Social Theory* (and related minor writings) constitutes an interesting starting point to assess this hypothesis. Coleman's understanding of MI has indeed received radically different interpretations, some scholars seeing it as the best example of micro-reductionism (see, in particular, the harsh critique by Jepperson & Meyer [2011]) while others reading it as the most structuralist variant of MI that admits "social wholes, in the form of structures of interrelated positions, which exist independently of the particular individuals who happen to occupy these positions" (Udhen, 2001: 347). In this sense, as Coleman's MI is seen to span from the "strongest" to the "weakest" forms of MI, it constitutes a useful benchmark to provide a first assessment of the presence of ABM's generic properties across a variety of possible specific accounts of MI.[11]

As to "change-level" propensity, which I defined as ABM's requirement of treating an explanatory problem by moving up and down across levels of analysis, Coleman clearly expresses this idea when he states that his mode of explanation "[…] of the behaviour of social system entails examining processes internal to the system, involving its component parts, or units at a level below that of the system" (Coleman, 1990: 2, 5). Some pages later, he even detaches the principle of not remaining at the same level of analysis from a specific type of entities that one should assign by construction the "lower" level (Coleman, 1990: 5).[12]

To the objection that Coleman would be in fact emphasizing here only one type of "level-change," namely "top-down" (whereas, for ABM, I stressed the equal importance of "downward" and "upward" level-changes), a response can be found in another remark where he clearly indicates that system-level regularities should be thought as generated by chains of macro-to-micro

11. Moreover, Coleman's diagram inspires large portions of contemporary empirical, experimental and formal sociology (see Hedström & Swedberg [1998]; Raub *et al.* [2011]) and, for this reason, it can be regarded as representative of the way a majority of social scientists nowadays understands MI.

12. Here is Coleman's full quotation: "Furthermore, there is no implication that for a given purpose an explanation must be taken all the way to the individual level to be satisfactory. The criterion is instead pragmatic […]. This criterion will ordinarily require an explanation that goes below the level of the system as a whole, but not necessarily one grounded in individual actions and orientations" (Coleman, 1990: 5).

constraints and micro-to-macro aggregative events.[13] This principle also clearly implies that Coleman sees moving up and down across set of entities conceived of as located at different levels of analysis as an iterative operation, a feature that I call "recursivity" and I regarded as ABM's second generic property.[14]

The third property, i.e. "fractality," which I defined as the possibility to operate "level-changes" every time a given level of analysis is required to be decomposed into more elementary mechanisms, is also visible in Coleman's comments on MI when he explicitly acknowledges that the concept of "system behavior" is relative, its content is not defined *a priori* once and for all, and the principle of looking into the internal component of a given set of entities located at a given level of analysis is independent from the specific types of entities and level at hand.[15]

"Generalized interdependence," the fourth generic property that I proposed for ABM, is the easiest feature to find within MI. ABM was imported within MI as the tool that finally enabled social scientists to handle interdependence structures potentially involved in the "transformation" of the "micro" into the "macro" (see section: The origin of the link between ABM and MI). Coleman explicitly stresses the importance of conceptualizing a variety of forms of interdependence that goes far beyond simple dyadic interactions among actors (Coleman, 1990: 20-21). Moreover, he makes the important (but unnoticed) observation that, in some cases, the "macro-to-micro transition" is contained within a given interdependence structure, which is in full agreement with the proposed idea that an ABM is designed to model interdependence both as an aggregation mechanism and a source of constraints.

13. Here is Coleman's full quotation: "[…] structure at one time (macro-level) generates the conditions which together with existing interests shape the actions of actors (micro-level) that jointly produce outcomes which modify the structure of a later time (macro-level) which generates conditions that again (through constraints and incentives) shape actions (micro-level) that jointly produce outcomes (macro-level) and so on" (Coleman, 1993: 63).

14. Abell and Engel also acknowledge this property of the Coleman's boat when they note that "The 'boat shape' is used to imply passage of time from left to right. Furthermore, repeated diagrams whereby the exogenous macro cause is the outcome/effect of a previous cycle may be conceived" (Abell & Engel, 2018; see Manzo [2007: fig. 2]) for an explicit graphical representation of idea).

15. Here is Coleman's full quotation: "The system behaviour, the macro-level in the terminology of this book, sometimes is appropriately conceived as being merely the behavior of a system of actors whose actions are interdependent. In some case the system behavior can be regarded as the action of a supraindividual actors, for example, the action of a nation resulting from the interdependent actions of actors internal to the nation. Similar to this is the case in which the macro-level is a formal organization and the micro-level is made up of departments in the organization or person occupying positions in it" (Coleman, 1990: 12).

The last generic feature that I suggested to be at the heart of ABM is "heterogeneity." Similarly to interdependence, the quest for a tool able to treat how heterogeneity dynamically travels through interdependent actions, thus affecting macroscopic patterns in not-easy-to-predict ways, was at the origin of the adoption of ABM by MI-oriented economists and sociologists. Despite the absence of an explicit representation of heterogeneity within his acclaimed diagram, Coleman's overt attack on the metaphor of the "representative agents" (see section: The origin of the link between ABM and MI)—an analytical strategy that ignores actors' heterogeneity—clearly suggests that he regarded this element as a crucial explanatory ingredient for MI-based theoretical models.[16]

In sum, Coleman's meta-reflection on MI is clearly characterized by a number of principles that hold independently of the specific type of entities one assigns a given level of analysis, and even independently from the specific levels of analysis a given explanatory problem may involve. These principles astonishingly resemble the features—namely, "level-change" propensity, "recursivity," "fractality," "generalized interdependence," and "heterogeneity"—that I suggested as the defining generic properties of ABM. As Coleman has been equally well interpreted as the most extreme "micro-chauvinist" (see Jepperson & Meyer [2011: 57]) or the most accomplished "structural individualist" (see Udehn [2001: 292-306]), it seems fair to consider him as speaking for a variety of MI accounts. In this sense, the resemblance that I found between ABM's and MI's generic properties within his master work can be regarded as a first test of the working hypothesis that ABM's generic properties are transversal to "strong" and "weak" forms of MI, and that, consequently, MI can legitimately be conceived in terms of (these) generic properties (i.e. as a generic instrument) rather than in terms of specific entities (and levels of analysis).

Concluding remarks

The rapid diffusion of ABM across disciplines over the last two decades has been scrutinized from various technical, methodological and epistemological points of view. In this paper, I focused on one of the most recent debates fueled by a set of articles systematically

16. On this point, I agree with Ylikoski, who, in an extensive analysis of the Coleman's boat, notes: "The second unrepresented but crucial idea is the heterogeneity of agents. […] Nothing in the logic of the diagram implies that we should think that the problem of micro-foundations could be resolved by intellectual compromises like representative agents" (Ylikoski, 2016).

studying the soundness of the link that computational modelers posited between ABM and MI.

I argued that the answer to this question is likely to continue to be controversial as long as the analysis starts with a "specific" understanding of MI, i.e. any interpretation of MI that, firstly, gives a specific content the entities that can be legitimately introduced within an explanatory model, and, second, argues in favor of the analytical primacy of these entities. When this is done, a cascade of issues that have historically proved to be difficult, if not impossible, to be settled arises, so that it suffices to change the premise—i.e. the chosen "specific" definition of MI—to challenge the conclusion—i.e. the claimed/denied existence of a connection between ABM and MI.

To overcome this pitfall, I took inspiration from the concept of "generic instruments" that sociologists of science and technology forged to describe mechanical and symbolic devices that have historically proved to be able to travel across application domains because of the flexibility of the principles and rules of functioning on which they were based (see Shinn [2008]). I proposed to look into ABM and MI as "generic instruments" potentially sharing similar generic properties, meaning, in my case, properties that are defined without reference to the specific entities (and levels of analysis) a given model may want to represent.

Thus, starting from the empirical observation that ABMs across disciplines involve an astonishing variety of specific entities, behaviors, connections, and (relationships between) levels of analysis, I identified "level-change" propensity, "recursivity," "fractality," "generalized interdependence," and "heterogeneity" as those generic properties that recur most frequently across ABMs with very different specific contents. Then, I moved on to MI and considered the possibility that this perspective can be characterized by the same generic properties. In particular, I inspected James Coleman's MI account and I have shown that this understanding of MI is in fact explicitly based on the same five generic ingredients that recur within ABMs. As Coleman's MI has received diametrically opposing interpretations with respect to the entities it is supposed to accept and the hierarchy among levels of analysis it is supposed to admit, thus arguably speaking for "strong" as well as "weak" forms of MI, I finally claimed that it seems realistic to formulate the hypothesis that ABM's generic properties are transversal to various forms of MI and that, consequently, ABM can (and should be) legitimately seen as a powerful technical support for the analysis of theoretical models conceived in MI terms.

I see two potential objections to this line of thought. First, one may object to my approach that in fact it is also based on a specific understanding of MI (and of ABM). The subtle relevant distinction here is between "particular" (or distinctive) and "specific." I certainly proposed an account of MI that is particular in the sense of being different from the way MI is usually described. However, this particular interpretation is not "specific" in the sense I used the term in this paper: my particular view on MI is not based on any claims concerning the type of entities (and level of analysis) that one should admit to remain within the realm of MI. The "genericity" of my account of MI thus makes it at the same time "particular" (in the sense of being distinctive) and transversal (in the sense of generalizable) to various "specific" interpretations of MI. And here comes the second objection. One may indeed retort that my analysis did not prove the compatibility of ABM's generic properties and MI across its multiple "strong" and "weak" versions, which weakens the claimed generality of the proposed interpretation of MI in terms of generic properties. I am obviously well aware that, given the variety of accounts MI has received, in order to establish whether ABM's generic properties are compatible with MI, one should in principle scrutinize every single proposed interpretation of MI. For this reason, as the production of a full empirical proof of this kind was out of my reach, I insisted several times that my modest goal was to formulate a working hypothesis that historically-minded philosophers of science and as well as historians of ideas and social theory may test in a more systematic way than I was able to do in this study.

For the time being, the reader could at least be ready to follow me in stressing the heuristic value of this working hypothesis. Conceiving MI and ABM as "generic instruments" indeed has the potential of teaching us something new about both ABMs and MI rather than obliging us to rehash old and endlessly controversial issues. As to the ABM, the focus on its generic properties forces us to consider that, while the link between ABMs and MI was historically created within this perspective to solve a specific methodological problem—i.e. the transition from interdependent actions to their unintended consequences—, ABM is a method that can be used to solve a much broader set of explanatory problems, where the entities involved are not necessarily human actors and the transition from the micro to the macro-level is not necessarily the main focus of the analysis. Without these generic lenses, it would not be possible to account for the impressive variety of specific entities, behaviors, connections, and (relationships between) levels of analysis that ABM

modelers have been able to treat across fields and disciplines. On the other hand, with respect to MI, the focus on its generic properties makes it possible to see that MI has a larger scope than sociological MI. Although this perspective has historically been forged within the social sciences to frame the explanatory problem of social order (see Udhen [2001: ch. 2]), many aspects of physical and biological life, too, require thinking in terms of the mechanisms that create complex and dynamic connections between the parts and the whole (see Lieberson & Lynn [2002]). Thus, similarly to ABM, to stop identifying MI with a specific set of entities and behaviors helps us to see how MI can travel across fields and disciplines.

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