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Agent-based Modeling and the Sociology of Money: a Framework for the Study of Coordination and Plurality^{***}

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Abstract. The institution of money can be seen as a foundational social mechanism providing communities with the ability to quantify the results of economic processes and collectively regulate independent activities of production and trade – money can be said, indeed, to constitute the micro-macro link in economics. As such, investigations of money’s role in the economy can be fruitfully combined with the tools of social simulation. This paper revisits some of the main positions taken in the contested landscape of monetary theory, evaluating how they might serve as a foundation for the development of a new generation of conceptual and empirical agent-based models. We start out by presenting a comparative review of the way different intellectual traditions in mainstream economics, heterodox economics, and economic sociology attempt to specify the nature of money as an institution and clarify its role in the economy. We extract the key "concepts of money" that each approach emphasizes, paying especially close attention to the contrast between the sociology of money and the microfoundations-related traditions in economics (focusing on "money is memory" models, search-theory and mechanism design). We then review the current literature applying agent-based modeling to questions surrounding the nature of money, assessing some of the main contributions from the perspectives of generative epistemology and of the key concepts identified above. We conclude by indicating different research directions in which we believe agent-based models, in combination with the sociology of money, still have the potential to provide new answers to old questions in monetary theory: by clarifying convergence processes related to money of account, by illustrating the formation of economic structure through symbolic mediation, by constructing tools for analyses of intersubjectivity and coordination, or by providing formal generalization to the social-monetary patterns that are currently being revealed in the wealth of empirical data originating from digital complementary currencies and new histories of money.

Keywords: monetary theory · agent-based modeling · economic sociology

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1 Introduction and scope

In this exploratory paper we outline some directions in which we believe social simulation methods could advance theoretical and empirical research on fundamental issues in the theory of money. Specifically, we will pursue two questions:

- how can agent-based modeling contribute to clarifying the nature of money as an institution, and to what extent should this build upon other modeling attempts?
- how can this effort benefit from reflection on the nature of money being conducted mostly within sociologically-informed intellectual traditions that are often critical of formal modeling?

The paper is organized as follows: this section lays out scope and objectives. The next section sets the context by revisiting classic and recent academic debates on the nature of money: we note the different positions taken by different approaches - some relying on formal modeling and others, often more critical traditions in line with some of the founders of economic sociology - and we extract the key concepts that characterize each approach. Section 3 presents a literature review of recent agent-based modeling contributions to this topic: we outline the general structure of the most important existing models, classify them according to components, strategies and results, and evaluate each from two perspectives: generative epistemology and the "concepts of money" that we identified above. This section includes an assessment of the potential explanatory value, as well as the likely limitations, of deploying agent-based methods to examine foundational questions of economic and institutional organization - many of which are brought into focus through a study of money. Section 5 then concludes by pointing out a few promising directions in which we believe social simulation methods might still make substantial contributions to the theory of money.

Investigations on the nature of money have been a relevant - but never primary - concern of both economics and sociology since the disciplines were established at the turn of the 20th century. Interest in this topic, within and across disciplines, has been particularly intense over the past few decades, a period marked by reevaluations of the notion of money in face of developments such as increased financial instability, growing monetary experimentation, and the consolidation of political movements arguing for the "redemocratization of money". The conceptualizations of money recently offered by economics and sociology, however, are markedly different - and these differences are relevant to the way each approach pursues its research questions and objectives. In fact, caught between macroeconomics' overriding focus on monetary management and microsociology's detailed investigations of the subjective consequences of money's use, conceptual reflection on the actual *nature* of money - on what kind of institution it is, on how to define it in face of its many different forms and transformations, on specifying its ontological status as a social form - occupy a secondary and uneasy position in both disciplines [36]. This middle ground will be our focus in this paper. Loosely adapting terminology from Carruthers [16], our concern

will be with specifying money as an institution at the level of *macrosociology*. We will refer to institutions as "integrated systems of rules that structure social interactions" [53], and we aim to *demarcate* [54] money as a unique and foundational institutional arrangement. We argue that, in combination with social simulation, this view can still generate both valuable insight and useful formal tools for the study of the nature of money and related monetary issues.

At this level of analysis, attempts to answer the question "what is money?" vary widely, with each discipline (and many subdisciplines) adopting a specific conceptualization, and often a different definition, of the institution. Although nominally sharing the same subject, each approach mobilizes its own set of concepts and methods, resulting not only in a variety of conflicting perspectives but in a series of long-standing, unresolved theoretical disputes. Further complicating matters, a recent part of this debate explicitly attempts to overcome conventional disciplinary divides [61, 35], generating intricate forms of collaboration and contestation across approaches. In fact, divergent conceptualizations of the nature of money can be seen as one of the main fracture lines separating economics and sociology - and creating rifts in the discipline of economics itself - since the field-founding disputes of the early 20th-century [60]; many of the lines drawn then still divide the camps of the debate surrounding monetary theory, and monetary practices, today. Far from merely abstract or theoretical disputes, these divisions are deeply consequential parts of current political economy, with implications playing out at many levels, from the grassroots design of local community currencies to the role of sanctions in the international monetary system.

2 Echoes of the *Methodenstreit*: concepts of money between economics and sociology

Debates surrounding the nature of money can be cast as an ongoing tension dating back at least to great theoretical debates of the *Methodenstreit*, the academic disputes between the Austrian marginalists (with Menger and Mises as central references) and the German Historical School (mostly associated with Knapp and Schmöller, in connection with Simmel, Weber and later Keynes) [33] starting in the 1890s. Central to the theme of this paper, an outcome of the dispute was directing the methodology of economics away from historical and sociological observation, and towards more abstraction, formalization, and modeling. This was also a key moment delimiting separate disciplinary spaces for economics and sociology, a separation later tacitly validated in Parson's paradigm [61].

Money is often considered an "orphan of the *Methodenstreit*", with these divisions arguably leaving both economics and sociology poorly equipped to provide a comprehensive account of its nature as an institution ([61], see [10, 97] for an even broader overview). These divides can be mapped fairly well onto opposing camps of major disputes in intellectual history, such as the opposition between metallism and chartalism in monetary theory [60], the socialist calculation debate (centered on issues of coordination and formative for both

Friedrich Hayek and Karl Polanyi) [20, 43, 86], the formalist-substantivist debate in economic anthropology (much of it derived from Polanyi's work), the macroeconomic clashes between monetarism and keynesianism in the postwar period [60], and broader divergences regarding the relationship between agency and structure, the externality of institutions, and social order in general (see [30]). Finally, traces of these disputes can also be found in the two schools of thought that are currently producing the most insightful new analyses on the theory of money: game-theoretical investigations of money as a form of coordination [12, 4, 15] and the reflections on institutional ontology that take money as their central case [54, 44, 50, 54]. In all these instances, money can be seen as both a central point of contention and a common object for interdisciplinary interaction. At the heart of this deeply contested role, we believe, lies the fact that money is *constitutive of the micro-macro link* in economics.

While it would be impossible to take stock of this entire debate here, below we outline the main features characterizing some of the most important ways of thinking about the nature of money in different traditions within economics and sociology, identifying (and marking in **bold**) concepts that each approach considers indispensable - and that many other approaches disregard.

2.1 "Models of money" and mainstream economics

Although much relevant work in mainstream economics attempts to define and explain the fundamentals of money through a descriptive or historical lens [106, 41], the largest and most influential part of this literature approaches the issue through formal models of postulated, abstract economic environments in which money either appears as a solution to specific economic puzzles [69, 15] or can be said to "play an essential role" [109]. Two older and well-established approaches within these "nature of money" models are traditional "**turnpike models**" with **spatial separation** [107] and random **search-theory** models focusing on money as a solution to the **double coincidence of wants problem** in an equilibrium setting (the foundational Kiyotaki & Wright models, henceforth "KW" [67]). More recent approaches, however, expand their focus to include concerns that overlap with the conventional domain of sociology: mechanism design, for instance, models **transaction costs** that could account for specific aspects of money [109] such as **imperfect monitoring**, **costly connections among people**, and **imperfect recognizability of assets**; an even more recent game-theoretical approach [11, 4, 15] weaves together themes like **gift-giving** and **reciprocity**, **anonymity** and **social memory**, or **coordination** into a modeling and experimental perspective. Most, but not all of this literature approaches modeling through the concepts of **rationality** and **equilibrium**. Although arguably sociological in concerns, this recent literature does not appear to reference classic work on the same subject from other social sciences; in any case, it might be considered the richest current incarnation of the winning camp in the post-*Methodenstreit* divides regarding the theory of money.

Many of these approaches refer in one way or another to the early Jevons/Menger descriptions of money as a solution, accomplished through **self-organization**,

to the difficulties of barter. A frequent criticism against this position [61, 36, 42] focuses on the a-historicity and implicit market-friendliness of looking at money as a solution to trade frictions. While the variety of views within mainstream economics means that this critique only partially hits its mark, it is still arguably true that the greatest share of formal modeling of "nature of money" issues takes as its starting point a loosely metallist conception of money as primarily a medium of exchange (following on the footsteps of Menger's position on the *Methodenstreit*). This raises a central question for the remainder of this paper: to what extent can a formal model - usually restricted to a few specific mechanisms, reliant on possibly arbitrary simplifying assumptions, and primarily logical instead of historical - be considered to *explain* an institution? We suggest that "representational" [2], "ideal-type" agent-based models of money can answer this challenge by finding explicit grounding both in current institutionalism and in generative epistemology [29], while game-theoretical and general-equilibrium approaches - the core of current mainstream modeling literature on money - have not engaged with the question in a sufficiently rigorous way.

2.2 Old and new references from the social sciences

The recent work of Geoffrey Ingham [61] has revitalized the macrosociology of money and provided well-documented theoretical and historical support for connections with heterodox economics. Ingham draws on classic sociological thought by Simmel, Weber and Polanyi to present a view of money as an institution that is irreducibly historical, and to draw attention to the **distributive conflict** that always characterizes the production and management of money across societies. The starting point for Ingham's reflection is seeing money as a "**structure of social relations**", more specifically a set of **anonymized** relations of **credit/debt** or "promises to pay". Ingham's work also underscores the extent to which comprehending money requires an analysis of what we could call its "**institutional embeddedness**", or the extent to which money can only be understood in relation to an environment composed of other institutions (such as markets, the state, private credit networks, or all of the above in different historical configurations). This perspective presents a sustained challenge to attempts at formal modeling, which tend by necessity to be reductive and focus on one or other closely delimited explanatory mechanisms. Following Keynes' and Schumpeter's positions on the state-and-credit origins of money as well as studies of metrology and of the ethnographic record, Ingham argues that it is the "money of account" and "means of payment" functions of money - thus not "medium of exchange" - that are essential to specify the institution. Ingham's work, in its connections with lineages in post-Keynesian economics [94] and political science [27], might be considered a current representative of the German Historical School (and of its constitutive interdisciplinarity).

Other recent anthropological studies of money [82, 23, 42] and finance [47], as well as the sociology of complementary currencies [13, 46], also draw attention to the extent to which money is an **embedded** part of other economic and non-economic actions rich with meaning, as well as a social practice marked by more

plurality of manifestations than is usually conceded by economic theory. In contrast, a very different line of thought provides penetrating institutional insight into money's **systemic socioeconomic role** by understanding it, in connection with Parsons and Luhmann, as a **generalized means of communication** [35] and as intrinsic to economic modernity: money is here precisely a tool for the **disembeddedness** [38] of human relationships from specific locations or social settings, permitting the **stretching in time and space** of economic activities and enabling increasing **anonymity** in wider and wider systems of mutually coherent economic actions. All of these can be said to follow the spirit and framework laid out by Simmel [102], as well as Weber's views on rationality and bureaucratization, and express aspects of the institution of money with which economic models often do not engage.

Finally, Simmel and Polanyi, whose contributions go beyond these more recent appropriations, can be considered founders of specifically sociological ways of thinking about money as an institutional form - and can provide theoretical foundations for very different abstract models from the ones offered by economics. Simmel's reflections on money as a paradigmatic form of **objectivity** or **relativity** can be seen as a proposal to understand the economy as a self-organized system - but, in contrast to Menger's, this is a version of self-organization through money in which the role of **representation, symbols** and **semiotics** is made explicit. Money is here a very particular shared **idea**, one embodied in **external social forms** and one that enables a form of systemic **economic coordination** that is not necessarily rational or strategic. More than that, money is here "**a claim upon society**" [102], a particular social configuration through which individuals interconnect with each other and with the institutional structures they inhabit. One of Polanyi's most significant contributions [95], in turn, is a typology of different institutional and organizational forms observed across the anthropological and historical record, built from a perspective that is critical of, but conceptually quite close to, catallaxy. Polanyi's central tools, such as the concepts of **special/general-purpose** money and the "forms of integration" through which societies' disparate parts form **interdependences** that grant coherence to overall economic activity, provide ways to look at social and institutional processes that can't be reduced to other approaches [19]. Money is at the very core of these bodies of thought - which, as a rule, are not engaged with by most work in economics. More generally, Simmel's notion of social process - as well as Polanyi's related view of the economy as an "instituted process" - provide one possibly privileged entrance point to the "computational modeling of social forms" [17]. Money, as a paradigmatic economic institution, is a promising candidate for simulation approaches relying on a sociological perspective.

2.3 Interlocked Economic Heterodoxies

Post-Keyensian economics and French Monetary Institutionalism, relevant traditions in the economic sciences that are deeply critical of mainstream economics, are closely intertwined with the work in economic sociology, anthropology and

political science mentioned above. As mentioned, Geoffrey Ingham's contributions provide a nexus between many of these disciplines, grounding what might be seen a broader interdisciplinary critical alliance between social sciences in the study of money. These traditions emphasize both money's nature as a **credit-debt relation** and the historical role of **coercion** and authority in the historical establishment of money as government-sanctioned tokens for tax payment. Post-Keynesians rely heavily on an understanding of money as a motivator for action and an abstract accounting phenomenon to emphasize the **disruptive potential and instability** intrinsic to the institution, as well as the extent to which money creation happens **endogenously** in the interaction between the productive and financial systems. Definitional concepts to understand the institution of money here are **uncertainty reduction** and socially-sanctioned **liquidity**. The french schools of "convention" [91] and "regulation" [1], in turn, build their critique of the mainstream upon different sociological and anthropological references (including Mauss and René Girard) to present an account for money's possible **sacrificial origins**, its ability to stand in for society itself as an **external social form**, and the **mimetic**, conventional processes through which the institution is formed; its macroeconomic analysis then privileges issues of the perceived **legitimacy** and potential **fragmentation** of the frail consensus that supports monetary institutions. In different ways, these traditions emphasize the need to understand the specific social and historical formations that sustain the production and management of money, and offer selective recombinations of the works of Keynes, Schumpeter and Marx. A close interplay between these references and work in law and international political economy [93, 22, 27, 83, 39] now form the theoretical foundation for current political movements advocating for the "redemocratization of money" [42, 58, 111, 10].

Lying at the other side of the *Methodenstreit*, then and now, are the Austrian and Free Banking Schools in economics. Even more closely connected to the thought of Menger than mainstream economics, these traditions also work closely with linguistics and sociology [56, 32, 98], and show great concern with the way institutional or social forms are established - usually seen as an evolutionary, decentralized and largely unconscious process through which fruitful accidents become adopted and reproduce into the future. Money is here, again, a paradigmatic case study for the formation and evolution of institutions. Somewhat paradoxically, the concepts that this tradition tends to emphasize when understanding money are much the same as their post-Keynesian opponents - **trust, legitimacy, liquidity, conventionality, instability** and even **reciprocity** [49] - but almost always in a fully-equipped defense of metallist understandings of money as a commodity used as medium of exchange. Hayek's penetrating insights into the decentralization and self-organization of economic activity inform much of this literature; we would argue that they are both crucial to an understanding of the institution of money and also hampered by this adherence to metallism. We deal with this in more detail on the next section, as many among the most interesting models addressing the fundamentals of money come from authors associated with these traditions.

Perhaps more promising, to conclude, are the variants of heterodox economics that do not subscribe clearly to any of the traditional camps of the post-*Methodenstreit* landscape. Complexity Economics [5] captures much of the Austrian insight on self-organization and institutions, but in a way perhaps less beholden to old theoretical disputes and more explicitly aware of the dangers of reductionism in formal modeling. Some of its key references - including Veblen, Commons and Simon - are also central to other economic heterodoxies. Finally, institutionalist and evolutionary economics [52, 21, 24] combine aspects of all these traditions and deploy tools that are very close to social simulation; we take it as the most promising framework with which to look at money through a rigorous modeling perspective invigorated by sociology. We return to these in the last section.

3 Agent-based modeling, economic sociology and "the emergence of money": a summary

It is precisely at this space of tension between sociological investigation and abstract, formal modeling of institutions that we want to situate our current reflection on social simulation [104, 30] and the nature of money. If mainstream and Austrian economics provide the field of money studies with sophisticated modeling traditions, the broad heterodox and sociological critiques provide the clearest empirical and historical discussion of money as an institution, and different strands of sociology and anthropology contribute with concepts and perspectives that cannot be reduced to either of the other camps. Agent-based modeling - a naturally interdisciplinary undertaking, much like the theory of money - has a potentially significant contribution to make at the hinge points between these lines of thought (for a related discussion, see [64, 80, 77, 112]). In contrast to modeling approaches relying on general equilibrium and game theory, ABMs are particularly well-suited to handle aspects of institutions that relate to structure, dynamics, emergence and interaction (the latter aligning particularly well with macrosociology's focus on money as a social relation). Theoretical, abstract or exploratory models (as are most of the references we review below) can leverage these features to bring conceptual exploration to the very institutional mechanisms that sociologists emphasize. Empirical, predictive or data-driven models, in turn, relying on the conceptual apparatus and the wealth of qualitative (and increasingly quantitative) data provided by sociological investigations, might find in ABM an appropriate methodological apparatus to study topics rarely addressed by economics. As a relatively recent field marked by both fast change and constant self-reflection, finally, agent-based modeling can also offer epistemological rigour and important counterpoints to older modeling traditions - and a space for renewed reflection on the meaning, potential and limitations of modeling institutions in general.

However, despite the wide possible scope of agent-based approaches to fundamental questions in the theory of money, most of the existing models so far have addressed what is perhaps the least interesting aspect of the institution: the

fact that, among several commodities, one of them may be eventually socially sanctioned as money. In other words, most existing models are illustrations or explorations of Menger's description of the emergence of commodity-money conventions in terms of increasing saleability. We consider this a missed opportunity for social simulation.

3.1 Modeling institutions and "the emergence of money"

We identify four main approaches to formalization of fundamental "nature of money" issues using agent-based modeling, each connecting in varied ways to the traditions that we noted above. Nearly all these models are conceptual, with the apparent purpose [26] of explanation or illustration; some interact with experimental economics, and very few are translatable into forms that can be empirically validated. Most of them make very limited effort to justify assumptions and modeling decisions, providing foundations neither on a well-grounded conceptual examination of monetary theories, in a discussion of how the model counts as an explanation of institutions, or through explicit mappings into the real world. At the end of the section we present a classification of these models in terms of the key concepts we have flagged above, and examine some of their results through the lens of generative epistemology [29].

The first of these model families is broadly in line with mainstream theories of money in economics and draws on the influential three-good, three-agent general-equilibrium KW framework [67]. A number of publications have been made following this line [87, 96, 105, 8, 63, 37, 48, 115, 66, 6], most of them exploring the effect of localized changes in setup or parameters on model results. Foundational to this section of the literature is Marimon's [78] application of Holland Classifier Systems to agent-based strategy learning in the KW environment, a contribution that dispenses with some of the assumptions behind equilibrium and rationality modeling, and focuses instead on the *emergence* of a commodity as money – as will many of the following models. This is, however, only a partial break, as the main focus of the simulations is on evaluating whether or not these emergent results converge to the equilibrium conditions defined in KW (for a critique, see [53]). One direction towards which these models have evolved is in combining ABMs, the KW framework and laboratory experiments with human subjects [25, 89]; these results are relevant but difficult to integrate into a broader understanding of money as a complex institution. Without a more rigorous discussion of modeling purposes, the meaning of emergence, the different non-commodity aspects of money, and of institutions and social processes - all frequently absent from these works - it is difficult to assess whether the contributions truly illuminate core institutional aspects constituting money. All the models in this tradition, finally, take "medium of exchange" as equivalent to money more generally, and can be said to be too attached to a commodity-based view of money as a solution to barter frictions; perhaps unsurprisingly, *fiat* money sits in somewhat uneasy coexistence with the rest of the framework [36]. Despite limitations, in any case, KW and Marimon remain foundational papers

in their sections of the modeling literature [59] and can be said to be central references structuring mainstream understandings of money.

A second set of approaches, one less reliant on the KW framework, occasionally critical of it, and showing more internal variety in model setup and findings, draws on Complexity and Austrian Economics and on their common criticisms of the mainstream. Models in these traditions are usually concerned with the insufficiency of some of the neoclassical assumptions that are an intrinsic part of many “fundamental models of money”, including the ones in the KW tradition. Agent-based modeling is a natural methodological fit for these perspectives, providing a fresh starting point for conceptual exploration of money that is sensitive to the formation of institutions and of economic structure, to the potential for systemic instability that is implied in social or economic arrangements, and to the way in which it might be the properties of agent interaction themselves - instead of any intrinsic feature - that is primarily responsible for the emergence of money. Gintis [40] (and related models [34]) sets up an environment composed of independent producers-traders and possible product demands (ensuring a lack of double coincidence of wants), then explores how rules of trade between agents may give rise, through self-organization, to something that resembles monetary trade. Relatedly, in a simpler approach, Klein and Selgin [70] propose an agent-based demonstration of a specific mechanism through which conventions might emerge as self-reinforcing choice process. Although the main theoretical focus of these models is to create artificial representations of economies that operate dynamically far from equilibrium, many of these results can be seen as a generalization of the KW framework allowing wider exploration of parameters and dynamics, and providing a general rationale for the evolution of institutions; while this broadens the discussion considerably, mapping with real-world institutions still remains little discussed and engagement with actual monetary theory is limited.

A different, major contribution to this literature is Howitt and Clower’s [57] account of the twin emergence of both money and productive organization in a decentralized economic environment characterized by trading intermediaries. This is arguably the most well-developed alternative to the KW framework: it builds on Clower’s and Leijohnfuvuhd’s contributions to both complexity economics and monetary theory, presents a conceptual entry point into the relationship between institutions and economic structure, and addresses some correspondences between formal modeling artifacts and the real economy. On the whole, however, this section of the literature offers innovative methods and far-reaching intuitions but does not truly address what it means to model an institution from an agent-based perspective – let alone one as foundational as money. Although focused on emergence as a principle of explanation, little effort is given to specify the concept and the relationship between emergence in abstract models and in real institutions. We view it as an open challenge to social simulation to supersede these important contributions - in particular the implicit metallism that underlies them.

A third family of models relates to theoretical-leaning research published in connection with physics and mathematics journals, especially in Japanese academia, and not often referenced by other works. The most relevant of these is Yasutomi [116, 117], a discussion on monetary convergence in terms of threshold dynamics with the important result of possible destabilization of previously formed commodity-money conventions. Other relevant contributions [73, 71] approach the issue through a "doubly-structural network" approach, where both the commodities space and agent's representations of it evolve. While providing insight and deploying simulation methods not covered by the work mentioned above, these papers tend to be more exploratory and less grounded on the discussions and concepts relevant to monetary theory in either economics or sociology. Connected to this literature, however, important work in econophysics addresses different aspects or mechanisms of the institution of money through agent-based models, be it general boundary conditions and systemic behavior [113] or the instability of money's value [7]. While not directly related to an exploration of institutional nature, these models have a bearing on it and testify to the flexibility of agent-based methods.

Finally, we also identify occasional attempts to deploy an institutionalist or sociological sensitivity to "nature of money" issues through agent-based modeling; although these are scattered references with limited impact, they come closer to the interdisciplinary point of view we have been defending. Yamadera and Terano [114] extend an analogy of conventional strategy choices to an introductory-level spatial analysis of emergent monetary spaces. Shinohara [100], in an engaging contribution to learning theory disconnected from other traditions of thought on money, proposes an understanding of monetary conventions emerging from reciprocity - providing a possible connection with the macrosociology of money. More than the contributions in themselves, these are relevant as pointers to the possibility of looking at money through a social simulation lens but outside of the commodity-money framework.

3.2 Money, models, coordination, plurality

As working reference to orient future reflection, Table 1 presents a summary review of some of these models, evaluating each according to the concepts - among the many possible ones mobilized by different approaches that aim to clarify the nature of money - that they rely on. As the table suggests, there is still ample opportunity for social simulation to provide contributions to the theory of money, especially when informed by an expanded theoretical framework that combines concepts and insights from economics and sociology.

To frame these investigations, it should be said of most of these models that, in the inevitable simplifying assumptions required for formal analysis, the most relevant or mysterious features of money as an institution, as well as key observations from monetary history, risk being lost. Approaching money as an increasingly commonly used commodity has obvious appeal - perhaps too much of it, as this provides a natural, intuitive way to construct models and a possibly

General Framework	Marimon <i>et al</i>	Howitt Clower	Gangotena Klein, Selgin	Yasutomi Kunigami	Yamadera Orléan	ABM?
School, affiliation	Mainstream	Complexity	Austrian	Econophysics	Institut.	
Double coincidence of wants	yes	yes	yes	yes	no	yes
Transaction cost	yes	yes	no	no	no	yes
Intrinsic features	yes?	w/y	no?	no	no	weak
Emergence	yes	yes	yes	yes	yes	yes
Formation of structure, mediation	no?	w/y	w/n	no	w/y	yes
Coordination	weak	w/y	weak	weak	weak	yes
Uncertainty	no	no?	no	no	w/s	weak
Imitation	yes	weak	w/n	no	no?	yes
Network effects	no	no?	w/y	no	no	yes
Path-dependence & Arbitrariness	yes	weak	yes	yes	yn	yes
Productive specializ.	no	yes	no	no	no	yes
Connectivity	no	no?	no	no	no	yes
Interdependence, systemic regularities	weak	weak	w/n	no	no	yes
State token	no	no	no	no	no	weak?
Anonymity and human economies	no	no	no	no	no	weak?
Institutionalization rationalization, (dis)Embeddedness	no	no	no	no	weak	yes?
Memory	no	no	no	n/w	no	yes
Unit of account, metrology, ideation	no	no	no	no	no	yes?
Symbols, representation	no	no	no	nw	no	no
Instability/Disruptive	no	weak	no	w/n	no	yes
Trust	no	no	no	no	n/w	yes
Habit, invisibility, legitimacy	no	no	no	no	w/n	weak?
Fiat, bootstrapping	no	no	no	no	w/n	yes?
Time-space stretching	no	no	no	no	no	yes
Plurality	weak	no	no	no	no	yes
Agent heterogeneity	weak	weak	w/n	no	no	yes
Material traces, institutionality	no	no	no	no	no	yes?
Social/distributive conflict	no	no?	no	no	w/n	weak?
Info asymmetries, recognizability	no	y/n	n/y	no	no	yes
Institutional, embeddedness	no	no	no	w/n	n/w	yes?
Reciprocity and generalized exchange	no	no?	no	no	no	yes
Public good, infrastructure	no	no?	no	no	no	yes
Institutional exteriority, social forms	weak	n/w	w/n	no	y/n	yes
Meaning, Culture, Violence, Morality	no	no?	no	no	no	weak?

Table 1. Evaluation table for "nature of money" agent-based models in relation to key concepts in the theory of money across disciplines

misleading mapping into institutions of the real economy. At least for illustrative [26] models, it is much more difficult, and potentially also much more meaningful, to *represent* money as an institution - as a system of shared rules structuring specific human interactions - and especially as an institution with varying, historically-specific forms. Many of the models also implicitly or explicitly present a process of formal *emergence* as somewhat equivalent to the historical *origin* of money, which in turn is presented as evidence towards the *nature* of the institution. In nearly all these models, then, the underlying epistemology is generative: the fact that something resembling the institution emerges in the model is considered an explanation of that institution. We believe that this is the right framing to ground a rich, renewed understanding of money - as long as it is explicit about the ontology of institutions and not built at the expense of empirical observation of actual monetary forms. On this point, Schumpeter [97] offers a distinction between "logical" and "historical" approaches to money, implying that, while the history and ethnography of money are somewhat bewildering and an uneasy fit with formal reflection, careful logical and abstract exploration still provides indispensable explanatory power and conceptual value. What is needed here is to strike a different balance between historical observation and formal models, and we believe that looking at money using the concepts of economic sociology and the tools of social simulation is a promising starting point. The next section explores ways in which this might be accomplished.

4 Agent-based frameworks and the sociology of money: an invitation, two provocations and some guidelines

In view of the above, we would like to invite closer cooperation between researchers working on both sides of the post-*Methodenstreit* divides. We outline below a few directions in which we believe a combination of agent-based models and historical-sociological thinking can still make distinctive contributions to important open questions in monetary theory. These suggestions are meant to be in line with the epistemology of generative social science [29] and the aim of building useful "computational models of social forms" [17]. We also indicate, but not pursue, some of the literature that these investigations could rely on - our intent here is simply to frame important open questions and points of debate on the theory of money in terms that lend themselves to answers deploying social simulation methods.

It should be noted that this might require some of the more insular intellectual traditions involved in monetary theory to take up the challenge of good-faith engagement. Modelers cannot shy away from thick sociopolitical description of actual institutional history, retreating into the models that are simply the easiest ones to formalize - this remains the case even though descriptive thickness risks taking theory into dead ends. This also means resisting the simplifying thrust of much abstract theory and conceiving of money in a strong, non-homogenizing sense; an institutionally meaningful account of the nature of money must have something to say not only about commodities convergence but also about com-

munity currencies, cryptocurrencies, monetary instability and fragmentation, and the great variety of monetary forms in the historical record. Most current models, in either the equilibrium, games or ABM traditions, fail this test [46]. In turn, researchers aligned with the more qualitative social sciences should not simply dismiss models as useless abstractions - when pressed, they must be able to respond upfront to the challenge of formalizing the mechanisms they consider relevant. This also remains the case even though many models fit almost perfectly the accusation of reductionism, and even though the entire set of extant models, taken as a whole, can appear inconsistent in its variety. There are clear social and historical patterns surrounding the emergence, establishment and spread of monetary institutions, and these are at least in principle amenable to formal modeling and to some degree of generalization. Ceding this ground to the most abstract sections of economics allows modelers to pursue their own, often limited and non-rigorous, uses of empirical evidence - and reinforces old intellectual divisions. The meaningful work left to be done in a conceptually-rich theory of money is precisely at this Schumpeterian tension point between logic and history. We suggest below a few different ways in which this might be pursued.

4.1 Theoretical, exploratory or illustrative models

"The Simmel Challenge": convergence to common quantification: While most of the agent-based attempts to illuminate money focus on the medium-of-exchange function and explore a convergence process starting out from a preset space of given commodities, a more relevant research question from a sociologically-informed perspective would be: how it is that different productive communities can reach an agreed-upon *standard of quantification of value* ("the working fiction of a monetary invariant" [85]), represented through the institution of money? Much of the sociological and heterodox views on money, from Simmel and Keynes to Ingham, relies on this "nominalist ontology of money" [99]. This is a broader issue than the conventional choice of a commodity as medium of exchange, but one that also touches on convergence processes that abstract agent-based models may be well suited to examine. Can agent-based models provide, at the very least, parameters and boundary conditions specifying, for a given theoretical production setup, what are the possible ranges for the value of money that are compatible with social reproduction? Relatedly, once a common standard of value has been established, can ABM illuminate what accounts for its stability or disruption? Places to start with this analysis would be [61, 113, 7] and the literature on decentralized social convergence.

"The Polanyi Challenge": structure, interdependences and economic organization: Polanyi's work poses important questions and provides innovative conceptual tools [43] with which to understand different socioeconomic formations. General-purpose money, here, is a central component of one specific "form of integration": in contrast to societies whose economy is integrated through redistribution or reciprocity, it is through exchange - thus money and

prices - that market economies establish the set of interdependences between separate economic processes that provide for its coherence and reproduction. From the perspective of (inverse) generative social science, and in light of the models discussed above, a potential contribution would be to examine which production and agent interaction setups might give rise to coherent, self-sustaining social/organizational forms that can reproduce in space and time - including, but not limited to, markets. Spatial models with heterogeneous production areas would be especially informative here, providing connections with concepts of institutional time-space stretching and possible correspondences with trade patterns in the historical record. More generally, Polanyi's notion of an "instituted process" could also benefit from formalization in an agent-based environment. The concept has proven powerful and influential for descriptive/qualitative approaches, has no clear equivalent in the game-theoretical or self-organization literature, and could provide the foundation for a formal treatment of money (and other institutions) more in line with current social-ontological approaches. Places to start for such an investigation might be generalizations of the Sugarscape tradition, including competing forms of agent interaction beyond trade, and the German Historical School literature on the division of labor and the establishment of different monetary forms.

Money as a form of coordination: While relations between money and social coordination have been a recent focus of the mainstream literature, much of the work addresses questions that are adjacent to, but not precisely about, the nature of money [4, 12, 15]. The "money is memory" tradition [72] and the emergence of money-related social norms [3] are immediate references here, but agent-based models can potentially contribute to a wider reflection, one closer to organizational theory and to the abstract study of social forms. Taken broadly as a case study in the formation and role of institutions, money can be seen as a solution to coordination problems (and ultimately a central piece in the answer to Parson's problem of order [60]). In line with [9], the question to answer is "what does it mean to have separate economic actions coordinated through the use of a shared money, and how can this be formalized?". Places to start for this reflection would be the vast literature on social coordination, in particular, sections of it that might intersect with organizational theory. Martignoni (forthcoming) and Nishibe [90] have ongoing work in this direction, and promising organizational frameworks such as Garcia-Diaz (forthcoming) could be adapted to investigations of money as a form of organization. The broader literature on money, coordination [79, 18] and games [44, 101, 28] provides very clear initial framing to the question.

Money, intersubjectivity and the exteriority of social forms: Most of the models above start off from some notion of individual (often bounded, sometimes perfect) rationality. The role of money then appears as one potential behavior choice after maximization, in (some sort of) equilibrium; this was a difficulty with the original search-theory models which often carries over to heterodox attempts.

These models attempt to answer central questions of social coordination, but often lack a reflection on what characterizes institutions and the extent to which they might have causal force upon agents, and not the reverse [53]. An alternative would be to take as starting points intrinsically social individuals (for instance, through a specification such as `Agent_Zero` [29]) or to directly model social forms external to individuals (e.g. through global variables). The research interest here would be in what forms of postulated social interaction might account for the dynamics of money as a phenomenon that implicates all individuals as they relate to each other - but that cannot be reduced to any of them. There is a long tradition of sociological conceptual reflection on this to draw from, especially in the work of Simmel [102] and Orléan/Aglietta [92, 1]. Closely related would be an evaluation of the embeddedness of monetary practices in other forms of intrinsically social action. All this would address the nature of money through its origins, in a way that is at least potentially compatible with parts of the anthropological and historical record.

4.2 Empirical or data-driven models: money forms, historical diffusion, complementary currencies

Akinobu Kuroda's *Global History of Money* [74], a sweeping historical and historiographic work, offers evidence that might redraw the coordinates of the old theoretical debates around the nature of money. Encompassing many of the more traditional approaches to the theory of money, Kuroda proposes a new framework to identify how different types of social and productive formations in history might give rise to predictably different forms of money - for instance, how it is that small and proximate productive spaces tend to adopt abstract tokens of small-denomination credit/debt as money, while long-distance trade tends to be associated with anonymous monetary transactions supported by large volumes of precious metals. Kuroda also presents detailed empirical data on the frequency, type and scale of transactions for different productive formations in the historical record. Forms of money are here understood in terms of what could be called their "productive embeddedness", forming patterns that can be analyzed, and perhaps generalized, through formal modeling.

In connection with the above, the *diffusion* of specific monetary forms (say, coinage) is also a potentially promising research direction combining agent-based models and historical or current data. The well-established literature on the diffusion of innovation [65] could serve as launch point, and new historical databases such as SESHAT [108, 31] might provide historical evidence on the emergence and adoption of specific forms of money, informing, for instance, old debates on role of states and markets in the evolution of monetary practices.

Finally, monetary forms complementary to state-and-bank-created modern money are an increasingly well-studied phenomenon. Especially in the case of digital currencies, recent studies relying on network science [81, 55, 88] have provided great wealth of high-resolution, individual-level data on money uses and transaction types. In combination with the notion of productive embeddedness,

this opens up the possibility that the measurable structure of economic transactions could be predictive of the social form taken by relationships mediated by money. Agent-based models could, at least in principle, be applied here to provide generality and predictive power to these investigations. As somewhat autonomous monetary spaces working at population scales that fit agent-base methods well, complementary currency environments can also provide a testing ground for many of the theoretical concepts discussed above, including the stability and collapse of monetary trust or what we might call "the scaling properties of human economies".

4.3 Final remarks: some modeling guidelines

In the terms of the two research questions raised at the beginning of this paper, we believe the lines of investigation indicated above hold the promise both to address questions in monetary theory through new methods and to provide significant use cases that take full advantage of the strengths of agent-based modeling. Previous traditions of formal modeling of money, such as general equilibrium and game theory, can offer tools and insight, as well as set out the parameters for the types of questions that might be addressed by rigorous abstract reasoning. Some of the limitations in more traditional modeling can also be superseded by newer methods: social simulation's attention to interaction, process, structure and dynamics, in particular, open up truly new types of formal representation of institutions (at the very least, as decision rules shared across agents in a virtual population). No less important, this effort can bring modeling much closer to well-established thinking in rich traditions of sociological thinking that are often disregarded by mainstream economics, providing new ways to operationalize ideas that often only find expression in descriptive or qualitative work.

Moving beyond the nature of money to more specific mechanisms or aspects of its operation, there are many other ways in which social simulation could join efforts with monetary theory: by formalizing the notion of money as a form of generalized reciprocity [28, 49, 100, 14], exploring doubly-contingent or "bootstrapping" processes [62], approaching institutional formation through the economics of surplus instead of double-coincidence and scarcity [51], or investigating uncertainty, instability and fragmentation [117, 94, 91, 32, 84].

In view of all the above, attempts at money modeling should be explicit about at least the following:

- does the model aim to illustrate the *nature* of money [18], provide justification for specific aspects of the institution [109], explore how some of its aspects can be affected by external influences [7], or investigate effects of its use at different levels [45, 23]? Especially for the first of these, formal emergent or origin models are still an appropriate tool (provided Schumpeter's logical/historical distinction is taken as a challenge for empirical rigor, and not a justification for abstraction)
- is the institution being understood from a subjective or systemic viewpoint? how do these interact?

- for subjectively-inclined models, what is considered the relevant individual action mechanism motivating the use of money - rationality [68], habit [54], drug or tool use [76], trust [102]? Different answers result in different models and reveal different conceptions of the institution.
- for models where an emergent structure is considered explanatory of an institution, how is this emergence characterized? Is this first- or second-order emergence [30]? What is the specific role of learning and adaptation, and how is it justified?
- is money being modeled as an object [40] or as a representation [50]? Is it constituted primarily by intrinsic features, or by institutional and relational characteristics?
- if money is not being modeled as a commodity, what is it being modeled as? A set of shared action rules [61, 53] (for instance, conditions for credit-debt concession)? An exogenous token issued by a coalition of agents [98]?
- in models where the explanation is geared towards one simplified mechanism (instead of, for instance, a group of interacting mechanisms or relationships to other institutions), what - from an empirical, historical perspective - justifies the simplification?

Tentatively, we suggest that a rigorous discussion of the above should be a precondition for moving models forward towards lab experiments and empirical analysis. Finally, this would allow for an explicit discussion of the mapping between the model and the real-world institution of money - preferably one couched in terms of which aspects of money are *not* covered by the approach employed.

Particularly promising, and tying together many of the points raised in this paper, would be conceptual and empirical models combining inverse generative social science, a sensitivity to the systemically-enabling role of money, and formalizations of rule ensembles in line with monetary institutionalism [authors, forthcoming work]. These would speak directly to the current literatures on game theory [12, 4] and social ontology [54, 44, 75, 50, 103]. We believe that money should be understood as a unique type of social accounting [97, 110], and ultimately as a *form of belonging to economic complexity* - and that useful, institutionally plausible formalizations of this perspective are yet to be developed. This can only be accomplished through self-organizing, interactive methods such as agent-based modeling.

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