



From Barter to Market: an Agent-Based Model of Prehistoric Market Development

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Abstract

Despite interest in preindustrial markets, archaeological discussions have largely been limited to proposing methods to determine the presence or absence of market exchange in ancient societies. While these contributions are important, methodological limitations have prevented theoretical considerations of the emergence and evolution of marketplaces and market exchange in prehistory. We propose that agent-based modeling provides a window to explore physical conditions and agent behaviors that facilitate the emergence of customary exchange locations and how such locations may evolve into socially embedded institutions. The model we designed suggests that simple bartering rules among agents can generate concentrated locations of exchange and that spatial heterogeneity of resources is the most important factor in facilitating the emergence of such locales. Furthermore, partner-search behaviors and exchange of information play a key role in the institutionalization of the marketplace. The results of our simulation suggest that marketplaces can develop, even with the absence of formalized currency or central planning, as a consequence of collective strategies taken up by agents to reduce exchange partner-search costs and make transactions more frequent and predictable. The model also suggests that, once established as a social institution, marketplaces may become highly conservative and resistant to change. As such, it is inferred that bottom-up and/or top-down interventions may have often been required to establish new marketplaces or relocate marketplaces to incorporate new resources, resolve supply–demand imbalances, or minimize rising economic costs that arise as a result of social, political, and economic change.

Keywords Market · Emergence · Evolution · Agent-based modeling · Resource heterogeneity · Partner-search behaviors

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Introduction

Although the development of market systems has long been regarded as one of the critical keys to understanding prehistoric and early historical economies, theoretical discussions that explicitly deal with the emergence and evolution of market exchange have been rare in the archaeological literature (Feinman & Garraty, 2010). Archaeological studies in the first half of the twentieth century took the development of the market as a natural by-product of growing economic complexity, commercialization, craft specialization, and urbanization (e.g., Childe, 1951). Since correlations between these processes were presumed rather than questioned, the development of marketplaces and market exchange was seldom an independent research concern (Stark & Garraty, 2010). Later, theoretical trends in neoevolutionism and processual archaeology that dominated much research in the 1960s to 1980s had all but solved the question of prehistoric economies, with Elman Service's stepwise model of political evolution providing a complementary economic structure for each level of political organization. For instance, the notion that chiefdoms were almost universally characterized by centrally redistributive economies managed by elites (Service, 1962) took interest away from exploring the potential importance of exchange among non-elites in non-state societies, while also shifting the focus towards long-distance trade among elites (e.g., Earle & Ericson, 1977; Renfrew & Cherry, 1986; Schortman, 1989; Smith, 1990). While they explicitly disagree with Service's neoevolutionary perspective, Brumfiel and Earle's influential paper (Brumfiel & Earle, 1987) challenged what they called the "commercial development model" and "adaptationist model" and stressed the importance of the "political model" of specialization and exchange, further reinforcing (perhaps unintentionally) archaeologists' reluctance to explore autonomous market exchange among non-elites in the 1990s. As Garraty (2010) points out, the long-standing substantivist view that has dominated economic anthropology can also be seen as responsible to some degree for a scarcity of interest in exploring potential prehistoric market exchange among economic anthropologists and archaeologists. Substantivists' reluctance to apply neoclassical economic concepts directly to understandings of premodern economies (Geertz, 1978; Mauss, 1954; Polanyi, 1944, 1957) was an important contribution that broadened conceptions of economic behavior, but one regrettable consequence is that some researchers equated market exchange with a distinct form of hyper-rational behavior that supposedly emerged only after industrialization and the development of capitalism.

We argue that despite extreme diversity in forms and motivations, the exchange of goods has always been essential to human lives. Archaeological studies indicate that exchange was an important activity even among small-scale hunter-gatherer bands in the Pleistocene (e.g., Conkey, 1980; Grove *et al.*, 2012; Seong & Kim, 2022; Whallon, 2006). While many forms of prehistoric exchange are largely reciprocal or aimed primarily at the establishment of social ties and the construction of social networks, exchange was unlikely to have ever been limited only to forms of gift exchange. Furthermore, forms of reciprocity and gift exchange

cannot always be easily decoupled from economically motivated exchange. Building social ties can facilitate exchange, while engaging in exchange can promote social ties (c.f., Geertz, 1978). Regardless of which comes first, any instance in which two agents are able to satisfy their needs or wants for any good through mutual exchange can include economically motivated exchange, regardless of how agents express and perceive their actions. While incipient/early markets must have substantially differed from those in the capitalistic era, market exchange still must be heuristically distinguished from informal gift exchange or reciprocal exchange between knowns (Blanton, 2013; Kohler *et al.*, 2000a, b). This, of course, does not imply that reciprocal exchange and market exchange must be dichotomously understood or humans should be viewed as hyper-rational profit-maximizers; it only suggests that humans have diverse needs and wants that arise in diverse contexts, and given the opportunity, they will often seek to fulfill those needs and wants. As Kohler *et al.* (2000a, b) suggest, economies based solely on reciprocal exchange between knowns would encounter limits as population grows over time. The emergence and evolution of markets can be seen as a result of the growing complexification, regularization, and formalization of exchange among multiple anonymous agents over time to overcome such limits.

Although there were some early pioneering works (Blanton, 1983, 1985; Fry, 1979; Plattner, 1989; Rathje & Sabloff, 1973; Sanders, 1956, 1962; Sanders & Price, 1968), it was during the last two decades that archaeologists began to appreciate market systems as critical to a thorough understanding of prehistoric economies. While many discussions remained preoccupied with determining whether premodern markets described in ethnohistoric records should be regarded as “real” markets, new significant research concerns have emerged, including investigating the limits of reciprocal exchange compared to market exchange (Kohler *et al.*, 2000a, b), the roles of market exchange in commodity distribution (Garraty, 2009; Hirth, 1998; Hodge & Minc, 1990), elite control over markets (Blanton, 2013; Chase & Chase, 2004; Hirth & Pillsbury, 2013; Hudson, 2004; Masson & Freidel, 2012), bottom-up processes of market emergence (Abbott, 2010; Blanton, 2013; Fleisher, 2010; Hirth & Pillsbury, 2013), markets as venues of information exchange and socio-political activities (Hutson, 2000; Skinner, 1964; Smith, 2003; Stanish & Coben, 2013; Wells, 2006), sociopolitical roles of markets (Berdan, 1994; Blanton, 2013; Hicks, 1991; Hirth, 1996), and the role of currency in market exchange (Baron, 2018; Baron & Millhauser, 2021; McKillop, 2021; Sampeck, 2021). These recent advances in archaeological research of market systems have deepened understandings of prehistoric economies and are worthy of close attention.

And yet, limits remain. Above all, market studies in archaeology have long wrestled with methodological difficulties (Kohler *et al.*, 2000a, b; see Shaw, 2012 for an example from Mayan market studies). Since it is difficult to identify marketplaces archaeologically, many studies have relied heavily on descriptions of historical-ethnohistorical texts (in particular, in Mesopotamia and Pre-Hispanic Mesoamerica) or ethnographic observations of small-scale societies. Depending on the kind of data researchers rely on, perspectives, assumptions, and definitions of not only exchange but also premodern market systems markedly vary (see Stark & Garraty, 2010). Research that focuses on the ethnography of small-scale societies tends to

emphasize the notion of markets as a venue of gift exchange and reciprocity to build social ties rather than purely facilitating economic activities (Geertz, 1978; Parry & Bloch, 1989; Sahlins, 1972), while those that investigate highly complex state-level societies of Mesoamerica, the Andes, and Mesopotamia tend to rely on (ethno-)historical records and emphasize political roles of markets and elite control over market exchange (Brumfiel, 1991; Finley, 1999; Hodge & Smith, 1994; Hudson & Wunsch, 2004), a view which Feinman (2013, p. 454) has called the “state-centric frames.” This difference in research trajectories broadly mirrors the long-standing substantivist-formalist debate over premodern exchange but also stems largely from different perspectives of premodern exchange and the roles of markets as depicted in sources of analogy.

To move beyond overreliance on ethnographic and historical data, archaeologists have attempted to develop novel methods of archaeologically approaching preindustrial market exchange (see Shaw, 2012). As Stark and Garraty (2010, p. 36) argue, “[a]rchaeologists have their best opportunity to study marketplace exchange through examination of circulation and disposal patterns for durable goods.” Hirth (1998), proposing the household distributional approach, summarizes previous approaches for detecting market exchange, including the configurational approach, contextual approach, and spatial approach. Years later, Stark and Garraty (2010) distinguish archaeological methods for market studies into long-standing approaches and current approaches. Long-standing approaches include central place theory (Blanton, 1996; Christaller, 1966[1933]; Skinner, 1964), regional falloff analysis (Hodder, 1974; Renfrew, 1975, 1977), and site-level artifact assemblage similarities (Fry, 1979, 1980; Hodge & Minc, 1990), and current approaches include the household distributional approach (Hirth, 1998; Minc, 2006) and regional production–distribution approach (Garraty, 2009). Other current approaches might also include the application of the Boolean network model to point out the limits of reciprocity (Kohler *et al.*, 2000a, b), a combination of multiple approaches (Chase & Chase, 2014; Minc, 2006), settlement-scaling approaches (Ortman & Coffey, 2019), network analyses (Watts & Ossa, 2016), and applications of micromorphology and soil chemistry (Cap, 2015; Dahlin *et al.*, 2007; Terry *et al.*, 2015; Wells, 2004) as well as provenance studies (Braswell & Glascock, 2002; Millhauser *et al.*, 2011; Nicholls *et al.*, 2002). While these efforts are noteworthy, it should be pointed out that these methods are mostly concerned with the *detection* of market exchange from archaeological data. For example, the household distributional approach designed by Hirth (1998) and the regional distributional approach by Garraty (2009) are two of the most significant methodological improvements in archaeologically investigating market exchange, but studies that employ these approaches are mostly occupied with detecting past market systems and struggle with equifinality in distinguishing market systems from centralized redistribution systems and other mechanisms of distribution (Feinman & Garraty, 2010; Stark & Garraty, 2010).

Important but less appreciated in archaeological studies of markets are the processes underlying their initial emergence and evolution through time. Despite a great deal of effort put towards theorizing the development of markets (Abbott, 2010; Blanton, 1996, 2013; Blanton & Fargher, 2010; Stark & Ossa, 2010), exploring the questions of how and why incipient markets initially emerge at certain places and

eventually grew into social institutions has rarely been attempted. In our view, the emergence of incipient markets is difficult to address as long as studies are based solely on purely archaeological and ethnohistorical data. Demps and Winterhalder's (2019) evolutionary ecological approach provides one exceptional example of an attempt to shed light on the emergence of market exchange from a more generalized perspective. Applying central-place foraging models to the problem, their "central-place marketing" model takes into account the marginal value theorem, and travel cost, use value, exchange value, and opportunity cost are adopted as major variables. Their approach is a very important contribution to understandings of the emergence of markets in the past. But by emphasizing the physical conditions and economic motivations that facilitate exchange between two individual agents in any given time or space, this approach fails to investigate how and why exchange between multiple agents can evolve into customary market locations, and how these, in turn, evolve to become social institutions.

Many researchers point out that the term "market" has multiple meanings and that market exchange and the marketplace should be conceptually distinguished. Hahn (2018) distinguishes the market as the principle of the availability of goods and a regulatory mechanism controlling access to and exchanges of goods and marketplace as a social and economic locality, often also a center in which many people actively participate. Feinman and Garraty (2010) define market exchange as "economic transactions where the economic forces of supply and demand are highly visible and where prices or exchange equivalences exist" (p. 169), and marketplaces as "physical places in which market exchanges are generally conducted at customary times" (p. 169). While definitions of market exchange and marketplace differ, it is apparent that the two are directly interrelated and provide necessary conditions for one another in the preindustrial era. In this regard, investigating *how and where incipient marketplaces emerge* and how they change over time, we believe, is an important research problem that must be addressed in order to understand the evolution of not only market exchange but also market systems.

We here define incipient marketplaces as locales in which transactions between multiple potentially anonymous agents originating from distinct locales or communities become concentrated. Our definition of marketplaces is closer to Shaw's (2012, p. 123) more generalized definition of marketplaces as "nodes within the larger movement of goods so that different scales of exchange can be identified," and Demps and Winterhalder's (2019) notion of the marketplace as the "physical setting in which individuals gather to participate in multiple types of material exchanges." In particular, we emphasize that spatial concentration and the mutual anonymity of exchange partners are important components of the definition because the concentration of exchange is a necessary physical condition of the emergence of marketplaces as nodes of exchange (Shaw, 2012), and exchange between unknowns is a critical component that distinguishes market exchange from intracommunity-level reciprocity that may have characterized much exchange within communities (Graeber, 2011). In incipient marketplaces, transactions between anonymous exchange partners originating from different communities become more weighted than reciprocity/gift exchange between knowns from the same community. As information regarding the marketplace location

as well as customary times and locations of gathering becomes shared more broadly, transactions between unknowns are facilitated through matching potential exchange partners. This process eventually results in a locale of concentrated exchange developing into a social institution characterized by persistent norms and rules. In our view, marketplaces are systems that have evolved from a simple place that was designated for exchanging goods to a complex social institution where not only diverse goods but also labor and services become concentrated and information is shared and gathered, although there is no single “type” of marketplace (Watts & Ossa, 2016; Wilk, 1998), and marketplaces will vary considerably depending on numerous conditions.

In this study, we explore processes related to the emergence and evolution of marketplaces, using agent-based modeling (hereafter, ABM). In order to explore these processes, we aim to compare a limited set of physical, social, and economic conditions that may facilitate and/or discourage the emergence of incipient marketplaces (see [Supplementary file](#)). The task of recognizing physical, social, and economic preconditions required for the development of incipient marketplaces—rather than independently occurring instances of exchange—should take into account the decisions of numerous autonomous agents and how these agents interact with a limited set of parameters to give rise to different nodes of exchange that may vary according to overall scale and diversity of participants and goods exchanged. ABM provides an ideal tool for such an approach because of its ability to take into account the dynamic interactions of numerous agents with different individual needs given relatively simple procedural rules within various and adjustable environmental and demographic circumstances, which can give rise to unexpected, complex, and emergent phenomena, such as marketplaces.

Our agent-based model aims to investigate the importance of two parameters that have been conceptually highlighted as preconditions for the development of market exchange and marketplaces in particular: heterogeneity in resource distribution and population distribution. Our aim in testing each of these parameters is to compare the relative importance of each variable in the development of marketplace locations in order to identify the sociogeographical conditions under which marketplace locations are most likely to arise. However, as marketplaces cannot arise spontaneously without the presence of active, participating agents, agent procedures—that is, agent-based behavioral strategies—must necessarily play a vital role in investigating the development of marketplaces. In our model, although all agents possess the potential to engage in exchange with other agents, different partner-seeking behaviors will be employed by agents in order to explore the role of individually driven and socially mediated behaviors in the process of developing marketplaces, which have rarely been taken into account in previous archaeological studies of markets to our knowledge. After considering the sociogeographic conditions that facilitate the development of markets, we move on to a different question, namely, the question of if and how established marketplaces may change given substantial shifts in the sociogeographic conditions that initially give rise to marketplaces. The aim of the second question is to consider how and why established marketplaces as social institutions evolve and become complexified, responding to newly emerging conditions that may affect the already-achieved equilibrium of market exchange.

Method and Model

Although much research has focused on the development of marketplaces in early states, city-states, and empires, we suggest that marketplaces in which exchanges among multiple parties occurred may have been commonplace in many pre-state societies. Rather than being complex institutions that require centralized, organizational coordination, we suggest that initial marketplaces may develop as emergent phenomena, given the presence of multiple agents seeking complementary exchange partners. In this sense, ABM provides an ideal toolkit to explore the spontaneous emergence of marketplaces as an aggregated consequence of the behaviors of multiple agents. ABM is widely used in evolutionary economics and various disciplines of social science and has also been increasingly applied in archaeological studies (Cegielski & Rogers, 2016; Flache, 2018; Haas & Kuhn, 2019; Kohler & Gummerman, 2000; Kohler & Varien, 2012; Lake, 2014, 2015; Premo, 2006; Watts & Ossa, 2016). ABM is a computer simulation method that explores how patterns emerge from a system as a result of aggregated, repeated actions of multiple agents that autonomously respond to given environmental conditions and other agents' behaviors (Lake, 2015). It is important to note that such simulations do not require agents to behave in a hyper-rational manner, or even behave in the same ways, as traditional static models assume. In ABM models, multiple agents with different needs dynamically respond to their environments and one another and multiple factors facilitate or constrain agents' decisions simultaneously. At the same time, it should be noted that ABM models must often rely on unrealistic assumptions and abstraction in order to isolate and compare specific parameters of interest. These will be discussed in further detail in describing our proposed model below.

The application of ABM to the study of market exchange is not completely new to archaeology. Watts and Ossa (2016) use ABM to test the expectations of the distributional approach and predict marketplace exchange of Hohokam pottery around the Phoenix Basin, USA. They illustrate the great potential of using ABM in studying prehistoric market exchange. Applying Hamill and Gilbert's model (2016) of capitalistic markets, Romanowska *et al.* (2021) also designed an ABM of prehistoric pottery exchange. Our application of ABM aims to look at a different aspect of market exchange from Watts and Ossa (2016) and Romanowska *et al.* (2021), by focusing on the social and environmental preconditions that give rise to the initial emergence of marketplaces and the evolution of market exchange. Our objective in creating an agent-based model is not to simulate the complexities of past realities. Rather, the goal is far more modest: to isolate a few physical and behavioral parameters that have been theoretically or empirically recognized as important to the flow of exchange in present and past societies and observe how these parameters facilitate and/or discourage the development of concentrated nodes of exchange and how the formation of nodes of exchange—marketplaces in the broadest sense—affects global exchange among agents. Through these “experiments,” we aim to monitor some of the key physical, social, and economic conditions that underlie the development of marketplaces, and with

it, increased market exchange, and observe how these conditions can interact with a relatively simple set of agent-based rules to lead to the formation of incipient marketplaces within a simulation setting.

In our proposed model, basic rules governing production, consumption, and transactions are assigned to agents, allowing us to examine quantities of transactions and their spatial distribution by implementing parameters related to two fundamental preconditions of transaction: (1) spatial distributions of the resources exchanged and (2) distributions of agents engaging in exchange. Here, resources exchanged refers to the heterogeneity of resource production and/or distribution, which is an element that provides agents with basic motivations for transaction (Demps & Winterhalder, 2019). The distribution of agents engaging in exchange refers to the spatial distribution and population concentration of agents, which influence the probability of transaction success and can be said to affect the spatial location and density of transactions. These two physical factors have been pointed out as important physical conditions among factors that promote exchange in multiple studies (e.g., Demps & Winterhalder, 2019; Hirth, 1998; Sanders, 1962), and have been premised as preconditions for market development. Many archaeologists have also suggested that environmental heterogeneity of resources facilitates the emergence of markets mainly because increasing heterogeneity in the acquisition and/or production of resources results in complementary needs that can be satisfied through exchange (Blanton & Fargher, 2010; Demps & Winterhalder, 2019; Rathje, 1971; Sanders, 1962). The concentration of population in a particular community has also been put forward as a major factor in the development of the earliest marketplaces, as larger populations necessitate greater demand for resources in a given area (Blanton & Fargher, 2010; Hirth, 1998; Smith, 1974).

Our model also takes agents' partner-search behaviors into account, assuming that agents that possess a demand for some resources or goods will act to increase the probability of successfully engaging in exchange. Humans, highly entuned with familiar surroundings and communities that occupy them, would not be expected to aimlessly wander landscapes in search of resources or other humans. We actively refer to our own experiences in order to inform decisions about where we travel for what we need. Similarly, the agent behaviors we incorporate into our model allow agents to make use of accumulated information and information shared by other agents to increase the probability of exchange success. These behavioral parameters dynamically interplay with the physical parameters in our model, allowing us to observe whether and how these parameters facilitate or delay the emergence of spatial concentrations of exchange. Combining these physical and behavioral parameters in the model, we intend to investigate whether concentrated nodes of exchange may emerge in the absence of currency or formal planning above the level of the individual agent.

We use NetLogo (v. 6.2.2), a software specializing in ABM (Wilensky & Rand, 2015). As an open-source programming language with accompanying software that supports visualization and ease of access to data results, NetLogo has in recent years gained popularity among archaeological researchers (e.g., Haas & Kuhn, 2019; Premo & Scholnick, 2011; Watts & Ossa, 2016; Wurzer *et al.*, 2015). Simulations in NetLogo generally consist of three major components: a spatiotemporal

environment, autonomous agents, and agent-based decision rules (Romanowska *et al.*, 2021). The spatiotemporal environment, or “world” in NetLogo, consists of “patches,” the spatial units that comprise the world and also discrete locations in which agents act. The agents inhabiting the NetLogo world, often referred to as “turtles,” are the principle agents that carry out the rules as programmed. The temporal component of this virtual world is called a “tick,” discrete units of time in which prescribed actions are performed by agents (for details of NetLogo, see Wilensky & Rand, 2015). The results of simulations are observed in time as ticks, and interactions between agents, agent-based decision rules, and parameters of the spatiotemporal environment accumulate. Although it is possible to visualize and observe the actions of turtles in real time in NetLogo, it is also possible to observe data pertaining to patches, turtles, and the entire world and record data accumulated throughout the simulation and at certain time slices within the simulation.

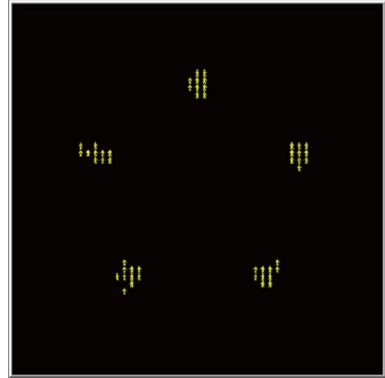
In this simulation, we first create a virtual world which forms the background of the simulation. Next, agents and agent rules and the parameters that determine the basic environment of the simulation are set. Finally, the simulation was run by adjusting multiple environmental and agent parameters of interest, and the results were examined to observe variations in the patterns of exchange between agents for each configuration. Details of each parameter and agent rule adjusted in the simulation will be covered below.

Overview of the World and Agent Rules

Our NetLogo model simulates a hypothetical “world” in which multiple agents engage one another in order to barter goods. As it is our aim to explore various conditions that may facilitate exchange among agents and not to identify specific factors that motivate agents to engage in exchange in the first place, we simplify mechanisms of exchange in our model: agents in our world simply exchange goods for which they have a surplus for goods for which they have a demand. Surpluses and demand both arise stochastically as agents both “produce” and “consume” goods. However, in our world, production and consumption, and resultant surpluses and demands, do not attempt to model a realistic economic system based on subsistence production. Rather, the production of surplus of some resources and arising needs or wants for other resources in our world simply provide the basic preconditions for exchange (Demps & Winterhalder, 2019). We allow that surpluses and needs/wants may simultaneously arise in many situations, including differential access to resources due to geographical heterogeneity of resource distributions or technologies of production or extraction, specialization in the production of resources, the introduction and spread of innovations, and even changing cultural preferences.

The world Our world consists of 51×51 patches, each of which contains a single resource. Some patches in the world are also populated by agents that produce or acquire resources located on their “home patch” (where each agent is generated) and nearby patches (four patches surrounding their home patch). Agents are organized into spatially differentiated “communities,” which consist of multiple agents

Fig. 1 Our world and locations of agent communities



occupying adjacent patches (Fig. 1). The differentiation of single agents into communities seeks to emulate the organization of humans in co-residential communities where exchange can occur within the group if the agents share complementary surpluses and demands. The number of communities, the total number of agents populating the world, and the spatial distribution of communities can be adjusted. In our simulations, we generate five agent communities comprising a total population of 50 agents. Initially, in order to remove distance between communities as a major barrier to exchange, we distribute each agent community spatially equidistant from its two closest communities. The total number of resources in the world and the heterogeneity of their distribution may be adjusted as continuous parameters (see [Supplementary file](#)). Adjustment of the total number of resources and heterogeneity in their spatial distribution is meant to simulate varying degrees of dispersion/patchiness in the environmental or productive distribution of resources, which has been identified as one of the major preconditions for promoting exchange between agents (Demps & Winterhalder, 2019).

Production, consumption, surplus, and wants (Fig. 2) Each agent has the potential to produce n resources determined by the user. Depending on how many resources the agents are assigned to produce, agents will produce the resource on its patch in addition to the resources on up to four other patches located in its vicinity. In this way, when resource heterogeneity is set high (see below), each agent is more likely to produce only one resource, as the likelihood that neighboring patches will contain the same resources, and therefore, agents of the same agent community are more likely to produce the same, single resource. However, when resource heterogeneity is set low, each agent is more likely to produce multiple different resources, as resources are more evenly dispersed among patches.

With each turn, an agent produces either 0 or 1 unit of the resources it is assigned to produce based on the resources on its home patch and surrounding patches. And then, it consumes 0 or 1 unit of all the resources in the world. Surpluses arise when agents produce quantities of any given resource greater than they consume, and demands arise when agents consume more resources than

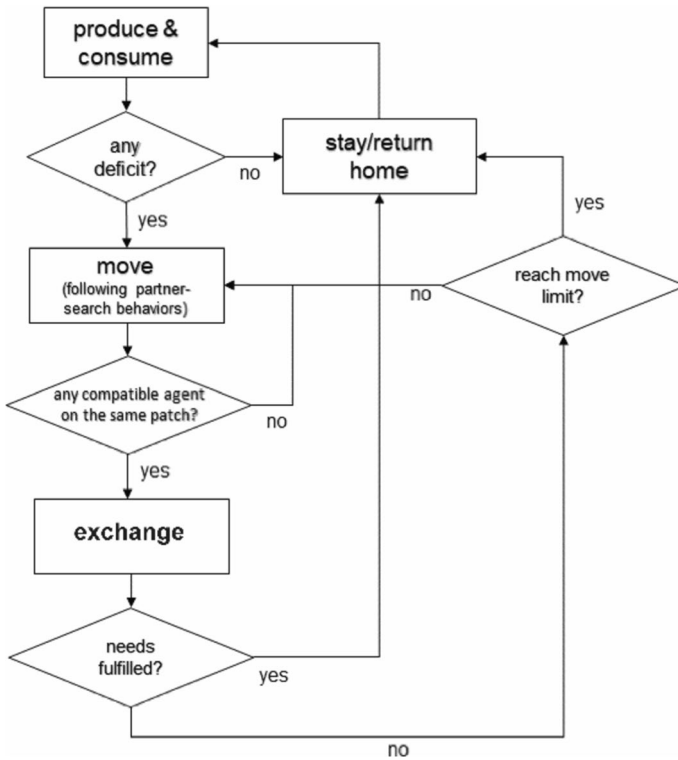


Fig. 2 Agent decision tree

produced per turn. After completing each iteration of production and consumption, agents are directed to meet a specific goal: attempt to remove demands by exchanging their surplus resources. To reiterate, we do not present this as a realistic rendering of a real-world economy, but rather, a means to generate simultaneous surpluses and wants among our agents that is dependent on the distribution of resources in their vicinity.

Mobility and exchange (Fig. 2) Exchange between agents is carried out in the form of barter. That is, resources are only exchanged directly for other resources for the purposes of use/consumption. Only agents that simultaneously achieve a surplus of one or more resources and demand for one or more resources in a turn seek other agents to exchange with. Those with only surpluses do not seek exchange partners as they have no consumption wants, and those with only deficits do not seek exchange partners as they have no surplus resources to exchange. As is the case with all barter transactions, all agents face the “coincidence of wants”: from the perspective of any agent seeking to exchange, an exchange partner must simultaneously possess a surplus of the resources the other agent demands as well as demand for the surplus that the other agent possesses (Jevons, 1896; Kiyotaki & Wright, 1989). Agents produce

and consume resources on their home patches, but those that possess simultaneous surpluses and wants become mobile and move to locate potential exchange partners. Agents are restricted by a mobility limit that sets the maximum number of patches an agent will traverse in attempting to exchange resources. Each agent is randomly assigned a mobility limit according to a normal distribution ($\mu=100$ and $\sigma=20$) so that mobility limits vary among agents, but the average agent can traverse the world about twice.

If an agent is unable to encounter an exchange partner before reaching the mobility limit, the agent returns to its community location and fails to exchange. When an agent seeking to exchange encounters a compatible exchange partner, each agent will attempt to exchange resources in the order of resources for which it has the greatest want. If it possesses the same wants for multiple resources, it will choose one of those resources randomly to exchange for first. Upon encountering a compatible exchange partner, agents will always engage in “satisficing” exchange. That is, even if the exchange partner does not possess the quantity of surplus resources needed to completely satisfy the wants of the agent, the agent will still engage in the exchange opportunity to decrease its wants as much as possible. This behavior assumes that agents will “take what they can get” to partially overcome the coincidence of wants and reduce the risk of failing to exchange in the turn. Furthermore, because agents are not limited to a single exchange per turn, this behavior also leaves open the possibility of meeting other exchange partners. After completing a successful exchange or exchanges, the agent returns to its community location to deposit surplus and received resources for consumption in subsequent turns (see Fig. 2 for agent decision tree).

Parameters

We ran multiple simulations using different parameter adjustments in order to monitor how variations in resource and agent distributions and agent procedures may facilitate and/or constrain the emergence of concentrated locations of exchange. These may be divided into the world’s “environment,” which include total number of resources in the world and their spatial patchiness; “agent community structure,” which refers to the population distribution of agent communities; and “agent-based procedures,” which involve behavioral rules that govern how agents in the simulations seek out potential exchange partners. These are described in more detail here.

Resource heterogeneity (environment) The world’s “environment” consists of a total number of resources that can be produced in the world and their spatial heterogeneity in terms of patchiness. Spatial autocorrelation is adopted to create the degrees of dispersion in resource distribution. In our model, as resource heterogeneity approaches 0, the distribution of resources becomes evenly dispersed among patches, and as it approaches 1, resources become concentrated into clusters of adjoining patches. When resource heterogeneity is set to 0.99, resources are most patchily distributed, with 99% of patches immediately bordering another patch with

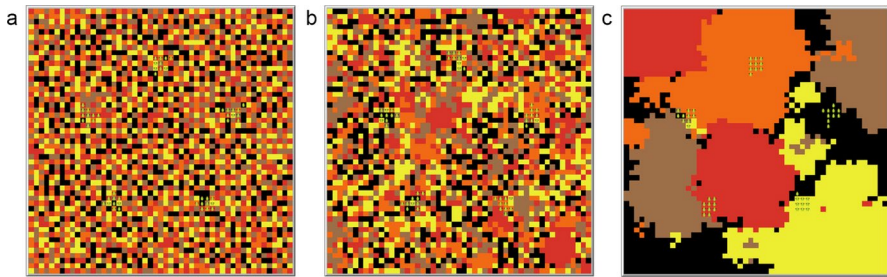


Fig. 3 Examples of the distribution of resources according to resource heterogeneity values (resource heterogeneity 0.1 (a), 0.5 (b), and 0.99 (c))

the same resource (Fig. 3c). This results in distinct resource “zones” in which a single resource is produced, and thus, agent communities in these zones often will produce many or all of the same resources. Resource heterogeneity (0.1) creates a fine-grained, dispersed distribution of resources across patches, with resources almost evenly distributed across patches (Fig. 3a).

To identify potential effects of resource heterogeneity, we ran simulations with the spatial autocorrelation of resource distributions set to minimal (0.1), intermediate (0.5), and maximal values (0.99).¹ In addition to these states, we test two heuristic “extreme” parameter states that model total homogeneity or total heterogeneity in resource production: “full homogeneity” adjusts production assignments so that all agents in the world produce the same range of resources, providing each agent community with a high diversity of resources produced. “Full heterogeneity” adjusts production assignments so that each agent community specializes in the production of a single resource: all agents of the same community produce the same resource, while all agents originating from different communities will produce a different resource. These two settings provide two heuristic extremes against which randomly generated distributions of resources adjusted in their patchiness/dispersion can be compared.

When resource heterogeneity is adjusted as a continuous parameter, each time the world is set up, a novel distribution of resources, or “environment,” is generated based on the resource-heterogeneity spatial autocorrelation value set by the user. Because we aim to test the effects of resource heterogeneity against different agent community structures and agent-based procedures, multiple iterations of the simulations were run using the *same* generated environment for each adjustment of population distribution parameters and partner-search behaviors.

¹ In our NetLogo model (Supplementary file), all parameters are designed as continuous variables and thus allow users to directly adjust parameters (e.g., 0.3 or 0.7 for resource heterogeneity, 40% or 75% for population distribution, 50 or 200 for memory size, 5% or 20% memory threshold) on the interface panel.

Population distribution (agent community structure) In order to test the effects of differential distributions of population across the world, we investigate the effects of increasing the size of a single community and decreasing the size of all other agent communities in the world. The adjustments in our model set one of the five agent communities as 30%, 60%, or 90% of the total population of agents ($n=50$) in the world to test how differences in population size between communities may affect global exchange and the concentration of exchange.

Partner-search behaviors (agent-based procedures) We compare agent procedures that direct exchange partner-search behaviors in order to investigate how the accumulation and use of information affect the development of marketplaces. Three partner-search behaviors are used in the model. First, *random walking*, in which agents randomly move throughout the world, provides a null strategy with which other agent procedures can be compared. When random walking, agents continue to move throughout the world until the mobility limit has been reached. When an agent encounters another agent with complementary surpluses and wants, the agents engage in exchange.

Individual information allows the agent to accumulate information regarding its history of successful exchanges in order to seek out future potential exchange partners. In this agent procedure, agents also begin the simulation by random walking throughout the world to initially seek out compatible exchange partners. When an agent successfully executes an exchange, the patch on which it engaged in exchange and the number and type of resources it exchanged are recorded in a “memory.” The memory size of agents—in other words, a list of the number of patches and number of resources exchange on each patch—can be adjusted. In the simulations carried out in this study, the memory size of agents was set to 100 to allow agents to accumulate a wide range of potential patches to select. In order to allow agents to accumulate at least a small number of patches for comparison, agents begin drawing from their memory pool after 10% of their memory (in this case, 10 exchanges) has been filled in order to seek potential exchange partners on patches on which they have successfully carried out transactions. This prevents agents from both becoming stuck in a loop of only returning to a single patch and having to accumulate an excessively large number of memories to begin applying their information towards making patch choices, both of which we believe are unrealistic decision-making behaviors.

Shared information follows the same basic procedures as individual information with the major difference being that the agent can also select patches from the memories of other agents within its agent community. After completing a round of consumption and production, the agent will compare its own memory with those of agents within its community, and then select the patch on which the resource it seeks was most frequently exchanged for. Just like individual information, this partner-search behavior begins with random walking and partner-search behaviors are implemented only after 10% of its memory is filled.

Running the Simulation, Monitored Indices, and the Detection of Markets

Our simulation was designed so that agents complete a set of actions each turn, which consists of three ticks: in the first tick, each agent produces and consumes resources; in the second tick, each agent attempts to exchange resources if it has simultaneous surpluses and wants; in the third tick, each agent updates its resource inventory with the resources it has gained and lost through engaging in exchange. Each iteration of our simulation consists of a total of 1,000 turns (i.e., 3,000 ticks). We ran simulations that account for different parameter adjustments in the model described above for 100 iterations each, and results are presented as averages of 100 iterations.

Incipient marketplaces, as we have defined them above, should be identifiable as concentrated locations of exchange that agents originating from multiple communities engage in and simultaneously match multiple potential exchange partners in order to facilitate global exchange. As such, patches that may be identified as marketplaces will have (1) relatively high exchange quantities, (2) a high diversity of agents that engaged in exchange, and (3) a large enough population of visiting agents to substantially increase global exchange. Multiple indices were recorded for comparisons of different combinations of parameter settings in order to observe the emergence of incipient marketplaces in our spatiotemporal environment. First, the number of exchanges carried out on each patch was recorded for each iteration of the simulation so that the total number of exchanges and locations where exchanges were most concentrated could be detected. Second, we also record the number of agents originating from each community that completed exchanges at each patch to determine the diversity of agents, expressed using Pielou's evenness index (Pielou, 1966), that engaged in exchange on each patch. Based on these indices, for each patch, percentiles of the number of exchanges and diversity of agents that completed exchanges at that location are calculated. Finally, total number of global exchanges and Gini coefficients were recorded for each combination of parameter settings in order to determine whether the matching of multiple potential exchange partners encouraged global exchange in the simulation.

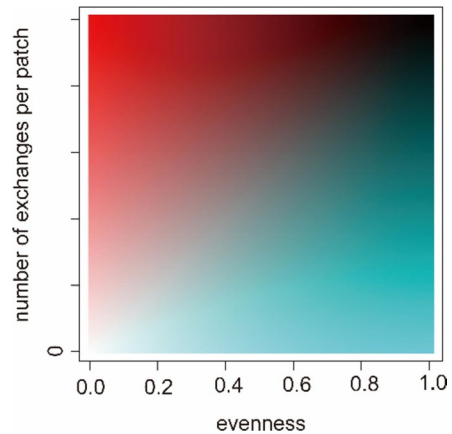
Exchange frequency grid maps that are colorized at the patch scale are occasionally presented to visualize spatial concentrations of exchange. For each patch, the number of exchanges (expressed in percentiles) and the diversity of agents, expressed as Pielou's evenness index, are visualized through a color spectrum. Patches with relatively low exchange numbers and low diversity are white, low exchange numbers, and high diversity are cyan, those with high exchange numbers and low diversity are red, and black patches exhibit high exchange numbers and high diversity (Fig. 4).

Simulation Results

Environment: Resource Heterogeneity

The results of our simulations reveal that the spatial distribution of resources, in particular, their dispersion and/or patchiness, has a substantial effect on global exchange

Fig. 4 Color spectrum used for visualizing number of exchanges and diversity of agents that engaged in exchange in grid maps



overall. Averages of 100 iterations for different resource heterogeneity values (“full homogeneity,” 0.1, 0.5, 0.99, and “full heterogeneity”) show that increased heterogeneity in the production of resources vastly increases the number of exchanges (Table 1). Regardless of agent partner-search procedures (see “Partner-search behaviors” below), increased patchiness of resource distributions results in numbers of global exchanges several times more than those of evenly or homogeneously distributed resources. Whereas resource heterogeneity values set at 0.1 result in an average of less than 4,500 exchanges globally per simulation, increasing resource heterogeneity to 0.99 increases average exchanges to between 9,866 and 19,433, depending on the partner-search behavior assigned to agents. The contrast is even clearer when full homogeneity is compared to full heterogeneity, with full heterogeneity resulting in an average number of exchanges between about 7.9 to 20 times greater than full homogeneity, again, depending on partner-search behaviors.

However, the relationship between resource heterogeneity and the concentration of exchange locations is more complex. When resource heterogeneity is adjusted (0.1, 0.5, and 0.99), the average Gini coefficient tends to fall lower than under conditions of full homogeneity (Fig. 5), suggesting greater dispersion in locations of exchange. Indeed, under the null random-walk partner-search strategy, increased resource heterogeneity results in decreasing Gini coefficients under all resource

Table 1 Total number of exchanges and Gini coefficients (parentheses) for each assigned resource heterogeneity value and partner-search behavior

Resource heterogeneity	Random walk	Individual information	Shared information
Full homogeneity	1,585 (0.743)	1,717 (0.877)	1,790 (0.900)
0.1	3,542 (0.573)	4,163 (0.853)	4,321 (0.888)
0.5	4,416 (0.500)	5,841 (0.843)	6,364 (0.890)
0.99	9,866 (0.325)	16,638 (0.822)	19,433 (0.895)
Full heterogeneity	12,562 (0.289)	26,227 (0.888)	35,007 (0.967)

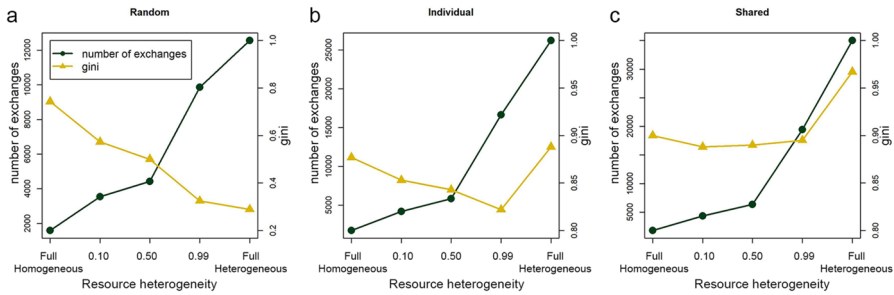


Fig. 5 Average total number of exchanges and average Gini coefficients for 100 iterations under different resource heterogeneity values (x-axis) for each partner-search behavior (**a** random walking, **b** individual information, **c** shared information, note different scales in y-axis)

distributions, suggesting that as more exchanges are carried out, the more dispersed exchange locations become. Even when individual information partner-search behaviors are assigned to agents, increasing resource heterogeneity results in lower Gini coefficients than full homogeneity. Only under the full heterogeneity setting do Gini coefficients exceed those of full homogeneity results.

Together, these suggest that even slight deviations in the range of resources produced by agents result in more dispersed exchange globally. Only when the shared information partner-search behavior is implemented, and resource heterogeneity is sufficiently increased (in this case, > 0.5), do we see a reverse in the downward trend in Gini coefficients as resource heterogeneity increases. In sum, while increased resource heterogeneity (spatially distributed or assigned) appears to be a vital precondition for facilitating exchange, increased resource heterogeneity alone, without partner-search agent procedures, does not result in highly concentrated locations of exchange.

Agent Community Structure: Population Distribution

Overall, inter-community population imbalances, tested in our model by enlarging the population of a single-agent community, generally stifle global exchange. Particularly, when resource heterogeneity is increased (0.99 or full heterogeneity), the number of global exchanges drops off dramatically as a single community size is adjusted to make up 30%, 60%, and 90% of the total agent population (Supplementary file).

Referring to averaged results allows us to more closely observe where exchanges tend to be concentrated when a single-agent community is enlarged. In Fig. 6a, b above, the majority of exchanges are concentrated in the location of the enlarged agent community (60% of the total agent population) when resource heterogeneity is adjusted to be homogeneous. Notably, however, the evenness values of the patches on which most exchanges occur are very low—between 0.0 and 0.2—suggesting that nearly all of the exchanges occur between agents originating from the same, enlarged community. This result may be expected, as agents within the large community likely produce different resources, and as a result are capable of meeting

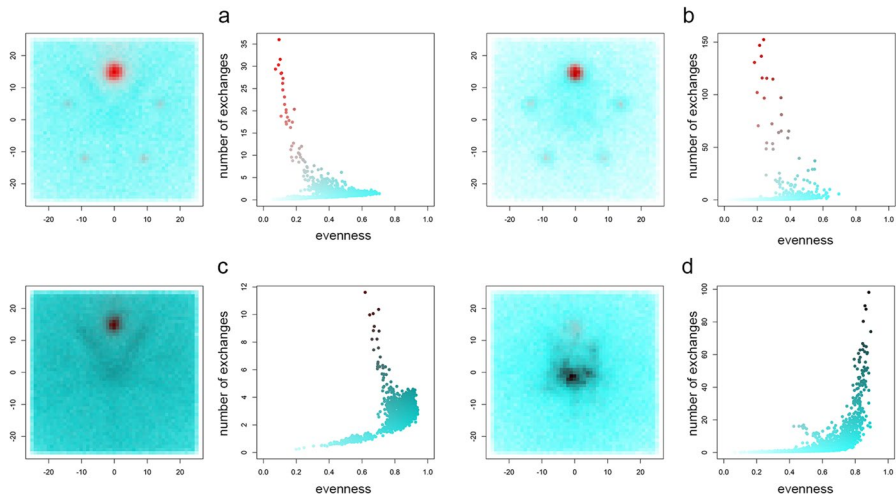


Fig. 6 Exchange density grid maps and total exchange number and evenness, **a** population concentration 60%, resource heterogeneity 0.1, random walk; **b** population concentration 60%, resource heterogeneity 0.1, individual information; **c** population concentration 60%, resource heterogeneity 0.99, random walk; **d** population concentration 60%, resource heterogeneity 0.99, individual information)

their demands within their community. While we cannot discount the possibility that such locations—communities with high concentrations of intra-community exchange—may have attracted exchange in real-world scenarios, in our model, these fail to develop into centers of concentrated exchange between unknowns from diverse communities, and thus, are difficult to view as evolving marketplaces.

When resource heterogeneity is increased (Fig. 6c, d), we see the same concentration of exchange in the enlarged community when the null, random-walk strategy is implemented. However, when partner-search behaviors are assigned (in this case, individual information), we see a tendency for agents to engage in exchange more in a central location, with much higher evenness scores between 0.8 and 1.0. Nonetheless, exchanges overall are highly dispersed among several patches, and compared to simulations in which agent populations are of an equal size, enlarging a single agent community greatly reduces the total numbers of exchanges, and therefore, cannot be said to be an important facilitator of exchange.

Considering that under high resource heterogeneity, most or all agents of the same agent community produce the single, same resource, it may be inferred that high population concentrations may result in an imbalance in surpluses and wants globally, where the most populous agent community produces too great a surplus of one resource without a complementarily increasing demand, which leads to an overall suppression of exchange. This implies that resource heterogeneity, one of the clear preconditions for facilitating exchange, must likely be coupled with some degree of balance in both surplus production and demand to concentrate exchange in a single location and increase global exchange.

As differences in agent community sizes (population distribution) appear to mainly result in reducing the overall frequency of exchanges and their concentration

on any given location, from here on, agent community populations will be set to equal size, and the following results will only take into account simulations with agent communities of the same size.

Agent-Based Procedures: Partner-Search Behaviors

As mentioned above, high degrees of resource heterogeneity is an important precondition for promoting global exchange but alone fails to result in concentrated locations of exchange. Our results suggest that agent-based procedures that inform how agents seek exchange partners, or partner-search behaviors, provide a complementary precondition for the development of concentrated locations of exchange in the world.

Under the null strategy (i.e., random walking), we find that exchange locations are highly dispersed, as agents randomly encounter one another at locations throughout the world, resulting in relatively low Gini coefficients and global exchange numbers regardless of resource heterogeneity. This is not surprising, as random-walking agents lack any procedure for seeking optimal locations for encountering complementary exchange partners, and therefore, exchange locations are randomly dispersed.

When agents apply individually accumulated information to their partner-search strategy, the number of global exchanges increases only slightly under homogeneous resource distributions (<0.5). However, when resources are distributed heterogeneously or heterogeneously produced by agents (0.99 or full heterogeneity), average global exchange numbers increase twofold to threefold from the null strategy. Moreover, exchanges in the world become far more highly concentrated on a small number of patches, which is also reflected in an increase in average Gini coefficients: 0.289 under full heterogeneity with random walking versus 0.888 for individual information (Table 1). Taken together, these results suggest that the use of individual exchange histories to select patches where each agent has the greatest likelihood to engage in exchange can result in concentrated locations of exchange. This in turn matches more complementary exchange partners, resulting in a global increase in exchange numbers. Nonetheless, observing all the iterations together (Fig. 7), there are many instances in which individual information fails to result in a high number of global exchanges and total numbers of exchange dip closely towards the null strategy. This suggests that, depending on resource distributions and resultant production assignments, there are many instances in which relying on individual exchange histories may not result in a dramatic increase in global exchange when compared to the random-walk strategy.

Like individual information, applying the shared information partner-search behavior leads only to minor increases when resources are homogeneously distributed, but substantial increases in global exchange are observed when resources are more heterogeneously distributed among agent communities when compared to the null, random-walk strategy. Moreover, when contrasted with individual information, the average increase in global exchange numbers ranges from 14% under 0.99 resource heterogeneity to 25% under full heterogeneity, indicating that the sharing of information among agents results in much higher global exchange. Gini coefficients also increase dramatically when partner-search behaviors are switched

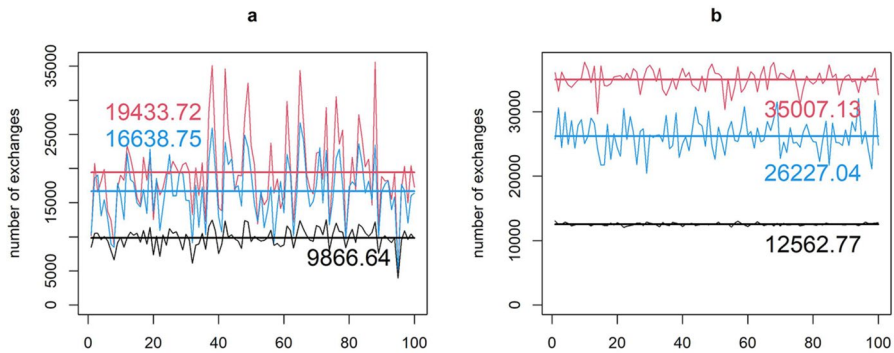


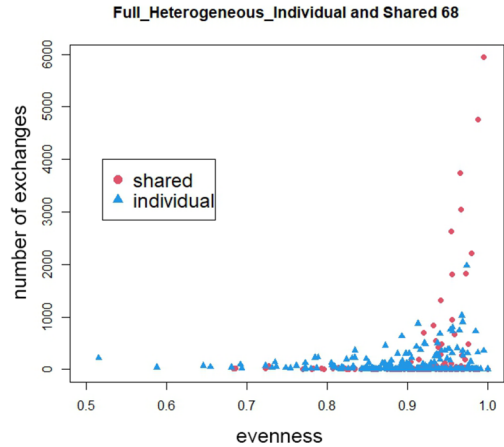
Fig. 7 Total number of exchanges for each of the 100 iterations and average number of exchanges under 0.99 resource heterogeneity (a) and under full resource heterogeneity (b): black = random walking, null strategy, blue = individual information, red = shared information. Note that shared information (red) results in the highest average number of trades under both 0.99 resource heterogeneity (19,433.72) and full resource heterogeneity (35,007.13)

from individual to shared information if resources are heterogeneously distributed, increasing from 0.888 to 0.967 under full heterogeneity resource settings.

However, while observing the averages across all iterations allows a general overview, taking only averages into account may mask important disparities between the two partner-search behaviors. When resource heterogeneity values are set to 0.99 (Fig. 7a), a clear relationship is viewed between the two partner-search behaviors: when global exchange increases under individual information, it also tends to increase under shared information, suggesting that certain resource distributions are ideal for facilitating exchange. However, it is also notable that the peaks in global exchange under shared information also tend to be much higher, resulting in far more total exchanges. Under full heterogeneity, where resource production distributions are predetermined, shared information results in consistently higher global exchange numbers (Fig. 7b).

Comparing individual iterations reveals these trends much more clearly. Iteration #68, for example (Fig. 8), is among the most “successful” simulation runs for shared information partner-search behaviors under full heterogeneity. Whereas individual information partner-search behaviors in iteration #68 result in a total of 28,954 exchanges throughout the run, shared information results in 37,701 exchanges, a nearly 30% increase in overall exchanges. Perhaps more importantly to the question of marketplace emergence, exchange under shared information is far more concentrated than under individual information. The Gini coefficient for the shared information run is 0.970 versus 0.915 for individual information. Moreover, in the shared information run, 5,941 exchanges occur on the patch that records the most exchanges versus 1,976 for individual information. With most exchanges involving two agents, across 1,000 turns, we can thus estimate that on average, roughly 4 agents engaged in exchange on a single patch per turn with individual information in iteration #68. By contrast, 11.9 agents engaged in exchange per turn on a single patch with shared information, suggesting that

Fig. 8 Number of exchanges and evenness of agents for each patch in iteration #68 (full heterogeneous). Blue triangles = individual information, red circles = shared information (2,601 patches each)



more than 23% of agents in the world engaged in exchange on a single patch per turn. This side-by-side comparison allows us to conclude that while there is some degree of variability in the success and/or failure of different partner-search behaviors to produce concentrated locations of exchange, shared information is far more likely to produce a single location that matches a high number of complementary exchange partners, thereby increasing global exchange.

In sum, partner-search behaviors in our model provide another important precondition for the development of concentrated locations of exchange, which, in turn, greatly increase global exchange numbers by simultaneously matching multiple exchange partners. A high degree of resource heterogeneity, balance in surplus and demand of the full range of resources in the world, and either individually or socially mediated partner-search behaviors are all important preconditions for the emergence of concentrated locations of exchange. The sharing of information among multiple agents in particular greatly increases the chances of concentrating exchange at a single location or a small number of locations, resulting in rising exchange numbers. At the same time, when we adjust resource heterogeneity, it is clear that not all of the resource distributions that were generated resulted in remarkably high global exchange numbers compared to the null strategy. And although it is difficult to reconstruct the processes that lead to these failures, it can be inferred that the distribution of resources relative to the distribution of agent communities results in imbalances in surplus and demand for certain resources. In other words, the development of incipient marketplaces is not inevitable in our model, and instead, requires a combination of high spatial heterogeneity and balanced production and demand of diverse resources. Finally, it should be noted that the behavioral strategies (individual information and shared information) rely solely on individual agent-based decisions in our model and do not involve any active coordination by multiple agents to, for example, collectively select locations to carry out subsequent exchanges following a successful exchange. Active coordination among agents is key to the development of occasional or seasonal markets (Ligt & De Neeve, 1988) or would likely

further reduce the risk of failure in matching complementary exchange partners and may be an avenue worth exploring in future extensions.

Model 2: the Introduction of New Goods and Market Change

In the above simulation, we investigated how adjusting various physical parameters and agent-based decisions leads to the initial emergence of marketplaces in different locations, of different scales, and incorporates different diversities of agents engaging in exchange. We now move on to another topic—the evolution of an established marketplace. Economic systems and markets are like organisms that aim to maintain equilibrium on the one hand and continuously change in response to external and internal conditions on the other. History suggests markets are ever-changing. The recent development of the internet has created new distribution systems that are replacing/changing traditional market exchange, and the recent pandemic has also significantly altered distribution systems. There certainly are a number of potential sociopolitical (e.g., elite control), technological (e.g., transportation), and environmental (e.g., change in resource distributions) factors that may give rise to changes in established markets. While we acknowledge that numerous causes can change the nature of market exchange and the spatial distributions of marketplaces and various factors can be modeled to monitor their impacts, we here focus on the introduction or development of novel goods that agents demand. Here, we can imagine what if a novel good such as iron were newly introduced to a society that quickly developed a demand for iron tools? What if, for example, the iron ore and iron specialists were located in nearby communities versus located distantly from communities that had a demand for iron tools? Would the introduction of iron and demand for iron result in a shift in the location of an established marketplace frequented by members of the communities? Would the introduction affect the equilibrium of the established market exchange and eventually lead to market change?

To answer these questions, we design two extensions to our initial simulations: (1) one in which four communities engage in production and exchange for 3,000 ticks, after which a new resource-producing community appears in the immediate

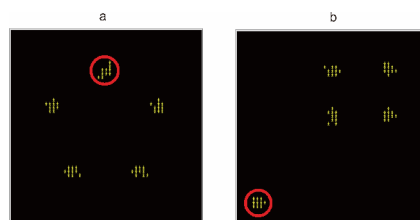


Fig. 9 Assigned locations of the new, novel resource-producing community (red): **a** the location of the novel resource-producing community places it within the mobility range of agents from all communities in the world in order to simulate close proximity to neighboring communities and the established marketplace and **b** the location of the novel resource-producing community places it outside of the mobility range of agents from other communities in order to simulate distance between an established market and the novel resource-producing community

vicinity of the existing communities and (2) another in which a novel resource-producing community appears but is located at a distance from the existing communities (Fig. 9). In the latter variation, we “increase” the size of the world by reducing the mobility distance of each agent from 100 to 20, simulating increased distance between the novel resource-producing community and the established marketplace. Importantly, in both variations, agents accumulate demand for the newly introduced resource after its introduction in the same quantity as all other resources. Both simulations are run for an additional 3,000 ticks (i.e., 1,000 additional turns) to determine whether the location of the existing marketplace shifts in response to the new resource-producing community and to observe the success rates for the exchange of the novel resource.

Figure 10a–c which show grid maps and scatterplots derived from simulations in which the novel-resource-producing community is located nearby other communities show that introducing the novel resource does not result in any significant change in the location of concentrated locations of exchange,

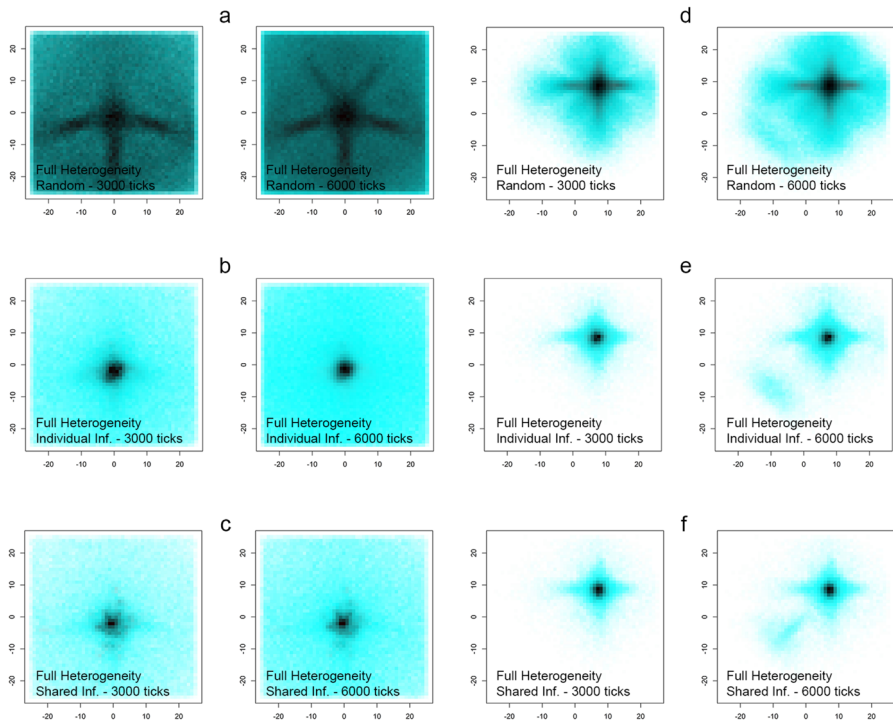


Fig. 10 Location of concentrated exchanges before (3,000 ticks) and after (6,000 ticks) the introduction of a novel resource-producing community under different partner-search behavior settings: **a–c** novel resource-producing community situated nearby the established marketplace (see Fig. 9a); **d–f** novel resource-producing community situated distantly from the established marketplace (see Fig. 9b). Whether the novel resource-producing community is in close proximity to neighboring communities or distantly located from the established marketplace, no apparent change is observed in the location of the marketplace. X- and y-axes display patch coordinates

regardless of the assigned partner-search behavior. When the new community is located distantly from other agent communities (Fig. 10d–f), concentrated locations of exchange shift slightly towards the novel-resource producing community. Under the null, random-walk strategy, we find that the introduction of the novel resource results in dispersed exchanges that occur on patches dispersed throughout the world. However, when partner-search behaviors are implemented, agents quickly adjust to attempt to engage in exchange with agents producing the novel resource, and a small number of exchanges can be observed roughly mid-way between the established marketplace and the new, novel resource-producing community (shown in cyan in Fig. 10e, f). Nonetheless, the number of exchanges on these patches remains very low and highly dispersed, suggesting that a new marketplace location does not emerge from 3,000 to 6,000 ticks, after the novel resource-producing community is introduced.

Figure 11 shows the total numbers of exchange for the five resources after the introduction of the novel resource-producing community (between 3,000 and 6,000 ticks) when the shared information partner-search behavior is implemented. When the novel resource-producing community is located near the established marketplace (blue), we find that the novel resource (Resource 1) is exchanged at nearly the same frequency as other resources in the world (Resources 2–5). This suggests that when the novel resource-producing community is located within close proximity of an established marketplace, the novel resource becomes quickly incorporated into the marketplace and is exchanged successfully among all agent communities. Furthermore, the introduction of the novel resource seems to have no detrimental effect on the exchange success of other resources.

By contrast, when the novel resource-producing community is located distantly from the established marketplace and other agent communities (Fig. 11, red), we find that the number of exchanges of the novel resource (Resource 1) decreases dramatically, falling below less than half of the number of exchanges of the other resources in the world. This implies that when located distantly from an established marketplace and other agent communities, new resources will often fail to

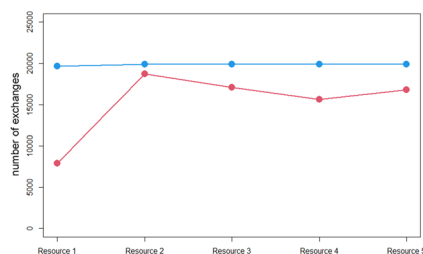


Fig. 11 Number of exchanges of each resource after the introduction of a novel resource-producing community (3,000–6,000 ticks). Resource 1 is the novel resource. (Blue: novel resource-producing community situated within the mobility range of agents from all communities; red: novel resource-producing community situated outside of the mobility range of agents from other communities)

be incorporated into the established marketplace, and, as a result, may disrupt the exchange of other resources, given a high demand for the novel resource.

Discussion

The Emergence of Incipient Marketplaces: Model 1

The development of marketplaces can be seen as an emergent phenomenon in which exchanges become spatially concentrated at a small number of locations that facilitate transactions between unknowns (i.e., agents originating from different agent communities). Some studies by economists (e.g., Anderlini & Sabourian, 1992; Crump, 1981) see bartering as a hindrance to the emergence of markets because it is often carried out as one-off transactions that rarely expedite further transactions, mainly because exchange partners face the issue of trade equivalence, and perhaps more importantly, it is difficult to locate complementary exchange partners. Along similar lines, archaeologists Stanish and Coben (2013) suggest that, due to these difficulties, the primary goal of bartering tends to be to increase potential future exchange partners rather than to meet current demands. While the use of currency would certainly increase the success rate of transactions, and thus, the development of marketplaces, it is unrealistic to completely eliminate the role of economically motivated bartering to meet demands in the context of prehistoric exchange and assume that the appearance of currency necessarily precedes the initial emergence of marketplaces (see Abbott *et al.*, 2007; Garraty, 2010; Hahn, 2018). Our model reveals that spatial concentrations of exchange with anonymous partners can emerge even when bartering is the only mode of exchange and external sociopolitical pressures are absent, if the appropriate conditions are in place. Value imbalances between goods exchanged, which may cause conflicts and failures in completing an exchange, are the most problematic factor that make barter an unreliable means of exchange. However, as more agents participate in exchange at a limited number of locations and as exchange increases, equivalences in value may begin to emerge, “most nearly approximating to notional ‘equilibrium rates’” (Humphrey, 1985, p. 66, also see Hahn, 2018). If bartering itself is not an impediment to the emergence of marketplaces and currency is not a precondition, it is necessary to look into other potential factors that facilitate the development of marketplaces. Based on the results of our simulations, we here discuss how and why marketplaces may initially emerge and eventually develop into a social institution.

Heterogeneity and Population Distribution

Our first model, which is primarily concerned with physical conditions, reveals that heterogeneity in the distribution of resources is a critical socio-spatial factor that provides a motivation for exchange in that it continuously generates balanced demands and deficits over a wide area. This suggests that, not surprisingly, the

more heterogeneity is increased in the production of goods, the more exchanges occur (Demps & Winterhalder, 2019). Especially, high inter-community heterogeneity provides agents with strong motivations for seeking and exchanging with partners located beyond their own communities. However, it is not necessary to limit this interpretation to spatial or environmental heterogeneity in the distribution of resources. For instance, the development of specialization, whether in economic (Brumfiel, 1980) or ritual contexts (Abbott *et al.*, 2007; Spielmann, 2002) and/or social stratification, will also be expected to increase the heterogeneity of production within and among communities (Costin, 2001). And while it is debatable whether craft specialization is a cause or consequence of the emergence of marketplaces (Brumfiel & Earle, 1987; Spielmann, 2002) and it is impossible to generalize the sequential relationship between the two, specialization and marketplaces are more likely to emerge out of a complex interplay between the two. Environmental heterogeneity may encourage some communities to specialize in the production of certain goods for exchange, but at the same time, the development of specialization will result in spatial heterogeneity in the availability of certain resources between communities. Although some studies suggest that craft specialization was a precondition for the emergence of market exchange (e.g., Hirth & Cyphers, 2020), we would point out that, at least according to the results of our simulations, environmental resource heterogeneity can sufficiently motivate market exchange even before the development of craft specialization (see Demps & Winterhalder, 2019). Importantly, however, we also find that spatial heterogeneity alone—whether brought about by specialization or environmentally mediated distributions of resources—is not sufficient to result in concentrated locations of exchange.

Population distribution, another physical condition taken into account in the first model, has been considered an important factor in large part determining locations of marketplaces: marketplaces tend to be located in the proximity of larger population concentrations, as concentrations of people reduce the time and effort associated with locating and procuring resources (Blanton, 2013; Hirth, 1998, 2010, 2020; Hirth & Cyphers, 2020). Our model shows that given low heterogeneity, spatial concentrations of exchange seem to emerge near large populations, but this is mainly because large amounts of resources are exchanged within the communities with the largest populations. Given the division of our agents into agent communities, these locations of exchange are not characterized by a high diversity of agents and do not provide locations of exchange for many agents outside of the largest community. These exchanges are, therefore, mostly occurring between knowns and may be more conceptually akin to intra-community reciprocal exchange. When heterogeneity is increased in the model, concentrated locations of exchange do not emerge and the majority of exchanges occur at locations between the agent communities. This suggests that disproportionately larger communities do not necessarily attract agents and that imbalances in the population sizes of community may result in imbalances in overall surplus and demand, which may stifle exchange.

Hodder's (1965) ethnographic observations of sub-Saharan African marketplaces lend support to these observations. His ethnographic studies suggested little association between the population size of communities and the location of

marketplaces. Instead, marketplaces were located along long-distance trade routes, contact zones between ecozones, such as forests and savannas, and at the junction of different groups of people. It is noteworthy that these locations all had a high degree of heterogeneity of goods/resources and in the rate of encountering complementary exchange partners. In addition, large seasonal aggregations also known as “rendezvous” or trade fairs in the precolonial Saskatchewan River Valley in Eastern North America are thought to have been located at central locations between productive hunting locations and areas located between important resource concentrations rather than population centers (Meyer & Thistle, 1995). The development of gateway communities (Hirth, 1978) and ports of trade (sensu Rathje & Sabloff, 1973) that link remote resources to agents’ habitation areas can also be understood in a similar vein.

Another point to consider is that periodic gatherings were often an important aspect of the social lives of pre-state hunter-gatherers and farmers (Conkey, 1980; Grove *et al.*, 2012; Whallon, 2006). While the perceived purposes of such gatherings were likely diverse, including cooperative subsistence activities, the performance of rituals and ceremonies, the sharing of information, and the building and maintenance of social ties, they often involved the exchange of goods (Whallon, 2006). Indeed, many early historical records of periodic marketplaces in the ancient world, from the Mediterranean to the Americas, suggest that periodic markets were often tied to religious fairs that were often held in otherwise unpopulated rural areas that became itinerantly flush with potential peddlers and customers during times of periodic gatherings (Abbott *et al.*, 2007; Ligt & De Neeve, 1988). As Ligt and De Neeve (1988: 401) note, such fairs were often situated in “periodic central places” so that they offered easy access to otherwise highly dispersed rural populations and attracted traders and pilgrims (often one and the same) from around the region.

Despite the results of our simulation and the above ethnographic observations, many archaeological and historical studies have shown that marketplaces that dominate other small local marketplaces in terms of diversity and amount of goods exchanged and participants tend to be located near large population concentrations and cities (e.g., Childe, 1951; Hirth & Cyphers, 2020; Hodges, 1982; Silver, 1995). Why do the empirical data and the results of our simulation conflict? Although it is extremely difficult to provide a generalized answer, there are a few possible explanations. First, as marketplaces grow and more people gather in a particular area, goods exchanged there would not be limited to commodities but extended to various services and labor, providing job opportunities and services for the constant aggregation of people and leading to population concentrations, and eventually, the emergence of towns (Berrey *et al.*, 2021; Bromley *et al.*, 1975; Hodder, 1965; Hutson, 2000; Skinner, 1964). This trajectory of the evolution of marketplace to market town to cities can be easily observed even in modern history. Second, although concentrating the overall population in a single community, according to our model, is not an independently critical factor in the formation of marketplaces, population centers where population sizes are much larger than other communities are often characterized by internal heterogeneity compared to other communities with smaller populations. The larger the population, the greater the diversity of goods produced through specialization (Berrey *et al.* 2021; Dunnell, 1971; Neiman, 1995; O’Brien

& Lyman, 2000; Ortman & Coffey, 2019) as well as social segmentation and stratification due to high scalar stress (Johnson, 1982, 1983). Applying distance-interaction principles (Olsson, 1965, 1970) to investigate six early chiefdom societies around the world, Berrey *et al.* (2021) also point out that “closer household spacing within local communities facilitated more frequent interaction and thus encouraged more production differentiation (p. 1).” If socioeconomic internal heterogeneity substantially increases within population centers and the diversity of goods in supply and demand increases, such population centers may attract exchange from further afield and develop into marketplaces. Third, political or economic powerholders may intervene in market exchange and attempt to locate or relocate marketplaces near population centers as a means to control markets. The intervention of power in market exchange will be discussed below in more detail.

The results of our model should not be misunderstood to imply that marketplaces in which agents from numerous communities gather necessarily precede large concentrations of populations. Rather, we suggest that population concentrations should not be taken as a determining factor of the locations of incipient marketplaces. The sequential relationship between the two varies according to various conditions including resource heterogeneity, degrees of specialization, and other socioeconomic factors.

The Roles of Information Accumulation and Sharing in Partner-Search Behaviors

The initial model suggests that resource heterogeneity and population concentration do not solely account for the development of marketplaces in our simulations. Partner-search behaviors based on accumulated and shared information reveal that partner-search strategies (i.e., how agents select their destinations to search for exchange partners) are one of the most critical factors in spatially concentrating locations of exchange, drawing a high diversity of agents, and simultaneously matching multiple exchange partners to facilitate global exchange. Given the heterogeneity in the distribution of resources, the use of information to determine potential exchange locations dramatically increases the number of exchanges and diversity of agents on a small number of centrally located patches. Exchanges can potentially occur anywhere in the world, as long as two agents encounter one another and share complementary needs, but not every exchange location is likely to develop into a marketplace. Marketplaces are locations in which numerous agents gather to satisfy demands, expecting to encounter complementary exchange partners. To understand why spatial concentrations of anonymous exchange emerge, we must consider the strategies agents employ to successfully engage in exchange, which have not been taken into consideration in previous archaeological studies of market exchange.

From an economic perspective, exchange entails costs. Putting aside production costs, agents seeking to engage in exchange must take into consideration transaction costs, including transport costs and partner-search costs. Among the many kinds of costs associated with exchange, partner-search cost substantially affects other costs because it positively correlates with transport costs and time expended before an exchange is completed (positively correlating with opportunity cost) as well as the risk of transaction failure. One problem all agents face is that partner-search costs

are rarely predictable. Where currency does not exist, even if an agent encounters another agent seeking to exchange, exchanges cannot be completed unless the demands of both are met. Failure to exchange results in a loss. In particular, in the case of barter and when the agents' goods are perishable, loss due to the failure of transaction will include not only the value of perishable goods, but also opportunity costs, labor, and time. An agent, regardless of whether they are rational, will attempt to reduce partner-search costs by increasing the chances of encountering complementary partners and/or by making partner-search strategies more predictable. An easy way of reducing partner-search time is to seek out a partner that is located in close proximity. In such cases, even if the potential partner does not need to exchange, reciprocal exchange or delayed payment can be expected. But, if the agent fails to find a partner in its vicinity, it must seek partners outside the community.

The direction of the first trip to locate exchange partners might be random, but it is unrealistic to assume that agents continue to random walk to find partners without gaining experience and learning from those experiences. The agent will instead likely choose to travel to a location that would raise the probability of a successful encounter as experience and information are accumulated over time. Agents may refer to their own experience of previous successful transactions and/or to information shared with other agents in order to increase the chance of encountering complementary partners. For example, Grove *et al.* (2012) suggest that even highly mobile Paleolithic hunter-gatherers do not move randomly and tend to move in directions that raise the chances of encountering other groups. As many previous studies have suggested, preferred destinations would include, as long as transport cost allows, nodes of large floating populations, and places of large-scale rituals where people from various locations aggregate (Hirth, 1998). Borders located between different resource zones would also be preferred (Demps & Winterhalder, 2019; Hirth, 2020).

In our model, partner-search behaviors involve the application of individually acquired information and information shared among agents. While we compare the two strategies, they should not necessarily be seen as mutually exclusive strategies. Rather, they should be understood as a learning process, and thus may be viewed as evolutionary social behaviors in the real world. Our model shows that while use of personal experience rapidly leads to the concentration of exchange and a diversity of participants, sharing of information greatly magnifies these outcomes (Figs. 7 and 8). As information regarding locations in which exchange is most likely to be successful becomes widespread, agents' destination selections will lean toward those specific patches, rapidly leading to spatial concentrations of exchange, because the more agents that visit a location, the higher the chances of agents completing successful exchanges at those locations. The mechanisms of information sharing vary, and information asymmetry may affect information flow (Kim, 2001), but agents will actively access information to increase their encounter rate. Sharing of information about concentrated locations of exchange by a majority of agents becomes analogous to an implicit or explicit agreement among exchange-seeking agents, perhaps the one key feature that separates a "marketplace" from a location where goods are simply exchanged opportunistically. Indeed, many scholars of rural markets have noted that market periodicity, the agreed-upon standardization of a time and place for consumers and suppliers to convene, played an important role in the

development of marketplaces (Hill, 1966; Obudho, 1976; Skinner, 1964). As agreements surrounding periodicity and location become regularized and customary, both supply and demand accumulate, and the market evolves into a social institution that involves not only the exchange of resources and services but also a wide range of non-economic social activities (Bromley *et al.*, 1975; Hirth, 2020).

Given ideal geographical conditions, central places where chances of encountering various exchange partners are higher would be strong candidates for the development of concentrations of exchange. However, it should also be noted that initial information is often imperfect and misleading, and the social agreements that create marketplaces do not always result in an optimal solution for all parties. Although on average, marketplaces may emerge in central locations, there are many instances in which marketplaces emerge in locations closer to some agent communities and further from others in our simulations. But regardless of optimality, once information regarding the location of marketplaces is shared, the locations will tend to draw more agents, firmly establishing the marketplace location.

Information sharing might also contribute to the diversification of marketplaces in the long run as information becomes more elaborated and reliable, although our simulation does not take this possibility into account. Depending on goods in demand, agents may choose smaller but proximate exchange concentrations (e.g., local markets and border markets), instead of the farther central marketplace, as long as the partner-encounter rates are expected to be high enough. If the transactions at these locations are successful and/or two or more agents agree to meet to complete future exchanges, such locations can develop into informal, alternative, or specialized markets. The diversification of marketplaces in terms of roles and distances to communities should also be understood as an important component of the evolution of a market system and the growth of economic complexity.

To summarize, it is suggested that the spatial concentration of exchange and the eventual emergence of markets are a consequence of a collective strategy and social agreement among multiple agents to reduce partner-search costs, make trade more predictable, and increase the success rate of exchange, while gift exchange and reciprocity would parallel such market systems and continue to play a critical role in producing and maintaining important social ties at the intra-community and inter-community scales.

Market Changes: Model 2

Among the many factors that may potentially cause changes in the spatial distributions of marketplaces, model 2 of our simulation attempts to explore whether a newly introduced good may result in a shift in marketplace locations. The simulation reveals that when the community producing the novel good is located nearby, new goods minimally affect the locations of marketplaces and are easily incorporated into the existing market, increasing the success of exchange overall. When the new good is produced at a distant location, once marketplaces are established and information regarding the location of the marketplace is widespread, it is very difficult to shift the location of the marketplace in order to accommodate the introduction of

new resources (Fig. 10). That is, widespread sharing of information, indicating that the firm establishment of a marketplace based on agreements shared among multiple agents, may work as a constraint to shift marketplace locations. In many contexts, this may be a realistic outcome that highlights the institutional nature and conservativeness of markets: if a marketplace is already well established at a particular location, newly formed communities and newly arrived producers would likely seek out the established market, as it provides a location and system that provides the greatest likelihood of encountering complementary supplier-consumers.

Nevertheless, it is unrealistic to conclude that, despite their conservativeness, marketplaces that have been established do not go through shifts over time. Market systems are not static; they constantly evolve and the locations and roles of marketplaces may change in complicated ways depending on changes in the environment, innovations in transportation, demography, and many other sociopolitical factors. If the novel good is not incorporated into the existing market system and its distribution to agents is very limited due to the high cost of access, the good will be expelled from the economy or threaten its equilibrium. Our simulation suggests that the difficulty in the distribution is not limited to the novel goods; it may also interrupt the exchange of other goods (Fig. 11). In such cases, myriad agents will respond to the economic crisis individually or collectively, and this will potentially lead to changes in the market system. Although these potential responses were not considered in our model, the results strongly suggest that this situation may provide opportunities or motivations for the evolution of a market system to agents as a response to the changing situation, and the responses of the system will vary from society to society. We here discuss some potential responses of the system.

New Strategies for Accessing Novel Goods

If there is a high demand for a newly introduced novel good or it is regarded as critical to the survival of agents but cannot be incorporated into the existing market system due to difficulties in access and high transport costs, a supply–demand imbalance will develop and overall transaction costs will substantially increase, eventually resulting in a loss of equilibrium and failure of the market system. In such a case, the necessity for new strategies for stably accessing the new goods may arise. For example, some agents may find it profitable to link the new goods to existing marketplaces. This creates a strong motivation for the appearance of specialized merchants or wholesale traders, who bring the goods to established markets (Hahn, 2018; Hirth, 2016; Hirth & Pillsbury, 2013; Larsen, 2008). The appearance of trade specialists and the development of the wholesale system per se are not expected to bring abrupt shifts in market locations. Rather, these strategies would likely complement and augment the existing market system. They may also lead to further diversification of marketplaces. For example, specialized/wholesale marketplaces for merchants may emerge, supporting and coexisting with the existing market system. We do not argue that the emergence of marketplaces necessarily precedes the appearance of specialized merchants. Instead, it is suggested that new strategies for accessing novel goods in high demand will emerge to accommodate the novel goods in the

existing market system, leading eventually to the evolution and complexification of markets. Unless there is a strong motivation for abandoning the existing agreement to access newly introduced goods and create a new market system that secures the supply of the goods, new access strategies should coexist with the existing markets, leading to a complexification of the market system.

Elite Interventions in the Market System

While there would not have been complex societies in history that left market exchange completely untouched, the emergence of highly complex state-level societies is unlikely to be a precondition for the emergence of marketplaces. However, once marketplaces become established as a social institution and exchange becomes concentrated within them, marketplaces quickly become an attractive venue in which elites can attempt to accumulate wealth and control the flow of materials, labor, and information (Blanton, 2013; Blanton & Fargher, 2010; Brumfiel, 1991; Hirth, 1996, 1998, 2020). This is what Hirth calls the “matrix control principle,” in which “elites seek to control resource-accumulation networks... by placing themselves at major matrix positions to influence... the production, and accumulation of resources (1996, p. 224).” As many historical records suggest, taxation, regulation, and value control are common strategies adopted by elites and states. Monopolization of critical resources and politically valued goods and regulation of their circulation are also commonly observed examples of elite control of markets.

Once elites intervene in markets and control resource accumulation networks, their accumulation of resources is secured by the stabilization and equilibrium of markets. If a newly introduced good unexpectedly creates a supply–demand imbalance or increases the overall costs of maintaining the economic system, threatening the equilibrium, then the elite accumulation of wealth will be at risk. Meanwhile, when gains from the control of markets are not satisfactory, elites wish to increase their gains, or the conservativeness of the existing market makes it difficult to control market exchange, elites will seek other strategies for market control. Faced with such problems, the relocation of marketplaces or the establishment of new markets would be a potential strategy that elites can adopt. Many early historical texts from East Asia note that monarchs were often directly involved in the regulation and establishment of marketplaces. *Sanguozhi*, a Chinese historical text that describes not only the history of China but also the customs and cultures of neighboring states, documents markets in Japan in the 3C CE as such: “Each country had a marketplace so the things that were available and lacking could be traded. The king appointed the *daiwa* to direct the marketplaces (*Sanguozhi*, Book 30).” *Samguksagi*, a Korean historical text that details the ancient history of Korea between the 1C BCE and 10C CE, also frequently describes monarchs decreeing the opening of new marketplaces:

Soji Maripgan (King Soji), 12th year (490 CE): For the first time, the king opened a marketplace in the capital to sell goods from throughout the country (The Annals of Silla 3, *Samguksagi*)

Jijeung Maripgan (King Jijeung), 10th year (509 CE): In the first month of spring, the king opened the East Market in the capital (The Annals of Silla 4, *Samguksagi*)

Hyoseo Wang (King Hyoseo), 4th year (695 CE): The West Market and the South Market were opened. (The Annals of Silla 8, *Samguksagi*)

Government Offices and Titles of Silla 1: King Jijeung established the East Market Office in his 9th year (508 CE). There were two directors. Their ranks were *nama* and *daenama* (Miscellaneous 7, Book 38, *Samguksagi*)

These ancient historical records of Korea and Japan indicate that ancient states actively and systematically intervened in market exchange by establishing marketplaces as designated places for exchange and appointing supervisors. It is noteworthy that the newly opened markets were located in capitals, presenting the geographical proximity between population concentrations and marketplaces. By newly opening marketplaces within or near the capital or population concentrations, control over market exchange could become more effective and efficient and overall costs of maintaining economic equilibrium resulting from possible supply–demand imbalances would decrease. States may also plant markets in an area where the system is less developed or incorporate the economy into their own market system, resulting in the abrupt appearance of markets in a particular area. As socioeconomic complexity increases, governmental control of market exchange must be reinforced, while agents' economically motivated transactions also remain important.

Conclusion

Recent concerns with market systems in archaeology have greatly enhanced understandings of prehistoric economies and sociopolitics. However, methodological difficulties constrain archaeology to move beyond the detection of market exchange. While we believe that the existing approaches to market exchange, such as analysis of archaeological assemblages and provenance studies, continue to remain valuable, the development of new methods is also necessary. Although not purely archaeological, agent-based modeling provides a simple but intuitive tool for exploring the emergence and evolution of markets, which archaeologists have considered key to understanding prehistoric economies and the growth of social complexity. Our simulations suggest that the emergence of markets can occur even in the absence of a formalized currency and centralized planning and can instead be viewed as a consequence of agglomerated individual efforts as well as social agreements to reduce partner-search costs and make exchanges more predictable. They also suggest that not only environmental conditions, but also agent-based decision rules shared among multiple agents affect the location and rate of market emergence and the process of becoming a socially embedded institution.

Our model suggests the initial development and establishment of markets be seen as a consequence of agents' collective attempts to reduce partner-search costs, which leads to spatial concentrations of exchange and the growth of marketplaces as social institutions. We argue that the bottom-up perspective better explains this process, as

many previous works suggest (Blanton, 2013; Blanton & Fargher, 2010; Hirth, 2010, 2020). However, as far as changes in established markets are concerned, it must not be dichotomously understood as either a bottom-up or top-down process. Our model shows that when markets are firmly established as social institution, new resources must be incorporated into the existing market system. When markets are unable to incorporate new resources or goods into the existing system, as a result of transport costs or supply–demand imbalances, resulting in increasing costs to the overall market system, motivations to develop new exchange strategies are likely to emerge. The development of new strategies can be both bottom-up-driven and top-down-driven processes. As a bottom-up process, some agents may attempt to find ways of accommodating the ever-changing internal and external conditions in the existing market system, and this effort will gradually make not only the market exchange but also the entire economy increasingly complex in the long run. Meanwhile, the intervention of elites and power would be one of the few mechanisms that can lead to somewhat abrupt changes in and restructuration of market systems. Direct intervention in market exchange by powerholders would significantly alter the forms and characteristics of market systems. Regardless of whether bottom-up or top-down processes better explain a specific change in markets, the evolution of and changes in market system should not be understood as an either-or problem. Rather, we argue that the evolution of market systems is the result of long-term dynamics of interaction between the two processes. The emergence, establishment, and evolution of market systems should not be understood as a series of events, but as emerging patterns and long-term processes in which multi-generational, myriad agents participate with various needs and goals, which eventually evolve into a social institution. Even after the establishment of markets as a social institution, they continuously evolve as internal and external conditions change. Elite control over market exchange would become increasingly complex as socioeconomic complexity increases, and so are agents' strategies for autonomous transactions and responses to elite control, leading to the growing complexity of market systems (Blanton, 2013; Blanton & Fargher, 2010; Hirth, 1996, 1998, 2020).

For the sake of simplicity, our model does not consider many important factors that potentially affect the emergence of markets and their evolution. These include geography, transportation, value systems, demographic changes, seasonal/annual variation in demand and supply, price elasticity, and so on. Incorporating these variables into the model will lead us to a more thorough understanding of the evolution of market systems and socioeconomic complexity. Despite all this, a more important next step, we believe as archaeologists, is how to elegantly apply heuristic models to on-the-ground, real archaeological data to empirically understand the emergence and evolution of market systems.

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Data Availability Data are available within supplementary materials.

Declarations

Competing Interests The authors declare no competing interests.

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