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Institutions and Culture in the Current Communication Environment

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Institutions and Culture in the Current Communication Environment

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Abstract

The relationship between culture and institutions has been a longstanding interest in social sciences. The field of communication provides a new approach to understanding this relationship as a dynamic process that emerged from communication behavior. This dissertation attempts to analyze the relationship and dynamics between institutions and culture in the current media environment through three studies. The first study focuses on the emergence and maintenance of cultural and economic disparities and proposes solutions to shift cultural norms that reinforce structural inequality. The second study investigates the coevolution between institutions and culture, establishing the causal relationship between institutional assimilation and cultural assimilation among online communities. The third study dives into the reasons that drive institutional evolution in its environment. In the three papers, I incorporate formal and agent-based modeling with network science to provide a systematic analysis of how institutional outcomes can be influenced by cultural values, norms, and strategies and how individual choices influences group level cultural and institutional results.

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Chapter 1 Theories of Institutions and Culture

The relationship between culture and institutions has been a longstanding interest in social sciences. The field of communication provides a new approach to understanding this relationship as a dynamic process that emerged from communication behavior. In this chapter, I review the theoretical framework and empirical work in studying the relationship between institutions and culture and identify the gaps in theory and empirics. I conclude this chapter with three studies that introduce my attempts to overcome the challenges in understanding the relationship between institutions, culture, and individual decisions.

1.1 Theoretical framework of the relationship between institution and culture

There have been many attempts to define institutions and culture, many of which articulate a tacit relationship between the two. However, as both institution and culture are endogenous social processes, it is not easy to properly disentangle these constructs. Researchers often draw constructs of institutions and culture from different social theories for the convenience of framing, while sometimes overlooking the inner logic of institutions and culture. To develop a systematic understanding of culture and institutions, we need to understand the approaches in social science to studying social processes. I recognize two traditions in social science that address the dynamics between institutions and culture-- the top-down approach and the bottom-up approach.

1.1.2 Top-down approach

The top-down approach holds the assumption of an existing structure of social processes, which guides the functioning of culture and behaviors. Structuralists, including Durkheim (1915) and Parsons (1949), are the first to theorize the relationship between culture and institution systematically. They theorize culture as a system that functions to fulfill society's needs and to

sustain the social structure. In other words, culture is a function of social institutions and maintains the functioning of social institutions. Berger and Luckman (1991) build upon the structuralist approach and theorize the relationship between culture and institution through the process of reality construction. Institutions in the dimension of objective reality and culture in the dimension of symbolic reality together serve as an input for the construction of the individual's subjective reality. In this process, the construction of subjective reality is social because it relies on individuals' social interaction and communication. Habermas (1985) further develops this relationship between institution and culture in connection with communication. Habermas argues that culture, society, and individual personality constitute the structural component of the lifeworld. The three components are correspondingly related to cultural reproduction, integration, and socialization. Communicative action in this system promotes the understanding of cultural meanings, social integration, and the formation of personal identities.

In the top-down approach, institutions are seen either as the externalization of the social structure or the source of social structure. Indeed, Habermas's definition of society, 'the legitimate orders through which participants regulate their membership in social groups and thereby secure solidarity,' is very close to the very widely adopted modern concept of institutions defined by North (1991) as "the humanly devised constraints that structure human interactions." In this approach, culture is defined not only as norms and beliefs, which guide individual and collective behavior considered appropriate and acceptable in society but also as frames and symbolic boundaries, which help individuals define their social situations. Although the relationship between institution and culture is consistent in this approach, the understanding of the goal of culture differs. Durkheim and Parsons consider the goal of culture to keep the institution

functioning well. Berger, Luckman, and Habermas develop on this basis and connect culture to both institutions and individuals, which together contribute to the functioning of the social system.

Communication is the connection between institutions and cultures. On one hand, the structuralist approach sees communication as the action through which culture can organize social behaviors and interactions to maintain the functioning and stability of society. Furthermore, communication can also facilitate this process for generations over time through cultural transmission (Weingart et al., 2013). James Carey theorizes this perspective as the ritual view of communication (2008). On the other hand, Berger, Luckman, and Habermas see communication as the connecting action between the objective social structure, culture, and individuals' perceptions. Berger and Luckman frame this relationship as the process connecting objective reality and symbolic reality, reinforcing the dominant ideology, thereby legitimizing the social order and maintaining the social status quo (Gitlin, 1979; Hall, 1977) and individuals' subjective reality. Mass media is thus responsible for and determines the modes of reality portrayal in media content.

1.1.3 Bottom-up approach

The Bottom-up approach, instead of building up from the structure, concerns more about how social structures and shared meanings emerge from individual interactions. The bottom-up approach has its roots in critical theory and was developed into mainstream social science through the post-structuralism movement.

Post-structuralism in social science and cultural studies provides intellectual sources for theories and empirical analysis in the bottom-up approach. Post-structuralism rejects the assumption that there is a pre-existing structure of society that helps us better understand, interpret, and alter our social environment by referencing the established meanings. Instead, post-

structuralism invites questions on the emergence of meanings and structures from two new aspects. First, following Foucault, post-structuralism asks how discourse and acts of communication are implicated in the power dimension and how structures and institutions are shaped through the discourse and practices (Foucault, 1971); Second, as power relations are always defined and re-defined through struggles between individuals and objects (Murdoch, 1998), post-structuralism asks for analysis on a dynamic relationship in acts instead of analyzing them as static and complete forms.

Thus, the discussion on institution and culture consistent with the post-structuralist tradition is concerned more with the dynamics of power relations. Foucault's (1995) discussion on institutions focused on their power in forcefully regulating how people define relations and how they interact with others. Culture is then understood as a complex of discourse and acts of communication embedded in power relations.

Two branches of sociology theories are closely related to this approach in understanding culture and institutions. The first branch is symbolic interactionism, which views interactions between individuals and groups as the building blocks of society. Symbolic interactionism has classical roots in Simmel (1968) and Mead (1970), who see culture as the symbolic system in terms of individuals. In contemporary sociological theory, this tradition is best explicated by Goffman (1978) and Blumer (1986). The premise of symbolic interactionism is that symbolic meanings are not inherent in the things themselves but arises out of interactions with other people (Blumer, 1986). Symbolic interactionism sees culture as subjective meanings and symbols arose from the process of interaction. Institutions, on the other hand, form individuals' social groups and constraints the way people interact with each other (Goffman, 1978). Symbolic interactionism challenged the functional structuralism tradition of viewing culture in its objective form and treat

it as the social product that has observable effects, instead, symbolic interactionism treats culture in its subjective form and treats it as a social process with effects that must be interpreted rather than measured.

The second branch is a set of ideas on cultural repertoires and rituals (DiMaggio & Mohr, 1996; Lave & Wenger, 1991; Swidler, 1986). It has some similarities with Berger and Luckman's idea on symbolic reality; however, the focus of cultural repertoires and rituals is on how individuals develop their repertoire and how they choose from their cultural repertoire to deal with specific situations. In this process, Institutions play an important role in creating a stable social context to structures and constraints cultural meanings and provide a coherent strategy for individuals' daily practices. The given institutionalized social context provided individuals a set of toolkits to face the challenge of the environment and reference to deal with interactions, without the necessity of internalizing the values and beliefs conveyed in those repertoire and rituals (Swidler, 1998).

In the bottom-up approach, culture is the focal point. The definition has shifted from considering culture as disembodied ideas toward thinking of culture as grounded in practice (Bourdieu, 1984; Ortner, 1984; Peterson, 1979). Institutions on the other hand are considered to be a dynamical structure that emerges from the relations and actions. This perspective of institutions can be summarized as "a system of social factors that conjointly generates a regularity of behavior" (Greif, 2006). Communication, in this perspective, plays an even more important role and has a closer relationship to culture. Symbolic interactionism considers communication as the source of cultural meanings. Swidler instead defines communication as a cultural practice. Despite the difference in the relationship between communication and culture, they both consider institution as a context or regulation over the communication behavior, usually mediated by culture.

The biggest difference between the top-down and the bottom-up approaches is the focus switching from the interaction of a set of concepts to the interaction of individual practices. We can view this transition as from macro to micro. The key question of the macro perspective is how the society maintains and reproduces its structure, whereas that of the micro approach is how individuals interact with the environment and each other and how they make sense of the interactions. This distinction is also represented through their discussion on institution and culture. The discussion in the top-down approach considers the relationship between institution and culture as a feedback loop. Institutions constrain the formation of cultural meanings and symbols, while at the same time, culture justifies and reinforces institutions. The discussion in the bottom-up approach focuses more on how the interaction between culture and institution influences individuals' behavior and interaction with others.

The two approaches are not completely independent of each other. Instead, they are often intertwined and contribute together to explaining social processes. Communication theories are the bridge between the two approaches. The macro perspective considers communication as the connector between institutions and culture. Mass communication theories, including agenda-setting (McCombs, 1977), framing (Scheufele, 1999), and cultivation theory (Shanahan et al., 1999), contribute explanations of how institutions influence culture through individuals' perception of reality to reinforce social organizations. Interpersonal communication theories, including self-presentation theory (Walther, 2007), social identity theory (Stets & Burke, 2000), and symbolic interaction (Goffman, 1978), explain how institutional context and cultural meaning guide individuals' communication behavior.

1.2 Current communication environment

In the current communication environment, digital technology changes both the form of communication and the structural context of society, which complicates the relationship between institution and culture. First of all, the creation of social media blurred the distinction between the two approaches through the social changes and complications brought by digital media technology (Beniger, 1987). The distinction between mass communication and interpersonal communication is blurred by digital media technologies, we also see more and more overlap and connection between the macro top-down approach and the micro approach. Second, information and communication technology has become a new component of the social infrastructure and create a whole new institutional context. The shift in the institutional context requires the update and creation of a new cultural repertoire for individuals to deal with the transition in their everyday life. Last, information and communication technology change the way people communicate, allow them more agency in two-way communication, and offer them the power to leverage institutions. This change complicates the power relations in the social system and establishes a more dynamic relationship between culture and institution.

1.2.1 Address institutions and culture in the current media environment

This dissertation attempts to analyze the relationship and dynamics between institutions and culture through three studies. The first paper focuses on the emergence and maintenance cultural and economic disparities from individuals' choices and proposes solutions to break the reinforcement of structural inequality. The second paper investigates the coevolution between institutions and culture, establishing causal relationships between institutional assimilation and cultural assimilation among online communities. The third paper dives into the reasons that drive institutional evolution in its environment. In the three papers, I incorporate formal and agent-based

modeling with network science to provide a systematic analysis of how institutional outcomes can be influenced by cultural values, norms, and strategies and how individual choices influences group-level cultural and institutional results.

Cultural Choice, Social Relations, and Structural Reinforcement The first paper closely examines how culture interacts with social structures and produces inequalities in the current media environment. In this paper, I designed an agent-based model to explore how different behavioral principles for cultural choice and communicative affiliation affect collective consumption patterns, social segregation, and resilience of the emergent dynamics during exogenous disturbance. I analyze the influence of individual agency on network structure, and vice versa, by simulating agents who pursue elite or popular culture, while communicating with others based on homophily, prestige, or randomness. I then used an exogenous disturbance on elite culture cost to test the resilience of social network structure. The result shows that only in societies where economic factors drive cultural consumption can increased access to elite culture reorganize the social network and reduce segregation between different social groups. This is because the disturbance in consumption provides agents with opportunities to connect with other social groups and opens a window for social mixing. I end by discussing how this model allows us to inform diverse empirical research questions, including the cultural markets of social media, the digital divide, and the split between free misinformation and established news outlets.

Causal Relations between Institutional Changes and Cultural Changes The second paper then looks further into the causal relations between institutional changes and cultural changes. Human organizations are driven by their rules and cultures. But the effects of rules and cultures on organizational development cannot be understood without untangling their effects on each other. People's values are contingent on how they have been enculturated within

organizations. Conversely, their values may influence the organizations they join, particularly in online community settings, where users have thousands of organizations to choose from and exert selection pressure in favor of communities with favorable rules. Using longitudinal data on the rules systems of thousands of online communities, as well as the traffic of millions of users between them, I apply the multiplex Markov chain method from network science to disentangle the relationship between cultural assimilation and institutional assimilation. The result shows that institutional similarities in administrative rules and informational rules drive cultural similarities. I then discuss the implications of these findings for research on organizational evolution, institution and culture, and the use of tracking data in organizational studies.

Quantifying Selective Forces in Institutional Evolution The third paper focuses on institutional changes and zooms into the reasons that drive institutional development in a changing environment. Institutions and culture often evolve in response to environmental incentives. However, sometimes institutional change occurs due to stochastic drivers, including drift, path dependency, blind imitation, and complementary cooperation in a changing environment. Disentangling the selective and stochastic components of organizational changes enables us to identify the key features of long-term organizational development. Evolutionary approaches provide organizational science with abundant theories to demonstrate organizational evolution by tracking beneficial or harmful features. In this study, focusing on 20,000 Minecraft communities, I measure these drivers empirically using two of the most widely applied evolutionary models: the Price equation and the bet-hedging model. As a result, I find strong selection pressure on administrative and information rules, suggesting that their positive correlation with community fitness is the main reason for their frequency change. I also find that stochastic drivers decrease the average frequency of administrative rules. The result makes sense when viewed in the context

of evolutionary bet-hedging. Through the bet-hedging result, I show that institutional diversity contributes to the growth and stability of rules related to information, communication, and economic behaviors.

Chapter 2 Cultural choice, social relations, and structural reinforcement

2.1 Introduction

The rise of social media and the commercial foundation it is based on rekindles a longstanding debate about the interplay between social relations and cultural consumption. It has long been argued that people's cultural choices — their expressed cultural identities, consumption patterns, and so on — are closely related to their social connections. On the one hand, their social positions and social groups influence the culture they consume (e.g., Marx, 1964; Bearman, 1993). on the other hand, similar cultural consumptions will drive people to reinforce or form social connections (Bourdieu, 1984; P. DiMaggio, 1987). In this way, the interaction between cultural choice and social network structure is considered a closed-form feedback loop that keeps reinforcing its own structure. Ever since these foundational works in communication, sociology, and economics, the question has become whether a shift in individuals' choices can break this self-reinforcing pattern and drive changes in the social network structure. And if yes, what kind of individual micro choices would create different social macro structures in this setup?

These questions have gained new relevance in the digital age (Friemel, 2020). Social networks are quickly created and reconfigured, and much of their content—and therefore, their underlying business models—are based on cultural consumption choices. This extends beyond the cultural consumption of videos or other social media content and expands into the increasing integration of online- and offline worlds, where every image is clickable and purchasable, and service provision becomes a global freelance phenomenon. Mass-produced media products and services are just one click away from high-brow elite culture as long as the networks link them. The blurriness of the distinction between elite culture and pop culture in the digital age urges us to

reconsider the theorization of cultural choice and social network in a more flexible way. People may pursue one type of culture to signify their social status through their artistic interests, establish common interests with members in their social group, or just as a convenient choice due to accessibility. People may also make social connections for different reasons, including contract-binding economic exchange, common cultural interests, or proximity. Does the distinction in cultural choice and segregation in social positions remain the same under different combinations of these behavioral principles? Can we still use tools in cultural sociology to theorize and predict collective patterns of cultural choice and network structure?

At the same time, technological innovation in the media market and cultural transmission provide opportunities for cultural consumption to shift from mass-produced popular culture to rare high-brow elite culture and lead to recurring changes in the culture industry. An elite cultural product can become accessible to the majority due to technological innovation (e.g., from theatre opera to CDs) or cultural imitation (e.g., fashion). Once it is no longer expensive or rare, technological advancement (high-quality digital music) or cultural innovation (a new trend in high fashion) will replace it with a new elite cultural product. In this way, a technological change provides an exogenous disturbance that can drive a reconfiguration of the social network structure via a change in consumption patterns. On the one hand, technology may lead to social mixing via individuals making social connections through shared cultural experiences. On the other hand, what looks like social mixing may be nothing more than a superficial or temporary exchange that masks persistent separation by class or income. Once the elite cultural goods recover the cost, the majority cannot keep up with the elite cultural expense, and the reorganized social network structure is likely to fall into social segregation again.

Whether this effect caused by consumption shift is superficial or structural in different social contexts remains an open question. The social theories on culture and social network structure have provided us with an approach to explore this question, but not the answer. Using the theoretical frameworks provided by social thinkers including Marx, Bourdieu, and DiMaggio, this paper aims to explore which type of behavioral principles in consumption and affiliation would allow social mixing after the exogenous changes in cultural product accessibility through an ABM model.

The modeling of individual behaviors and the computer simulation of various social realities allow us to articulate the underlying mechanism of those social science theories and test the effects of exogenous disturbance on system dynamics. After a literature review and an introduction to our chosen method, our analysis specifically focuses on three questions of the cultural choice and social network structure: (1) How do individual's behavioral principles in making cultural choices and social connections influence collective cultural choice patterns and the segregation structure of the social network? (2) How does cultural consumption shift influence the segregation structure in the social network structure in various social environments? (3) Which affiliation and consumption principles allow for changes in network structure when we introduce exogenous disturbance? After discussing what we have learned from our computer simulations of the involved dynamics, we close by discussing potential areas of application. We argue that our model can inform ongoing debates about cultural consumption in social media, the opportunities and threats of the digital divide, and the omnipresent debate of the power of fake news in social media.

2.2 Literature Review

2.2.1 Social network structure influences individuals' cultural choices

The relationship between culture and social structure, especially social network structure, has attracted longstanding interest in the disciplines of sociology, anthropology, economics, and communication. It first recognizes that the socio-economic structure has a dominant effect on individuals' cultural choices. The purpose of consuming expensive cultural goods is to signify economic status. Classical statements raised by Marx (1964) and Durkheim (1984) aim to explain how patterns of social structures influence the composition of cultural systems (Bearman, 1993; Douglas, 1978; Martin, 1997). This approach sees culture as a reflection of the social structure. In other words, individuals with certain cultural tastes consume certain cultural products because they are at a particular position within the social structure. The purpose of pursuing certain cultural goods is thus to signify one's economic capacity or social status.

With the shift from considering culture as disembodied ideas toward thinking of culture as grounded in practice (Bourdieu, 1984; Ortner, 1984; Peterson, 1979), empirical research explained the connection between culture and social structure by demonstrating how individuals' cultural preferences and practices are influenced by their relations with others in social groups (Anheier et al., 1995; Kay & Hagan, 1998; Mische, 2011) and their position in their social network (P. DiMaggio & Mohr, 1985; Erickson, 1996; Mark, 2003; McLean, 2016). In other words, this approach suggests that individuals pursue certain cultural goods with the intent to maintain their relations with others or their positions in social networks (McPherson, 2004).

2.2.2 Individuals' Cultural Choices Influence Social Networks

Individuals' cultural choices and preferences, in turn, also influence the social structure through social relations and social networks. Bourdieu (1984) proposed the concept of cultural

capital, which refers to socially distinctive cultural knowledge, tastes, and skills. Cultural capital can be used to gain social and economic resources in two ways.

First, individuals with specialized cultural knowledge and tastes approved by a specific social group can gain or reinforce their membership in the group through their cultural preferences and consumption. The access to particular cultural knowledge and the opportunity to cultivate particular cultural tastes are rare resources that only people in specific social groups have. This resource provides the symbolic recognition afforded by specific cultural skills, knowledge, and tastes of collectively valued cultural goods (DiMaggio & Mohr, 1985). Bourdieu theorized this process as the conversion between cultural capital and social capital. More specifically, the cultural knowledge and skills allow the individual to engage in symbolic interactions and gain membership to prestigious groups, forming social connections with other group members (Carley, 1991; P. DiMaggio, 1987).

Second, individuals with general knowledge and preferences for mass-produced culture can form social connections with those with similar interests through conversations on those shared interests and knowledge. One significant change in modern societies is the role of arts and mass-produced culture in maintaining interactions between people across different social groups. This change becomes more significant with increasing geographic mobility and mobile communication, leading to more social connections both within and between different social groups (DiMaggio & Mohr, 1996; Fiske, 2002). The cultural knowledge and practices not only create these more frequent opportunities for conversations to happen but also make the shared social life meaningful and pleasurable, which is fundamental in constructing social relations and social identities. This socially connective process usually happens in the context of mass-produced popular culture.

The two approaches in this model both produce a homophily phenomenon, that is, people with the same cultural preferences, practices, and consumption patterns are more likely to connect with each other or strengthen the existing social connections.

2.2.3 Communication Approach

This relationship between cultural preference and social relations has also been broadly discussed in the field of communication. Specifically, communication research focuses on how cultural choice and social relations influence each other through communication processes. This question has been studied in at least two domains of communication: mass communication and interpersonal communication.

First, interpersonal communication theories posit that people's cultural choices and cultural preferences can be cultivated through repeated interactions within their social groups (Lee et al., 2016). Their cultural choice and preferences, in turn, become a symbolic resource to strengthen their relationships with other members of the group. For example, Hughes and Peterson (1983) and Johnson (2002) established causal links between social network relations and music choice, demonstrating how music choice is a product of interaction within social groups.

Second, mass communication theories point out that the rise of mass media created an assimilated cultural environment for society (McQuail, 1987) as well as opportunities for communication based on common ground (Clark, 1992). Mass media enables the representation of certain aspects of our social experiences in collectively meaningful and pleasantly received ways. The cultural choices and preferences that are shaped by mass media provide a basic form of capital that helps foster new social relations and a sense of identity. On the other hand, the representation of different experiences broadcasted through mass communication reinforces an

existing sense of social identity, thus also providing references for cultural choices that are already perceived to be endorsed by the group (Gamson et al., 1992).

2.2.4 The Evolving Media Environment

The difference between the mass communication and interpersonal communication approach is in their explanation of how the relations are formed due to similar cultural choices. Lizardo (2006) used the distinction between elite cultural taste and popular cultural taste to theorize the two types of processes. Elite cultural taste is characterized by an emphasis on the consumption experience, in which cultural products are seen as a conduit of specific moral and aesthetic values endorsed by certain social groups (Van Eijck, 2001), whereas popular culture consumption is seen as a more generalized engagement with culture. Following this distinction, Lizardo (2006) formulated a specific model encompassing an elite culture conversion process and a popular culture conversion process. Consumption of popular culture provides forms of cultural capital that lend themselves to conversation topics between people from different social groups for fostering weak social connections, whereas consumption of elite culture will enable individuals to form strong social connections with members of the same initial social group.

As with all models and typologies, the distinction between elite culture and popular culture and their respective conversion approaches is not always so straightforward in practice. First, different from Bourdieu's assumption, the aesthetic dispositions of elite culture and popular culture are not completely correlated with social positions and economic values in contemporary cultural markets. For example, the Internet grants much free access to information and cultural products that may traditionally carry high cultural value, leading to shifts in economic and cultural paradigms. For instance, one can watch a free, culturally esteemed Mozart Concert on YouTube, whereas a Super Bowl ticket costs 7,000 dollars regardless of origin in the poor and working-class.

The symbolic value of those cultural products no longer matches the economic capacity required to pursue them. Additionally, an increasing number of online cultural products, including music and video services, provide both free and paid services with overlapped functions. The small cost difference and the unclear symbolic value difference make it even more difficult to distinguish between "elite" and "popular" through their accessibility and economic value.

Second, the distinction between culture specific to one group and culture generally accepted by a mass audience is blurrier than theorized to be because the aesthetic values of some cultural goods can be accepted by different social groups for different reasons (Baek, 2015). This pattern becomes more evident in the contemporary world and media market because cultural paradigms and production have witnessed great changes (Manovich, 2009), making it increasingly difficult to infer status directly from cultural preference (Foster, 1985). Many of the distinguishing traits of popular culture and mass reproduction have provided topics and inspirations for elite contemporary. Additionally, many popular cultural forms are produced and consumed in similar forms using similar symbols as modern art, which is considered the elite culture of the contemporary world Fiske, 2010).

At the same time, social networks in the online media environment evolve at a much faster rate. Internet and current social networking sites make it easier for individuals to form and drop connections with others, including both weak ties (Kahne & Bowyer, 2018) and strong ties (Vriens & van Ingen, 2018). The online social network is thus always in a dynamic process. The intensity and meaning of social connections in the online media landscape have also changed drastically. The distinction between acquaintance and general friends has been less clear. Strong ties might be eroded or strengthened under different contexts (Vriens & van Ingen, 2018).

The blurriness of the supposed distinctions between elite culture and pop culture and the fast-changing online social network urges us to reconsider the model of interaction between cultural consumption and social connections and theorize this process in a more real-time flexible way (Mangold & Scharkow, 2020). Can people pursue elite culture and form social connections with out-group members with the same aesthetic values as a pop-culture conversion approach? Can people pursue pop culture based on a particular perspective that popular cultural goods provide and then also reinforce their membership in a niche cultural group? Most importantly, does the distinction in cultural choice and segregation in social positions between the rich and poor still remain the same as theorized by Bourdieu? These questions emerge from the different possible combinations of principles for pursuing culture and making social connections:

RQ1: Which cultural product, elite or popular, does a collective of individuals prefer when different principles drive:

RQ1a) their cultural consumption choice?

RQ1b) their social connections?

RQ2: Which social network structures, segregated or well-mixed, does a collective of individuals form when different principles drive:

RQ2a) their cultural consumption choice?

RQ1b) their social connections?

The conversion from cultural capital to social capital is a dynamic process. The accessibility of cultural goods changes over time, as well as the symbolic meanings of culture. On one hand, the increased availability of elite cultural goods may change the dynamics of the

interaction between culture and structure. On the other hand, individuals with increased spending power may also change the system dynamics through consumption. Veblen's (2005) conspicuous consumption theory mounts to a prediction that individuals with increased spending power will emulate the consumption patterns of those at higher positions in the social hierarchy. Thus, whether the reconfiguration caused by the external disturbance can push the model into a different equilibrium from Lizardo's model is also the key to addressing the neglected role of individuals' agency in the interaction between culture and structure. Salganik, Dodds, and Watts (2006) found that social influence leads to higher levels of unpredictability in individuals' cultural choices, indicating that the effects of external disturbances on the segregation structure may vary across social contexts where influence flows through social relations in different network structures. Thus,

RQ3: How will exogenously induced consumption shifts change network structure?

2.3 Method

We designed an agent-based network model (network ABM) to explore the combinatorial space created by cultural choice and social connections and the effects of consumption shifts on social network structure. ABMs force us to specify the parts and relationships of a system that are consistent with concrete assumptions, facilitating falsifiability and therefore accelerating the scientific process Smaldino, 2017; Reynolds, 2020). ABMs also enable systematic process tracing, following the generativist motto: "If you didn't grow it, you didn't explain its emergence" (Epstein, 1999; *p.43*). Most empirical models estimate relationships within an input-output model, which is usually not sufficient to explain the causal mechanism; instead, ABMs capture and produce the dynamics of a process (Alvarez-Galvez, 2016). A good fit between ABMs and empirical data

provides not only statistical evidence for the result but also the validity of the process (Waldherr, 2014).

2.3.1 Agent-Based Model

We set up a model with a population consisting of n agents aggregated into a rich group and a poor group in a continuous 2D space with periodic boundaries in the modeling software NetLogo (Wilensky, 1999; Detailed code in https://github.com/qkzhong/Cultural-ABM; see Supporting Figure 1 for model interface). The 2D space is created solely for visual purposes and does not have an influence on agents' behaviors. Two types of cultural products are available in the model: elite cultural products at cost C_e and pop culture at cost C_p. The model initiates with no social relations. The agents update the social network in each iteration by creating, maintaining, and dropping connections. Agents run through the following interactive steps:

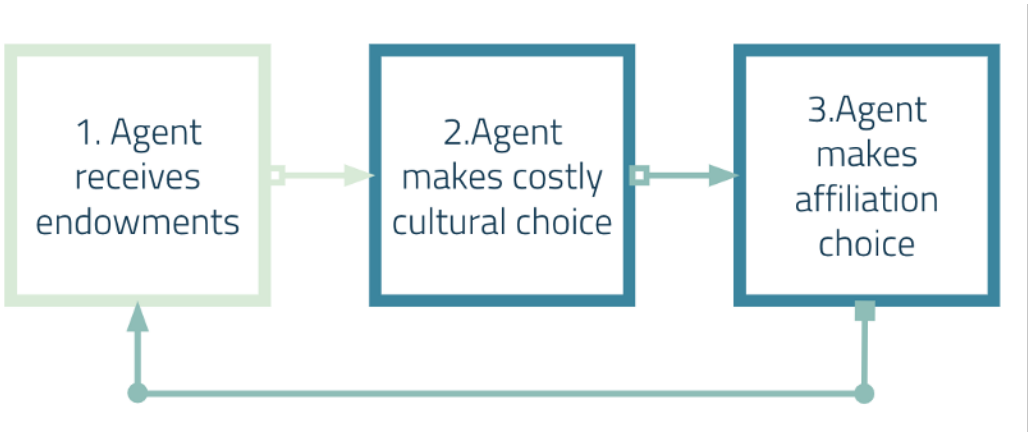


Figure 1-0-1. Agent itinerary in the model We model the interaction of social structure and cultural consumption with a population of agents who iteratively invest in cultural consumption and then affiliate with others whose own consumption can influence future investments. Our simulation experiments manipulate steps 2 and 3 with the parameters representing each varied over a 10x10 grid. Cultural choice (step 2) varies along with a strictly economic criterion (buy the best you can afford with available resources) or social influence-based criterion (buy what your peers tend to buy). Affiliation choice (step 3) varies from full homophily (link to agents with similar cultural choices) to complete randomness (link to random agents).

(1) Agents receive endowments based on the social group they are associated with. Every timestep, agents in the rich group receive an endowment of I_r. Agents in the poor group receive an endowment of I_p. The endowment not spent at this step will be saved for the following steps, but

agents in this model do not purposefully plan to save more through particular cultural choice strategies.

(2) Agents make costly cultural choices. Agents make a probabilistic decision between price-driven choices (naive Marxist approach) and peer-driven choices (Bourdieu/DiMaggio approach) on a scale from 0% to 100% price-driven. A price-driven choice is to consume the most expensive cultural product the agent can afford. When the elite culture is at the same price as the popular culture, a price-driven agent will choose to consume elite cultural products due to the prestige advantage of a more selective 'elite' (as per definition of the term). A peer-driven choice is a probabilistic choice proportional to the peer's cultural choice. Peers are defined by the network structure. The probability of an agent choosing elite culture is the same as the proportion of agents that choose elite culture in the agent's ego network. Because agents' purchasing power is limited by their economic resources, price-driven choice sometimes comes before peer-driven choice regardless of the parameter settings in conditions when pop culture is the only choice an agent can afford. This also happens when agents don't have any social relations, in which case they cannot make peer-driven choices.

(3) Agents make affiliation choices. Agents will reach out to a fixed percentage of all agents by a reach-out threshold and take decisions about making, dropping or maintaining connections based on the homophily level. If the other agent is a stranger, the agent can make a probabilistic decision about whether or not to form a connection with the stranger by the level of homophily in this run. Bourdieu proposed the homophily mechanism of social connections driven by consuming the same elite culture, while DiMaggio extended it to social connections driven by the same pop culture consumption. Thus, when agents make highly homophily-driven connections, they will only make connections with the other agent that have the same culture as them. If the other one

they reach is a friend, the agent will make a probabilistic decision about maintaining or dropping the connection with that friend based on the level of homophily. In a high-homophily situation, agents will be more likely to drop ties with friends who don't pursue the same culture as them anymore (See the model and supplements for detailed specifications of this step).

Table 1. Experiment Parameters

Experiments	Parameters	Simulation steps	Repetitions
Simulation Experiment 1 (RQ1 & RQ2)	N = 100, rich income, I_r = 5, poor income, I_p = 2, elite culture cost, C_e= 5, pop culture cost, C_p = 2, rich-poor ratio, $r = 1$, reach out percentage = 0.04, choose as peers = [0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1], homophily = [0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1]	1000	50
Simulation Experiment 2 (RQ3)	C_e before price change = 5, C_e during price change = C_p, C_e after price change = 5	1000	50
Robustness Checks	I_r / I_p *ratio* = [2, 2.5, 3.33, 5], C_e / C_p *ratio* = [2, 2.5, 3.33, 5] benchmark network = [random network, preferential attachment]	1000	50

2.3.2 Model assumptions

In this model, we built in some assumptions in modeling agent behavior either based on real world experience or to stress the key causal mechanisms. Those designs and assumptions may have an influence on the model results. First of all, in each step, agents are assigned a probabilistic rule to choose elite/pop culture instead of a fixed culture to choose culture. the probability each agent in each step is assigned to choose as peers or make homophily connections is based on the condition of the level of homophily norms and price-driven norms in that run. For example, in a condition with peer-driven at 0.8, agents at each step have an 80% probability of choosing culture as peers as opposed to a 20% probability of choosing culture based on their economic condition. Therefore, throughout the whole simulation, 80% of the time, agents will make peer-driven cultural choices, and about 20% of the time, they will make price-driven cultural choices. This modeling strategy is more realistic when considering how individuals follow social norms and make decisions. In a society with a strong norm about group conformism, it is more realistic to have all individuals violating the norm at a smaller chance (e.g., 20% of the time) than 20% of the population violating the norm all the time while the rest of the population never violate the norm.

Additionally, we create social connections from scratch in order to reduce the effects of initial network composition on the overall network dynamics and consumption patterns. Growing from an empty network, we can make sure that the affiliation principles we built in the model is the only mechanism for the network dynamics, although this design makes it difficult and probably not reasonable to analyze the network structure and consumption pattern before the equilibrium state. For its application and mapping to real-world examples, this design in the model is unrealistic for some social contexts. For example, it is hard to imagine upper-class and working-class people in a real-world society having a starting point of no social connections. However, it might still be

directly applicable in some social contexts, such as online communities and online social networking sites where users start from an empty profile and establish their online social connections from scratch.

2.3.3 Simulation Experiment

Three main simulation studies were conducted to investigate RQ1 - RQ3. Table 1 provides parameter values, simulation steps, and simulation repetitions for the simulation studies reported below.

Simulation Experiment 1

These simulations aimed to answer RQ1 and RQ2 by assessing the difference between different cultural choices and affiliation choice conditions with an equal rich-poor population ratio. The manipulation is on the probability of cultural choice principles and the probability of homophily in affiliation.

Simulation Experiment 2

These simulations aimed to answer RQ3 by assessing the effects of consumption shift on social reorganization. We use cost changes to operationalize an exogenous disturbance on cultural consumption. This disturbance occurs in the real world periodically in the forms of technological innovations, policy interventions, and mass production. We first decrease the elite culture cost to the same as the pop culture cost at timestep 500, which allows the model to reach a stable state before introducing the shock. After 50 timesteps, we recover the elite culture price to see if the equilibrium condition changes after the cost recovery (as a structural change) or if the equilibrium returns to the state before disturbance (as a superficial change).

Simulation Experiment 3

As a robustness check of the effects of exogenous disturbance on social network structure, we also conduct experiments with various cultural choice and affiliation choice conditions, cost and income ratios, and benchmark networks. Benchmark networks refer to the null network model with no homophily. In this paper, we test whether the observed result is robust to different network-generating models, including Erdős–Rényi model (random network) and Barabási–Albert model (preferential-attachment network).

2.3.4 Simulation Data and Analysis

For each simulation experiment, we collect data on elite and pop culture consumption within rich and poor populations, overall network ties, ties between rich and poor agents, and individual degree centrality at each step of each run.

We measure the elite culture ratio by calculating the percentage of agents that pursues elite culture among all agents at each step. We then measure the segregation by the percentage of ties between agents with the same nodal attributes among all ties. Our measure of segregation is different from the commonly used structural measures in community detection (Fortunato, 2010) and component analysis (Osei-Asamoah & Lownes, 2014) because rich and poor in our model are nodal attributes instead of structural features. In other words, if all rich agents are connected to rich agents only, and all poor agents are connected to poor agents, the segregation will be the highest at 1. If all rich agents are connected to poor agents only, the segregation will be the lowest at 0. For further analysis, we also calculated the percentage of rich agents that consume pop culture and the percentage of poor agents choosing elite culture at each step.

We first aggregate 50 runs of simulation at each step by average, minimum, and maximum. To compare collective patterns between different experimental conditions, we also aggregate elite

culture ratio, segregation, and degree centrality by the average of all iteration steps in each condition.

2.4 Result

2.4.1 Cultural Choice

To analyze the difference in cultural choice influenced by consumption principles and affiliation choice (RQ1), we compare the average number of agents consuming elite culture through 1000 timesteps across all conditions (See Figure 2). We find that in a population with equal proportions of wealthy and poor, different principles of cultural choice and affiliation type lead to variation in elite cultural consumption. Regarding variations in cultural consumption choice (RQ1a), in conditions where agents' consumption follows their peers' cultural choices (right-hand-side of Figure 2), elite culture is less preferred. In those conditions, agents with a popular-dominant ego network will prefer popular culture regardless of their economic resources, and those with an elite-dominant ego network additionally require the economic resources to access elite culture. Regarding variations in affiliation choice (RQ1b), there is not much difference in cultural choice between a high-homophily condition and a low-homophily condition when the main behavioral principles for cultural choice are driven by the price of cultural products because cultural choices are independent of the social connections when the behavioral principle is entirely price-driven. Whereas with more influence from peer's choice on cultural choice, elite culture is more preferred in a high-homophily condition (upper right corner) than a low-homophily condition (lower right corner). In a high-homophily peer-driven cultural world (higher right corner), the result produced Bourdieu's hypothesis of a highly segregated society where the wealthy constantly choose elite culture and the poor pop culture. The two social groups keep reinforcing their cultural choice patterns to stabilize the segregated social network structure, so the percentage of elite cultural

consumption stabilized at the same ratio as the wealthy population ratio. This is the same in a low-homophily peer-driven cultural world (lower right corner) that an agent needs to have both the economic capacity and a friend circle of wealthy agents to choose elite culture. However, the chance of meeting both is smaller when the affiliation mechanism is more random, so we observe a preference towards pop culture in the lower right corner.

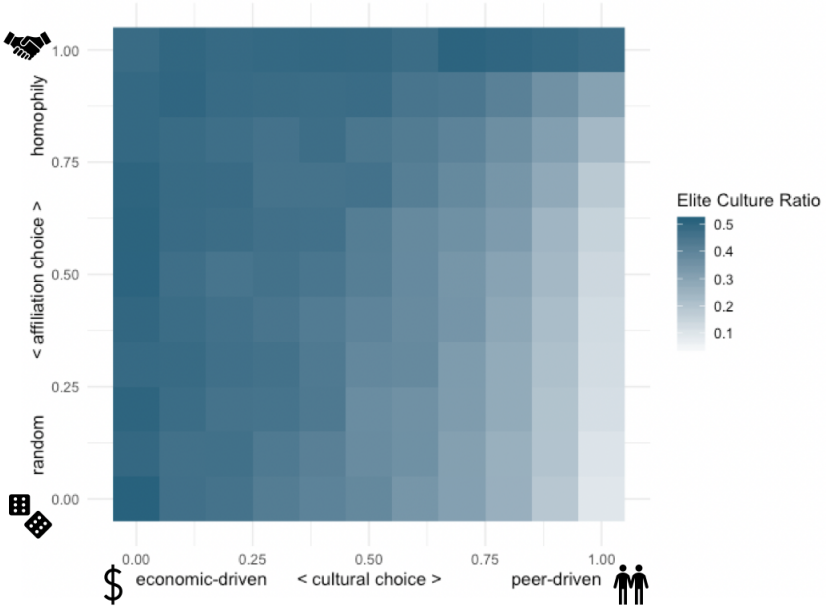


Figure 2. Elite cultural choice ratio among various model conditions. In this figure, preference for elite culture (Elite Culture Ratio) increases with economic-driven choice but shows slightly more nuance with decreases in homophily. Even in a population with equal proportions of wealthy and poor, different principles of cultural choice and affiliation type lead to biased cultural consumption. (All values are averaged across 50 runs.)

2.4.2 Social Segregation

The variation in Figure 3 illustrates the influence of cultural choice and affiliation choice on social network formation (RQ2) in terms of social segregation. We observe a monotone increase of social segregation from peer-driven to price-driven conditions, as well as from random affiliation to homophily affiliation principles. The monotone increase from random affiliation to homophily affiliation can be explained by the homophily process as a social segregation mechanism that people who choose the same culture are more likely to form their closed social

group. At the same time, price-driven cultural choices are less likely to be influenced by agents' affiliation choices, making the segregation more stable against other confounds or stochastic factors in the network process.

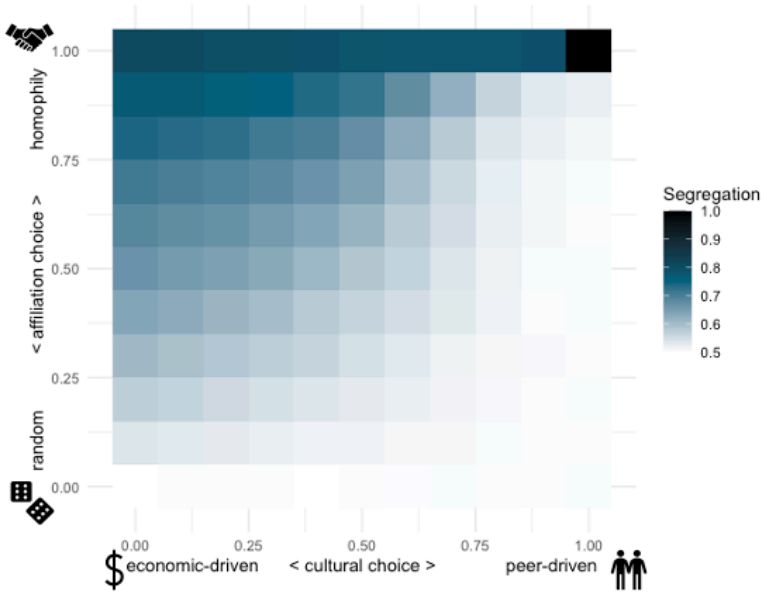


Figure 3. Social segregation among various model conditions average. In this figure, A higher level of heterogeneous tie ratio indicates a lower level of social segregation. We observe a monotone increase in social segregation from peer-driven to economic-driven conditions and from random affiliation to homophily affiliation principles. (All values are averaged across 50 runs.)

2.4.3 Response to Exogenous Disturbance

We use one specific exogenous disturbance to reveal the adaptiveness of the model. We choose an exogenous disturbance on elite culture price, which changes the availability of elite culture and causes consumption shifts in price-driven conditions. The disturbance first decreased the cost of elite culture to the same cost as popular culture at timepoint 500. After 50 timesteps, elite culture will recover to its original cost. This duration is long enough for us to observe the influence of cost change on the collective consumption patterns and the resilience of the segregation structure. The recovery of the price then allows us to assess whether the disturbance has lasting effects on the system.

The consumption shifts caused by exogenous disturbance have different patterns under different behavioral principles of individuals' cultural choices. At the same time, different levels of homophily determine whether the changes in network structure caused by consumption shifts would be reinforced or diminished. During the time when the elite cultural cost is decreased to the same as popular culture, although all agents can afford to consume either culture, agents whose cultural choice is driven by price will tend to choose elite culture, whereas, in peer-driven conditions, agents will not switch their cultural choice unless their peers switch.

The result in Figure 4 shows that networks whose affiliation choice is driven purely by homophily have identical behavior in both cultural choice and network structure in terms of degree centrality at equilibrium state regardless of consumption is driven merely by the price and prestige of the cultural product or peers' choice. However, they react very differently to the disturbance. When the cultural choice is determined by peers' choice, the network structure and cultural consumption pattern absorb the disturbance. This does not happen when the cultural choice is determined by price. The degree centrality increases during the disturbance period for price-driven high-homophily boundary condition, because when everyone pursues elite culture, homophily will drive agents to make friends with anyone they reach out to and maintain their connections with all the friends. The disturbance-induced changes happen due to the interaction between homophily principles and cultural choice principles. In random network boundary conditions, the disturbance will not cause changes in the network structure because network processes are independent of agents' cultural choices (See Supporting Figure 2).

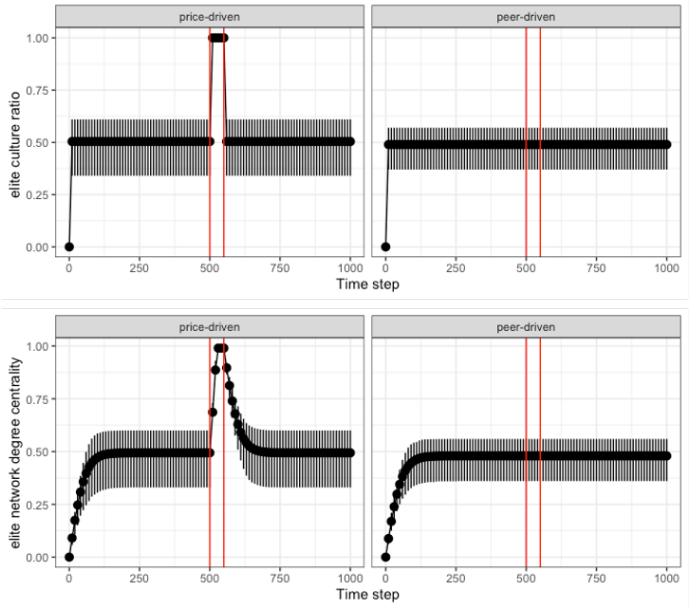


Figure 4. Elite culture ratio and elite network degree centrality response to shock under homophily affiliation principle with different consumption principle After iterating the model, we introduce an exogenous disturbance that lowers the cost of elite culture consumption (evident at time 500 in left two panels, though not in the other two), as in the emergence of mass culture production, which increases the accessibility of elite symbols of status. The shock ends after 50 ticks so that we can observe whether and how the social system recovers to its original equilibrium under choose-as-peers and choose-as-price conditions with homophily as the affiliation principle. We find that homophily leads to a similar equilibrium network structure in terms of degree centrality regardless of how cultural choice is made. However, when the cultural choice is determined by economic factors, the social network structure and cultural choices absorb the economic shock. This does not happen when the cultural choice is determined by peers' choices. (All values are averaged across 50 runs.)

We found that the increased availability of elite culture causes transient structural changes in social segregation, measured by the proportion of heterogeneous ties in particular conditions. Figure 5 illustrates how the segregation structure in the network reacts differently towards disturbance across four conditions. The results show that, consistent with Figure 4, social mixing increases after the disturbance in conditions with price-driven cultural consumptions only (Figure 5 (a) and (c)). During the decrease of elite culture cost, segregation drops to 0.5, indicating that agents have an equal chance to connect to another agent from a different class or the same class. In other words, the disturbance provides a chance for complete social mixing. We extend our analysis to various levels of homophily condition and found that for a higher level of homophily, although the segregation reduces at a greater level during the shock, the system bounces back faster

($t_{0.9homophily}$ = *250;* $t_{0.8homophily}$ = *410*) than conditions with a lower level of homophily ($t_{0.7homophily}$ = *650;* See Supporting Figure 3). The duration of the disturbance effect does not depend on the length of the shock (See Supporting Figure 4). Here we use a short enough disturbance to explore whether a short-duration shock can still alter the network structure.

The equilibrium in panel (c) moves after the shock because the disturbance happens when the system is not in an equilibrium state yet. The disturbance maximizes the social mixing and then proceeds to the equilibrium state in advance. To confirm the equilibrium state, we applied a disturbance at timestep 1500 for 50 timesteps and found that the disturbance effect reduced to the initial level after 2620 timesteps (see Supporting Figure 5).

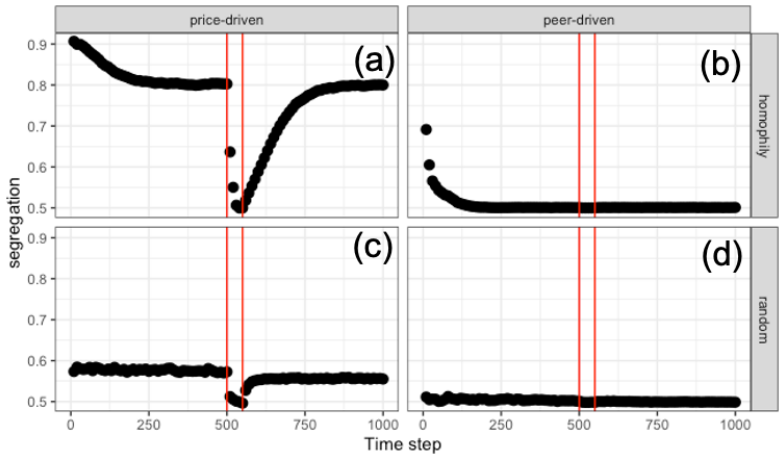


Figure 5. Social segregation dynamics through economic shocks The principles of cultural choice influence the power of disturbance on elite culture availability to reorganize the social structure. Under the price-driven cultural choice condition, a change in the availability of elite goods causes a temporal increase in social mixing that last for more than 8 times of the stimulus time. When the cultural choice is peer-driven, the disturbance does not cause a change to the social structure (All values are averaged across 50 runs).

Why does this structural change happen in conditions with price-driven cultural consumption?

To answer this question, we look into the cultural choice dynamics during the price changes separately among rich agents (Figure 6) and poor agents (Supporting Figure 6). We observe that

the ratio of rich agents choosing pop culture has a similar pattern as the dynamics of social segregation in the corresponding conditions. This similar pattern, along with the economic limitation on poor agents' choices, allows us to provide a possible explanation for the observed structural change. First, the decreased cost of elite culture leads to a consumption shift among poor agents in all conditions because elite culture is preferred in the model even when it has the same cost as pop culture. Rich agents instead continue their consumption pattern because they are free from economic limitations. This consumption shift among poor agents increased their probability of affiliating with rich agents in high-homophily conditions. After the price recovers, poor agents can no longer afford elite culture, so they switch back to the pop culture consumption pattern. Will their tie with rich agents be maintained? In a dominantly peer-driven society, poor agents cannot afford to choose what their rich friends choose, and their ties with those rich friends will be dropped in a homophily-driven society. The network structure will bounce back to normal. However, in price-driven conditions, rich agents don't originally have much chance to be connected to poor agents and be exposed to pop culture before the price decreases. The price change provides them with a chance to be connected to the poor agents. After the price recovers, although most of the rich agents will keep pursuing elite culture and form connections with rich agents only, a small number of them (by the small probability of peer-driven principles) will use the poor connection they never had before to choose pop culture and maintain their connections.

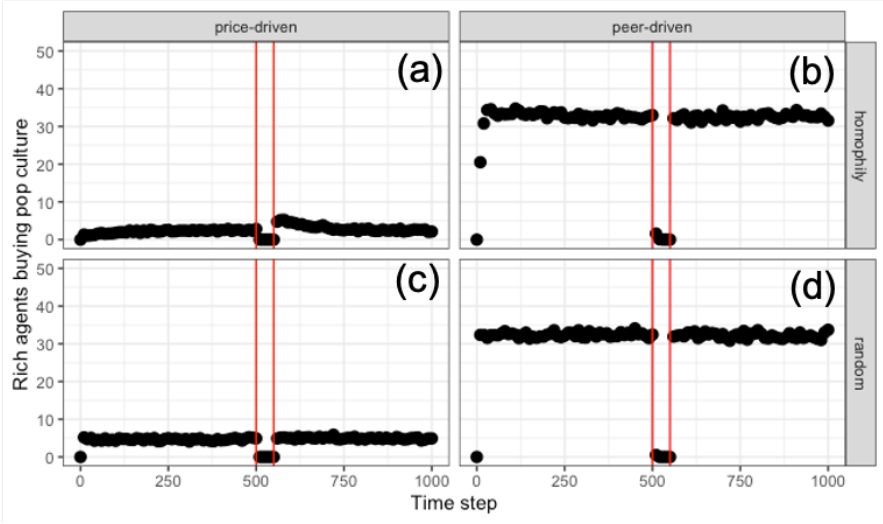


Figure 6. Percentage of rich agents choosing pop culture The lasting effect in panel a of Figure 5 is mostly caused by rich agents starting to switch to pop culture once the social segregation is broken by mass production and price change. After the shock, rich agents are affiliated with poor agents that buy elite culture, which keeps influencing their cultural choice even after the price recovers. (All values are averaged across 50 runs.)

2.4.4 Robustness hecks

We compare the direct and lasting effects of the disturbance on social segregation across different setting parameters (See Table 1) and found that the effects of the disturbance are robust against changes in cultural consumption and affiliation principles (See Supporting Figure 7) and income and cost ratio (See Supporting Figure 8). We also test the results against a different benchmark network, preferential attachment null model (See Supporting Figure 9). The results during the decrease are identical to effects in conditions with random network as the benchmark network. However, the effects after the recover does not show the same pattern as the random network, indicating that the null network model may have an influence on the overall segregation structure.

2.5 Discussion

2.5.1 Findings

When can shifts in individuals' cultural consumption lead to structural changes in network segregation? Through an agent-based model, we found that the increase in access to elite cultural products can lead to social reorganization in particular social contexts where the price of cultural products drives cultural choices and homophily characterizes the formation of social ties. Specifically, the disturbance of lowered costs to accessing elite culture reduces the social segregation between agents with different incomes. This effect on the network structure is stronger but decays faster in conditions with higher homophily, while weaker but lasts longer in conditions with lower homophily. The duration of the disturbance effect on network structure is not influenced by the duration of the disturbance.

The model's reactions to the disturbance in elite cultural choice and elite degree centrality at boundary conditions demonstrate that the disturbance influences the network structure through homophily, while cultural choice principles alter the resilience of the network structure. The consumption patterns of the rich and poor populations around this disturbance further explain the transient effect on network structure in particular conditions. The decrease in elite culture cost provides a chance for poor agents to pursue elite culture in conditions where cultural consumption is price-driven. With elite culture, the poor agents will be able to form ties with rich agents when tie formation is driven by homophily. At the same time, when homophily is too high, poor agents will lose connections with rich agents faster when they cannot afford elite culture anymore. Additionally, we found this structural effect robust to the income ratio and cost ratio, but not the benchmark network process.

By exploring the different possible combinations of cultural choice and social affiliation principles, we found that preference for elite culture increases with price-driven principles. This difference in collective cultural choice patterns between price-driven and peer-driven conditions is less prominent in low-homophily conditions (RQ1). At the same time, social segregation is higher in conditions with higher homophily and conditions where cultural choices are price-driven (RQ2). The results of RQ1 and RQ2 constitute the explanation for each other, that is, social structure and cultural choices are more easily reinforced through the homophily in price-driven conditions, because agents' economic conditions in the model are more stable than their social groups.

2.5.2 Connections to Microeconomics Theories

The model has a close connection to microeconomics theories, including conspicuous consumption and fads. Conspicuous consumption describes the behavior that consumers will purchase or use goods of a higher quality or in greater quantity than might be considered necessary (Veblen, 2005). Conspicuous consumption is a way of signaling one's economic status. We considered the same motivation and assumptions of conspicuous consumption as theoretical support in modeling agents' behaviors, but we also constrain the possibility of continuous conspicuous consumption in our model.

First, Veblen's theory has a deep theoretical connection to Bourdieu's theory of habitus and distinctions (Trigg, 2001). To make conspicuous consumption, an individual has to have knowledge about the prestige conveyed in the cultural product and have an audience to signal this prestige to. At the same time, the individual has to be able to afford the expensive product with prestige. To create this possible theoretical space in our model, two parameter conditions should be satisfied: (1) Homophily cannot be at the boundary condition. In this case, a poor agent has a

higher-than-zero probability of having connections with rich friends, which ensures that a poor agent can get information about what elite fashion is to pursue elite fashion; (2) A poor agent can afford to consume elite fashion. In our model, poor agents' endowment at each step is not enough to buy elite culture products. At the same time, although the model allows agents to save, it does not motivate agents to save for continuous conspicuous behavior. An agent's ability to consume elite culture is thus constrained by their fixed endowment. In this way, our model constrains the possibility for continuous conspicuous behavior.

However, we consider conspicuous behavior key theoretical support in modeling agents' behavior after the shock. Conspicuous consumption theory mounts to a prediction that individuals with increased spending power will emulate the consumption patterns of those at higher positions in the social hierarchy; thus, we build in our model the assumption that poor agents would pursue elite culture after the shock.

Fad refers to a product that is popular for a time and then unpopular (Aguirre et al., 1988). Our model also demonstrates the possibility that when an elite cultural product is more accessible to everyone, everyone seems to switch to the initially elite culture. And then, when the elite culture cost recovers or a new elite fashion trend is created, poor agents stop buying the elite culture in most social situations in the model. In this case, the shock does create a fad.

Our model does not explain the mechanism for the shock; in other words, we do not attempt to explain fad but demonstrate one possibility that fad might be a result of the shock on elite culture and conspicuous consumption.

In general, this model is designed in a simplistic manner to incorporate several social science theories driven by similar causes. The simplicity of the model also allows for extension to

explain specific microeconomics phenomena. Admittedly, the model touches upon microeconomic theories, including conspicuous consumption and fads, but it goes one step further in exploring how different types of social connections (at various levels of homophily) might change the consumption behaviors addressed in those theories.

2.5.3 Contribution to communication theory and empirical research

Communication theories have a long tradition of explaining how mass media and interpersonal communication shape cultural preferences and cultural identity. At the same time, recent development in social network analysis provides rich implications for how people make social connections (Welles et al., 2014). These two areas are deeply linked, and their interaction offers a cultural approach to explaining the dynamics of social processes. Our model advances this approach by specifying this interaction through agent-based modeling and demonstrating how network segregation structures emerge from individuals' cultural choices and social affiliations in different contexts. The flexibility of our model demonstrates interesting grey zones among the classical positions taken at the time of Marx (1964) and Bourdieu (1984). Here we illustrate three examples to demonstrate how this model can inform a diverse set of empirical research questions, including the cultural markets of social media, the digital divide, and the split between social media information and established news outlets.

Example application 1: Social Network on the Internet

Such a flexible model is especially important today, as the Internet and today's increasing economic inequality transform how people make cultural choices and social connections. First, social media allows people to bridge the elite-popular gap with much more ease than before. Second, the Internet grants free access to multiple cultural products, some of them with much value. For example, music service provider including Spotify offers users not only both music

streaming services and opportunities to connect with other users through collaborative playlists, following, and recommendation (Park et al., 2019). The premium version of Spotify provides the same social functions as the paid version, but some music may be unavailable in the free version (Spotify, 2021). Thus, free version users may not be able to express their music preferences as well as premium users due to the lack of certain functions. For example, free users do not have access to some music they like, and they cannot select to play the one song they like without shuffling through other songs. Although they can create a playlist to shuffle play their preferred music, they will still be interrupted by frequent advertisements. These less pleasant experiences reduce their motivations and ability to connect to premium users by common music preference. The model may require specific extensions (e.g., users' ability to express their music tastes) to simulate the connecting mechanisms on Spotify. Nevertheless, this network mechanism creates a similar condition in a price-driven condition in our model, which provides predictions for the collective patterns of cultural choices and social networks and predictions on the influence of a free trial of the premium version on the user music choices, generating new theories for empirical research on user preferences.

This model allows us to explore the theory in various social contexts and exogenous disturbances. We use two more examples to illustrate the implications of this model in a broader communication context.

Example application 2: Digital divide

For example, one of the most frequently discussed phenomena in current communication research is the digital divide. The digital divide refers to the issue of technology and information as limited resources unevenly distributed among distinct social groups (Loges & Jung, 2001; Helsper, 2017). People choose and consume information and technology based on their living

environment, including economic capacity and their peers' choices (Norris, 2001). At the same time, people with digital access also shape the digital environment, possibly making access even harder for those without it. How to reduce the digital divide has been a critical question in contemporary communication research (van Dijk, 2020). The structural effects produced by the disturbance of elite culture availability in our model suggest a potential approach to this question. The result predicts that in environments with homophily as the affiliation principles and cultural price as the consumption principles, even a temporary price decrease or easier access to information and technology (offered by technological innovation or policy intervention) may cause a temporary structural change to the digital divide. In high homophily conditions, the temporary changes can be strong enough to change the social network structure drastically but decay fast. Thus, we may need a timely and short-term policy in a high homophily society to create social changes within this short window, whereas in a moderately lower homophily condition, the structural change may not be as strong but lasts longer, which creates space for a long-term policy to have a better performance.

Example application3: News consumption

Another area of application has become relevant, given the importance of misinformation and 'fake news.' Social media has become an important source of news, which is free and low-brow, but also often of questionable quality, while higher-quality news from newspaper outlets usually requires a subscription (high-brow). Some people can afford an annual subscription to high-quality news outlets at over 100 dollars, whereas some people don’t have that budget for news and tend to read news from social media and other free outlets. Audiences who are exposed more to social media news are likely to agree with each other comparing to those that are exposed to newspaper outlets due to the similar agenda, perspective, and logic. Similarly, those who are

exposed more to newspaper outlets may tend to agree with each other comparing to social media users. This segregation may lead to a different type of echo chamber caused by media channels other than political affiliations.

Furthermore, the cost of elite culture in the model can be interpreted as resources other than money, including attention, time, and literacy. One example that captures the influence of the cost difference in attention, time, and literacy is news sharing. Communication theories and research pointed out that serious news that contains detailed information, credible sources, and a complete logic frame requires more cognitive resources (Sterrett et al., 2019), time (DeAngelo & Yegiyan, 2019), and literacy (Tully et al., 2020) to process compared to the news with brief content, shocking titles, and social gossip. On the other hand, people are more likely to connect with those who share similar types of news due to selective exposure to reinforce their preference (Messing & Westwood, 2014).

The model contributes to understanding this problem by identifying two main factors in news consumption: The cost of news consumption (cultural cost) and the social function of news consumption to connect with others (affiliation principle). The model predicts that when people are more willing to talk to audiences of similar news outlets (high homophily), the gap between the audience of free social media news and those of high-quality news from credible sources will be reinforced and widened.

The solution provided by the model suggests that when people choose news outlets mostly in consideration of economic or cognitive cost, we can apply a short shock to the high-quality news by either reducing the economic cost (e.g., publishing a few free news articles every month on social media) or reducing the cognitive cost (e.g., publish more news photos or shorter summaries

of investigative news) to temporarily reduce the segregation between different audiences and create windows for information exchange between them.

2.5.4 Future work

Other important questions can be addressed in future investigations using this model. For example, we can consider how a different income distribution would influence cultural choice and network structure. Our model provides equal proportions of rich and poor groups to focus attention away from the established subject of wealth inequality and instead toward neglected issues of cultural consumption. Our result suggests that cultural forces should be able to amplify the perception of wealth inequality well beyond their actual level in two ways. First, although we implement an equal number of rich and poor populations, in most conditions, less than half of the agents choose elite culture. As agents can only tell if other agents consume elite or pop culture rather than their actual wealth, agents may perceive the proportion of the rich lower than the actual level. Second, the segregation between rich agents and poor agents can create a perceived distinction in cultural tastes and social positions, which amplifies the actual difference between the rich and poor and impedes social mobility. Based on this result, it is reasonable to use our model setup to investigate how income distribution and other social group statuses may influence cultural consumption and network structure.

Another interesting question that can be explored in future studies is how the duration of disturbance may cause further changes in network dynamics. In this model, we focus on how a short-term disturbance may lead to long-term transient effects on the network structure, but in real-world settings, long-term cultural shifts do happen from time to time and it may lead to some permanent structural changes to the social network structure. This is because a long-term cultural shift may also influence cultural choice and affiliation choice principles and norms. How the

duration of the disturbance interacts with the model parameters and network dynamics is a meaningful question, especially when there is cultural resistance to environmental changes or when the disturbance emerges from bottom-up individual practices.

Additionally, the model presents an opportunity to investigate the social network structure's permeability and raises more questions about the role of individual agency. Future extensions can focus on whether and how individual agency can influence the programmed network structure through learning and aspiration towards particular social positions.

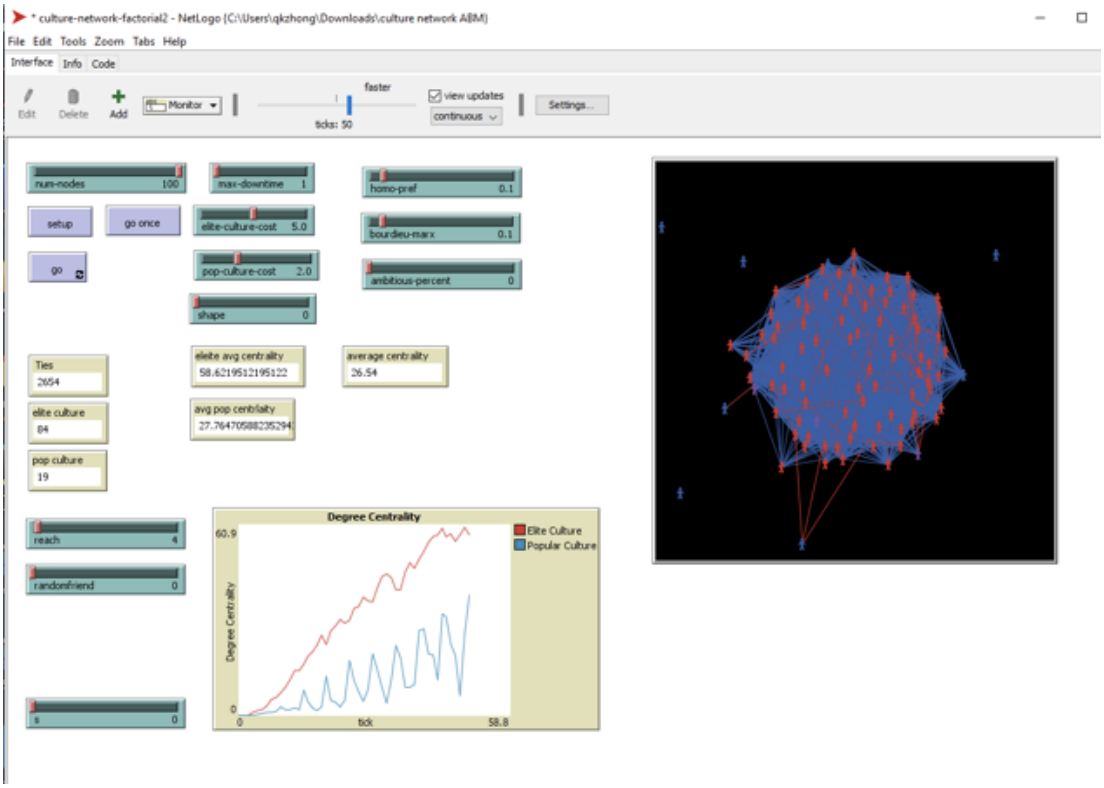
Finally, it is crucial to find empirical examples to test the theoretical claim of this paper. Online venues with both social network services and cultural references (e.g., Spotify, Salo et al., 2013; Goodreads, Worrall, 2019; YouTube, Hussain et al., 2018, etc.) can be useful resources to validate the model.

2.6 Conclusion

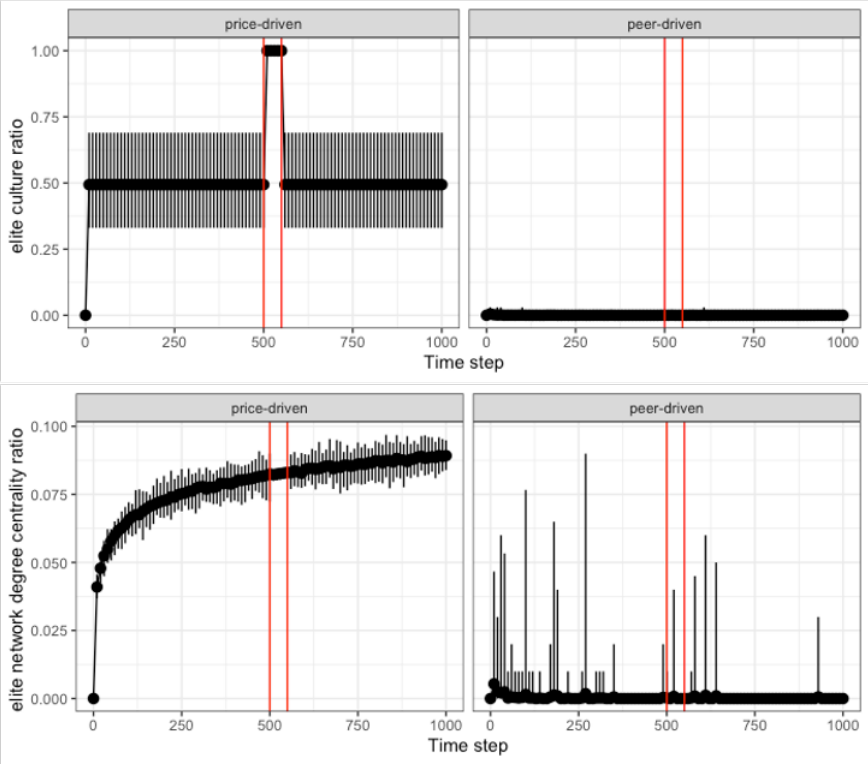
Individuals' cultural choices and social connections are deeply connected and together influence the formation of the network structure. This interaction between agency and structure has been a constant interest in social science. This paper used agent-based modeling to bridge the two in the context of one theoretical framework. Within this framework, we explored flexible approaches to examining culture and social network structure. We found that temporary shifts in cultural consumption can lead to transient changes in the social network structure at different decay rates by homophily level. Our result suggests a possible approach to social reorganization, even under fixed income and social group composition. Lastly, our model highlights the advancement of ABM in social science, allowing us to explore the space between positions set forth by existing social theories and to address individuals' agency under the restriction of social network structure.

In the final discussion, we find a myriad of applications and empirical studies that can be informed by our theoretical setup.

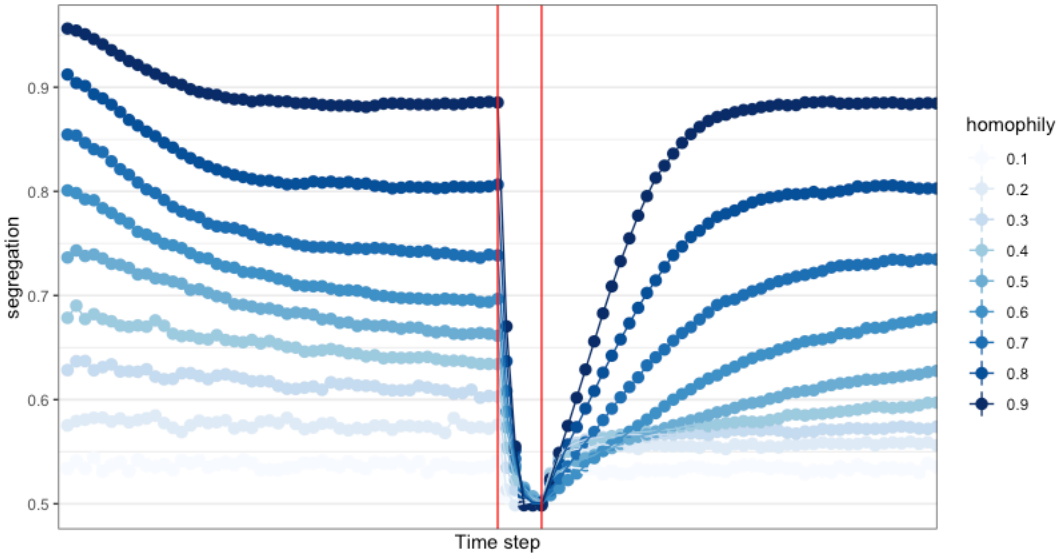
Supplements



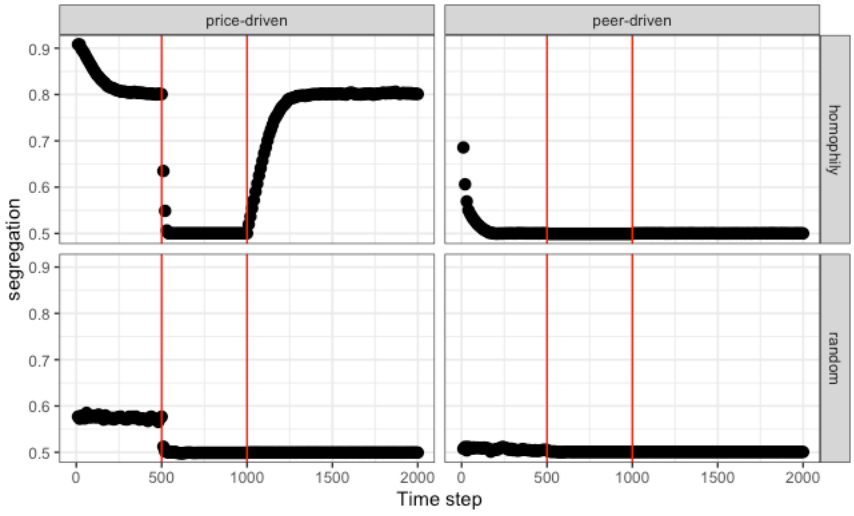
Supporting Figure 1. Model interface from Netlogo The Netlogo interface includes all variables in the model, a visual network monitor and a real-time degree centrality monitor. In this figure, the network monitor displays the agent network in one run around step 58.



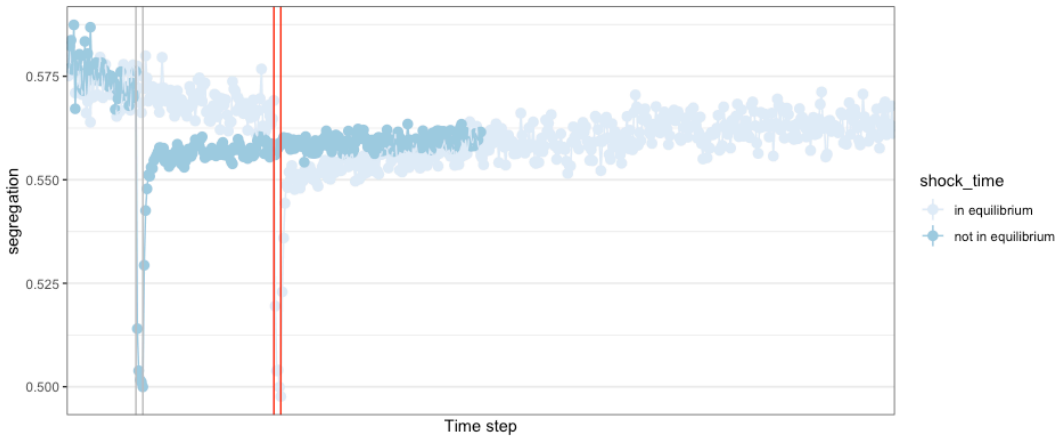
Supporting Figure 2. Elite culture ratio and elite network degree centrality response to shock under fully random affiliation principle with different consumption principle After the elite culture price decreased, all poor agents switch to elite culture. Similarly, after the price recovers poor agents return to their previous consumption patterns. Poor agents pattern alone cannot explain the changes in network we observed in Figure 5.



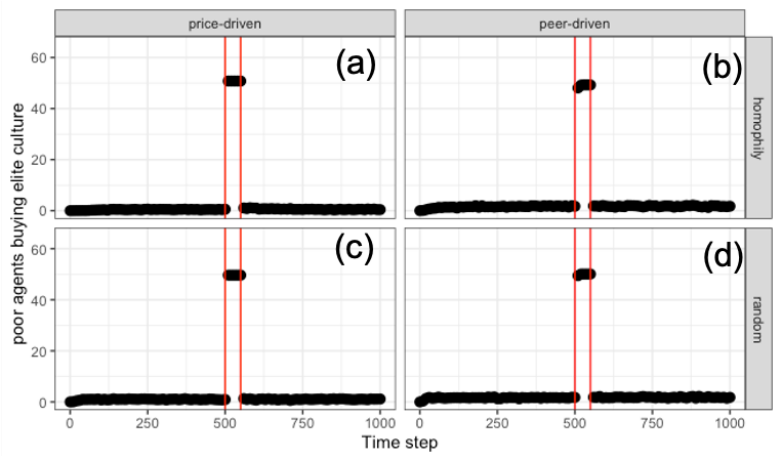
Supporting Figure 3. The reaction of network segregation structure to the disturbance in price-driven conditions are consistent at different homophily level.



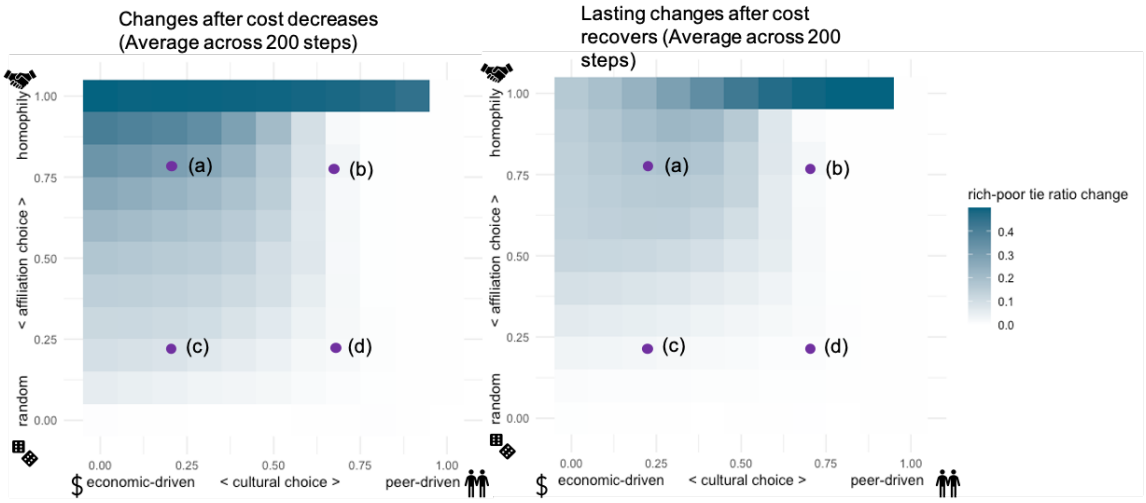
Supporting Figure 4. Segregation dynamics with a long-time disturbance The segregation dynamics with a long-time disturbance (*t = 500*) on elite-culture cost resembles the pattern of the network segregation under a short-time disturbance. The seemingly changed equilibrium in the bottom left panel is explained by the same reason in a short-disturbance condition—the disturbance happens long before the equilibrium and thus advances the equilibrium.



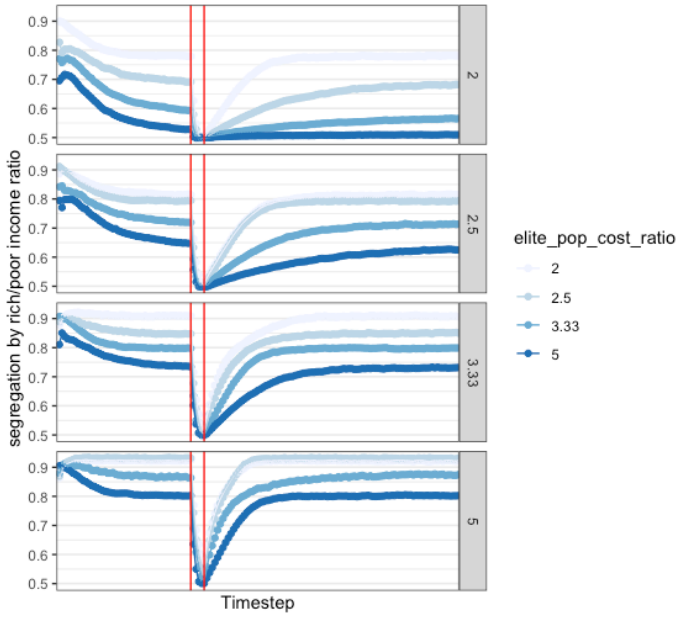
Supporting Figure 5. Comparison between response to shock in equilibrium and not in equilibrium The seemingly moved equilibrium in panel (c) is due to the shock happens when the system is not in equilibrium yet. The disturbance maximizes the social mixing and advances the equilibrium state. We then apply a shock at timestep 1500 for 50 timesteps and found that the network segregation comes back to the initial level after 2620 timestep.



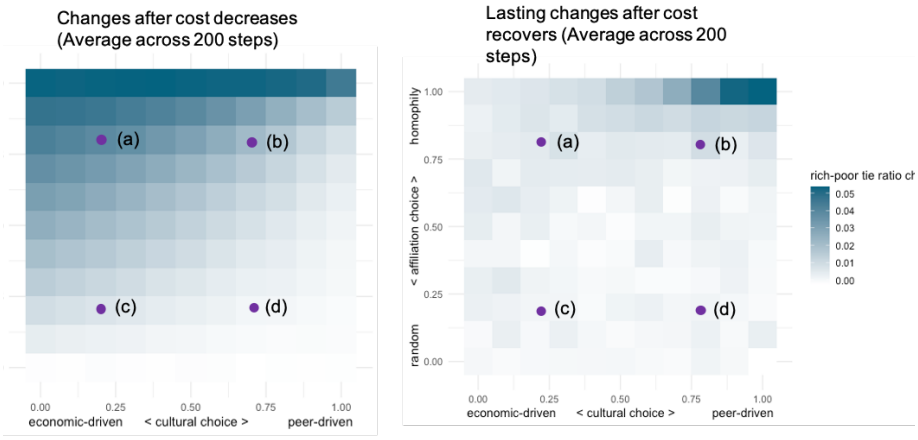
Supporting Figure 6. Poor agents' cultural choice patterns before and after the price change do not vary across conditions After the elite culture price decreases, all poor agents switch to elite culture. Similarly, after the price recovers poor agents return to their previous consumption patterns. Poor agent patterns alone cannot explain the structural change we observed in Figure 5.



Supporting Figure 7. The effect is robust to changes in cultural consumption principles and affiliation choices We mark here the four conditions (a)(b)(c)(d)presented in Figure 5 to provide a more complete comparison across the 10 X 10 conditions. Consistent with Figure 5, the structural effects caused by the economic shock is the most evident in the condition area around (a) where economic motivation drives cultural choices and homophily drives affiliation choices. The effects around this condition area also last after the cost recovers.



Supporting Figure 8. The structural effects are robust to different income and cost ratios The results presented in the figure show that the structural effects we observed in Figure 5 panel (a) is robust to most income ratio and cost ratio, except for the conditions where the elite culture cost is much higher than pop culture cost while the rich and poor income does not differ as much or when the rich income is much higher than the poor income while the cost ratio is low.



Supporting Figure 9. Effects of the disturbance in preferential attachment network. This figure presents the effects of the shock on social segregation during the time when the elite culture price decreases, and 200 timestep after the price recovers the null-model is a scale-free network. The results during the decrease are identical to effects in conditions with random network as the benchmark network. However, the effects after the recover does not show the same pattern as the random network, indicating that the null network model may have an influence on the overall segregation structure.

Chapter 3 Coevolution of Institution and Culture

3.1 Introduction

How communities and organizations develop depends greatly on their institutions and cultures. Culture provides community members with a group identity and behavioral guidance, while institutions constitute a set of structuring rules that constrain members' behaviors. Yet, it is difficult to disentangle the effects of institutions and cultures on a community's evolution due to their mutual effects on each other. For example, Alesina, Cozzi, and Mantovan(2012) show that various preindustrial institutions can lead to long-lasting cultural differences in people's perceptions of poverty and wealth. These differences in cultural values, in turn, influence policy choices and their effects today. Thus, to understand how institutions and cultures affect community development over time, we have to investigate the relationship between these two factors. Indeed, the importance of the relationship between institutions and culture has been widely recognized in economics (Tabellini, 2008; Bowles, 1998), sociology (DiMaggio & Powell, 1983; Freeman & Hannan, 1983; Perrow, 1967), anthropology, (Silva & Mace, 2014), political science (Putnam, 2000) and communication (Cheney, 1983; Monge et al., 2008).

Cultural effects are typically more difficult to detect than institutional effects because "top-down" institutional changes work more directly and are easier to operationalize and observe than changes in culture. Individuals in most institutional or organizational settings do not have any power over those institutions, making it more difficult for their cultural preferences to directly influence institutional development. However, there is one domain in which the tangled relationship between culture and institutions is more direct, observable, and mutual: online communities. Online communities are an ideal laboratory for understanding the mutual effects of institutions and culture for three reasons: (1) They are similar to real-world communities in that

institutions directly regulate community members' behaviors, and members can internalize the rules into their cultural values and preferences (Bowles, 1998; Elias, 1994; Foucault, 1995; Fouka, 2020); (2) They are different from real-world communities in that members of online worlds can choose to migrate between communities at low cost, offering them more bargaining power over institutional structure. Community members can then select against or directly shape the institution's development towards their own cultural values and preferences. (3) Users who self-select into the same communities share a sense of identity and preferences that form the community group culture, making it possible to infer similar cultural preferences from communities that share overlapping group membership. This observable pattern provides a unique lens into the effects of culture on a community's formal rules.

3.1.1 Player traffic between customized self-governing Minecraft servers

The video game Minecraft provides a useful context for discussing the relationship between subcommunities and their rules. Minecraft is a massive multiplayer online game that allows for various autonomous user activities, including building with blocks, exploring a virtual world, gathering resources, exchanging goods, and engaging in game combat. Importantly, in Minecraft, users can establish and manage their own private servers for playing the game. These servers function both as spaces other users can explore and communities that users can engage with (Frey & Sumner, 2019). Someone who sets up a server, the system administrator, takes the responsibility of governing it. To achieve success at building a community of players around their server, administrators have to recruit and retain repeat visitors who can and do migrate between servers at a low cost. Administrators also face constraints in physical resources (e.g., RAM, CPU, bandwidth, monthly server fees) and virtual resources (e.g., software-based currency, reputation systems), all of which must be carefully managed to provide the membership with a quality game

experience. Minecraft has been used in science for education(Bar-El & E. Ringland, 2020; Bourdeau et al., 2021), design(Al-Washmi et al., 2014; Salge et al., 2018), and the study of self-governance(Frey et al., 2022; Frey & Sumner, 2019).

3.1.2 Rules in Minecraft

In the Minecraft ecosystem, administrators who run private servers rely on custom software-based governance institutions to manage limited resources, solve collective action problems, and eventually maintain a corps of quality community members. These software "plugins" are modular programs that administrators can install on their servers to automatically implement rules and other political-economic constructs. Plugins can allow for certain behaviors or activities, or improve the experience of them. For example, "factions" is a plugin that allows administrators to socially subdivide their community. Others prohibit abusable behaviors or make it easier to administer punishments for rule violations (e.g., the "AntiCheat" plugin prohibits cheating behavior in the game, while "Combatlog" is used to punish unwelcome aggression. By "mixing and matching" plugins and fine-tuning their settings, server administrators craft highly customized formal institutions and implement a social structure that can solve problems and achieve governing goals. In Minecraft's setting, players can switch between servers at a low cost, which leads to fierce competition between servers. To recruit and retain members, administrators have to implement plugins that benefit players' experience.

So far, the Minecraft community has developed almost 20,000 plugins. To assist administrators in selecting and using the plugins effectively, the software requires plugin developers to assign each plugin to at least one pre-specified category. As of 2016, when our data collection ended, the Minecraft developer community listed 16 types of plugins administrators

could use to implement rules[1]. Among those, Frey and Sumner (2019) identified four types that directly related to governance: top-down administration, communication, economy, and information.

Plugins in the administration category allow administrators to execute additional control over server states and player behavior toward preventing or remediating problem behaviors among the games anonymous and young users. Plugins like WorldGuard permit the administrator to manage vandalism by rolling parts of the world back to prior snapshots, while GroupManager and Nations help administrators distribute administrative burdens over a hierarchy of "moderator" users with elevated rights. Plugins in the communication category facilitate interpersonal communication by providing additional or higher bandwidth channels for peer-to-peer communication. For example, the popular "Dynmap" plugin renders a dynamic web-based map of the entire world that players use to coordinate their actions and find each other. Informational plugins provide more channels for broadcasting messages and regulations to the community. For example, the "AutoMessage" plugin makes it easier for administrators to send specific contextual information to users automatically in response to environmental triggers, while "LogBlock" helps players resolve conflicts on their own by encoding by making publicly accessible all prior changes to all locations of the world. In contrast to the peer-to-peer communication facilitated by communicative plugins, informational plugins promote top-down communication. Economy plugins protect private property rights and facilitate resource exchange. Plugins like "iConomy", "ChestShop", and "Signshop" all support market exchange, either peer-to-peer or peer-to-

[1] The plugin categories are Admin Tools, Anti-griefing Tools, Chat Related, Developer Tools, Economy, Fixes, Fun, General, Informational, Mechanics, Role Playing, Teleportation, Website Administration, World Editing and Management, World Generators, and Miscellaneous. See https://www.curseforge.com/minecraft/bukkit-plugins/world-editing-and-management.

administrator, while plugins like “Lockette” and “Townies” implement private property rights on top of Minecraft's common property default.

3.1.3 Culture and membership in Minecraft

Drawing from one element of the sociological conceptualization of culture, we understand the culture in Minecraft as a set of cultural repertoires based on shared practices and experiences, and isolate it behaviorally in terms of the server communities that players self-select into: a major part of the ecology of the game is that players can choose what community they join. A cultural repertoire is acquired through players’ experiences in different servers and interactions with other players. The communities that a user selects into thus give a sense of the range of identities that the user holds. And when many users share overlap in their range of identities, evidenced by their tendency to traffic in the same subset of servers, we infer that they share this sense of culture, operationalized here both as overlap in the set of subcultures, and frequent interaction over a set of similar communities. To be clear, we are not attempting here to define the cultural identity of users in terms of the communities they visit, nor the subculture of a community by the users who visit it: we are attempting to define a set of communities as culturally similar by the existence of a large and consistent group of users who travel together between them.

Based on our definition of Minecraft culture — repertoires of shared meaning that provide references for preference and behaviors — it is reasonable to measure the cultural similarity between servers by dual membership; servers with a high share of dual membership will share a similar cultural repertoire either because, having advertised on similar markers of identity, they attract the same types of users, or because of the knowledge and practices that their dual-membership users contribute to both group repertoires. Accordingly, servers with a low share of

dual membership are less likely to share a similar group repertoire because their members are less likely to have similar identities or experiences in Minecraft.

Given the close connection between shared membership and server culture similarities, two claims become apparent. On one hand, shared membership can lead to institutional similarities. First, shared membership facilitates information transmission in institutional isomorphism, which refers to a process that drives one organization to resemble others in the same environmental condition (DiMaggio & Powell, 1983). DiMaggio and Powell (1983) provide one explanation for the institutional isomorphism in Minecraft, that is, the uncertainty and risk in the organizational environment drive the communities to mimic the institutions of each other. Second, shared membership can influence institutional development through user preferences. Server success is almost solely dependent on recruiting and retaining repeat visitors, so users indeed have the bargaining power to negotiate with administrators about institutional decisions. Through this kind of mechanism, users' preferences can possibly influence institutional development. Thus,

H1: Shared membership between Minecraft servers causes them to become more institutionally similar.

On the other hand, Institutional similarity can drive shared membership. Individuals' behavioral and cultural preferences in Minecraft are cultivated and internalized through institutions. When individuals internalize an institutional logic, they may self-select to the institutions close to their previous institutional experience in Minecraft. First, individuals who learned certain behaviors in their first Minecraft community might suffer social costs in institutions that do not reward those sets of behaviors. Compared to learning new behaviors and preferences in a different environment, choosing a similar enough environment provides lower learning cost and a higher average payoff. Second, individuals may normalize institutional logic and

enforcement, resulting in cultural persistence (Abdelgadir & Fouka, 2020). Although cultural persistence may also happen in Minecraft, given the low cost of migration between Minecraft communities, it is more likely that individuals will migrate to communities that provide similar institutional experiences. Thus,

H2: Institutional similarity between Minecraft servers causes them to exhibit more shared membership.

Although they are phrased in a way that may sound mutually exclusive, our method, grounded in network dynamics and dynamical systems, permits an approach under which both or neither may be true simultaneously, as in the case that institutional similarity and shared membership are mutually constitutive.

3.2 Method

3.2.1 Data

We analyze longitudinal data of user visits and rule changes between week 5 and week 22 in 2016 among 1097 Minecraft servers. Full details of our data processing and analysis are available in the supplementary text.

3.2.2 Method and Analysis

To quantitatively pose our questions about mutual influence, which is dynamic and involves several types of relationships between many communities, we resorted to a recent network analysis approach, the dynamical multiplex spillover method (Vijayaraghavan et al., 2015). We use dynamical multiplex spillover to represent governance similarity relationships and membership similarity relationships as different networks over the same nodes ("multiplex") and quantify the effects of link additions and deletions in one network on the corresponding links in

the other ("dynamical"), relative to a theoretical null model that estimates baseline probabilities of links appearing and disappearing. Multiplex networks provide a way of representing a system when nodes can be linked by links with different meanings. For example, Szell, Lambiotte, and Thurner (2010) take a multiplex approach to link entities in terms of ties denoting several different kinds of relations, including friendship, enmity, and economic partnership.

The dynamical multiplex spillover is well suited to exploring the causal pathways between (1) cultural similarities between servers, measured by *shared membership*, and (2) institutional similarities between servers, measured by *shared server rules*, servers' similarities in their extent of use of each institutional plugin type. Under this method, if links representing, for example, governance similarity show significant changes after a change in their membership links, that would constitute evidence in support of the hypothesis that cultural factors drive institutional factors. Of course, dynamical multiplex spillover models do not offer experiment-quality causal inference. But their use of change over time in combination with a well-formulated null model of change puts them above, for example, a design based on a simple pre/post comparison.

Using longitudinal data on shared membership traffic and servers' rules, we first constructed a network of five layers (*Figure 1.*), combining *shared membership network* dynamics with four kinds of *server rule network*, corresponding to each of the four types of governance institution: administrator-focused mechanisms, chat mechanisms, information distribution mechanisms, and economic mechanisms. In our network, nodes signify servers, whereas links can have different meanings depending on what layer they are in. By analyzing the network processes both within and across layers in the multiplex, it becomes possible to use social network statistics to represent the idea that cultural and institutional processes interact.

We construct the shared membership traffic measure by calculating the number of users who visit two or more servers within the same month. Constrained by our statistical approach, which cannot leverage continuous link weights, we dichotomize the shared membership traffic by a median split (Borgatti & Quintane, 2018). The users with shared server membership bring to both servers their experiences and practice, which weighs in the creation and development group cultural repertoires in both servers. Therefore, servers with a high share of mutual visitors should be more similar in culture, compared to those with a low share of mutual visitors. At the same time, we use server rules to measure shared server rules. A server's relative preferences for rules in different categories provide a proxy for its style of governance. The dynamics of rule establishment, including increasing or decreasing the number of rules of each type, proxies institutional development within each server. For each server, we create dummy variables for each of the four types of rules to characterize the servers as either high or low in each of the four types of rules. We determine "high" and "low" on the basis of a median split.

In the community network, the presence of a link indicates that two servers have a high number of shared members. In the rule networks, the presence of a link between two servers indicates that the two servers have implemented a similar number of rules of that type (i.e., similar numbers of administrative, informative, communicative, or economic plugins; see *Figure 1.* below).

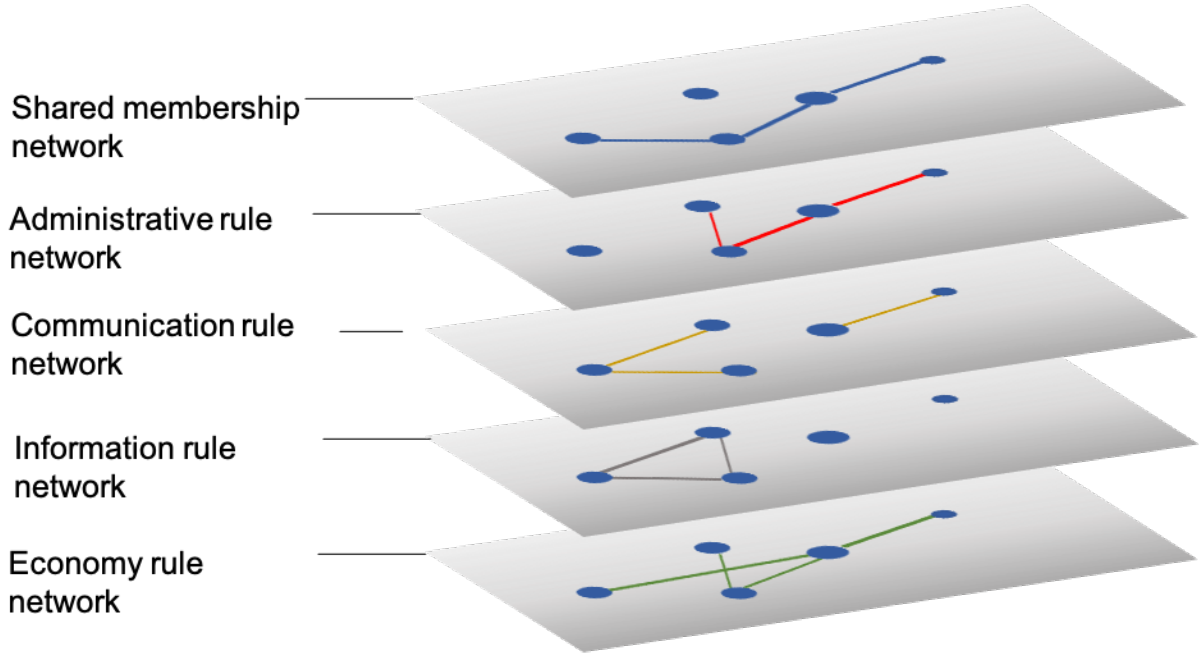


Figure. 1. A multiplex network representation of many servers' patterns of shared membership and common institutional structure. We layered the community network and four rule networks on top of each other to construct a multiplex network. The nodes in each layer, which signify the servers, are the same, whereas the relations in different network layers have different meanings. We consider servers to be culturally similar if they attract the same type of user. If the deletion or formation of links in, for example, the shared membership network influences the deletion or formation of links in a rule network, above baseline, then there is evidence that culture affects institutions, rather than the other way around. The position of the networks in the figure does not indicate the order of layers in the multiplex. Relational effects might occur between any of the two layers in the multiplex, but we focus on only four comparisons, those of the shared membership network with each type of rule network.

If culture and institution have no effect on each other, the dynamics of link appearance and disappearance in the five-layer multiplex network should be indistinguishable from the link dynamics of the five networks considered independently. On the other hand, if rules have an effect on culture, or vice-versa, we should observe that when links in the rule (or shared membership) network change, links in the shared membership (or rule) network change at a different rate than that expected from two statistically independent networks. The method draws these null predictions from the statistics of Markov chains, a well-understood theoretical model of how systems change over time.

Our approach allows quite fine-grained investigations, permitting us to ask not only what kinds of changes in one elicit changes in the other, but also the strength and direction of these interrelations, whether an increase, decrease, or persistence of links at one layer is associated with an increase, decrease, or persistence of links at another layer. This approach also required differentiating between the incremental, sequential "slow-timescale" transitions and more sudden "fast-timescale" transitions. In the type of slow time-scale transition at the root of our inquiry, a pair of nodes linked at only one layer might transition to being linked at two. By contrast, in fast-timescale transition, a pair of nodes linked at neither the membership or rule layers are in the next time-step linked on both. When a dyad changes slowly from having high similarity in one layer to having high similarity in both that and the community layer, we can interpret that within one of our directional hypotheses. But when a dyad changes from being low similarity on both layers to high on both, any direction of influence between the layers is impossible to discern. Measuring both slow-timescale and fast-timescale transition gives a full picture of the co-evolution dynamics in *Minecraft*. Of course, this same flexibility meant an explosion in the number of statistical comparisons we could perform (4 types of change in shared community link (*continued presence, continued absence, appearance, disappearance,*) × 4 types of rule link change × 4 types of rule = 64 potential comparisons), a problem we use theoretical constraints and specific hypotheses to tame (*Figure 2.*).

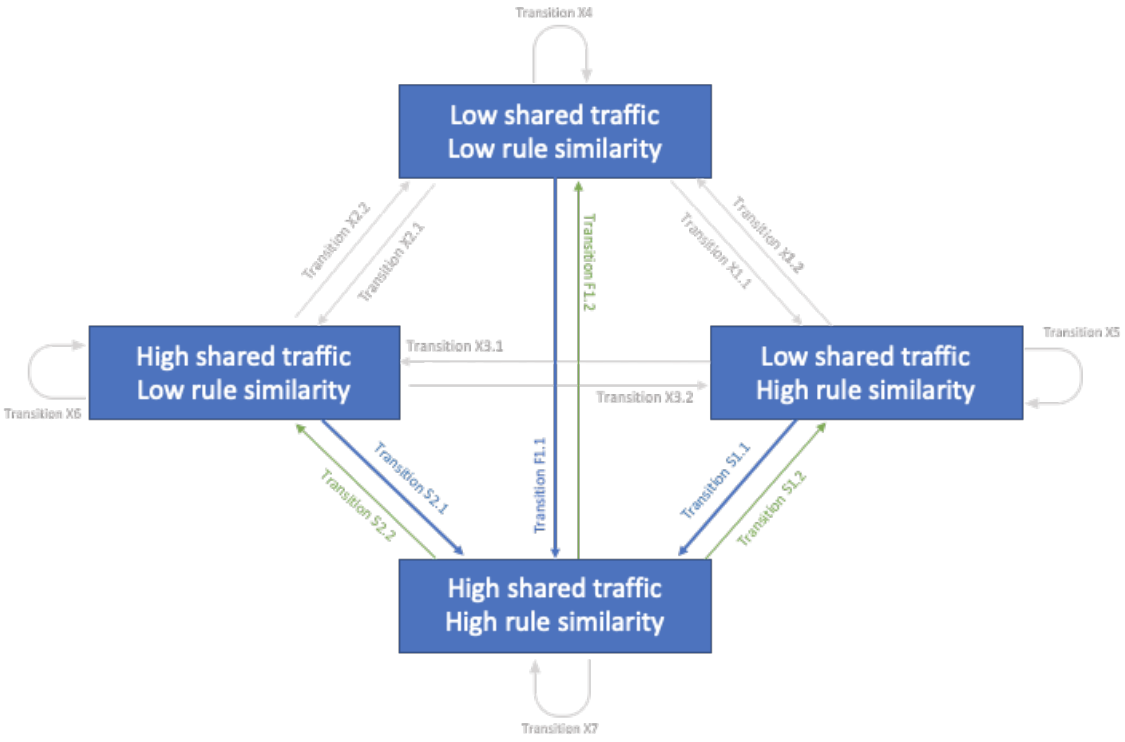


Figure 2. Dynamics of culture/institution interactions in terms of patterns of changes in the types of links that can connect two nodes We illustrate all possible transitions of interactions between shared traffic and rule similarities throughout the process of community development, which renders visible institutional processes over several timescales, and pits predictions of institutional effects on culture and cultural influence on institution. F represents fast-timescale transitions (in which the extent of shared governance and membership changed simultaneously in a month); S represents slow-timescale transitions (in which one changed before the other); X represents transitions that are irrelevant to the hypotheses.

3.3 Results

We begin by calculating the slow-timescale changes to investigate the central interest to this work: the spillover from culture to governance and governance to culture; the probability that two servers will gain in institutional similarity given that they share cultural similarity (Hypothesis 1, captured by S2.1 having a positive value in *Figure 2.*), and the probability that they will gain in cultural similarity given they already share institutional similarity (Hypothesis 2, captured by S1.1 having a positive value in *Figure 2.*). Then we also investigate the fast-timescale changes to explore the co-evolution between cultural similarity and institutional similarity.

Here we use the example of administrative rules to illustrate the interpretation of spillover coefficients. The slow timescale processes evident in other transitions (S1.1, S1.2, S2.1 and S2.2 in *Figure 2.*), in which two servers were already similar on one dimension (culture or institution) and then became similar on the other, are more amenable to directional or causal interpretation. For example, S1.1 represents two servers with high rule similarity transitioning from low shared membership at one timepoint to high shared membership at the next timepoint. This transition is significantly above its expected value ($S1.1_{diff.} = 0.146$ *[0.036, 0.256];* square brackets indicate 99% confidence interval around all statistics; See *Figure 3.*), whereas the spillover effects in S2.1, indicating the reciprocal effect of shared membership similarity on rule similarity, are not significant ($S2.1_{diff.} = 0.068$ *[–0.052, 0.188])*, indicating that cultural similarities are not strong driving factors of institutional similarities. As a corroborative test of our directional hypotheses, we also check the probability that two servers similar on both dimensions will stop being similar on one dimension (S1.2 and S2.2 in *Figure 2.*). Our hypotheses predict a decrease: that these transitions will be observed significantly *less* often than would be expected by the null model. We find servers that are similar in one dimension are less likely to stop being similar in another dimension ($S1.2_{diff.} = –0.147$ *[–0.351, 0.056]; S2.2*$_{diff.}$ *= = –0.151 [–0.275, –0.028]; Fig. S3.*).

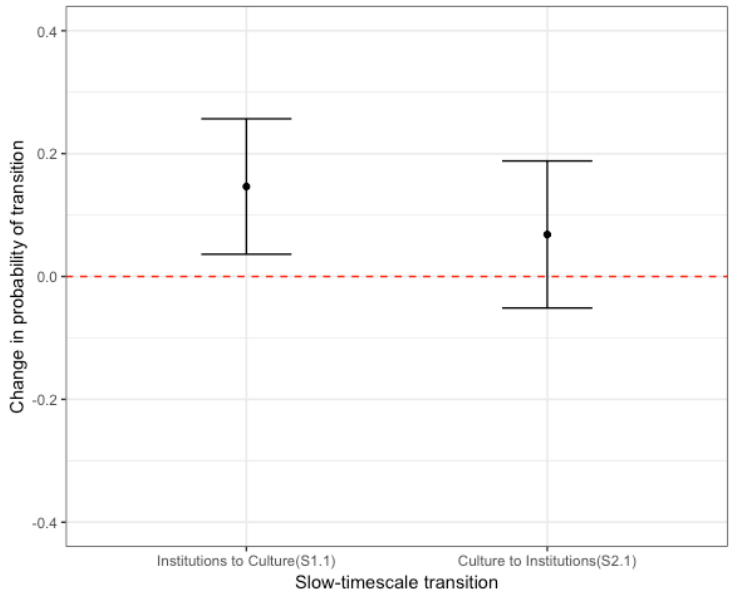


Figure 3. Institutional effects over cultural effects comparing to the other way round in the administrative rule type Among plugins that focus on administrative rule type, two communities with the same focus on administrative capacity are more likely to have shared traffic, while two communities with different degrees of reliance on this rule type are less likely to have a shared culture.

Looking at the fast-timescale co-transitions, institutional and cultural links appearing or disappearing simultaneously (F1.1), there is a general trend from low to high in both shared membership and rule similarity for two types of rules: the difference between the observed and null probability of transition F1.1 is greater than zero with at least 99% confidence for both administrative rules ($F1.1_{diff.}$= *0.0007[0.0004, 0.0010]*; see *Figure 4.*) and informative rules ($F1.1_{diff.}$ = *0.0008 [0.0005, 0.0011]*). These results are ultimately consistent with a positive feedback effect. The other two rule types were insignificant: the observed/null differences were not distinguishable from zero for economy rules ($F1.1_{diff.}$ = *0.00018 [–0.0003,0.00066]*) and communication rules ($F1.1_{diff.}$ = *0.0000003 [–0.0000005,0.0000011]*). In other words, dyads that gain cultural or institutional links tend to simultaneously gain the other types of links at a higher-than-expected rate for some types of rules.

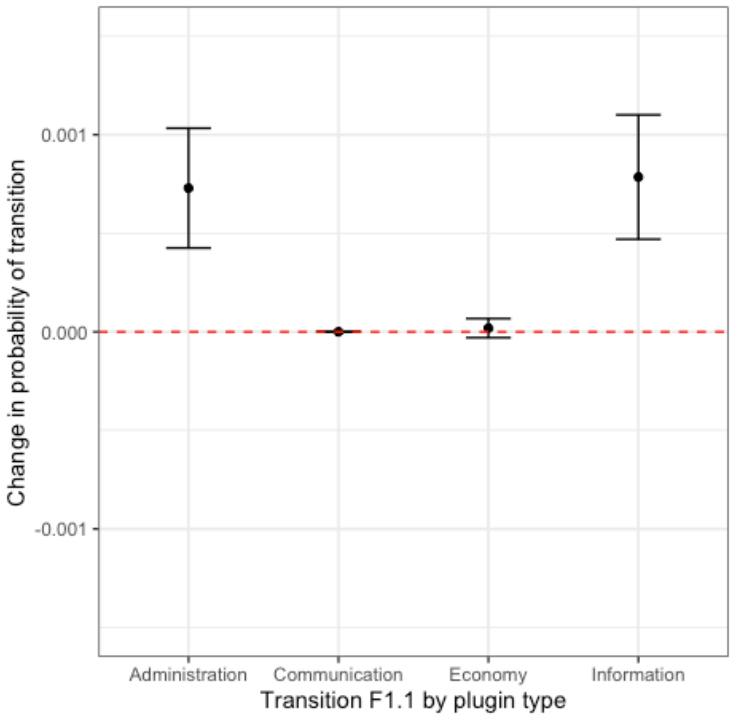


Figure 4. Evidence for correlations between similarities in cultural and institutional development Between two communities, a common trend was for an increase from communities with low similarity to high similarity in both membership and rule type, in the administrative and informational rules among the four rule types (Transition F1.1). This figure represents those link changes from Figure 2 that demonstrate the existence of "cross-layer" influence between our rule and cultural networks.

Repeating the above analysis on the other three rule types, we find the same asymmetric pattern of two servers with high rule similarity transitioning from low shared membership to high shared membership ($S1.1_{diff.} = 0.124[0.029, 0.219]$) and marginal reciprocal effects of two servers with high shared membership transitioning from low rule similarity to high rule similarity ($S2.1_{diff.} = 0.0306[–0.0479, 0.1091]$) for information-type rules. For communication- and economy-type rules, we find no effect in either direction (See *Figure. 5.*).

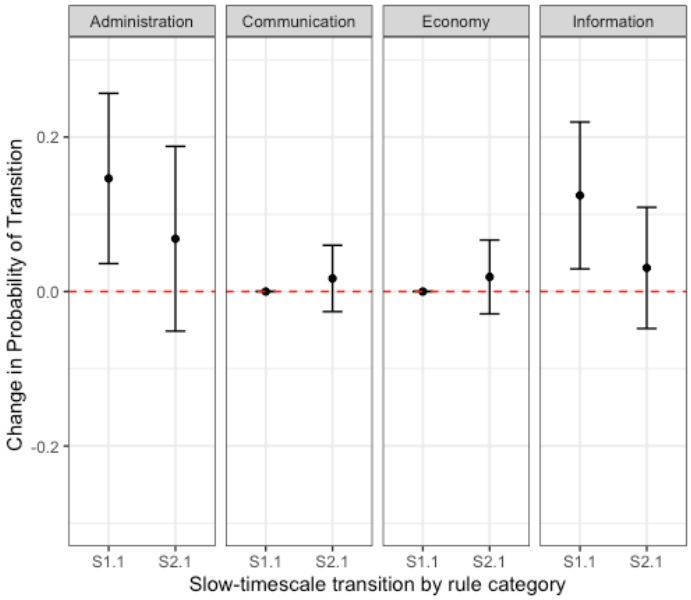


Figure 5. Institutional effects over cultural effects in the administrative and informational rule category. We test the effects between institution and culture for all four rule types, finding influence from institutional to cultural similarity (The relationship shown in Fig. 4. is repeated in the first panel to provide an aid to comparison). We produce the same effect for administrative and informational rules, but find no effect for communication or economic rules.

To summarize, these results suggest that online community's cultural and institutional dimensions are interlinked in several senses: a pair of communities that become more similar on one are significantly more likely to simultaneously become more similar on the other, and servers that are already similar in terms of governance are significantly more likely to become more similar on culture as well. All of these results hold for two rule types only: administrative and informational, with no deviations from null for any of the transitions linking economic and communication rules to the community network. Although there are many interpretations of these results, H2 is the hypothesis that is most consistent with what we observe: institutional similarities increase patterns of shared culture among *Minecraft* servers. That said, our hypotheses are not mutually exclusive, and we also find some evidence consistent with H1, namely that communities that are already similar in both governance and culture are slightly less likely than expected to become dissimilar in governance in the next time interval.

3.4 Discussion

Our results connect and contribute to institutional theories and organizational evolution literature in three ways. First of all, it provides empirical evidence for neo-institutionalists' view of environmental and ecological effects on institutional development (DiMaggio & Powell, 1983; Freeman & Hannan, 1983). The empirical findings indicate that institutional development can be due to non-functional reasons, such as shared membership with other communities. This result is then aligned with the two perspectives neo-institutionalism offers. (1) Institutional change can occur for non-functional reasons, including norms and rituals. In the Minecraft example, it is the shared membership or as we theorized, shared culture. (2) The institutional development of an organization is related to the field of organizations it operates in. In this paper, we demonstrated how the institutional development of communities can be attributed to other communities in the same exogenous environment where every community struggles for the same goals under the same pressure. The result also provides a pathway to operationalize and test DiMaggio's theory of mimetic isomorphism. Although in this study we do not have the data or empirical evidence to reveal how institutional assimilation happens, the result of this study posits possible mechanisms of institutional isomorphism. Specifically, the effect of shared membership on institutional similarity can be understood as mutual members socially learning from each community and exchanging knowledge. Second, it offers empirical evidence for the culture-institution co-evolution literature(Monge et al., 2008; White et al., 2005), demonstrating an average positive feedback effect between culture and institutions among all communities. Third, we introduce a novel method in network science to theories in organizational studies. We address the duality of organizations as cultural groups and as system of rules by analyzing organizations as units in two layers of social networks.

Although we focus on the online community context, our results, to some extent, can be generalized to real-world communities and provide some implications. The results show stronger institutional effects on culture than the other way round, even in online settings in which individuals have more bargaining power over the institutional development (Frey & Schneider, 2021). This validates the empirical work in real-world research that supports more direct institutional effects and demonstrates that this effect is robust to changes in individuals' agency. Another real-world implication is that administrative and informational rules can be the most effective in stabilizing and internalizing norms, even in an environment with many uncertainties and changes. Admittedly, we still need to be aware of the difference in individual interactions and the emergence of culture between online and real-world contexts when generalizing to a broader context. Specifically, cultural identity and cultural resistance in the online world might not be developed to a comparable strength within just a few months due to the nature of computer-mediated communication and the fast-evolving environment.

Although this paper provided causal pathways to the relationships between institutions and culture, it still cannot make true causal inferences because it is not an experiment with random assignment. We cannot control for time-varying network-specific variables that might also influence network processes. For example, non-stationarity might affect network dynamics, which would undermine the result. Other hidden instrumental variables that correlate with changes in one layer but not with another may also alter our results.

Constraints of the method made it difficult to include in our model the effects of overall community size on shared membership. It is possible that communities with a larger size are more likely to have shared membership with others over time, which may confound the network processes.

The use of high/low splits in constructing the multiplex network can sometimes generate results that are sensitive to the choice of cutoff. It is possible that nodes near the median are more likely to be observed transitioning between the two categories. The median split is proven to minimize the bias generated from converting continuous variables to dichotomous measures.

We examined institutional development in *Minecraft* and its interaction with culture, which provides a framework for future institutional analysis and computational studies of cultural dynamics. The different effects of rule types provide an opportunity for future research to identify the effectiveness of specific rules. In this research, we found significant effects among administrative and informational rules, but no effects from communicative or economic rules. This result motivates valuable research questions, including how do different types of rules work? Who do they affect the most? One possible explanation is that administration and information rules promote a top-down centralized institution compared to communication and economics rules. Previous work on Minecraft communities found that only administrative and informational rules have positive effects on community survival and success in terms of attracting and maintaining members (Zhong et al., 2022), which might explain their distinctive spillover effects. Future research can investigate why players hold preferences toward different types of rules. The focus on different rules marks the institutional difference between *Minecraft* servers, which provides us with several dimensions to evaluate and compare the organizational institutions.

3.5 Conclusion

In this study, we support theories positing a positive feedback loop between culture and institution, finding, however, that institutions in *Minecraft* communities have stronger effects on culture than culture on institutions. Specifically, we show that communities that govern themselves with similar types of rules are more likely than expected to subsequently attract similar users. Our

approach to this challenge not only reveals interactions between culture and institutions but also shows the dynamic processes occurring over different timescales.

We highlight a fundamental advance that made it possible for us, in this work, to endogenize and interrelate governance and culture at the "micro" societal scale: the opportunity provided by large collections of online communities to track and compare thousands of similar but largely independent small-scale sovereign social systems.

Supplement A Data

We analyze longitudinal user visit data from 370,000 Minecraft servers contacted through API queries bi-hourly between Nov 2014 and Nov 2016. The scraper accessed each server for their visitors' anonymous user ID and visit times, plugins installed, and other server features. An important feature of the Minecraft ecosystem is that user IDs persist across servers, making it possible to observe a user's trajectory across many otherwise independent communities. Following Frey and Sumner (2019), we first filtered out servers that were disconnected for the duration of data collection (~220,000), those that did not survive for at least a month (~70,000), and those that did not report full governance information (~75,000). We then further refined the resulting 5,215 servers in order to create the minimum conditions for the viability of our analysis (we address the potential effects of bias due to non-random deletion of data in the Limitations). To capture network formation and evolution continuously, we selected servers that were live for over 16 weeks in a 5-month timespan. Our analysis required us to aggregate over weeks to make the month the basic temporal unit of analysis. As the median "lifespan" of a server is 9 weeks, and administrators pay for server space monthly, the timescale of a month gives a suitable level of granularity. To match the timing of visit data on each server with the timing of rule changes, we selected servers that were operating between week 5 and week 22 in 2016 and had a final corpus of 1097 online server communities. Among these servers, we identified 2,791 unique plugins in use in the four governance plugin categories: 1,310 administration plugins, 520 communication plugins, 369 economy plugins, and 735 information plugins.

Our analysis used five months of server and user dynamics, which might not seem long enough to capture the transition and learning in *Minecraft*. Within the five months, servers might be at different stages of their life. Some servers might be at a more stable state than others, whereas

some might be expanding at the time and eager to get experiences from successful neighboring servers who share members with them. Indeed, it is possible that the five months only covers certain parts of servers' life. However, the median life of *Minecraft* servers is nine weeks. Given that *Minecraft* servers evolve quickly, our assumption still holds that our data capture transitions and learning over the course of a server's life. It is also possible that the effects we observed among particular categories are due to exogenous temporal factors. Mostly, the null model we constructed already takes into account exogenous factors and produces direct correlations between different layers of networks.

Supplement B Figures

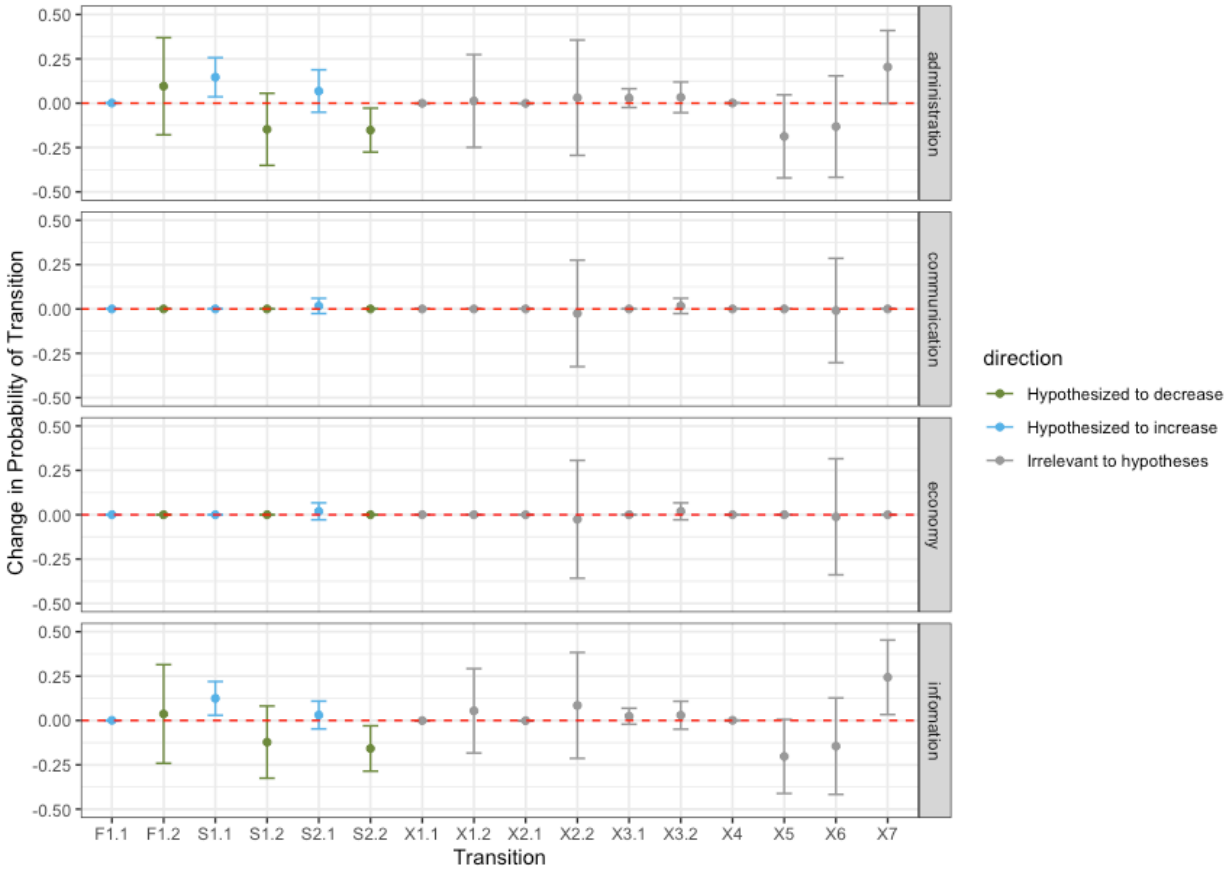


Fig. S1 All transition spillover probability within four rule categories. Across governance capabilities, we produce the effects of all transitions grouped by relevance to the hypotheses.

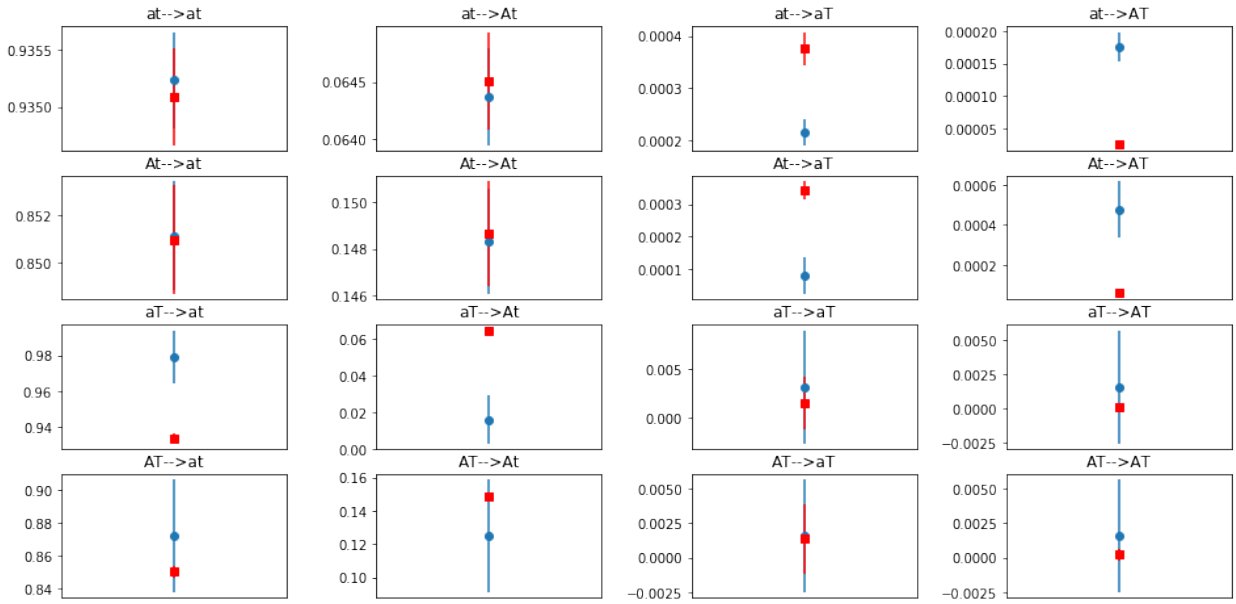


Fig. S2. Comparing mutual effects of the administrative rule network and the community network, compared to null model statistics This set of figures shows the state transition probabilities estimated for a multiplex Markov chain (blue error bar) and those of the null Markov model (red error bar), where states are the presence or absence of links across different layers of the network. This figure presents the same result as the first row of Fig. S1., the difference being that this figure shows both the null and multiplex transition probabilities, rather than their difference. We label the absence of a link with a lower-case letter. In the panel titles, lower-case a represents absent ties in administrative rule network, and lower-case t represents absent ties in community traffic network, while we indicate the presence of a link with an upper-case letter, so that A represents existing ties in administrative rule network and T existing ties in community traffic network. For example, an at → AT transition is a transition from no ties in both networks to existing ties in both. We observe a positive (negative) effect for a transition when the confidence interval around the multiplex Markov chain's estimated transition probability (blue error bar) lies entirely above (below) the confidence interval of the null (non-multiplex) Markov model's transition probability (red error bar).

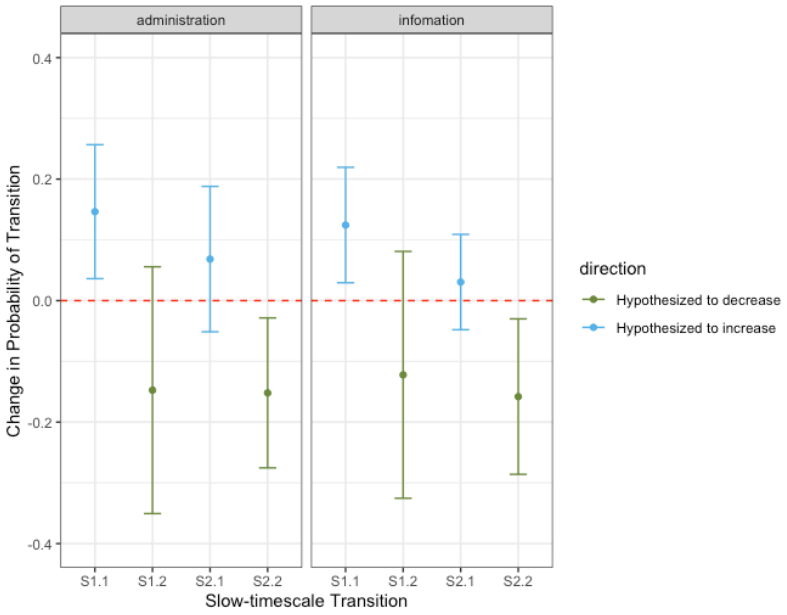


Fig. S3. For administrative and information capacities, we also produced negative effects for the opposite-direction transitions. The transition S1.2 and S 2.2 offer complementary result to S1.1 and S2.1 The positive effects in S1.1 and S2.1 indicate that servers similar in one dimension are more likely to become similar in the other dimension. Correspondingly, servers that are similar in one dimension are less likely to stop being similar in another dimension.

Chapter 4 Quantifying selective and stochastic forces in institutional evolution

4.1 Introduction

What are the main reasons that drive institutional changes in organizations? This is a central question across organizational theories. Indeed, the major reasons that lead to institutional changes can often be taxonomized by the type of answer they provide: internal stability, external pressure, information transmission, institutional isomorphism, path dependency, and so on. Some of those reasons are directly related to the payoff of implementation of the institutions, whereas some are driven by stochastic forces. While stylized facts and intuition abound in this area, we have little empirical evidence, which hinges both on the availability of adequate data and on general frameworks for comparing these sources of change and showing how they work together.

The migration of organizations to digital platforms allows researchers to obtain more adequate data, thanks to the digital footprint online organizations inevitably leave behind. Traditionally, it was very difficult to obtain statistically significant samples on comparable organizations. Lab experiments with a large N of communities are expensive and nearly impractical to run. Natural experiments cannot ensure similar enough samples to accurately infer the effects of the variable. Digital trace data on online communities make it possible to monitor the intergenerational frequency changes in the rules (Plant, 2004) because it provides fine-grained information on exactly when rules are implemented, changed, and removed among thousands of similar enough online communities

As for adequate frameworks for the quantification of the resulting dynamics, the evolutionary framework adopted by researchers in various social science disciplines, including communication (Monge & Poole, 2008; Monge et al., 2008, 2011), economics (Nelson & Winter,

1973; Nelson, 1985; Wilson & Kirman, 2016; Currie et al., 2016), and sociology (Freeman & Hannan, 1983; Padgett & Powell, 2012), provides theoretical and methodological support to answer this question. In the past few decades, social science researchers have used concepts from biological evolution as an analogy to characterize four main stages of institutional development: variation, selection, retention, and struggle (Aldrich, 1999). This framework categorizes the various institutional changes by the mechanism that drives them and provides explanations from the perspectives of both the organization and the environment. At the same time, the evolutionary framework provides adequate tools to help us represent this analogy with mathematical relationships and explain the macro-dynamics based on a few first principles in given conditions (Richerson & Boyd, 2001). With empirical data, evolutionary models allow for quantifying the strength of different drives behind institutional changes and predicting future development.

One of the most comprehensive and successful models to describe the biological evolutionary process is the Price equation (Price, 1970). The Price equation partitions total evolutionary changes into two components: deterministic changes driven by natural selection and stochastic changes driven by all other forces, including adaptation, mismatch, drift, and biased transmission. The Price Equation thus provides mathematical tools to separate selective forces and stochastic forces and reconcile different sources of change in a community (Frank, 2012a, 2012b).

At the same time, the digital trace data on online communities make it possible to monitor the intergenerational frequency changes in rules (Plant, 2004) because it provides fine-grained information on exactly when rules are implemented, changed, and removed among thousands of similar enough online communities. In this study, we take the advantage of online community data and monitor rule changes among 20,000 Minecraft communities over two years. Online platforms including Wikipedia, Reddit, and Minecraft, provide a great opportunity to study the

intergenerational changes of the modular institutional traits among thousands of small-scale communities.

Using the Price equation, we are able to quantify how much of community fitness is derived by natural selection and how much by stochastic forces that are not directly related to the success of the communities. We can also explore further in the institutional structure among online communities to ask whether evolutionary forces are different among different types of rules. For example, are rules facilitating centralized top-down communication driven by more selective forces compared to rules promoting more decentralized interpersonal communication? Are stochastic forces more prevalent in rules regulating user behavior compared to rules regulating administrative behavior?

Furthermore, is this result robust to the changes in the environment? The bet-hedging method provides us with a tool to use the information from the environment to match the frequency of rules, which produces a benchmark for the theoretically optimal strategy of rule distribution. The bet-hedging method thus allows us to ask two questions: First, is the frequency change in one type of rules caused by this rule type only, or is it also influenced by other types of rules? Second, is the optimal distribution of rules consistent with the Price equation result? If the two models produce consistent results, we can conclude that the selection and stochasticity calculated through the Price equation are robust against the changes and uncertainty in the environment; Otherwise, we expect that the environmental changes play a bigger role in the evolutionary dynamics of institutional changes.

As a result, we found that there is strong selection in the Minecraft environment that drives the frequency changes of some rules, while at the same time, drift also exists among administrative rules that reduces their frequency. At the same time, the bet-hedging result suggests that the

communities need to subsidize other types of rules to build resilience against environmental fluctuation.

4.1.1 Institutional Change

The development of institutions has been a key research aspect of organizational studies(Coase, 1998; North, 1991; Williamson, 1991). To understand why and how institutions change, social science disciplines including communication (Monge et al., 2008), sociology (Padgett & Powell, 2012), and economics (Wilson & Kirman, 2016) have adopted an evolutionary framework to understand the dynamics of institutional development. Institutions as a set of rules to constrain behavior can be transmitted via communication processes and social learning (North, 1991; Currie et al., 2016). The evolutionary approach to institutions allows us to examine both the processes involved in the origin, maintenance, and spread of specific rules as well as the complex ways different rules can interact to produce emergent properties at the populational level.

The arguments for adaptive selection

The evolutionary framework in organizational studies focuses on natural selection over rules. The selection of rules is a process by which rule frequency increases or decreases as a result of the direct payoff contributed by the implementation of rules. All selective processes are characterized by variation, heritability, and competition (Lewontin, 1970; Aldrich, 1999). In an institutional context, variations of rule arise across groups and with this variation. With the variation and differential payoff of the rules, there should be also some forms of competition between the institutions on how they are beneficial for achieving organizational goals in economic growth (North & Thomas, 1973), political stability (Acemoglu et al., 2001; Boix, 2003), successful localized management of common-pool resources (Ostrom, 2005), and long-term resilience (North, 1991; Jen, 2005; Page, 2010). Selective forces over institutions can occur in three

conditions. First, groups with high-payoff institutions outcompete other groups, replacing those groups or imposing their institutions on them (Wilson et al., 2013). For example, the rise of information and communication technologies (ICTs) has enabled a shift from group-based societies to network-based societies because the latter gained a higher benefit with ICTs (Castells, 1996); Second, group members have high leverage to migrate to the communities with better institutions at a low cost (Frey & Schneider, 2021). Banzhaf and Walsh (2008) provided empirical evidence that supports the notion that households "vote with their feet" for better institutions that promote environmental quality; Third, certain institutions are more likely transmitted from one group to another. Zhong and Frey (2020) found that centralized rules are more likely to be transmitted than decentralized rules between online communities with overlapped membership.

The arguments for stochasticity

Although social science research that adopts an evolutionary framework mostly focuses on natural selection, many institutional changes are not driven by selective forces. Those non-fitness-related changes are categorized as drift or stochastic forces (Wilson & Kirman, 2016). Two major mechanisms in organizational research characterize this type of change in institutional settings: path dependency and institutional isomorphism. Path dependency refers to the process by which institutional development depends on a unique series of past events. The path cannot be retracted, nor can it be easily deflected on. Path dependency can be explained through diverse mechanisms, including self-reinforcement (Acemoglu et al., 2011; Greif & Laitin, 2004), positive externalities (Bergek et al., 2008), and lock-in (Martin, 2010). Although institutional changes driven by path dependency can be beneficial for organizational success, for the time being, the increased frequency is not related to organizational success. Institutional isomorphism (DiMaggio & Powell, 1983) refers to the process that organizations borrow routines, rules, and behavior from other

organizations regardless of the possible mismatch between the adopted institution and the organizational context. Institutional isomorphism is explained through the organization's internal bounded reality and the uncertainty or pressure of the external environment (Cohen & March, 1974; Orru et al., 1997; Owen-Smith & Powell, 2008).

4.1.2 Integrating and Disentangling Selective Forces and Stochastic Forces

But even if natural selection is overemphasized for explaining organizational change, the evolutionary framework has major benefits for studying institutional and organizational development. Among other things, it provides a formal theoretical framework based on first principles about how inherited traits will change over time given certain conditions. It is precisely these tools that let us articulate the relationship of natural selection to the many other evolutionary processes at work in social system change. In social sciences, evolutionary explanations are often conflated with selective processes. Stochastic processes, although well-studied in organizational studies, are usually not considered from the perspective of institutional evolution. The separation of the two main forces leads to some problems in identifying the true mechanisms of institutional changes. For example, institutional development driven by path dependency may also have direct benefits that are selected for in the competition with other institutions. For example, the rise of platforms, including Apple's iOS and Google's Android, gained both builders and developers benefits at the beginning. But the lock-in benefits gained from the platform discourage the construction of gateways, and thus it forces developers to commit to just one platform or to build and maintain multiple versions of the same product (Plantin et al., 2018). On the other hand, rules that can help achieve institutional goals may also be borrowed by other groups blindly without considering the context. Lowrey found that although there is blind isomorphism among the partnership between newspapers and TV stations, the level of partnering is predicted by concrete

benefits and availability of resources (Lowrey, 2005). These examples show that the selective and stochastic forces are often conflated in institutional development. Focusing on one side of the story cannot provide a full picture of how different mechanisms work together in institutional changes. If we can integrate different institutional change mechanisms, we will be able to answer one of the most important questions through this integrated evolutionary approach: How can we tell apart the selective and stochastic forces in institutional development? In other words, how do we know whether the rule frequencies increase or decrease for their contribution to the organizational goals or for other reasons, including path dependency and institutional isomorphism?

It has been difficult to answer this question empirically. First of all, institutions and other social-environmental processes, especially culture, are all endogenous processes. It is not straightforward to establish causal links between institutions and other factors (Monge et al., 2003, p. 242; White et al., 2005; Alesina & Giuliano, 2015). Second, the evolutionary processes can be separated into discrete phases analytically, but they are often linked in continuous feedback loops, making it difficult to map evolutionary stages in theory to empirical data (Aldrich, 1999). Variation provides sources for selection, but the selected traits after transmission and retention will in turn reduce variation among populations. As a result, the evolutionary process cannot help us decide any moment in the process but rather forms a dynamic system driven by different evolutionary forces. Third, selective and stochastic forces can vary across time. Institutions that have been beneficial in the early times can end up reducing the growth speed (e.g., the lock-in effects). It requires both a clear identification strategy and longitudinal data to calculate their time-variant and average strength. Last, it is difficult to quantify institutions and institutional changes due to their complex natures. There is no clear definition that decides whether two institutions are comparable or whether we should take into account the interactions between rules within one institution.

In this paper, we address those difficulties by using the Price equation and longitudinal data on Online communities to disentangle different mechanisms in institutional evolution. We use the longitudinal online community dataset to make quantitative comparisons on institutions between thousands of organizations and apply the Price equation as a statistical strategy to make a clear estimation of selective and stochastic forces.

4.1.3 The Price Equation

The Price Equation (Price, 1970) is one of the best-known biological evolutionary models with wide applications. It is a theorem that represents any system of differential transmission (Frank, 1997). In its original form in population biology, the Price equation provides a way to understand the effects gene transmission and natural selection have on the frequency of alleles within each new generation of a population. Due to its abstract mathematical articulation, the Price equation is applied broadly in anthropology and economics (Frank, 2012a). With the evolutionary framework we illustrated in organizational studies, it is reasonable to also apply the Price equation to organizational studies. The Price equation partitions total evolutionary change into two components: an abstract expression of natural selection (selective forces) and all other evolutionary processes (stochastic forces). The two pieces of the Price equation together can represent multiple evolutionary forces such as natural selection, shift, and biased cultural transmission. One most general partition of Price Equation is:

$$\Delta z = COV[\frac{w_i}{w}, z_i] + E[\delta_i]$$

In which w_i refers to the direct fitness-related change in community i associated a cultural trait. In situations where we can draw direct causal between the cultural trait and the change in fitness, w_i can be interpreted as the payoff of the cultural trait. z_i refers to the frequency of the

trait in community i ,and δ_i refers to the random change of the trait frequency in community i. This equation establishes that the fitness-correlated selective forces ($COV[\frac{w_i}{w}, z_i]$) and the fitness-uncorrelated, stochastic forces ($E[\delta_i]$) contribute together to the frequency change of a cultural trait Δz.

With the theoretical mapping from cultural and biological evolution to institutional evolution, we can use the Price equation to estimate the selective and stochastic forces in institutional changes at the level of rules.

4.1.4 Online Communities

Longitudinal data from online communities make it possible for us to quantify institutional changes and extract the measures to apply the Price equation empirically.

Online platforms, including Wikipedia, the discussion platform Reddit, and the game Minecraft offer a meta-population of online communities. This type of large-scale groups of communities makes it possible to compare the institutions of thousands of communities within the same macro environment and cultural context (Hill & Shaw, 2017; Frey et al., 2022). The communities within the same platform often face the same collective action problems and pursue the same organizational goals, allowing for meaningful comparisons of institutions.

In recent years, through methods including API and webscraping, we have been able to acquire longitudinal data on online communities and study the long-term institutional development of many thousands at the same time (Faraj & Johnson, 2011; Hill & Shaw, 2017; Sproull et al., 2007; TeBlunthuis et al., 2017; Vincent et al., 2018; Xing et al., 2018). In this research, we monitored over 20,000 Minecraft servers, which allow various user activities, including building with blocks, gathering resources, and interacting with each other. The servers thus function as

communities users can engage with. The Minecraft environment hosts millions of communities that compete for scarce physical and virtual resources and struggle for the same organizational goal — to recruit and retain members. The same collective problems and goals they face put them under selection pressure, whereas the various choice administrators and community members have granted them space for stochastic drift. We collected data on the rules each community implements over two years. The modular rule sets, which are called "plugins" in the Minecraft world, provide a standard measurement to quantify institutions and set the unit of analysis at the rule level. The plugin types can then be used as a measurement for institutional traits. By calculating the frequency change and variance of one type of plugins, we are able to apply the Price equation in institutional settings.

Using the Price equation and online community data, we try to answer:

RQ1: What are the selective and stochastic forces that drive frequency changes in different kinds of rules among online communities?

4.1.5 Time variance and institutional diversity

Environmental fluctuation exogenous to culture and institutions have a large influence on cultural and institutional evolution. The frequency and intensity of environmental changes affects which type of cultural and institutional trait is selected and stabilized in the long run. For example, Roger's model explains how conformity evolves only in situations where environmental changes are not frequent (Rogers, 1988, p. 1). Giuliano and Nunn use a set of historical data and validate that populations that experience more cross-generational temperature instability attribute less importance to traditional values (Giuliano & Nunn, 2021). Richerson and Boyd (2001) attribute the emergence of cumulative culture to climate change in the late Pleistocene.

In the case of Minecraft, the software environment and version change may cause changes in the payoff of implementing one type of rules and influence its evolutionary trajectory. The environmental influence in Minecraft can thus operate on both the selective forces and stochastic forces. For example, when the overall online community environment becomes more unpredictable or unstable, it is possible that institutions with decentralized rules that promotes peer interactions are more likely to be selected for comparing to centralized rules that reinforces top-down hierarchies (Levitt & March, 1988). At the same time, the uncertain environment may increase blind imitation (DiMaggio & Powell, 1983) and leads to stochastic institutional changes. Thus:

RQ2: Is the evolution trajectory of rules influenced by environmental changes among online communities?

So far, we consider how single institutional traits (rules) evolve in various environments. However, oftentimes organizational development relies on complementary rules functioning together. Ostrom proposed the Institutional Analysis and Development framework to analyze various social institutions and provided empirical evidence the contribution of institutional diversity on robust self-organized institutions (Ostrom, 2005). Page provided evidence that supports the benefits of diversity in complex systems, especially in response to external shocks and internal adaptations (Page, 2010). In Minecraft, we have four types of meaningful rules related to governance. However, when we zoom in and only focus on a single type of rules, the Price equation forces us to include the influence of other types of rules in stochastic forces and environmental factors. Whether other types of rules can interact with one particular type to operate

together on institutional evolution through rule diversity requires further analysis. Motivated by Ostrom's and Page's theory, we ask:

RQ3: Is the evolution of a single type of rules influenced by rule diversity among online communities?

4.2 Methods

4.2.1 Data

We collected longitudinal plugin implementation data from 370,000 Minecraft servers through API queries bi-hourly between Nov 2014 and Nov 2016. After filtering out servers that were disconnected for the duration of data collection (~220,000), those that did not survive for at least a month (~70,000), and those that did not report full governance information (~75,000), we end up with a sample of 14,859 servers (we address the limitation resulted from this data deletion process in the Limitations).

In Minecraft, plugins are modular programs administrators rely on to manage the servers. These plugins are modular programs that administrators can install on their servers to automatically implement rules and other institutional constructs. In the digital world, code is law (Lessig, 2000) By mixing and matching plugins, Minecraft server administrators establish formal institutions to maintain community survival and achieve community success. The Minecraft community has developed almost 20,000 plugins listed under 16 categories, among which Frey and Sumner concluded 4 rule types directly related to governance: top-down administration, information broadcasting, communication, and economy (Frey & Sumner, 2019). Administration rules enhance administrators' control over community and user behavior; Informational rules facilitate information sharing from administrators to users; communication rules improve communication between players; economic rules protect private property and enable trades. To

quantify institutional changes and analyze the evolution process in Minecraft, we used this classification to categorize the plugins. To fit the Price Equation, we summarize community-level data at the unit of one month. As the median "lifespan" of a server is 9 weeks, this aggregation provides an appropriate timescale to capture the dynamics of intra- and inter-generation cultural transmission.

We take a community as an organism and the share of rules (plugins) as the institutional trait or cultural variant it displays. In this large group of communities in Minecraft, we see the different communities exhibit different institutional traits (cultural variants), which constitute the overall distribution of institutional traits in Minecraft.

In Minecraft, we do not know if after a community dies, the governing knowledge is inherited by its members to pass on to the next generation. In this sense, we do not strictly follow a genetic inheritance model. However, when a new community starts, to maintain community survival and deal with collective action problems, the community administrators need to learn socially from other communities or learn independently from the environment to establish their institutional traits or governing styles. The process of learning can be seen as cultural transmission that changes the overall distribution of rule shares.

Different forces contribute to the distribution changes. Selective forces act on Minecraft communities in two ways. First, communities that employ the governance style beneficial for community survival will last longer. For example, if administrative rules are the most beneficial for community survival, communities that employ a large share of administrative rules will last longer. In contrast, communities that employ a governance style with a small share of administrative rules will die out faster. This differential survival rate of different governing styles will shift the overall distribution of administrative rules. Second, communities that employ the

governance style beneficial for community success are more likely to be copied by other communities. The spread of successful governance styles can also change the overall distribution of rule shares.

Stochastic forces also act on Minecraft communities mostly in two ways. First, communities learn from other communities blindly. When the learning is not led by success bias but rather by proximity or uncertainty, this type of copying will lead to drifts in the overall distribution. Second, when players cultivate cultural preferences of specific governance styles, they are likely to spread these specific rule shares to other communities they migrate to (Zhong & Frey, 2020).

Additionally, mutation provides additional variation for selection. In Minecraft, the introduction of new plugins or individual learning to establish new governance styles can be seen as mutation.

Administrators do not know whether their implementation of one type of rules instead of other types of rules is due to selective or stochastic forces. We also cannot accurately identify from the interactions between communities the selective forces or stochastic forces. What is available in this dataset is the collective pattern of rule distribution. The advantage of using the Price equation is that, in this case, it isolates the selective forces from the stochastic forces statistically without specifying a large number of possible mechanisms of each basic process.

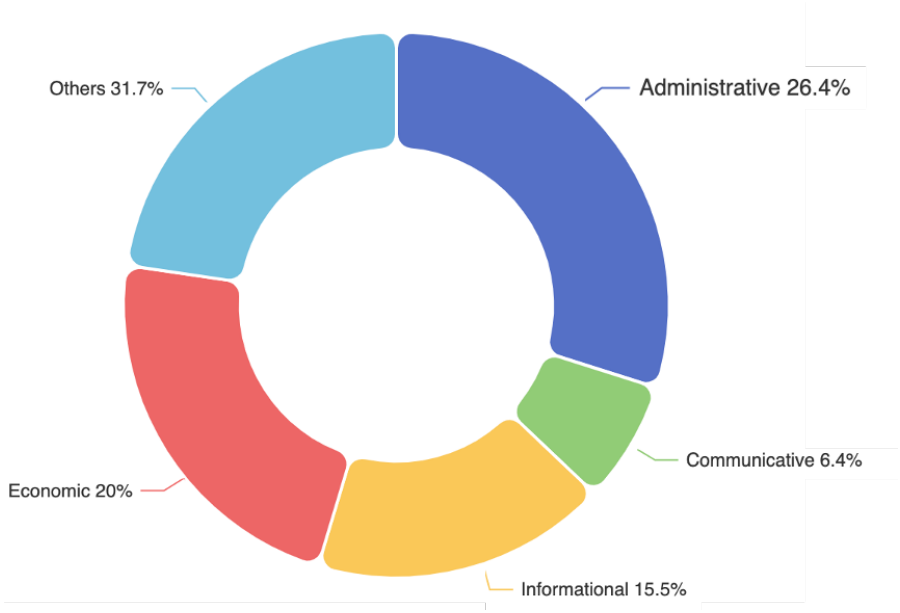
4.2.2 Price Equation

The Price equation provides a powerful generalization of the forces contributing to evolutionary changes in institutional structures — analogous in our framework to biological traits — among online communities — which correspond to individual organisms, the population of

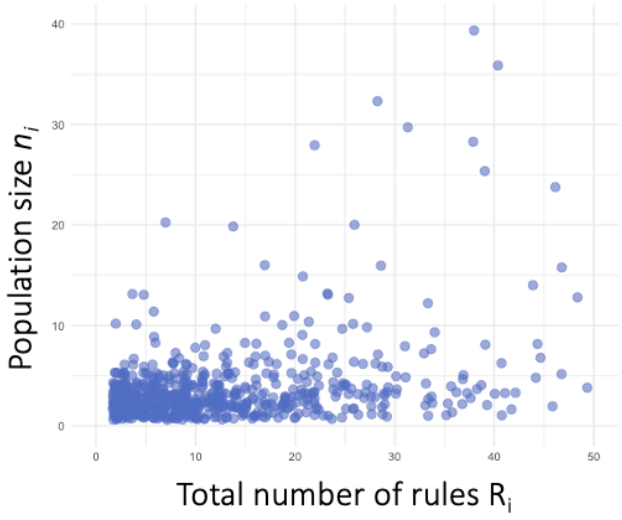
communities corresponding to the population of organisms. Here we demonstrate one possible decomposition of the Price Equation that focuses mainly on distinguishing between the strength of the correlation between the relative growth of the population ('fitness') and the presence of a certain community trait ('selection' based on that trait), and the strength of other stochastic fluctuations.

Consider the Minecraft environment consisting of multiple servers each indexed by *i* (*N = 13,859* servers). Within each community, we identify rules of four categories, administrative, informational, communication, and economic rules (see Figure 1a). Taken administrative rule as an example, the relative frequency of administrative rules in community i is $z_i = r_i/R_i$where r_i is the number of administrative rules and R_i is the total number of rules in community i. Some communities might have many rules, but a small population (see Figure 1b), so we consider it useful to create a measure of rule fraction weighted by membership population size. In most cultural evolution work, to estimate the fraction of a cultural trait within a population, researchers would either calculate the number of individuals that carry a specific cultural trait weighted by the overall population size (Boyd & Richerson, 1985) or the number the artifacts with a kind of cultural feature weighted by the production size (Brantingham & Perreault, 2010). It is a bit tricky to do this kind of calculation in organizational and institutional evolution because conceptually the individuals in the organization do not directly carry the cultural trait, and the total number of rules does not reflect the "reproduction size" of the community. Therefore, to establish the connection between the rule frequency to organizational size and the make sense of differential cultural transmission, we use the frequency of administrative rules weighted by population to estimate the fraction of the institutional trait among all communities. For simplicity, we refer to this measure as the reach of rules (their contact with the population).

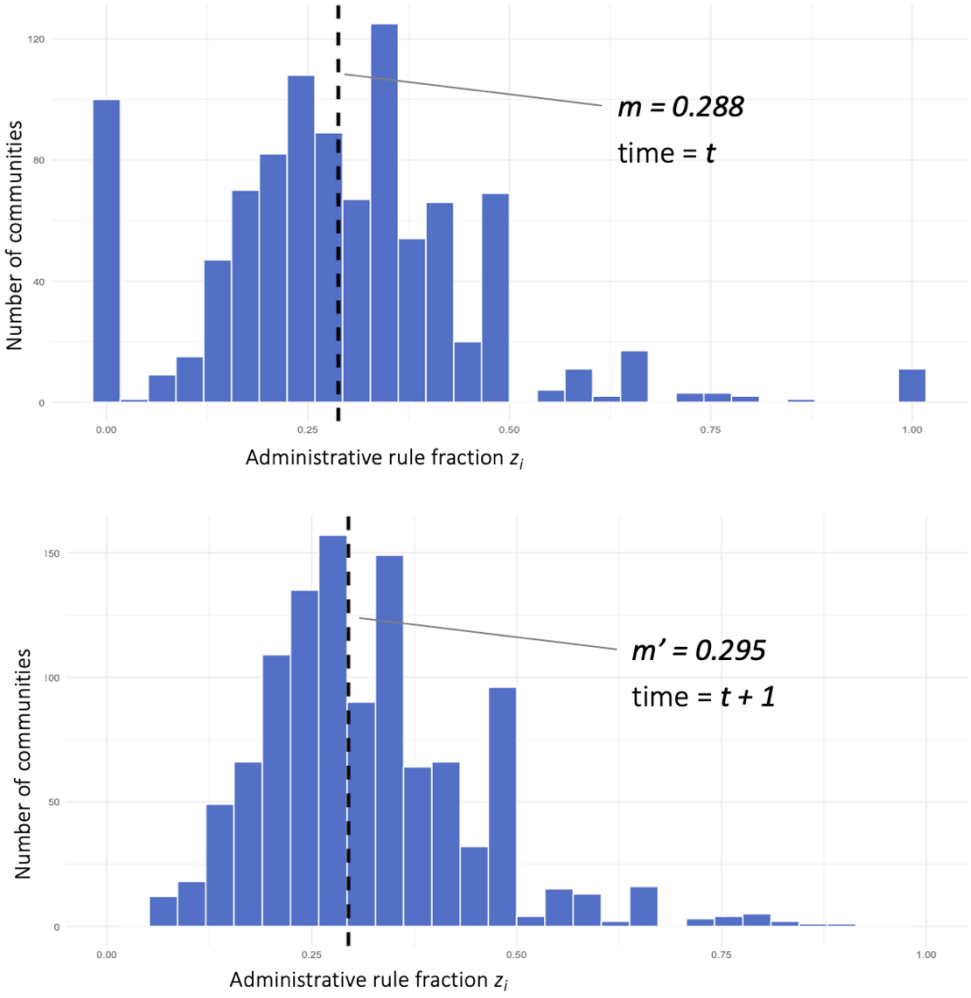
We calculate the mean reach of administrative rules across all communities $m = \sum_i p_i z_i$, where $p_i = n_i/n$ is the relative membership size n_i of community i over the total amount of active population n among all communities, and z_i is again the relative frequency of administrative rules over all rules in community i (see Figure 1c).



(a) The rule fraction z_i of a community i at time t



(b) **Membership size (p_i) by total rule number (n_i) scatter plot at time t**



(c) **Histogram of the administrative rule fraction (z_i) changes from time t to to time $t+1$**

Figure 1 **Model setup (a) Rule share pie chart of a sample community i at time t:** each community has a fraction of administrative rules (z_i); **(b) Membership size (p_i) by total rule number (n_i) scatter plot at time t;(**c) **Histogram of the administrative rule fraction (z_i) changes from time t to to time $t+1$, which also changes average population reach m.**

The fitness of the reach of administrative rules (tracked with the letter m) is therefore dependent on the differential growth of certain kinds of rules (tracked with z_i) and the population size of the respective community that uses these rules (tracked with p_i). The Price equation decomposes the change in the reach of rules (change in m) into how much the presence of these

rules covary with the growth of the population (a strong positive covariance would detect that more of this kind of rules goes together with an increase of the population size) and into all remaining stochastic fluctuations observed in the number of this kind of rules. This allows us to quantify how strongly the presence of a certain kind of rules covaries with change in population size, plus a remaining stochastic term.

In this sense, we consider two sources of change in the frequency of administrative rules. The first source is dependent on differential membership population growth (fitness) associated with the different share of administrative rules within each community. This derives the covariance term of the Price equation. In Minecraft context, we aim to covary the differential membership growth rate in a community with a specific share of administrative rules. For example, if administrative rules are related to a higher population growth rate within a community, we may see that communities that implement 100% administrative rules have a higher-than-average population reach growth. Several mechanisms may lead to this relationship.[2]

We now introduce a new variable, w, to track the rate of change of population shares, where p_i' is the proportion of administrative rules in the next time interval.

$$p_i' = p_i \frac{w_i}{w} \quad (1)$$

The mean rate of change will then be $w = \sum_{i=1} p_i w_i$. When the size of a population increases, the relative reach of the used rules increases. In Minecraft communities, community goals are to survive and to recruit and retain more members, $\frac{w_i}{w}$ tracks the relative fitness change

[2] We will not know the reason of why this happens. Perhaps communities with a large share of administrative rules are more likely to cultivate a good environment to attract more visitors. Or perhaps an increased population requires a higher (or lower) proportion of administrative rules to manage the public goods.

of communities. This source of change in the reach of the administrative thus can be seen as fitness-related change and is tracked by expanding equation (1) with the static number of rules:

$$p_i' z_i = p_i \frac{w_i}{w} z_i \quad (2)$$

When the increase rate of the membership population is greater than the mean growth rate (i.e., $\frac{w_i}{w} > 1$), the population reach of administrative rules in community i m_i increases without the frequency change of administrative rules within the community z_i. This fitness-correlated process is conceptually equivalent to selection acting at the scale of organizations.

It is worth noting that this is not a perfect replicator at the individual level in the Minecraft context because communities may start (birth) or go offline (die) during the time period we collect data. However, at the group level, when new communities come online and copy those are successful, the fraction of active populations that are constrained under the same rule strategy increases. When a community goes offline, it does not only lose its own share in the population that is governed by its rule strategy but also does not provide sources for other communities to copy anymore and thus will reduce the population share of this type of rules. Thus, even without a perfect individual-level replicator, the cumulative institutional changes at the group level remain the same.

A second source of change in the weighted frequency of administrative rules is stochastic fluctuation, which may arise from drift (Wilson & Kirman, 2016) or transmission errors (Gong et al., 2012). In this case, we can write

$$p_i z_i' = p_i(z_i + \delta_i) \quad (3)$$

Where δ_i is some small random change in the frequency of administrative rules and z_i' indicate their frequency within community *i* in the next time interval.

Equation (2) and (3) can then be combined into a single specification that simultaneously accounts for both selective and stochastic forces operating over time:

$$p_i' z_i' = p_i \frac{w_i}{w}(z_i + \delta_i) \quad (4)$$

Change occurs both in the population size of each community and in the frequency of administrative rules. Using the above rules, it is straightforward to derive the Price equation (Price, 1970).

$$\Delta m = m' - m$$

$$= \sum_{i=1} p_i \frac{w_i}{w}(z_i + \delta_i) - \sum_{i=1} p_i z_i$$

$$= \sum_i p_i \frac{w_i}{w} z_i - \sum_i p_i z_i + \sum_i p_i \frac{w_i}{w} \delta_i$$

$$= \sum_i p_i \frac{w_i}{w} z_i - \sum_i p_i \frac{w_i}{w} \sum_i p_i z_i + \sum_i p_i \frac{w_i}{w} \delta_i$$

Price recognized the first and second terms are equal to $E[\frac{w_i}{w}, z_i] - E[\frac{w_i}{w}]E[z_i]$, which is the covariance between $\frac{w_i}{w}$and z_i. The third term can be rewritten as $E[\frac{w_i}{w}, \delta_i]$. But since the fluctuation δ_i has no correlation with $\frac{w_i}{w}$, the third term can also be written as $E[\delta_i]$. The equation thus can be simplified as

$$\Delta m = COV\left[\frac{w_i}{w}, z_i\right] + E[\delta_i] \quad (5)$$

The Price equation derived (did not postulate) a covariance between the relative population growth $\frac{w_i}{w}$, and the relative frequency of a certain kind of rules, z_i. If this covariance is positive, it tells us that a presence of a certain kind of rules goes together with population growth. Since there is no intrinsic directionality in a covariance, this can be interpreted in two ways: the presence of a certain kind of rules helps the population to grow; or, the growth of the population helps the reach of the rules to increase its reach. Both help to increase the reach of the rules within the total population among all communities (measured by Δm).

The totality of the equation implies that the selective forces (the first term) and the stochastic forces (the second term) contribute together to the frequency change of institutional traits Δz . For empirical application, this can be reformulated as

$$\Delta m = \beta VAR[z_i] + E[\delta_i] \quad (6)$$

with the product of the coefficient β of the relative population growth $\frac{w_i}{w}$ on the frequency of administrative rules z_i, and the variance $var[z_i]$ in the frequency of administrative rules. In this equation, the slope reflects the strength of selective forces, and the intercept represents the strength of stochastic forces (Brantingham & Perreault, 2010).

The intuition behind the equation can be understood through two levels. At the individual community level, when a community first goes online, it needs to install rules from the pool of plugins. The community administrator can learn the governance style from other successful servers (success-biased learning) or the more popular governance style (frequency-biased learning). The administrator can also try out new governance styles or new plugins developed in the Minecraft community (mutation), and they can also learn from other resources (individual learning). The result is that some of those implementations are beneficial for the community to survive longer for

this governance style to retain in the population for longer or for the community to be more successful so that other administrators are more likely to learn from them. It could also be the case that the type of rules the community installed are detrimental to the community's success and thus will lead to a shorter lifespan or less of a success to be copied by other communities. At the population level, the average share of rules that benefit the community's survival and success will increase due to the communities sustained in the population or social learning mechanisms.

In an organizational context, the process we described here may seem overly simplified and abstract, especially considering all other third variables that may cause membership population increase or community death. Nonetheless, the Price equation describes the system of institutional evolution in a minimal manner and offers a way to identify and quantify selection or fitness-related rule change (Nettle, 2020). The fitness-correlated process is conceptually equivalent to selection acting at the scale of organizations. It is also worth noting that although we construct those process in the model, it does not establish the causal link between rule frequency change and actively population share change. Instead, the empirical estimation will help us to establish the connection between the two.

As a result, the final linear equation form demonstrates a relationship between rule frequency, variation, and selection: different types of rules have variations in their correlation to population growth. When the relationship of variation to total frequency changes (beta) is negative, it indicates that the administrative rule has a negative correlation to the community membership growth. When communities have many variations in the proportion of administrative rules between each other, the high variation provides sources for selection and thus leads to a higher frequency change rate, whereas when there is less variation, the competition will be tight and the rate of change will be lower. A positive slope indicates a positive correlation between rule frequency and

population growth. It suggests that over time, the communities with a higher fraction of administrative rules will increase the population reach of administrative rules. Similarly, a negative slope indicates selection against administrative rules, suggesting a higher proportion of administrative rules will decrease its population reach over time.

4.2.3 Bet-hedging and information theory

We take an inductive approach of the Price equation to estimate the strength of selection from frequency change, which enables us to estimate the fitness-related frequency change of a particular rule through the coefficient β. However, this approach also forces the growth rate to be fixed throughout time: an average relative growth rate is assumed for each group of rules. This modeling strategy is reasonable in a stable environment, but when the environment is changing, it might not reveal the true dynamics in frequency change due to two reasons: First, the selection forces on one type of rules depend not only on how well this rule does on average (arithmetic mean of the fitness-related growth), but also on whether implementing this rule instead of other rules would lead to community failure in a vulnerable time (geometric mean of the growth)(Sæther & Engen, 2015). The Price Equation uses the arithmetic mean and thus cannot provide an explanation for changing environments. Second, the selective forces on communities depend not only on the quantity of rules that covary positively with population growth but also on the combination strategy of rules. It could be that some rules are beneficial in some periods, while others are useful in other periods. The average over all periods might suggest favoring one rule over the other, but eliminating the other rule entirely might crash the population in certain periods. In the Price Equation, to estimate the selection over one type of rules, we subsume the influence of other rules within our stochastic forces residual $E[\delta_i]$. It helps us focus on the dynamics on a single type of

rules, but it does not explain much how different types of rules can work together to prepare communities through changing environments in a synergistic dynamic over time.

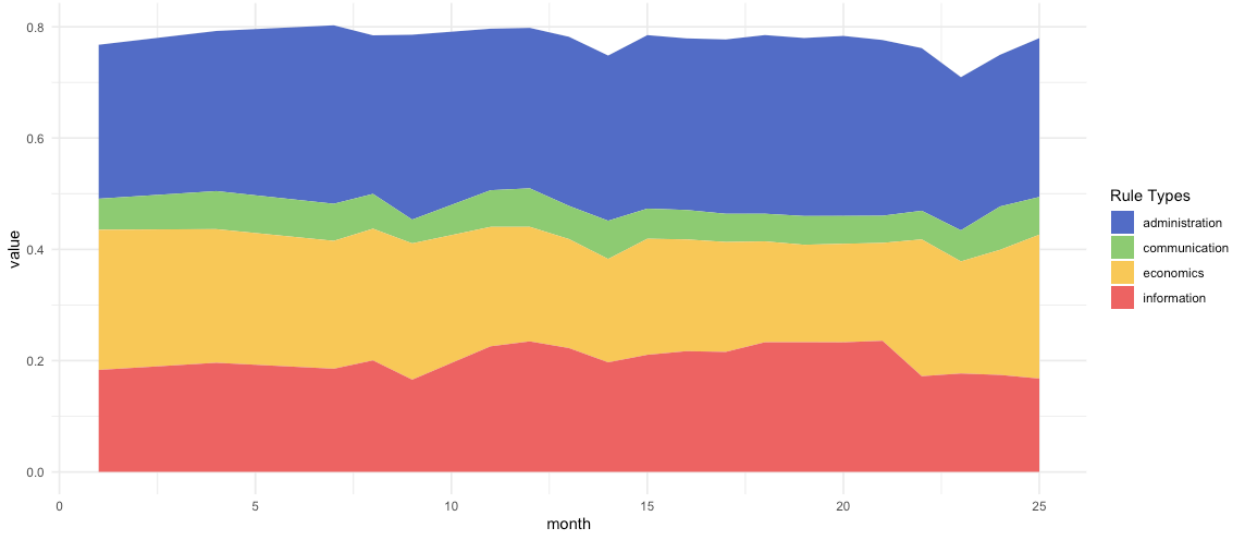


Figure 2 **Environmental changes throughout time cause changes in the number of communities but do not seem to change the overall relative proportions of rule types in the population, except for administrative rules**. The Price equation assumes a constant correlation between population growth and the implementation of one type of rules. However, the correlation may vary across time in a fast-changing environment. The changing bandwidth of administrative rules in this figure demonstrates that different rules are influenced differently by the environment.

One of the methods that can incorporate the two factors not addressed in the Price equation is bet-hedging. Evolving biological and socio-economic populations can sometimes increase their growth rate by cooperatively redistributing resources among their members. In unchanging environments, this simply comes down to reallocating resources to fitter types (Hilbert, 2017a). This would suggest that rules that are not useful for quite some time will get eliminated by natural selection. However, they might become useful later again, and their premature elimination would then reduce fitness. Whenever there is a repeating cycle or seasonality in fluctuating environments, it could be useful to restrict the forces of blind natural selection during certain periods to be prepared for subsequent periods (59). For example, it would not be useful to allow natural selection to eliminate all food storage during summer, even if 'blind' natural selection cannot see its utility

during periods when the environment provides abundant food sources, as it will be an essential pillar of fitness during the upcoming winter. Neglecting such predictable seasonality and merely working with cross-seasonal averages might suggest that the contribution of the "food storage rule" is on average neglectable over the "go out and forage" rule and might suggest to eliminate it. However, the population would starve during winter and not make it to the next thriving summer. Any kind of anti-cyclical governmental policy or any kind of temporal economic subsidy exploits the same logic of maximizing overall fitness in predictably fluctuating environments by combining different kinds of institutional mechanisms over predictably fluctuating periods of the evolutionary trajectory (Gong et al., 2012).

The utility of such portfolio theory-based bet-hedging over time depends on the predictability of the environmental pattern. If the future cannot be predicted, there is nothing to prepare for. However, if a predictable seasonality is known, one can adjust for it. The predictability depends on the amount of information in the pattern, which leads us to information theory.

In technical terms, if the information about the future pattern is completely unrelated to the state of the environment, the mutual information between the cue and the environment is zero. The cue does not help to increase the 'fit' between the evolving population and the environment. At best, a perfectly informative cue would exactly reveal the state of the environment and the remaining uncertainty about the environment would be zero and the population could be adjusted to grow optimally. This can be formalized by the mutual information between the environment and the evolving population: the more you know (about the environment), the more you can grow (the population) (Hilbert, 2017c).

This problem is formalized by portfolio theory and is the basic idea behind bet-hedging. It uses information about in the environment to maximize the long-term increase rate (Kelly, 2011).

Built upon Kelly's idea, and subsequent expansions (Haccou & Iwasa, 1995; Kussell & Leibler, 2005; Donaldson-Matasci et al., 2010; Rivoire & Leibler, 2011), Hilbert derives a measure to establish cooperative resource-redistribution strategy to maximize socioeconomic growth (Hilbert, 2017c). By establishing fitness matrices of rules in different environmental states, we can find out the most efficient rule distribution strategy that allows the sustainability and incrementation of this type of rules. Here we illustrate the bet-hedging method in Minecraft.

First, we need to understand how the environment changes throughout time. The most efficient way to benefit from the changing dynamics in the environment is represented through information theory. Information by definition is related directly to the reduction of uncertainty. The 'mutual information' between a cue about an environmental pattern and a random environmental state measures how much the cue reduces the uncertainty about the state and can be directly translated into growth potential (Donaldson-Matasci et al., 2010). It turns out that the search for optimal growth consists of the search for the mutual information (or unequivocal signals) between the environment and the evolving pattern (Hilbert, 2017b).

In the case of Minecraft, if we already know the unfolding dynamics of environmental changes, we then have no uncertainty about the environment and perfect information to predict the state of the environment at any given time. In an ideal world like this, we can quantify how well one type of rules work in different environmental states and make confident decisions about implementing or removing this type of rules accordingly. However, in Minecraft, we have a high-level of uncertainty about the environment changes. What's the most efficient way for us to use the information from previous event to predict the mechanisms of the current environment? Shannon answered this question by calculating the opposite side of information, uncertainty (Shannon, 1948). According to Shannon, the likelihood of getting one specific environmental state

from all possible environmental states is equivalent to the reduced uncertainty caused by the knowledge on this specific environmental state. We use a probability distribution of whether the environment is friendly for one type of rules to represent the dynamical patterns of the environment. To minimize the number of assumptions to measure the environment and establish one environmental measurement to consistently compare the changes of all four measures, we decide the good or bad state by whether the growth of the centralized rules (top-down administration, information broadcasting) outcompetes the growth of decentralized rules (communication, economics). This is aligned with hypotheses proposed by Perrow that the paradox between centralization and decentralization grows with organizational complexity (Perrow, 1977, 1991). This cut-off allows to fit our data in a binary framework of the computation.

Table 1 Rule growth rate partitioned by environmental state and rule categories

State	growth of rule *i*	growth of other rules
Good state for centralized rules	G_1	g_1
Bad state for centralized rules	g_2	G_2

To optimize the rule increment in a changing environment, we need to redistribute the rule shares to match the environmental-state probabilities. In extreme cases, rules that don't work best for the environment have a growth rate of 0. The optimal strategy then is to maintain the shares of rule types just as the corresponding environmental-state probabilities. In between extreme cases, we may find that some rules in an unfavorable environment may still have a positive growth rate. This requires us to adjust the rule shares based on both the growth rate of different types of rules and possibilities of different environmental states. Table 1 listed the growth rate different type of rules in a good or bad state, where W refers to the growth rate in a good state for this type of rules and w refers to the growth rate in a bad state for this type of rules.

Solving for the optimal distribution of administrative rules sometimes results in undefined combinations of rule shares, including cases where the optimal share of rule i is negative (d <0) or above 1 ($d > 1$). For $d < 0$, it suggests that the optimal strategy is to implement other rules only. Accordingly, for $d > 1$, the optimal strategy is to implement rule i only. The two extreme cases are the so-called "pure strategy". If the optimal strategy for rule i is a pure strategy of full investment on rule i, it indicates that (1) the frequency change in rule i can be attributed to the earlier investment on rule i other than any other rules. In other words, the frequency change of rule *i* is driven by selection solely over rule i; (2) environmental changes do not alter the growth rate of rule *i* (Hilbert, 2017c).

Optimal solution with rule share between 0 and 1 is called "region of bet-hedging"(Donaldson-Matasci et al., 2010), which suggests a mixed proportion of different rules. The conditions on when it is beneficial to take advantage of cooperation among types to outperform blind competitive selection depends on the particular shape of the fitness landscape. The more complementary the fitness of types in different environmental states, the proportionally larger the potential benefit of strategic cooperation over competitive selection. If the optimal strategy for rule *i* is in the region of bet-hedging which suggests implementing p rule *i* and $1 - p$ other rules, it indicates that (1) the frequency change in rule *i* can be attributed to earlier implementation of both rule *i* and other rules. (2) The environmental changes do alter the growth rate of rule *i* and that's why we have to use a mixed rule combination (resources in the space) to deal with the environmental changes (risks in time; Hilbert, 2016).

4.3 Results

4.3.1 The Price equation result

To match the rule data with membership data, we marked 23 timestamps to estimate the rule changes over time. At each time point for each community, we measured the fraction of each type rules (z_i), membership size (p_i); We then calculate the average rule proportion weighted by membership size (m) and variation of rule proportion among communities. We partition the Price equation into slope-intercept forms (equation 6). In this equation, the slope reflects the strength of selective forces, and the intercept represents the strength of stochastic forces (Brantingham & Perreault, 2010). As shown in Figure 3, each data point refers to a timestamp placed in the coordination of the variation of rule fractions $VAR[z_i]$ and the average population reach m derived from . We show that communities with administrative rules installed face positive selective forces ($\beta_{admin} = 0.117,\ p < .001$) and negative stochastic forces ($E[\delta]_{admin} = -3.602,\ p < .01$). This indicates that, on the one hand, administrative rules have a high positive correlation to community success of recruiting and maintaining members, resulting in a higher probability for this type of rule structure to be learned by other communities. This direct fitness-related benefit contributes to the growth of administrative rules. On the other hand, driven by stochastic factors, including lack of information, cultural preference/resistance, path dependency, or individual learning, administrators tend to reduce the proportion of administrative rules regardless of their direct positive correlation with community fitness.

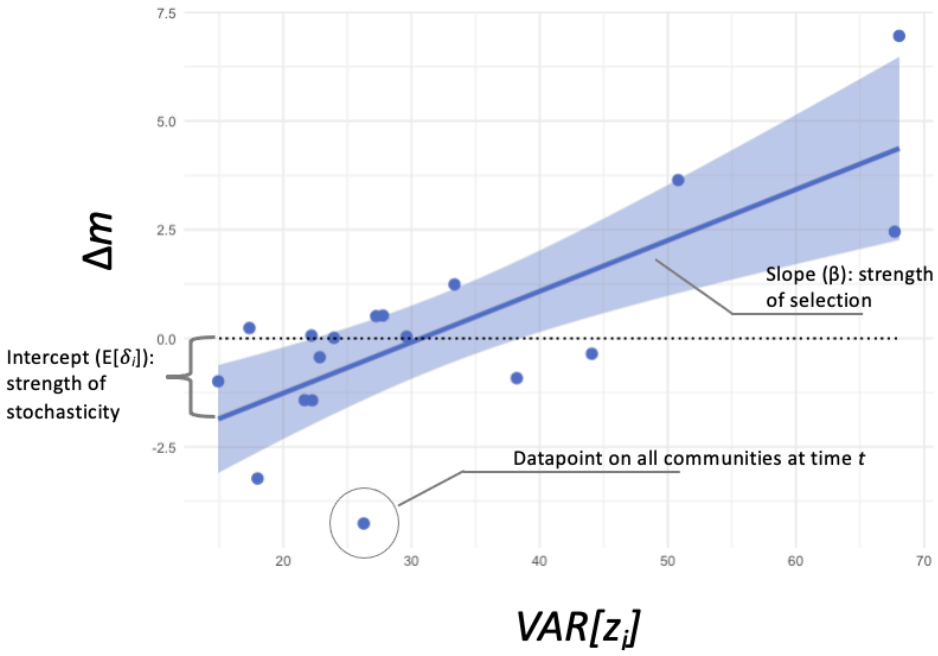
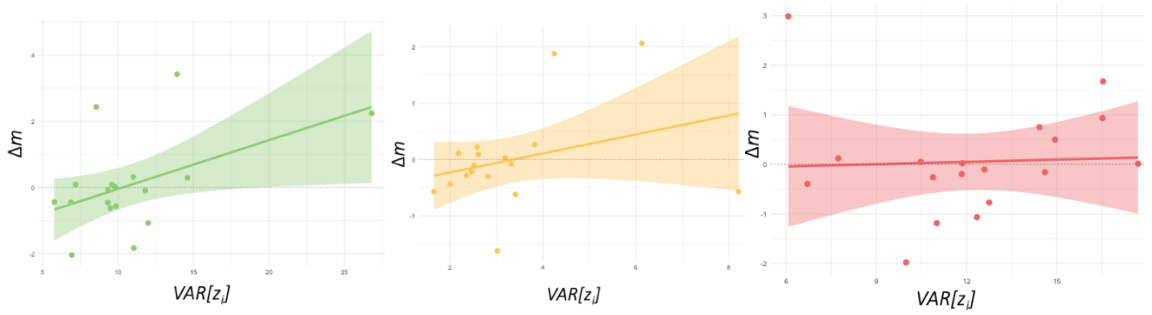


Figure 3 Communities with administrative rules installed face positive selective forces and negative stochastic forces. Administrative rules have a positive correlation to community fitness, which also lead to a higher probability for this type of rule structures to be learned by other communities. This direct fitness-related benefit is associated with the growth of administrative rule. On the other hand, other "stochastic" forces including lack of information, cultural preferences, cultural resistance, and random experiment reduce the implementation of administrative rules.

We also find positive selection over information rules ($\beta_{admin} = 0.147, p < .05$), indicating that information rules are beneficial for community survival.

We do not find statistically significant selection (slope) or stochasticity (intercept) different from 0 in communication rules and economic rules, indicating the frequency change of communication and economic rules are not significantly different from 0.



(a) Information (b) Communication (c) Economics

Figure 4 Communities with informational rules face positive selective forces, while there are no effects of communication and economic rules on community prevalence. We found positive selection over informational rules but not negative stochastic forces (a). At the same time, both selection (the slope) and stochasticity (intercept) in communication (b) and economic rules (c) are not significantly different from 0 throughout time.

4.3.2 Bet-hedging result

We use bet-hedging to validate the Price Equation result and see how the combination of different rules contributes to the rule frequency change.

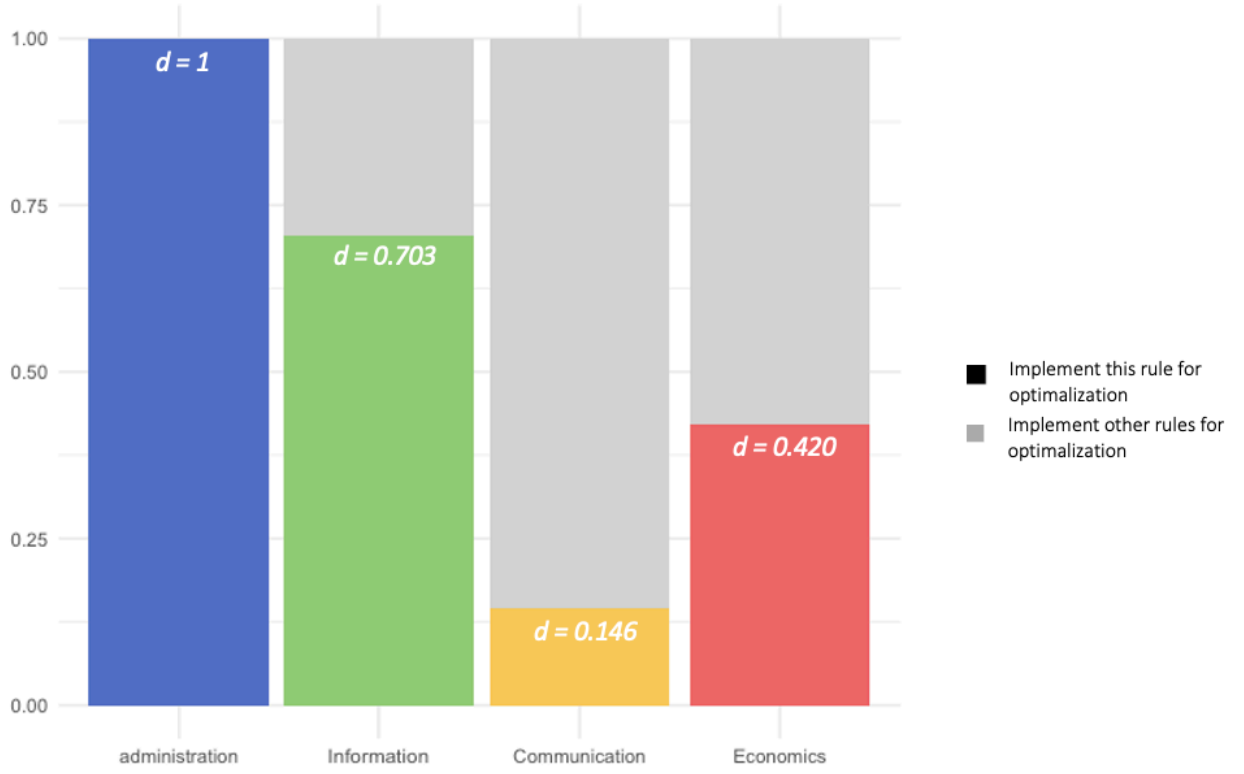


Figure 5 Most rules show a maximum in their selective effect in combination with the other rule types. The bars in the figure illustrate the optimal distribution of rule implementation to maximize the growth rate of one type of rule, demonstrating the influence of implementing other types of rules on this type. For information rules to be expressed at a maximum rate in the population, the calculation suggests that they should be implemented with a 30% mix of other rule types. (This is distinct from the question of whether that maximum is positive: whether information rules are positively selected for, as show in Fig. 3). Implementing a mix of rules can help communities survive the period when the direct benefit of information rules are low. As a result, institutional diversity contributes to the long-term growth of communication, information, and economic rules. The optimal distribution of administrative rules, 100%, suggests an absolute strategy for the growth of this most dominant rule type. This may be an artifact of the strong positive selection that communities with administrative rules face, particularly relative to the other rule types. It is also consistent with the conclusion that the correlation between administrative rules and community fitness does not vary as much across time as the other rule types.

The direct result of bet-hedging shows that the optimal distribution of rules for administrative rules to increase is to implement administrative rules only ($d_{admin} = 1$; See Figure 5). In other words, the incrementation of administrative rules can be attributed solely to the earlier implementation of administrative rules. The Price equation suggests that the theoretically optimal strategy is equivalent to the end result of pure natural selection. As such, it is consistent with the Price equation result that the positive selective force is the only reason for the increase of administrative rules.

At the same time, for information, communication, and economic rules, the optimal share for them is within the region of bet-hedging ($0 < d < 1$; see Figure 5), indicating the environmental changes do alter the growth rate of the three types of rules, resulting in optimal strategies of mixed rule combinations (resources in the space) in response to the environmental changes (risks in time). For these rules, it is useful to keep natural selection in check, as it would overexpose the community to rules that are less favorable in certain kinds of recurring environmental states. There is a "complementary variety" among the diversity of the fitness of these rules in different environmental periods (Hilbert, 2017a).

Combining Price Equation results, the optimal rule combination for informational rule growth ($d_{information} = 0.703$) shows that although informational rules have a general positive correaltion to community survival and success, this correlation varies throughout time. In a period when the growth rate of informational rules is low, the share of other rules helps the community throughout those difficult times. As for communication rules and economics rules, although they do not have individual selective advantages, they can be subsidized to help communities through environmental changes ($d_{communication} = 0.146$; $d_{economics} = 0.420$).

Overall, we found that the environment for administrative rules is a winner-take-all selection-driven situation. But for the other three types of rules, institutional diversity drives rule increment instead of fierce competition and selection. In the long term, it is beneficial overall to maintain a certain mix of rules, even against the elimination pressure exerted by natural selection.

4.4 Discussion

In this study, we use the Price Equation and the bet-hedging method to quantify and isolate the drives of rule frequency changes among online communities. Under the relationships that the Price equation articulates, we found positive selection forces over administrative rules and

informational rules. At the same time, stochastic forces, including random trials and cultural preferences, lead to rule reach decrease in administrative rules. We do not find significant rule reach changes in informational and economic rules. The bet-hedging result of optimal rule share supports this result and provides additional explanations for the stochasticity quantified through the Price equation. We found that the increase in administrative rules is only driven by its positive selection, whereas the increase in information, communication, and economic rules is driven by institutional diversity as well.

The result also provides access to the environmental states of rules. Administrative rules are in an environmental state where competition and selection dominate institutional evolution, whereas, for other rules, diversity and cooperation are the keys to success.

4.4.1 Contributions and Implications

This study used evolutionary frameworks and models to explain institutional development. By using an evolutionary framework, we do not disregard "agency" in institutional changes, but emphasize that in the long run, agency itself becomes endogenous through iterated learning, selection, and reproduction of practices and beliefs. On this basis, we integrate the theories in organizational studies and formal models from evolutionary biology to explain the macro dynamics based on first principles in given conditions. The empirical application of the Price equation in this paper helps us quantify selection and stochasticity and thus answers one of the fundamental questions in organizational studies: Are rules and institutions implemented for their direct benefit or for other reasons?

Our approach combines the advantages of comparative studies and mathematical models to show the dynamics and reveal collective patterns of institutional evolution (Jen, 2005). Through

comparative analysis of thousands of communities in the same Minecraft environment, we can control for the spillover effects of other social processes and focus on the frequency change in rules. Through the non-linear mathematical models, we assess institutional development not as a moment of equilibrium but as an evolving system where changes emerge based on some first principles and stochastic processes. The use of bet-hedging models complements Price equation results, demonstrating a practical application of information theory to answer evolutionary questions.

Additionally, our bet-hedging results show the influence of environmental fluctuation in evolutionary processes and point out a path to identify the current environmental state for particular institutional traits. The estimation of the environmental states and their influence can provide valuable information in general risk-avoiding and decision-making, especially when other variables are fixed or controlled. This approach loosens up the fixed environment assumptions in evolutionary models and thus helps make more accurate predictions in an uncertain and risky environment.

The bet-hedging results also contribute to the literature of institutional diversity in three perspectives. First, our results support empirically that institutional diversity is beneficial for institutional and organizational development for certain rules. Second, we are able to calculate the boundary conditions of environmental states and specific rules in which institutional diversity have the maximum benefit. Third, we extend the theory of diversity by demonstrating that diversity does not only benefit the overall collective fitness (Page, 2010) but also contributes to the growth of a single rule (trait).

Although we focus on the online community context, our results, to some extent, can be generalized to real-world communities and provide some implications for policymakers and

practitioners. The empirical evidence in this paper suggests that in a fast-changing environment, institutional diversity can be helpful for organizations to build resilience.

Overall, in this research, we join the conversation with the population ecology research of online communities (Monge et al., 2011; P. Monge & Poole, 2008; Lamberson & Page, 2012; TeBlunthuis et al., 2017; Bednar & Page, 2018) to further understand organizational development. Ecological thinking and evolutionary thinking provide two approaches to understanding the frequency change in organizations. In recent years, researchers in different disciplines are trying to bridge the two grand theoretical frameworks and produce more integrated models (Johnson & Omland, 2004; Barker & Odling-Smee, 2014). Our work contributes evolutionary thinking to the recent empirical development and advances the development of integrated models and model selection in organizational studies.

4.4.2 Limitations

The Price equation is powerful in explaining the macro patterns of the system, but it does not provide direct causal inferences. This is because the Price Equation is ultimately a tautology (Frank, 2012a) that describes frequency change. Thus, although we are able to estimate the strength of selection, we do not know what drives frequency changes aside from selection. Anything not directly related to community fitness is concluded in stochasticity, which we cannot explain through the model. At the same time, the Price equation, when applied to cultural and organizational evolution, is difficult to map accurately to organizational activities. In this research, we do not have perfect replicator of rule change mechanisms. Although replicators are not necessary for cumulative, adaptive cultural evolution (Henrich et al., 2008), but it makes estimation and interpretation of the model less accurate than biological evolution estimation.

Additionally, we use GLM to estimate selection and stochasticity to guarantee the robustness of the estimator. However, we cannot be sure that the current estimation method may not be the most efficient. It is still debatable which estimation method is the most effective to estimate the slope of selection.

Our application of the bet-hedging method assumes a fixed fitness matrix due to the limitation of the technique (Kelly, 2011). Limited by the computation, we can only assume a two-state environment and calculate the shares for the binary rule categories. This limitation simplifies reality and also forces an arbitrary choice of deciding the environmental state. In this paper, we use the relative growth of centralized rules (administrative and informational rules) as the indicator to decide environmental states. This allows us to answer the research question, but at the same time this categorization is still relatively arbitrary and less theoretical. In future work, we may introduce more context-based measures of environmental state based on organizational theories.

Finally, we studied fitness in terms of the reach of rules. We tracked the reach of rules among Minecraft communities for the sake of the influence of their reach, which is a justifiable definition of 'rule fitness' (the selfish rules are propagating). However, it does not tell us anything about some other utility of the rules (e.g., the growth of the satisfaction of users, their enjoyment, the economic or entertainment benefits of rules). This additional step could be achieved by relating the reach of rules to other performance measures of communities, as can be done with structural equation modeling (Frank, 2013).

4.4.3 Future work

Our methods make the first attempt to demonstrate evolutionary thinking in institutional development and point out where to look into the data when analyzing institutional development.

The general contribution is that we show that it is practically possible to apply long-standing formal theories of evolutionary change to calculate concrete and insightful aspects of the evolution of institutions. The digital footprint produced by online communities and organizations allows researchers to advance to more formal style of empirical testing and quantification. Existing evolutionary frameworks from evolutionary biology, such as the Price equation and bet-hedging, allow researchers to calculate long-standing measures and interpret them within solid conceptual frameworks.

The Price Equation pointed out where to look at when analyzing other influences aside from selection. For future research, we may want to use this information to look into the influencing factors in stochastic forces. At the same time, the bet-hedging method points out where to look to identify the efficiency of institutional diversity in a changing environment. Future research may narrow the scale of institutional analysis to particular time periods and rule shares to identify institutional effects. Future research can also look into the reasons for subsidizing particular rules.

To summarize, this research highlights the evolutionary thinking of institutional analysis and embraces the opportunity of macro-scale longitudinal analysis on online communities provided by digital trace data. By applying evolutionary models empirically, we are now able to answer fundamental questions of institutional evolution quantitatively and open the door for future research to study institutions from an evolutionary-system perspective.

Chapter 5 Summary

The three papers examined how institutions interact with cultural preferences, repertoires, and values and investigated reasons that influence institutional evolution using theories from

cultural evolution and cultural sociology, and methods from network science. These efforts extend theories in cultural and institutional evolution and demonstrate how we can use modeling and statistical methods to identify the relationship between two endogenous social processes.

5.1 Theoretical contribution

Chapter 1 reviews the traditions and theories in social science to understand the relationship between institutions and culture and provides a systematic framework for communication researchers to approach this big question.

Chapter 2 formalizes multiple conflicting theories in cultural sociology about how people make cultural choices and extends the theories to changing social environments. Through agent-based modeling, this chapter dissects these theories in varying social contexts, shedding light on their respective applicability and explanatory power. In this way, this chapter illustrates how agent-based modeling, often seen as an independent tool, can be judiciously used to test and expand upon verbal sociological theories. It stresses the importance of formalizing and building upon existing theoretical constructs in social science rather than starting repetitive theories, ensuring continuous progress in social theory building.

Chapter 3 & 4 delve into the theories of institutional evolution. In these two chapters, I join the organizational theories and cultural evolutionary theories. Evolutionary theories provide great metaphors for cultural institutional development, yet it still requires organizational theories to bridge the metaphors to specific human and organizational behaviors. Similarly, abundant organizational and cultural theories require an overarching framework to organize repetitive and conflict arguments. The contribution of these two chapters is organizing the complex and scattered theories in organizational studies into the cultural evolution framework. *Drawing on foundational theories* from cultural sociology, organizational studies, and institutional evolution, these essays

mostly adopt a top-down approach to study how the environment shapes institutional development, cultural preferences, and individual choices, shedding light on the broad relationship between institutions and culture.

5.2 Methodological contribution

Institutions and culture are social processes that are usually difficult to disentangle. In this dissertation, I used a collection of different modeling and empirical methods to quantify and isolate the influence of institutions and culture.

Chapter 1 demonstrates how to articulate components and model relations in classical sociology theories, paving a pathway for a comparative theory analysis using agent-based modeling. Chapter 2 introduced a new approach to using network science for causal inference and analyzing institutional changes at different timescales. The pipeline developed in this paper can be used for future research to isolate endogenous social processes' influence. Chapter 3 offers an application of the Price equation and the bet-hedging model in quantifying institutional evolution, bringing models from population biology to the field of communication.

5.3 Limitations and Future Directions

The three essays take a top-down functional approach to analyze the relationship between culture and institutions. As a result, the analyses focus on the macro patterns (e.g., Whether the effects exist? Which effects are stronger? What are the long-term effects compared to the short-term effects?) and overlook the micro-mechanisms that lead to the collective phenomenon (e.g., How do organizations learn from each other? Why do they learn some institutional features better than others?) Chapters 3 and 4 provide some possible explanations but do not empirically test these hypotheses. Bridging macro-patterns and micro-mechanisms should be a priority for future endeavors.

Another limitation is that although the essays attempt to combine modeling and empirical research in understanding institutions and culture, the two approaches in the paper are, to a large extent, independent from each other. Future research needs to find better ways to combine empirical research with modeling to explain institutional and cultural evolution.

Despite the overarching theme of the dissertation resonating with broader definitions of institutions and culture, data opportunities have led my research to focus on online communities. In the future, the ideas proposed in these essays should be applied to real-world organizations and cultural groups to show more generalizable results.

Another direction worth further exploration is organizational learning. Following my three essays, it's interesting to ask further how learning biases influence organizational outcomes and shift the environment.

In conclusion, the study of institutions and culture has fascinated social scientists for decades. I am one of them. Through this dissertation, I've sought to extend our understanding of institutions and culture through theories in organizational communication, cultural sociology, and cultural evolutionary theories and methods from computational social science. My results show the necessity of understanding culture and institutions as dynamic and complex systems. Additionally, we have to acknowledge reasons for institutional and cultural changes besides selective forces in the environment. As we are facing challenges in understanding new forms of organizations and changes in the current media landscape, it is important to develop new theoretical tools and empirical methods to deal with the big data, the new forms of organization, and the new challenges of cooperation.

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