THE EVOLUTION OF KNOWLEDGE SPECIALIZATION: EXPERTISE, TRUST, AND THE SUPERNATURAL ACROSS TRADITIONAL CULTURES

By

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Abstract

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Evolutionary approaches to the acquisition and transmission of cultural knowledge are diverse, and they have motivated much theorizing among anthropologists and other social scientists. However, fewer have focused on cross-cultural and data-driven approaches to investigating specialists who invest heavily in locally useful knowledge, who will be referred to as *knowledge specialists*. This dissertation therefore analyzes how and why knowledge specialists acquire useful cultural knowledge, and explores how they provide services to others in their communities. Conversely, it also investigates the criteria by which others come to trust the information provided to them by a knowledgeable source, such as a specialist. The key findings in this dissertation

suggest that (1) most individuals are skeptical of socially learned information when it might not stand to benefit them personally, and (2) knowledge specialists who socially supply individuals with information either effectively provide a beneficial service in exchange for payment, and/or mentor their acolytes in exchange for status and prestige. The extent to which individuals trust socially learned information is associated with external influences such as acculturation and market integration, and the extent to which knowledge specialists provide effective services vs. mentorship is associated with characteristics of their domain of expertise, such as how rare and uncertain the problems they resolve are, and whether or not their skills involve readily observable behaviors that are easy to copy. When a domain of expertise involves rare, serious, and mysterious phenomena, specialists frequently provide services to clients while invoking the supernatural and keeping their proprietary know-how a secret, whereas their clients judge specialists' services based on their effectiveness. Throughout this dissertation, this idea is developed into a hypothesis to be tested in future research, referred to as a *market for specialists*. In general, the findings in this dissertation speak to a broader trend in the current cultural evolutionary literature, which favors a continuing convergence of previously disparate schools of thought. Specifically, they demonstrate that the relevance of existing theoretical models of cultural transmission and knowledge specialization might depend strongly and non-randomly upon context.

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To Ryan and Alex, whose inspiring wit, kindness,

and mentorship meant a great deal to me.

CHAPTER 1. INTRODUCTION

Anthropologists have documented a wide range of diverse systems of *knowledge* about people's social and natural worlds. Systems of traditional and culturally-specific knowledge, or *ethnoscientific knowledge*,[1] are typically associated with locally adaptive practices that are well-equipped for dealing with local important social dilemmas and ecological challenges (Bliege Bird, Tayor Nyalangka, Codding, & Bird, 2013; Lansing & Kremer, 1993; Purzycki, 2016). Some have argued that humans, as a species that so reliably adapts to such diverse socioecological contexts, are *intuitive scientists* who inhabit a cognitive niche (Gopnik, Meltzoff, & Kuhl, 2000; Szollosi & Newell, 2020). That is, we possess sophisticated capabilities for communicating and cooperating with each other (Pinker, 2010), making inferences about causation (Sperber, Premack, & Premack, 1995), and acting on uncertain outcomes based on past observations (Gigerenzer & Murray, 2015).

And yet, despite our sophisticated cognition, complete with an ability to communicate orders of magnitude more information with each other compared to other organisms, human minds seem to be able to bear a great deal of unreality (Boyer, 2018). People are prone to biases, illusions, and flawed intuitions (Kahneman, 2013), and

[1]"Ethnoscience" can also refer to a particular Western scientific approach to studying indigenous knowledge systems, today referred to as cognitive anthropology. Throughout this dissertation, and in the Human Relations Area Files, "ethnoscience" instead refers to the content of indigenous knowledge systems, which are often culturally specific.

they accept useless, unrealistic, and even actively harmful explanations about their social and natural worlds (Aunger, 1994; Boyer, 2007; Richerson & Boyd, 2005). As an example (that I will take up in detail in Chapter 4 of this dissertation), practical systems of knowledge used for important tasks, such as healing serious and mysterious illnesses, frequently involve religious rituals and supernatural explanations (Winkelman, 2010, 2020), invoking concepts such as gods, ghosts, and witchcraft. Why should people rely on "religious" beliefs where "scientific" ones are more effective, especially when a scenario such as a serious unknown illness can be so consequential to fitness?

This question, which I will critically address in this dissertation, actually entails two questions that are worth separating. First, why should people trust the testimony of others, such as religious leaders or authoritative experts, even when it conflicts with their direct experiences and/or personal incentives? Second, why should people entertain supernatural explanations at all, particularly when by definition they conflict with the laws of nature?

To the first question, many evolutionary anthropologists have argued that this is a consequence of our generally adaptive capacity for culture (Henrich, 2017). According to this view, humans rely far more heavily on social learning compared to other sources of information, and have therefore evolved a number of social learning biases for detecting which members of their community are the most trustworthy sources of knowledge (e.g., Boyd & Richerson, 1985; Henrich & Boyd, 1998; Henrich

& Gil-White, 2001). Others have countered this position by arguing that humans are epistemically vigilant, meaning that they do not blindly copy the knowledge of others, but they accept it based on some combination of direct experiences, personal incentives, and expectations about future outcomes (Mercier & Sperber, 2017; Morin, 2015).

To the second question, most theorists have argued, in some form or another, that our capacity for "religious" imaginings emerges as a cognitive byproduct of otherwise adaptive capacities (Pyysiäinen, 2001). A widely discussed example of this is our ability to make inferences about other minds, which can be inappropriately applied to our observations, thereby leading to anthropomorphic assumptions about unthinking processes in the natural world (Guthrie, 1995). And yet, the diverse but finite number of religious beliefs in the world could not possibly reflect the far more vast possibility space of human cognition (Dennett, 2006). The inferences that could possibly result in religious ideas about the supernatural must therefore gain traction in a social setting somehow, elevating their status from transiently entertained thoughts to more stable and socially important *beliefs*. Some have argued that beliefs in the supernatural feed back in culturally useful ways, such as solving collective action problems (Norenzayan et al., 2016; Sosis & Alcorta, 2003). Others have argued instead that "religious" beliefs actually reflect ordinary and pragmatic explanations, rather than doctrinal beliefs, deployed by specialists (such as healers) while assisting their clients (Bloch, 2008;

Boyer, 2020; Sperber, 2018).

This particular view of supernatural beliefs raises a broadly important and underappreciated problem of interpretation in ethnography, which I will revisit throughout this dissertation while addressing each question raised in this section. A well-documented psychological tendency is for people to assume, by default, that behaviors are a reflection of internal mental attributes, typically with a diminished focus on the role of external influences (Andrews, 2001; Granot & Balcetis, 2013; Norenzayan, Choi, & Nisbett, 1999). This can lead theorists to overemphasize people's internal mental lives, misleadingly positing cognitive biases (social learning or otherwise) when external influences have an overlooked (but important) explanatory role (Brighton & Gigerenzer, 2015; Sabini, Siepmann, & Stein, 2001).

Moreover, an ethnographer's observations are not passively observed, but they are inevitably constructed with cultural concepts that he or she uses to interpret observations (Sperber, 1985). Although Westerners do have religious institutions, it cannot be taken for granted that "religions" beliefs among non-Western societies similarly reflect a coherent doctrine as seen among Western hegemonic religions (Boyer, 2020).

1.1 The overarching aims of this dissertation

The overarching aim of this dissertation is to investigate the social and cultural dynamics of knowledge, while emphasizing the external and material influences that shape its content and transmission. It is overly simplistic to claim that knowledge is reducible to the content of individuals' heads alone – even experts frequently rely on what other experts know (Keil, 2003), and laypersons routinely overestimate how much they know about familiar observations (Rozenblit & Keil, 2002). Instead, knowledge is a complex and relational social system of ideas between senders and receivers, or, in many cases, between specialists and clients (Sloman & Fernbach, 2017).[2]

This dissertation address a gap in the literature by compiling and analyzing systematically gathered cross-cultural data on *knowledge specialists* – individuals who possess relatively high levels of conceptual knowledge compared to others in their society – from the Human Relations Area Files in 55 traditional cultures. Many of these specialists are medicinal specialists who provide services to a clientele, on whom I focus in Chapter 4, but as I discuss in Chapter 3, specialists also frequently possessed high levels of knowledge in a variety of conceptual domains, such as botany

[2] A caveat, which I will raise throughout this dissertation (particularly in Chapters 3 and 4), is that knowledge transmission between senders and receivers vs. transmission between specialists and clients differ in important ways, e.g., involving transmitted know-how and/or transmitted services that are difficult to reverse engineer. These types of relationships are not always clearly distinguishable.

and meteorology. This dissertation will also use empirical data from a Tanzanian Maasai pastoralist population with whom I conducted field research, where I asked questions about trust, medicinal knowledge, and mutually beneficial sharing practices. I also conducted in-depth interviews, results of which I include in Chapter 4, with knowledge specialists who provide medicinal services to their clients.

The external influences on knowledge systems that this dissertation will clarify include acculturation, market integration, and socioeconomic variation, along with the characteristics of the knowledge domain itself. The latter is particularly important for knowledge specialists, as it shapes the ways that existing theories of cultural learning apply to the ethnographic observations that we, as anthropologists, are interpreting.

My somewhat roughshod framing of *knowledge* systems as comprising receivers and senders of informational content will be useful for framing the remaining chapters of this dissertation.

Chapter 2 focused on interviewing receivers, taking on the broader problem of trust about other people's reported knowledge amidst a risk of misinformation. Chapter 2 is based on surveys with Maasai participants, and it tests two mutually compatible factors in decision-making about whether or not a source's testimony should be viewed as trustworthy without available evidence. One factor is how people might weigh an important indirect social cue of competence, prestige, over their own personal experiences suggesting how knowledgeable a person is (Henrich & Gil-White, 2001;

Henrich & McElreath, 2007; see Henrich et al., 2001 for the clearest elaboration of this particular claim). Another factor is how people might weigh the decision task as a gamble, taking their own material incentives and the resources they would stand to lose, if incorrect, into account. We also consider the extensive acculturation and market integration that occurred in the past generation or so at the fieldsite, and how these influences might also shape decision-making. The paper was co-authored with Ed Hagen, and is now published in *Evolutionary Human Sciences* (Lightner & Hagen, 2021).

Chapter 3 focuses on senders, i.e., the experts and knowledge specialists who teach others and provide services to clients across 55 cultures in a variety of conceptual domains. As my collaborators and I showed, sometimes experts are relatively knowledgeable compared to a generally knowledgeable public – that is, their knowledge is not restricted to the expert in any way. In other cases, however, the expert's knowledge and skills are restricted only to experts. These outcomes, and how the expert relates to non-experts more generally, depend largely on the characteristics of the task domain that the expert specializes in. By task domains I mean the type of knowledge and skill an expert possesses, such as medicine, food preparation, or construction. The paper was co-authored with Cynthiann Heckelsmiller and Ed Hagen, and is currently accepted for publication in *Evolutionary Human Sciences* (Lightner et al., 2021a).

Chapter 4 focuses on the content of specialists' knowledge by investigating the supernatural theories of disease that healers tend to possess – though it also investigates how senders (specialists) and receivers (clients) relate to each other. It specifically combines a modification of the cross-cultural analyses in Chapter 3, along with qualitative and quantitative data collected during fieldwork with Tanzanian Maasai pastoralists. The modification to our cross-cultural analyses included a focus on medicinal specialists, who represented a large proportion of our data in Chapter 3, and it includes several additional variables relating to religious beliefs and behaviors. We found that many medicinal specialists who heal others are also religious leaders who use supernatural theories of disease, and clients defer to them based on their efficacy. This paper was co-authored with Cynthiann Heckelsmiller and Ed Hagen, and is currently under review at *Review of Philosophy and Psychology* (Lightner et al., 2021b).

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CHAPTER 2. ACCULTURATION AND MARKET INTEGRATION ARE ASSOCIATED WITH GREATER TRUST AMONG TANZANIAN MAASAI PASTORALISTS

Aaron D. Lightner, Edward H. Hagen

Abstract

Acting on socially learned information involves risk, especially when the consequences imply certain costs with uncertain benefits. Current evolutionary theories argue that decision-makers evaluate and respond to this information based on context cues, such as prestige (the *prestige bias model*; PBM), and/or incentives (the *risk and incentives model*; RIM). We tested the roles of each in explaining trust using a preregistered vignette-based study involving advice about livestock among Maasai pastoralists. In exploratory analyses, we also investigated how the relevance of each might be influenced by recent cultural and economic changes, such as market integration and shifting cultural values. Our confirmatory analysis failed to support the PBM, and partially supported the RIM. Exploratory analyses suggested that regional acculturation varied strongly between northern vs. southern areas, divided by a small

mountain. Consistent with the idea that trust varies with socially transmitted values and regional differences in market integration, people living near densely populated towns in the southern region were more likely to trust socially learned information about livestock. Higher trust among market-integrated participants might reflect a coordination solution in a region where traditional pastoralism is beset with novel conflicts of interest.

2.1 Introduction

Individuals must often make critical decisions based on information provided by others who might be untrustworthy, either because their information is poor or they have incentives to deceive. As an example, suppose that a herder suggests to another where he should move his livestock during the dry season to find grass and water. In a semi-arid ecology such as northern Tanzania, this advice implies an unavoidable cost (moving the herd to another area) with a large but uncertain benefit. How should the herder decide if this advice is trustworthy? (Here, we define "trust" as "reliance upon [socially learned] information... about uncertain environmental states and their accompanying outcomes in a risky situation"; Schlenker, Helm, & Tedeschi (1973), p. 419; see also Yamagishi, Kikuchi, & Kosugi (1999).)

Current theories of social learning focus on the source of information and/or risks of acting on the information. Some theories emphasize evolved learning biases, triggered by cues such as the prestige of the information source (Henrich, 2017; Richerson & Boyd, 2005), which we refer to as the *prestige bias model* (PBM). Other theories emphasize flexible copying based on incentives, i.e., expected outcomes of acting on the information and possible conflicts of interest with the information source (Binmore, 2011; Mercier, 2020; Morin, 2015), which we refer to as the *risk and incentives model* (RIM). In a preregistered study, we test the PBM and the RIM among Maasai pastoralists. Evaluating socially learned information is further complicated when individuals traverse varying cultural and economic contexts: Individuals who might be trusted sources of information in one context might be mistrusted in another. We investigate these effects in a *post hoc* exploratory analysis.

2.1.1 Prestige bias model of trust (PBM)

In the simplest models of social learning, individuals simply learn from a random individual in the population (Rogers, 1988). Social learning can be enhanced, however, by preferentially copying more knowledgeable individuals. One strategy would be to assess the knowledge of all group members via personal experience over time, and then choose to copy the most knowledgeable individual(s). But this would be time consuming and error prone – *directly* observing performances can be noisy, leading a learner to misperceive competence (e.g., see Boyd & Richerson, 1985, pp. 92–94, ch. 8). Alternatively, dual inheritance theorists argue that evolved context biases can solve this problem by exploiting simple and *indirect* social cues, triggering simple decision rules (Richerson & Boyd, 2005). Prestige bias involves preferentially copying individuals with *prestige* gained by "freely conferred deference" (Boyd & Richerson, 1985; J. Henrich & Gil-White, 2001). This is efficient because it simplifies a complex learning task into a much simpler one. Relying on such a cue can reduce noise by "averag[ing] over many performances, which can help reduce the error in the learner's assessment of who to learn from" (Henrich & McElreath, 2007, p. 559; see also Hill & Kintigh, 2009). Prestige bias is also adaptive because this simplification can be trusted across socioecological contexts and generational time (Henrich & McElreath, 2003). Modeling studies demonstrate that prestige can signal locally relevant skills and/or expertise (Plourde, 2008), and naive learners can trust prestige signals to acquire locally adaptive knowledge ("information goods") quickly and accurately in a wide range of conditions (Panchanathan, 2010). As J Henrich et al. (2001) explain (p. 345, emphasis added):

> A substantial amount of cross-cultural ethnography (e.g., Dove 1993; Hammel 1964; Rogers 1995; Moore 1957) and laboratory psychology (for a summary, see Gil-White and Henrich 1999) suggests that humans everywhere possess a tendency to copy prestigious individuals, i.e., those who

> receive the most displays of respect/deference from others. This mechanism embodies two shortcut heuristics. First, by preferentially copying a "bundle" of cultural traits from prestigious individuals (prestige correlates with skill/knowledge and often wealth) copiers can rapidly acquire a repertoire of fitness-enhancing or success-oriented traits (i.e., better-than-average solutions to the problems of life). Second, *rather than gradually learning via individual experience who the most successful, knowledgeable, or skillful individuals are, copiers rely on honest ethological and sociolinguistic signals of respect that other individuals display toward such high status individuals.*

Empirical support for the PBM is mixed (Jiménez & Mesoudi, 2019). In support, food taboos among pregnant and breastfeeding women in Fiji largely improved their health outcomes, and some of these taboos were transmitted by prestigious elderly women (J. Henrich & Henrich, 2010; cf. Placek, Madhivanan, & Hagen, 2017). Prestige was also a reliable indicator of hunting skill among the Hadza (Stibbard-Hawkes, Attenborough, & Marlowe, 2018) and Tsimane (von Rueden, Gurven, & Kaplan, 2008), although for the latter, ethnobotanical knowledge did not predict prestige (Reyes-Garcia et al., 2008). In experiments, children and adults use prestige cues to improve their performance in a novel task, especially when they are performing poorly (Atkisson, O'Brien, & Mesoudi, 2012; Chudek, Heller, Birch, & Henrich, 2012). Experiments have also found that when cues of success are available, participants will favor those cues over prestige cues (Brand, Heap, Morgan, & Mesoudi, 2020). Surveys of the ethnographic literature on social learning among hunter-gatherers and on leadership, however, found little evidence of prestige biased learning (Garfield, Garfield, & Hewlett, 2016; Garfield, Hubbard, & Hagen, 2019).

Because the PBM relies on a narrow, restricted range of cues, a cost-accuracy tradeoff leaves room for costly or "irrational" behaviors with specific, unavoidable, maladaptive side effects (e.g., see Richerson & Boyd, 2005, pp. 119–124, 156 for discussion). In weaker versions of the PBM prestige is conceptualized as one important cue among many, whereas in stronger versions of the PBM prestige can override other cues and decisions thus sharply diverge from individual self-interests, including non-adaptive food taboos (Aunger, 1994; J. Henrich & Henrich, 2010), market bubbles (Bell, 2013), and suicide epidemics (Henrich & McElreath, 2007; Mesoudi, 2009). This ambiguity among possible interpretations in the prestige bias literature is discussed in Morin (2016).

2.1.2 Risk and incentives model of trust (RIM)

People might also be "epistemically vigilant", or largely resistant to social influence while conditionally trusting advice based on message content, risk, incentives, and perceived conflicts of interests with the sender (Mercier & Sperber, 2017; Trouche, Johansson, Hall, & Mercier, 2018; see also Binmore, 2011; Hess & Hagen, 2006; Mercier, 2020; Morin, 2015). If the trustworthiness of socially learned information is questionable, the RIM emphasizes that acting on it is a *gamble* between two options, possibly with equivalent expected values, with a low-variance safe option (high probability of receiving a low payoff) and a high-variance risky option (lower probability of a high payoff). Individuals preferring the safe option are *risk averse*, and those preferring the risky option are *risk seeking*.

Which of these option types is adaptive depends strongly on an organism's current state: Foragers with a sufficient energy budget, for example, should be risk averse, whereas foragers with a dangerously low energy budget should be risk seeking (Stephens, 1981). The relationship between resource scarcity and risk seeking, mediated by stress, is supported in non-human animal experiments manipulating energy budgets (Caraco et al., 1990; Kacelnik & Bateson, 1996), as well as observational studies in humans (see Winterhalder, 2007 for review). As biologists and economists have observed, this apparent risk sensitivity of decision-making might be explained as maximizing long-term growth rates under multiplicative dynamics (Kacelnik & Bateson, 1996; Peters, 2019; Peters & Gell-Mann, 2016; Price & Jones, 2020).

Theoretical distinctions between social vs. individual learning strategies could distract from the fundamental task in most real-world decision-making: weighing the expected costs and benefits (Morin, 2015). If acting on social influence is cheap and outcomes are trivial, then a useful decision rule should not seek more expensive cues; but if the stakes are high enough, then a high cost for accuracy might be worth paying.

Experimental evidence has supported some key aspects of the RIM in humans. People are more likely to take high-risk decisions under stress and resource scarcity (Dalton, Nhung, & Rüschenpöhler, 2019; Kirchler et al., 2017; Putman, Antypa, Crysovergi, & van der Does, 2009), although some experiments show that poverty induces risk aversion (a poverty trap; Yesuf & Bluffstone (2009)). Kuznar (2001) also showed that higher levels of wealth were associated with risk aversion among moderately wealthy herders, but with the exception of risk prone herders in the highest wealth class. In social contexts, participants' evaluations of argument persuasiveness are conditioned on how relevant the consequences of its message would be for them (Petty & Wegener, 1998). If consequences are not relevant, then people rely on social information and heuristics such as expertise and audience approval (Axsom, Yates, & Chaiken, 1987). If they are relevant, then they evaluate the content of the message (Petty, Cacioppo, & Goldman, 1981). Content evaluation might trend toward psychologically attractive ideas (Miton, Claidière, & Mercier, 2015), individual preferences (Acerbi & Tehrani, 2018), or attempts to reduce the ambiguity of social cues when multiple cues are available (Conway & Schaller, 2005). People are sensitive to conflicts of interest and social informational "dependencies" (Hess & Hagen, 2006; Mercier & Miton, 2019), and are more likely to trust expert advice when they are given clear demonstrations of expertise rather than an argument from expertise (Mercier et al., 2019).

2.1.3 The impact of changing ideational and material culture on trust

Another perspective, which is consistent with the RIM and some interpretations of the PBM, is that decisions about social information can flexibly adapt to variation in "ideational" (values and norms) and "material" (economic) culture. If widespread incentives are suddenly distorted by changing material conditions, such as market integration and/or developing infrastructure, then ideational changes might predictably follow (Aoki, 2011; Binmore, 2011; Yamagishi & Suzuki, 2009). Proponents of this view often start from an assumption of *methodological individualism*, similar to the RIM (i.e., social phenomena are grounded in individual incentives; see North (1990)). Market integration in developing nations and small-scale societies imposes novel transaction costs, which can in turn disrupt existing sharing institutions and undermine widespread trust (e.g., Ensminger, 1992; Baird, 2014; Kasper & Borgerhoff Mulder, 2015). This might render social status, kinship, and reciprocity insufficient for establishing trust in most social interactions. This would create a demand for culturally evolved norms to sustain mutually beneficial exchanges, such as fairness and/or religious beliefs that stabilize trust by manipulating perceived incentives (J. Henrich et al., 2010) or encourage use of inferred mental states in moral judgements (Curtin et al., 2020). Costly religious rituals also signal trustworthiness among strangers (Ensminger, 1997; Power, 2017), and religious beliefs in omniscient, moralistic gods stabilize trust in large-scale, market-integrated communities (Lang et al., 2019; Purzycki et al., 2016).

2.1.4 Study aims and context

Here, we (1) test the PBM and RIM as models of trust using a vignette-based experiment involving advice about livestock among Maasai pastoralists, and (2) conduct an observational study of the impact of recent cultural and economic changes, such as market integration and shifting cultural values, on trust.

Preregistered predictions

We preregistered predictions for strong and weak versions of the PBM, and for the RIM.

Our prediction for both the strong and weak versions of the PBM model was: (i) advice about livestock would be more likely to be trusted and acted on when it comes from a prestigious person than when it comes from a person deemed generally knowledgeable from personal experience. Our prediction for the strong version only was (ii) trust would not be impacted by material incentives, such as household resource scarcity or livelihood diversification (i.e., how much they depend on livestock for subsistence).

Our predictions for the RIM were: (i) advice would be more likely to be trusted when resources are scarce (i.e., participants are more likely to take a risk), and less likely to be trusted when a participant is wealthy and mostly depends on livestock for subsistence (i.e., participants are more risk averse). Additionally, it predicts (ii) no additional effect of prestige cues on trust over other social cues, such as knowing from experience that someone is generally knowledgeable.

Our prediction for the weak version of the PBM only was (i) advice would be more likely to be trusted when it comes from a prestigious person and when resources are scarce (PBM+RIM).

Preregistration materials can be viewed at https://osf.io/5p7ut.

Description of the field site

This study took place in Eluwai, a Kisongo Maasai village in Monduli Juu highlands of northern Tanzania. (In Tanzania, "villages" refer to administrative jurisdictions, and do not necessarily imply that households in the community are clustered together.) Kisongo Maasai groups in Monduli Juu have depended mainly on cattle for centuries. Rainfall occurs bimodally and consists of short, massive downpours separated by long, hot dry seasons. Maasai have traditionally been semi-nomadic, patterning seasonal movement with expected rainfall while navigating livestock risks, such as drought and disease (Jacobs, 1965; Spear & Waller, 1993). Strategies for reducing risk can include manipulating herd composition and breeding rate in ways that maximize long-term household survival (Dahl & Hjort, 1976; Mace, 1993), and avoiding energetically expensive migrations into overgrazed or excessively dry areas (Butt, 2016). Cattle herding is a high-risk livelihood, and in a semi-arid ecology such as Monduli Juu, a successful herder is a risk averse and mobile herder.

In the present day, however, people in Monduli Juu are almost completely settled into sedentary lifestyles, a result of postcolonial land privatization and the Ujamaa villagization initiative that divided rural regions into administrative jurisdictions termed "villages" (Boesen, 1976). Land conflict and overgrazing now make pastoralism an exceedingly difficult subsistence strategy (McPeak, Doss, & Little, 2011). The last two decades or so have seen a sharp uptick in agricultural practices, land privatization, spreading urbanization, and infrastructure development. Now, more than ever before, herd movements are restricted by property lines, and the grass and water on which livestock rely are scarce resources. These changes are accompanied by market integration and a steady influx of cash from safari tourism, non-government organizations investing in formal education, and increasingly influential local Christian missionaries (Hodgson, 2005). As a result, there is some tension between traditional vs. modern lifeways: Maasai value their traditions, and pure reliance on cattle is considered an ideal, but a growing number of Kisongo Maasai see ongoing cultural and economic changes as opportunities they should embrace (Heckelsmiller, 2015; Hodgson, 1999; see also Galaty, John G, 1982; Homewood, Trench, & Kristjanson, 2009; Jandreau & Berkes, 2016).

Eluwai village spans a wide range of rural landscape in Monduli Juu, and is roughly split into northern and southern regions by a forested mountain, about 600 meters in height (average base to peak). See figure 1. The southern region is connected by a walking path to Emairete, a small but densely populated town with a weekly market, multiple churches, and a few small businesses. Cell phone communication in the southern region is both possible and frequent, and Emairete has an Airtel retailer for purchasing cell phone minutes. Emairete itself is linked by paved road to Monduli Chini, a much larger town nearby consisting of several businesses and biweekly markets. The northern region, in contrast, is relatively isolated, surrounded by sparsely populated highlands and the Rift Valley running along the northeast. Cell phone reception is mostly lacking. Contact from the northern to southern region can require about a day or so of walking during the dry season, but is difficult when walking routes and erosion canals are flooded in the rainy season.

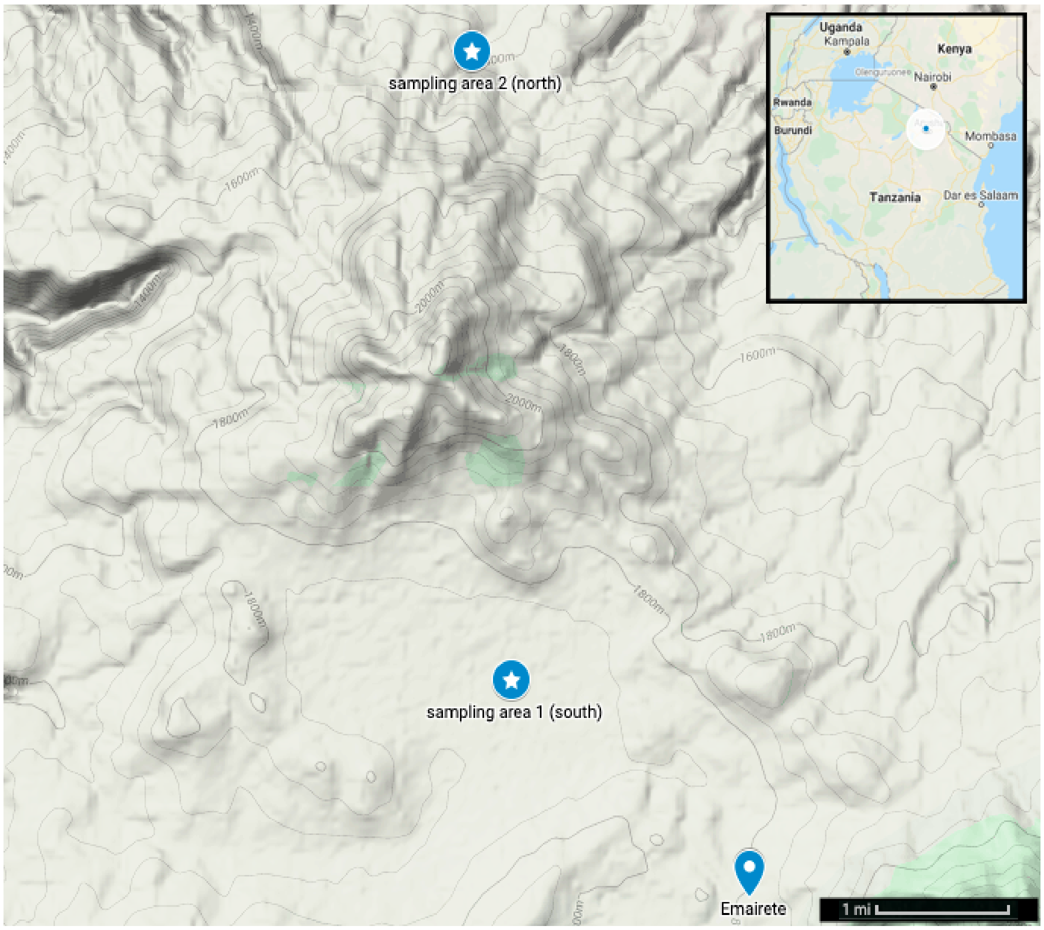

Figure 2.1.1: Eluwai village area with terrain image showing the approximate center of sampling area 1 (southern region) and sampling area 2 (northern region), both of which are separated by a small mountain (center). Emairete town neighbors the south of sampling area 1, and is connected by paved road to a larger town, Monduli Chini, which is slightly further south (not included in this map). Inset: Map of Tanzania showing the approximate location of the fieldsite in northern Tanzania (blue point, encircled in white).

2.2 Methods

Data collection involved structured surveys and a trust vignette experiment with adult Kisongo Maasai pastoralists ($N = 225$; 41% female, 59% male) in both northern ($N = 141$) and southern ($N = 84$) regions of Eluwai. Surveys in the southern region were collected by A.D.L. with assistance from a Maasai translator, and by an additional local Maasai research assistant. Surveys in the northern region were collected by another local Maasai research assistant. Both research assistants have more than ten years of experience administering surveys to local populations, and were trained to conduct the survey by A.D.L. Data were collected January through March 2020. Interviews took about 30 minutes. Each participant was paid 10,000 Tanzanian Shillings (about $4.35 USD) for their participation (about the price of lunch at a local restaurant). All preregistered predictions, models, and analysis scripts can be found at https://osf.io/5p7ut. All protocols and survey materials were approved by Washington State University IRB and Tanzanian Commission for Science and Technology (COSTECH) prior to data collection.

2.2.1 Study design

To test the PBM and RIM, we conducted a vignette experiment in which a hypothetical person from the community describes an inconveniently faraway location (about a day walking), where he says the participant should move their livestock to find plenty of available grass and water. The advice presents a conundrum: Should the participant trust the advice and act on it? Should they be skeptical and fact-check it first? Should they reject the advice altogether? If the advice is accepted, then it would lead to a large benefit if true, but a large cost if false. If it is rejected, then it would be an opportunity cost if true, but avoid a large cost if false. If the advice is fact-checked before acting on it, then a smaller cost is taken on to reduce the risk of accepting the advice and acting on it. (In the literature on the evolution of social learning, asocial learning is (*a priori*) more costly than social learning. It is worth emphasizing that our study does not compare social to asocial learning. Instead, it compares social to state-dependent learning, with asocial learning as one of our two outcomes (i.e., the "fact-checking" outcome variable), consistent with the literature we cite on trust. In other words, *given social learning*, what predicts trust – prestige or state?)

Each participant was randomly assigned to either a *prestige* condition or a *participant experience* condition. In the prestige condition ($N = 113$) the source of advice was described as a person with high levels of *nkanyit*, an important Maasai prestige concept that translates in Maa to "respect", but also has connotations of fear and deference, cattle wealth, and indisputable authority (Spencer 1965, 1988). To confirm these connotations, we asked a subset of our participants to freelist what gives a person nkanyit. The most salient responses included cattle weath, caring for a large family, having good moral character, helping others, and being knowledgeable (see the SI). Consistent with the assumptions in our study design, informants also emphasized that although nkanyit can imply knowledge, knowledge does not imply nkanyit.

Prestige bias theorists argue that cues of prestige can be more reliable than "gradually learning via individual experience who the most successful, knowledgeable, or skillful individuals are" (Henrich et al., 2001, p. 345). In the participant experience condition ($N = 107$) the source of advice was therefore described as someone the participant has known from personal experience to be generally knowledgeable. (Our use of the term *experience* refers to the participant's experience that the fictional advisor is generally knowledgeable, and does not imply that the fictional advisor actually has experience of the grazing conditions that he is describing.)

Participants were then asked how much they trusted the advice, and whether or not they would fact-check it first (i.e., personally visit before taking their livestock there). A more comprehensive structured survey was then conducted (described below). It is worth noting that in neither condition was the fictional source of advice described as having specific or direct knowledge of grazing conditions. See the SI for complete vignette text and nkanyit freelist data.

2.2.2 Measures

Experimental outcomes

Our two post-intervention outcome variables were *trust* (stated level of belief that the advice given is true) and *fact-checking* (if the participant would verify the advice before acting on it). Trust outcomes were coded on a three-point scale (1 = completely trust, 0.5 = somewhat trust, 0 = does not trust). Fact-checking outcomes were measured as simple yes/no responses (1 = yes, 0 = no). See the preregistration https://osf.io/5p7ut and section 3 of the SI for details.

Observational measures for preregistered tests

Household-level resource scarcity was based on food insecurity scores and a proxy measure of household need. Food insecurity scores were determined by a modified 5-item version of a standard 6-item household food insecurity survey, where higher values indicate higher insecurity (Blumberg, Bialostosky, Hamilton, & Briefel, 1999). (Prior to data collection, a question about diet breadth was removed because it did not make sense for participants in this region, where narrow diets of milk and meat are ideal.) Household need was approximated using consumer-to-producer ratios (i.e., total number of people living in the household, divided by people reported to regularly contribute to subsistence in the household; more consumers per producer implied higher need). Measures of household wealth were based on an index consisting of three reliable wealth indicators in the region: presence/absence of a solar panel (1 = presence, 0 = absence), roof material (1 = metal, 0 = grass), and number of wives in the household. To measure how dependent a household was on livestock, we collected a list of the different ways people in the household made a living, using freelists and prompted options with yes/no responses. Prompts were livestock, farming, milk/meat sales, crop sales, handcraft sales, wage labor, owning a business, teaching, and other (if yes, specify). Dependence on livestock was then estimated by dividing presence/absence of herding livestock for subsistence (1 = yes, 0 = no) by the total number of subsistence sources listed, creating a proportion of livelihood strategies involving livestock (1 = completely dependent on livestock, 0 = not dependent on livestock at all).

Exploratory measures

Our survey included several measures across two domains – ideational and material – for which we had no preregistered hypotheses. Measures of traditional beliefs (TB) included cultural values, such as religious beliefs and practices, e.g., religious affiliation, frequency of prayer (coded on a ranked scale between 1 = never and 5 = very often), and beliefs about god's characteristics. Whether or not god punishes misbehavior; rewards good behavior; and is omniscient, omnibenevolent, and/or omnipotent were each measured as yes (1), no (-1), or don't know (0). Cultural values involved agree/disagree responses to divisive statements that are rooted in traditional

Maasai ideals. Traditionally agreeable statements include: females should be circumcised, all cattle in the world rightfully belong to Maasai people, it is acceptable to raid cattle from people who are not Maasai, and it is ideal for elder men to have multiple wives; a disagreeable statement includes: it is acceptable for women to see a warrior eat meat. Traditionally neutral statements held mostly by Christians in the region include: belief in god is the most important thing in life, and women and children should be educated in school (e.g., Jacobs, 1965; Hodgson, 1999; Spear & Waller, 1993; Spencer, 1965). Responses to each statement in the cultural values survey were measured as strongly agree (2), agree (1), no opinion (0), disagree (-1), strongly disagree (-2).

Material domains included an *a priori* index of market integration (MI) to approximate frequency of cash sales and purchases, based on how often people made purchases at the market (coded on a ranked scale between 1 = never and 5 = very often), whether or not participants sold handcrafts, crops, and/or dairy products at markets (0 = no, 1 = yes for each), and frequency of cell phone use (1 = never, 2 = sometimes, 3 = often), yielding an index range of 2-10. Measures also included level of education (0 = none, 1 = primary, 2 = secondary) and literacy (0 = no, 1 = yes). Herd size and composition (e.g., cattle, sheep, goats, donkeys, and chickens) were self-reported and also included as tropical livestock units (TLU), an estimate of livestock resources based on grazing capacity (Jahnke & Jahnke, 1982).

Although our use of nkanyit as a prestige cue was motivated by prior key informant interviews and existing literature (e.g., Spencer, 1965, 2004a, 2004b), we also collected freelist data ($N = 57$; south: $N = 41$, north: $N = 16$) about nkanyit to validate this choice. See SI for details.

2.2.3 Confirmatory analyses

We tested our predictions using separate sets of logistic regression models for the PBM and the RIM, as specified in our preregistration, with $\alpha = 0.05$. For the strong version of the PBM, our independent variable was the vignette condition only (VC: 0 = experience, 1 = prestige). To adhere to our preregistration, we modeled both outcomes using logistic regression, despite the trust outcome being on a three-point scale (0, 0.5, and 1; see Britt & Weisburd (2010) and the SI where we fit ordinal regression models). We predicted a statistically significant positive coefficient for VC for the trust outcome, and a statistically significant negative coefficient for the fact-checking outcome:

$$\text{logit}(\text{trust}) = \beta_0 + \beta_1 VC, \text{where we predicted } \beta_1 > 0$$

$$\text{logit}(\text{check}) = \beta_0 + \beta_1 VC, \text{where we predicted } \beta_1 < 0$$

For the RIM, our independent variables were food insecurity scores (F), household need (N), wealth (W), and dependence on livestock (D) for subsistence. We predicted that for trust outcomes aggregated across conditions (i.e., ignoring any effect of VC), we would find statistically significant positive coefficients for F and N, and statistically significant negative coefficients for W and D. We predicted these coefficients to be reversed for fact-checking outcomes:

$$\text{logit(trust)} = \beta_0 + \beta_1 F + \beta_2 N + \beta_3 W + \beta_4 D,$$

$$\text{where we predicted } \beta_1, \beta_2 < 0, \text{and } \beta_3, \beta_4 > 0$$

$$\text{logit(check)} = \beta_0 + \beta_1 F + \beta_2 N + \beta_3 W + \beta_4 D,$$

$$\text{where we predicted } \beta_1, \beta_2 > 0, \text{and } \beta_3, \beta_4 < 0$$

We then compared the PBM, RIM, and PBM+RIM (PBM+RIM was the RIM models with an additional term for VC, which corresponds to the weak version of the PBM) using the corrected Akaike information criterion (AICc), preferring the model with the lowest AICc value (Burnham & Anderson, 2004).

2.2.4 Exploratory analyses

Prior to fieldwork, we anticipated cultural and economic variation would be associated with different response patterns but did not know how it would be distributed. To explore covariation of all diverse variables characterizing sociodemographic, economic, and ideational aspects of participants in our dataset, we conducted a principal components analysis (PCA) on all quantitative observational measures on households and participants for which there were 10 or fewer missing values, resulting in 53 measures across all domains in the survey. If the principal components were interpretable, we aimed to test if one or more of them was associated with our *trust* and *fact-checking* outcomes. (The PCA excluded both outcome variables, region, and experimental condition.)

To use data from all participants, we imputed missing values using the *mice* package (van Buuren & Groothuis-Oudshoorn, 2011) for multiple imputation by chained equations (MICE; Azur et al. 2011), with the default predictive mean matching method for numeric and logistic regression for binary variables. MICE assumes that data are missing at random (MAR). That is, after controlling for all other variables in the study, any remaining missingness is completely random. All exploratory results, including the PCA, are pooled estimates from five imputed datasets (Rubin, 1988). See the SI for a walkthrough of variable selection, multiple imputation processes, and quality checks on imputed datasets. (Because we did not preregister imputation, we did not use it for the confirmatory analyses.) Two participants had extremely high numbers of children, which had an undue influence on the PCA, and were therefore removed from the exploratory analyses.

2.3 Results

2.3.1 Cultural and regional variation

Summary statistics are in table 1. PCA results showed systematically different response patterns corresponding to ideational, material, and regional variation around Eluwai. The variables with high negative loadings on PC1 exclusively represented adherence to traditional Maasai ideals, beliefs and material practices (large herds; high dependence on livestock; approval of cattle raiding, female circumcision, and polygyny; and agreement with traditional Maasai beliefs about cattle ownership). The variables with high positive loadings on PC1 represented adherence to more recently introduced ideals, beliefs and material behaviors, such as crop sales, farming, higher education, literacy, handcraft sales, and prayer frequency (prayer frequency is generally higher among Christians, mean = 3.6, than among traditional Maasai believers, mean = 2.5; $t = 5.1$, $p = 10^{-6}$). PC2 reflected household size. See figure 2A.

We therefore interpret PC1 as a latent *acculturation* variable corresponding to *both* ideational and material changes in the area (e.g., market integration, missionization, education). (Acculturation is defined as an exchange of cultural features resulting from different cultural groups coming into continuous firsthand contact, such that cultural patterns of either or both groups might be changed and the groups remain distinct. See Kottak (2013, p. 569). Here, it refers to Tanzanian Maasai adopting ideas and behaviors that are a consequence of globalization.) Ideational and material variation along PC1 largely mapped onto regional variation, such that participants living north of the mountain clustered along the lower end of PC1 (more traditional) and participants living south of the mountain (near town, markets, churches, paved roads, and schools) clustered along the higher end of PC1 (more acculturated). See figure 2B. We found no meaningful sex differences in our PCA results. See SI for details.

name	complete	mean	sd	range	histogram
age	0.99	42.3	16.0	19 - 80	
wives	0.98	2.3	2.0	0 - 12	
children	0.98	6.5	6.8	0 - 40	
literate	0.99	0.2	0.4	0 - 1	
education	0.99	1.3	0.5	1 - 3	
sells dairy	0.98	0.1	0.3	0 - 1	
sells handcrafts	0.98	0.1	0.3	0 - 1	
wage labor	0.98	0.1	0.3	0 - 1	
farms	0.98	0.8	0.4	0 - 1	
sells crops	0.98	0.4	0.5	0 - 1	
owns a business	0.98	0.2	0.4	0 - 1	
teaches	0.98	0.0	0.2	0 - 1	
household size	0.98	9.2	10.8	1 - 105	
household labor	0.98	4.5	8.7	1 - 100	
freq. urban travel	0.99	1.8	1.1	1 - 5	
Engai/Christian same	1.00	0.6	0.7	-1 - 1	
god has a mind	0.99	0.2	0.8	-1 - 1	
god has a body	0.99	-0.2	0.8	-1 - 1	
god omnipotent	0.99	0.8	0.5	-1 - 1	
god omniscient	1.00	0.8	0.5	-1 - 1	
god omnibenevolent	0.99	0.8	0.6	-1 - 1	
god punishes	0.99	0.3	0.7	-1 - 1	
god rewards	0.98	0.5	0.6	-1 - 1	
freq. church/rituals	0.97	2.1	1.4	1 - 5	
freq. prayer	0.96	3.1	1.6	1 - 5	
freq. talk abt. god	0.96	1.5	1.1	1 - 5	
Maasai cattle rights	1.00	0.8	1.3	-2 - 2	

name	complete	mean	sd	range	histogram
polygyny	1.00	0.8	1.1	-2 - 2	
warrior food taboos	0.98	-0.5	1.2	-2 - 2	
cattle raiding	0.96	-0.1	1.3	-2 - 2	
educate children	1.00	1.2	0.9	-2 - 2	
educate women	0.97	0.9	1.0	-2 - 2	
cattle > cash	0.99	0.7	1.1	-2 - 2	
belief in god is important	0.98	1.0	0.9	-2 - 2	
children share religion	0.98	0.9	1.0	-2 - 2	
people share religion	0.98	0.8	1.0	-2 - 2	
farm for most food	0.99	1.0	0.9	-2 - 2	
female circumcision	0.98	0.3	1.3	-2 - 2	
worry about future of Maasai	0.96	0.3	1.1	-2 - 2	
god gives comfort/safety	0.99	1.1	0.9	-2 - 2	
donkeys	0.98	6.0	11.7	0 - 92	
chickens	0.99	5.3	19.0	0 - 250	
cattle	0.98	34.7	90.6	0 - 1000	
goats	0.97	32.5	67.3	1 - 750	
sheep	0.97	26.4	59.6	0 - 520	
metal roof	1.00	0.2	0.4	0 - 1	
solar panel	0.97	0.3	0.4	0 - 1	
market integration	0.96	4.1	1.2	1 - 7	
food insecurity	1.00	1.0	0.4	0 - 1.75	
household need	0.97	2.6	1.8	1 - 20	
dependence on livestock	0.97	0.5	0.2	0 - 1	
freq. cash purchases	0.99	3.5	0.7	1 - 5	
trust	0.97	0.3	0.4	0 - 1	
fact-check	0.92	0.8	0.4	0 - 1	

Table 2.3.1: Summary statistics for most of the quantitative and ranked observations data used in this study. This includes data used to model and test our study predictions, but also includes descriptive variables about the sample and a few key variables systematically varying across different regions of the field site. Trust and check refer to our two outcome variables, and food insecurity, household need, wealth, and dependence on cattle were used as observed predictors. Excluding both outcome variables, each variable showed here was included in the PCA described in this section.

2.3.2 Confirmatory analyses: testing the PBM and RIM

In both the vignette prestige condition and the experience condition, advice was treated with strong levels of skepticism (experience condition: 32% did not trust, 5.5% somewhat trusted, and 11% completely trusted; prestige condition: 33% did not trust, 4.6% somewhat trusted, and 14% completely trusted), and most participants stated that they would fact-check the advice before acting on it (86% in the experience condition, 82% in the prestige condition). Thus, participants had approximately equal, but low, trust for advice from both the prestigious individual and from the individual known to be knowledgeable from personal experience.

In our confirmatory analyses for trust outcomes, the RIM was supported (see table 2 for logistic regression model parameters and statistics, and figure 3 for RIM effects plots). AICc model selection suggested that the RIM had better support than the PBM (strong version) and PBM+RIM (weak version). (We re-ran trust models using an ordered logistic regression and found similar effects in each of our models. See the SI for additional analyses and weighted AICc table.)

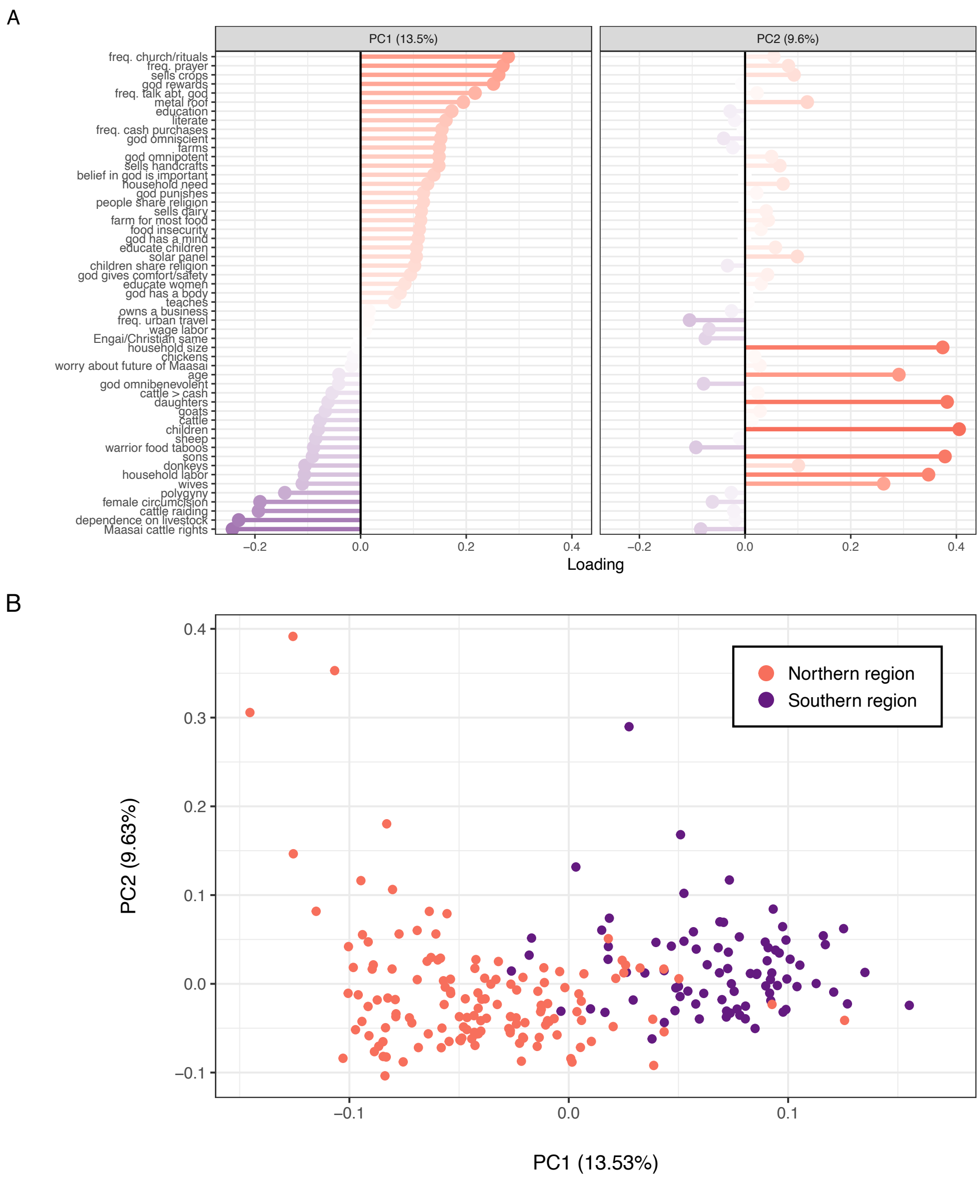

Figure 2.3.2: A: PCA loadings on PC1 and PC2, after including 53 quantitative variables from diverse domains in our analysis. B: PCA biplot, with each point representing one participant. Point colors correspond to participant region.

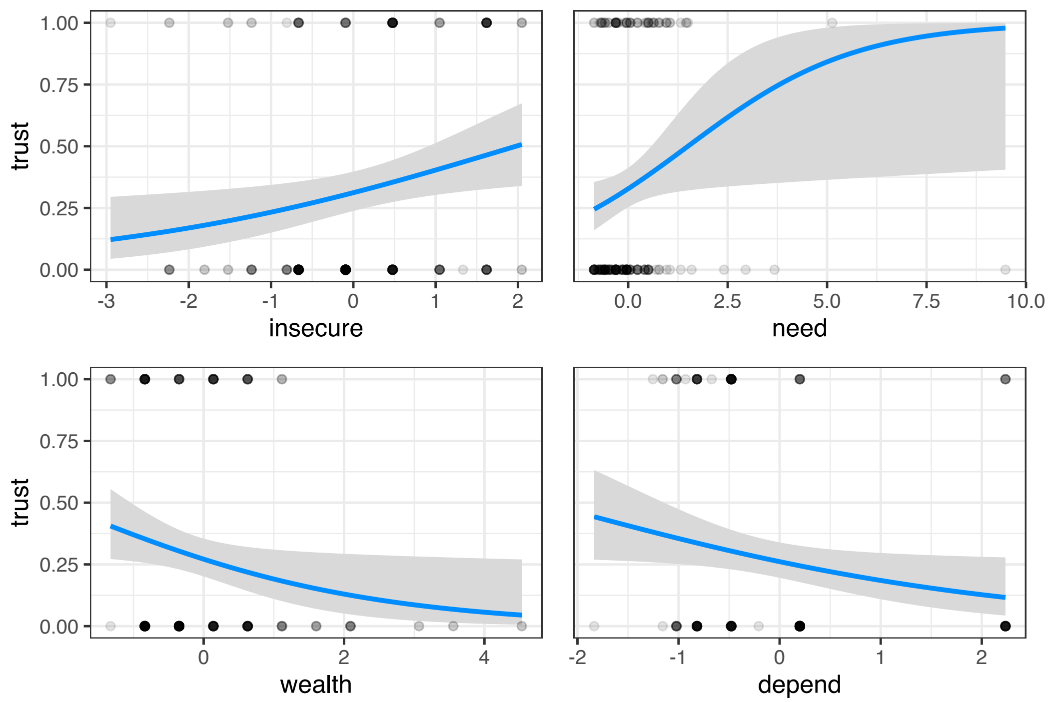

Figure 2.3.3: Logistic regression models for RIM predictors on trust outcomes. Model coefficients are in table 2 (column 2). Trust outcomes equal to 0.5 were rounded to 0 or 1 if their residuals were negative or positive, respectively.

Table 2.3.2: Logistic regression models for trust outcomes (left three models) and fact-checking outcomes (right three models). Estimates are log odds, with standard error in parentheses. For each outcome variable, output is shown for preregistered models PBM, RIM, and PBM+RIM.

	Dependent variable:					
	trust			check		
	PBM	RIM	PBM+RIM	PBM	RIM	PBM+RIM
conditionprestige	0.11		0.22	−0.32		−0.52
	(0.30)		(0.35)	(0.38)		(0.42)
	$p = 0.70$		$p = 0.53$	$p = 0.41$		$p = 0.22$
insecure		0.40	0.40		−0.16	−0.15
		(0.17)	(0.17)		(0.20)	(0.20)
		$p = 0.02^{*}$	$p = 0.02^{*}$		$p = 0.43$	$p = 0.45$
need		0.48	0.45		0.08	0.12
		(0.23)	(0.23)		(0.21)	(0.23)
		$p = 0.04^{*}$	$p = 0.05^{*}$		$p = 0.70$	$p = 0.62$
wealth		−0.46	−0.45		0.30	0.28
		(0.22)	(0.22)		(0.25)	(0.25)
		$p = 0.04^{*}$	$p = 0.05^{*}$		$p = 0.23$	$p = 0.26$
depend		−0.44	−0.47		0.36	0.44
		(0.21)	(0.22)		(0.26)	(0.27)
		$p = 0.04^{*}$	$p = 0.04^{*}$		$p = 0.17$	$p = 0.11$
Note:						$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

2.3.3 Exploratory analyses

Regional variation at the field site

We interpreted PC1 (figure 2) to be a latent acculturation variable, which was systematically lower in the northern region and higher in the southern region. Responses in the northern vs. southern regions varied on trust outcomes (north: 1 = 51%, 0.5 = 24%, 0 = 25%; south: 1 = 7.8%, 0.5 = 1.4%, 0 = 86%) and fact-checking outcomes (north: 1 = 69%, 0 = 31%; south: 1 = 92%, 0 = 8%). See figure S7. We therefore modeled each outcome variable as a function of PC1. Consistent with regional patterns, more acculturated participants were more likely to trust livestock advice and less likely to fact-check it, whereas less acculturated participants were less likely to trust and more likely to fact-check (figure 4).

Hierarchical cluster analysis

Variables belonging to both ideational and material categories had high loadings on PC1 (figure 2a), which in turn distinguished the northern and southern regions (figure 2b). To explore if response patterns naturally formed ideational vs. material clusters, we conducted a hierarchical cluster analysis using the Ward agglomeration method, with distances as $1 - corr$, and cluster p-values computed via multiscale bootstrap resampling (Suzuki, Terada, Shimodaira, & Suzuki, 2019). We identified five clusters that were reasonably well-supported by the bootstrap procedure ($p >$

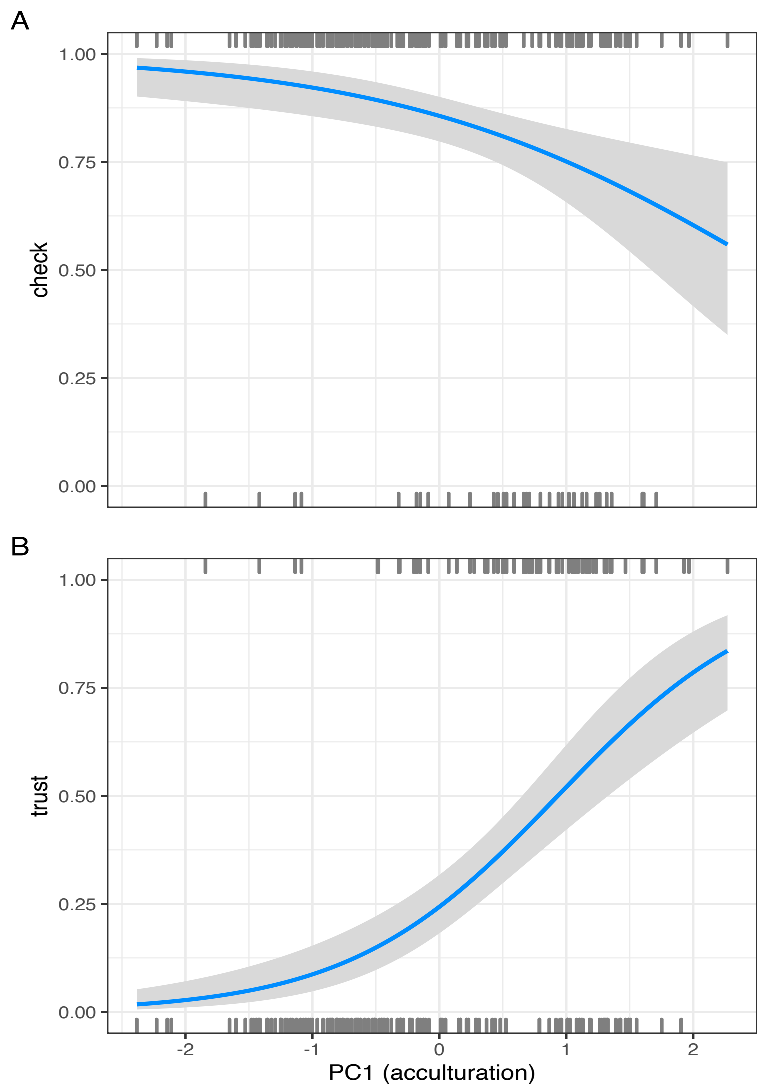

Figure 2.3.4: Fact-checking outcomes (A) and trust outcomes (B) predicted by PC1, the acculturation variable characterizing response patterns along the northern vs. southern sampling areas. Higher levels of PC1 correspond to higher levels of acculturation, such as Christianization and market integration. Lower levels of PC1 correspond to lower levels of acculturation, or traditional Maasai beliefs and economic practices.

0.8). These were education/urban, elder/household size, farming/religious, market integration (MI), and traditional beliefs/large herds (TB). See figure 5. Two of these (TB and MI) were clearly interpretable as ideational vs. material. Because we also developed an *a priori* MI index (see Exploratory measures), we denote the MI cluster here as *empirically determined MI* (EMI). (Note that we made no *a priori* TB index, as we did with MI.)

To explore if material or ideational clusters better predicted trust than PC1, we used MI, EMI, TB, and dependence on livestock for subsistence each as separate predictors of trust and fact-checking outcomes. (We included a model with dependence on livestock (referred to in the RIM as *depend*) because it strongly correlated with PC1, and varied markedly by region. In figure 6, this model is abbreviated as *DEP*.) Comparing these models to each other and the confirmatory models, we found that MI and EMI each predicted higher trust and lower fact-checking, and while these effects were larger than those in the RIM, neither were as large as the effect of PC1. Compared to MI, TB weakly predicted lower trust and higher fact-checking. (Because the effects of MI and EMI were similar, we refer to them interchangeably in the Discussion section as "market integration".) See figure 6. AICc model selection consistently suggested across imputations that PC1 models outperformed the other models, including the MI, EMI, TB, depend, and confirmatory models (table S5). Market integration nevertheless appeared to have a large impact on trust, compared to adherence to traditional beliefs and values. See SI for a more detailed discussion.

2.4 Discussion

In a preregistered vignette-based experiment, we tested the roles of learning biases (PBM) and incentives (RIM) in evaluating socially learned information about grazing conditions for livestock. The PBM predicted that if a source of information is prestigious compared to known from personal experience to be knowledgeable, people would be (1) more likely to trust and act on their advice, and (2) less likely to fact-check it first. Neither of these predictions were supported. Regardless of whether the source was prestigious vs. believed from personal experience to be generally knowledgeable, trust in socially learned information about grazing conditions was equally low in both conditions, and preferences for fact-checking were also equally high in both conditions. This lack of support was found when considering "strong" and "weak" versions of prestige bias (*sensu* Morin (2016); see Preregistered predictions and Study design sections); we tested the weak version in PBM+RIM but did not find a statistically significant effect of prestige (table 1). Nevertheless, 24% of participants did trust the fictional advice giver, suggesting that persons known to be knowledgeable via either their prestige or via personal experience are trusted to some extent.

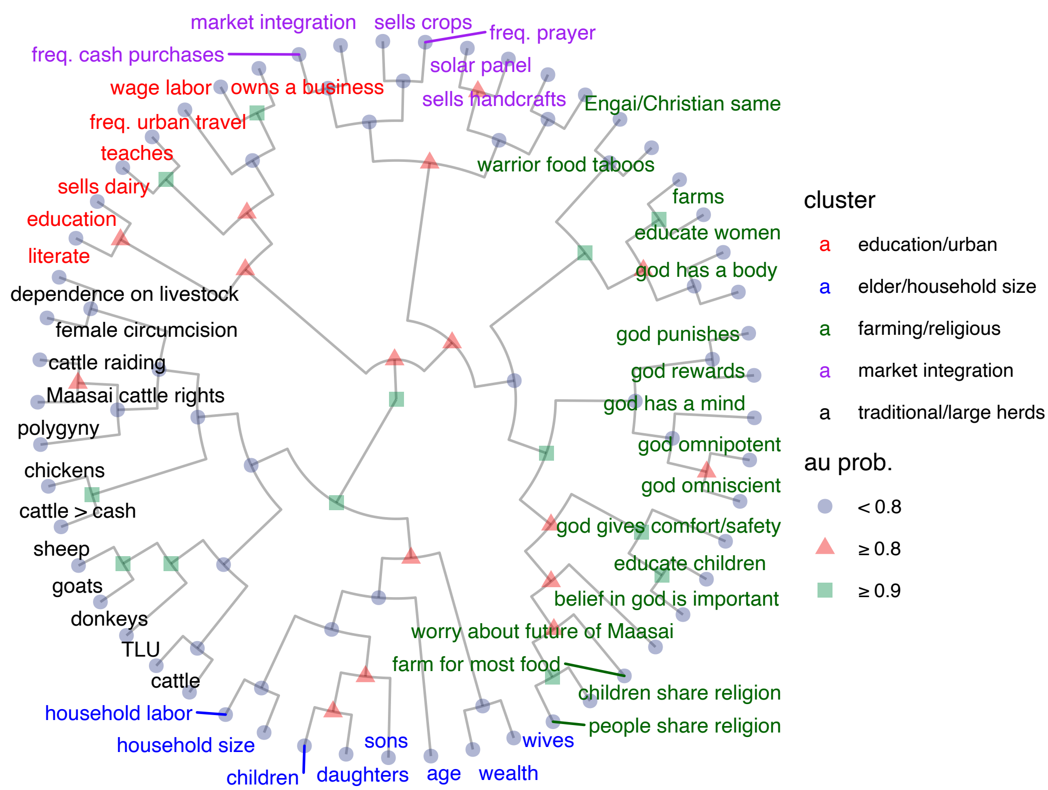

Figure 2.3.5: Hierarchical clustering dendogram with shapes corresponding to approximately unbiased (au) branching probabilities (bootstrapped n = 10,000), and colors corresponding to cluster ID. Each cluster is based in part on au probabilities and our interpretation of cohesive clusters (e.g., market integration, traditional livelihoods) Some clusters are less straightforward than others to interpret, but we nevertheless include a short cluster description next to each color.

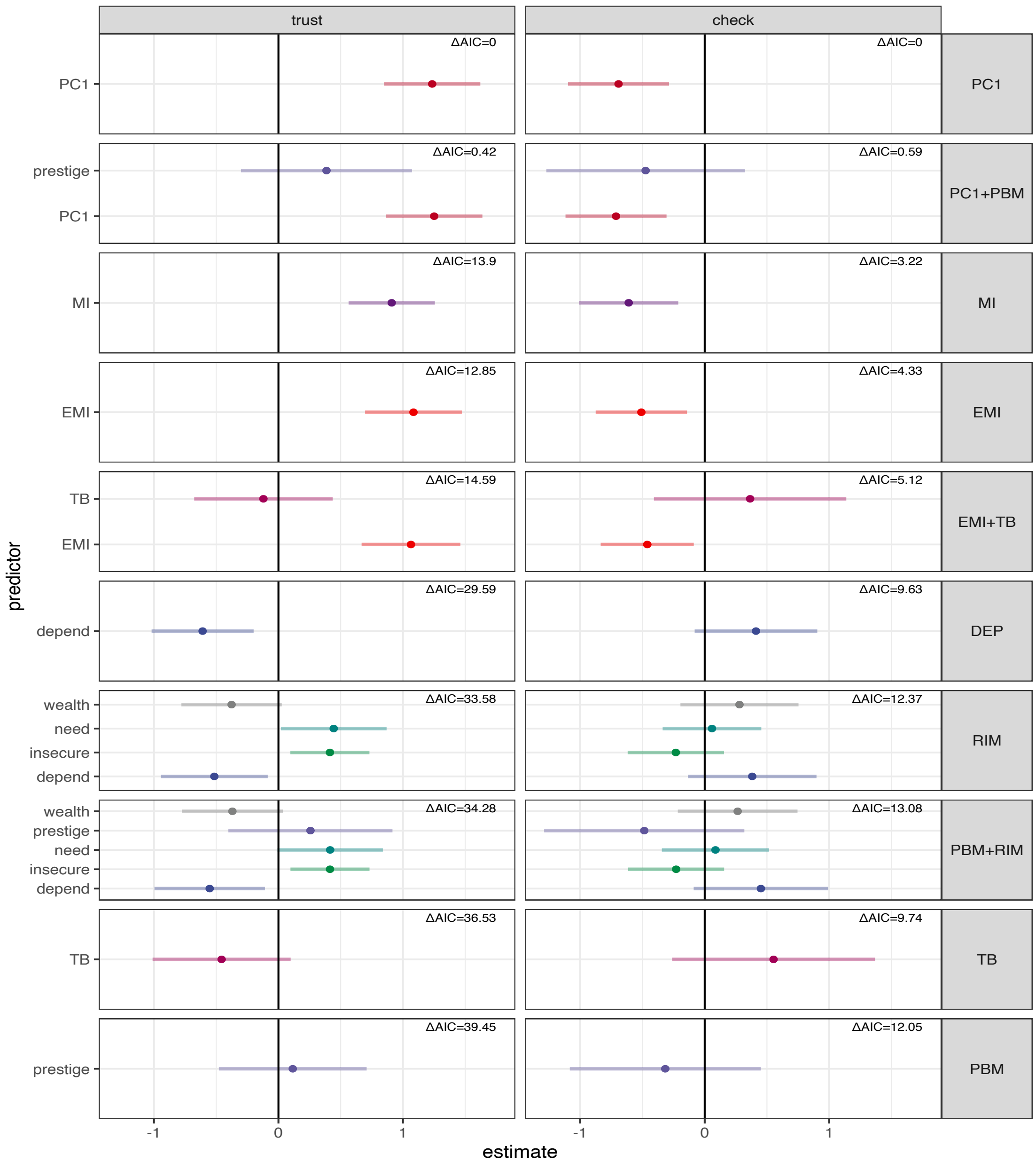

Figure 2.3.6: Coefficients plot for exploratory logistic regression models predicting trust and fact-checking outcomes. Points indicate regression coefficients (log odds scale), and error bars are +/- 2 SE. Facets are ordered from top to bottom in order of AICc score in weighted model selection.

The RIM predicted that resource scarce participants who are less dependent on cattle would be (1) more willing to take a risk and act on socially learned information, and (2) less likely to fact-check it first. Prediction 1 was supported, and prediction 2 was not. Observational measures of resource scarcity (household food insecurity scores and need) significantly predicted higher trust in, and willingness to act on, advice about livestock. Conversely, as predicted, proxy measures of livestock dependence for subsistence and household wealth predicted lower trust in the same advice. These measures, however, did not significantly impact participants' stated need to fact-check before acting on information.

The RIM outperformed the both strong and weak versions of the PBM by AICc on both trust and fact-checking. See tables 1 and S2. These results imply that for Maasai in this region, risks and incentives influence trust about livestock advice, whereas the effect of prestige is indistinguishable from assessments of knowledgeability based on participants' personal experiences. More notably, trust and reliance on social learning, at least for advice about livestock movement, was generally quite low (see also Toelch, Bruce, Newson, Richerson, & Reader, 2014; Mesoudi, Chang, Murray, & Lu, 2015).

2.4.1 *Exploratory analysis of regional acculturation as a predictor of trust*

Regional acculturation strongly predicted trust. Acculturation was the first principal component of variables reflecting market integration vs. dependence on livestock, and traditional vs. non-traditional views about polygyny, female circumcision, and cattle raiding (figure 2). The study site comprised two distinct regions separated by a small mountain, with southern, more acculturated participants living closer to densely populated towns exhibiting higher trust, and northern, less acculturated participants living on a more rural and isolated side of the mountain exhibiting lower trust (figures 1 and 4).

To more precisely characterize acculturation, we identified clusters of variables related to material culture (market integration, MI) and ideational culture (traditional beliefs, TB). MI was a stronger predictor of trust than TB, and a model with MI alone outperformed a model with both, suggesting that MI better explained the strong positive relationship between regional acculturation and trust. Nevertheless, the model with acculturation, which reflects covariation among many variables beyond MI, had the best performance of all (see SI for AICc tables). This suggests that acculturation was irreducible to either economic or ecological accounts alone (e.g., Edgerton, 1971). Our results also suggest that acculturation has a larger influence on advice-taking than do risks and incentives.

2.4.2 Material and ideational culture

Material vs. ideational theories of culture have a long history in social sciences. Materialist accounts emphasize environmental feedback and incentive structures: individuals must learn to maximize resources, and behavioral patterns varying between groups correspond to different relevant features in the environment (e.g., MI, livelihood risks). If risk and uncertainty are part of a local subsistence strategy, cultural adaptations might feature heightened sensitivity to risk (Goldschmidt & Goldschmidt, 1976; Steward, 1972). East African pastoralists optimize herd size and composition (Mace, 1990; Mace & Houston, 1989; see also Næss, Bårdsen, Pedersen, & Tveraa, 2011), and pattern herd movement based on past and current payoffs (Butt, Shortridge, & WinklerPrins, 2009; see also Domjan & Burkhard, 1986).

Ideational accounts, in contrast, emphasize beliefs, attitudes, and values. Socially transmitted information can establish complex behavioral conventions (Boyd & Richerson, 1985; Tennie, Call, & Tomasello, 2009), and acculturation can be driven, at least in part, by novel ideational changes such as religious conversions or Westernization. In Monduli Juu, missionaries fund organizations, led by Maasai locals, that advocate helping women and children gain access to formal education. Efforts to convert Maasai to Christianity have largely succeeded, in part, by appealing to women (Hodgson, 2005) and prioritizing compatibility with some (but not all) Maasai traditions (Rigby, 1989). More broadly, Maasai in Monduli are well-aware that their culture is shifting as a consequence of globalization, and many anticipate that adopting new ideas will improve their lives (see also Hodgson, 1999). In our data, ideational variables covaried with materialist ones (figure 2).

2.4.3 Conflict and coordination by region

Land conflicts over grazing are a primary cause of neighbor conflicts across the broader Monduli Juu region, and large sisal plants now fence many property lines. This increases resource scarcity (e.g., available grass) and conflicts of interest among herders. Payoffs to individual vs. social learning strongly depend on the accuracy of learning (McElreath, 2004), and when misinformation is incentivized, the accuracy of social learning is reduced, and thus so is trust.

Regional variation in trust might reflect different culturally evolved solutions to a coordination problem (Binmore, 2011; Yamagishi & Suzuki, 2009), which is mutually compatible with materialist and ideational accounts. Evidence for this would include low variation within regions, and sharp discontinuities between regions (Efferson, Vogt, Elhadi, Ahmed, & Fehr, 2015; Mackie, 1996). Our data are partially consistent with this: only 8% of participants in the north trusted livestock advice compared to 51% in the south.

Based on the RIM, which was partially supported, herders should be skeptical about possibly deceptive advice about their grazing routines (e.g., Trouche et al., 2018). This is what we observe in the less market integrated, more cattle dependent northern region. Kinship is an important criteria for trust among Maasai (Fratkin, 2001; Spencer, 1965), and northern herders might generally mistrust non-kin with livestock advice – regardless of prestige or experience. The advice-giver in the vignette was not specified to be kin (if participants asked, they were told he was not kin).

In the south, however, trust outcomes were more split. Southern herders must routinely trust non-kin and distant relatives to successfully participate in markets. This is a novel coordination problem, because cash markets and fewer livestock also reduce the scope for land conflict among herders (see also Cronk & Leech, 2013). Market-integrated southern herders might therefore see a demand for "market norms", e.g., expectations for fairness beyond kin groups (J. Henrich et al., 2010), which can be transmitted socially (Richerson & Boyd, 2005) or preferentially attended to by content biases (Cronk, 2017). This account was particularly well-supported by regional variation in trust outcomes. Controlling for region, individual incentives did not predict additional variation in trust, possibly supporting group-level social learning processes. (Although, as noted here and in figure 2, these incentive variables were confounded with region.)

Mistrustful southerners might reflect the recent and ongoing nature of market expansion, infrastructure development, and formal education (Hodgson, 1999; Swebe, 1984). Multiple small-scale societies, including a separate Maasai community near Monduli Juu (Baird & Gray, 2014), saw disruptions in traditional social conventions after market expansion (e.g., Ensminger, 1992; Gurven, Jaeggi, von Rueden, Hooper, & Kaplan, 2015; Kasper & Borgerhoff Mulder, 2015; North, 1990). Higher livelihood diversification and lower dependence on cattle could motivate some southern herders to take strategic risks with their livestock, but cattle remain common among southern herders. This alone might explain split trust outcomes, which we did not see in the north. Alternatively, it is difficult to overstate the importance of cattle to Maasai culture, regardless of actual subsistence strategy used (Spear & Waller, 1993). It is therefore possible that these split trust outcomes near town result from risk aversion, not due to livelihood risk *per se*, but to risk to cultural valuation of cattle (see also Herskovits, 1926; cf. Dahl & Hjort, 1976).

2.4.4 Limitations

This study involved testing preregistered hypotheses using both experimental and observational study designs. Only one of the preregistered hypotheses regarding the RIM was supported, with observational data. Compared to experimental studies, observational studies provide weak evidence for causality, but allow researchers to study real-world behaviors that experimental studies usually cannot (e.g., Hutchins, 2000). Evidence supporting the RIM is therefore suggestive, and results should be interpreted with caution. Our vignettes also did not include a condition in which the advice giver was depicted as unknowledgeable, so we cannot determine if knowledgeability, inferred from either prestige or personal experience, influences trust. It is also worth noting that our study investigated trust in a single domain, namely, advice relating to livestock. Whether or not the findings in this study generalize to trust in other domains, such as farming, medicine, or conflict resolution, is an open question.

Although we found clear evidence that acculturation was associated with trust outcomes, this key finding was not from the preregistered hypotheses but from *post hoc* exploratory analyses. Exploratory analyses are especially vulnerable to misinterpreting noise as genuine signals. Also, data in the northern vs. southern regions were collected by different research assistants, raising the possibility that regional differences in acculturation and trust were somehow a consequence of the procedures followed by each assistant. Although we cannot completely rule out an interviewer effect, we doubt it for the following reasons: both assistants were local adult men with many years of experience administering surveys. One assistant and A.D.L. separately collected data in the southern region, and their results were quite similar (i.e., a term for interviewer in regression models of data only from the southern region was not statistically significant; see the SI). Further, many of the survey items were relatively objective questions involving roof material, solar panels, number of wives, household size, and so forth, where interviewer effects would not be expected, and these also differed systematically by region (see SI for tests of differences by region).

2.4.5 Conclusion

Socially learned information can imply non-trivial costs and benefits, including risks of misinformation. Risk and incentives predicted increased willingness to trust in advice, but prestige did not increase trust compared to knowledgeability learned from personal experience. Acculturation, which varied markedly by region, was found to have an even larger positive association with trust. Much of this effect was due to the positive effect of market integration on trust, but weaker adherence to traditional Maasai values was also positively associated with trust to some degree. The causal pathways among market integration, acculturation, and trust remain to be clarified.

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Data availability

All preregistration materials are publicly available at https://osf.io/5p7ut. Data are available at https://doi.org/10.5281/zenodo.4118454, and supplementary information and analysis scripts are available at https://doi.org/10.5281/zenodo.4118474.

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CHAPTER 3. ETHNOSCIENTIFIC EXPERTISE AND KNOWLEDGE SPECIALISATION IN 55 TRADITIONAL CULTURES

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Abstract

People everywhere acquire high levels of conceptual knowledge about their social and natural worlds, which we refer to as *ethnoscientific expertise*. Evolutionary explanations for expertise are still widely debated. We analysed ethnographic text records (N=547) describing ethnoscientific expertise among 55 cultures in the Human Relations Area Files to investigate the mutually compatible roles of collaboration, proprietary knowledge, cultural transmission, honest signalling, and mate provisioning. We found relatively high levels of evidence for collaboration, proprietary knowledge, and cultural transmission, and lower levels of evidence for honest signalling and mate provisioning. In our exploratory analyses, we found that whether expertise involved proprietary vs. transmitted knowledge depended on the domain of expertise. Specifically, medicinal knowledge was positively associated with secretive and specialised knowledge for resolving uncommon and serious problems, i.e., propri-

etary knowledge. Motor skill-related expertise, such as subsistence and technological skills, was positively associated with broadly competent and generous teachers, i.e., cultural transmission. We also found that collaborative expertise was central to both of these models, and was generally important across different knowledge and skill domains.

3.1 Introduction

Humans are intuitive scientists (Kuhn, 1989; Szollosi & Newell, 2020). People everywhere acquire knowledge about fitness-relevant properties of their social and natural worlds (Albuquerque, Medeiros, & Casas, 2015; Atran, 1993; Gopnik, Meltzoff, & Kuhl, 2000), sort novel stimuli into classification systems (Ellen, 2006; Lakoff, 1987; Ortony & Medin, 1989), and infer patterns and causation from noisy phenomena (Cosmides & Tooby, 1996; Gigerenzer & Murray, 2015; Sperber, Premack, & Premack, 1995). Individual knowledge becomes cultural knowledge via social learning (Henrich, Boyd, et al., 2001; Henrich & McElreath, 2003; Richerson & Boyd, 2005), and discourse and argumentation (Mercier & Sperber, 2017).

Existing research has focused on the cognitive, social, and ecological factors influencing the formation and dissemination of *ethnoscientific knowledge*, defined as culturally varying and locally useful bodies of conceptual knowledge about the social and natural world (Atran & Medin, 2008; see also Heintz, 2007). It is less clear, however, how and why some individuals might pursue relatively high levels of domain-specific conceptual knowledge compared to others within their population, which we will refer to as *ethnoscientific expertise*. ("Ethnoscience" can also refer to a particular Western scientific approach to ethnographic research on indigenous knowledge systems (Sturtevant 1964), which today is usually referred to as cognitive anthropology (Kronenfeld 2011). This is in contrast to our usage, which refers to the *content* of these indigenous knowledge systems, which are often culturally specific.)

3.1.1 The conundrum of ethnoscientific expertise

Levels of knowledge and skill vary for almost any ability. Expertise refers to domain-specific knowledge or skills reliably performed in a way that is superior to that of most other people (Ericsson & Charness, 1994) (For our purposes, expertise will be defined relative to other people in an individual's local community.) Explanations of how and why experts emerge with extensive knowledge often focus on proximate-level descriptions (Tinbergen, 1963). In the mainstream psychology literature these explanations typically focus on natural ability, favourable circumstances during development, and/or dedicated and systematic practice (Ericsson & Charness, 1994). In the genetic-developmental literature, these explanations focus on the closely related cognitive, genetic, and developmental aspects of expertise (Dukas, 2019; Plomin, Shakeshaft, McMillan, & Trzaskowski, 2014). Some consensus exists among scholars about the necessity-but-insufficiency of each of these predisposing factors. Ultimate-level functional and strategic explanations for investing in expertise vs. other uses of one's time and energy, however, are lacking.

Multiple open questions therefore remain about the evolution of expertise. First, acquiring expertise in one domain, such as botany, zoology, physiology, or meteorology, incurs an opportunity cost due to time and energetic constraints, e.g., by reducing knowledge of other domains and reducing investment in other fitness increasing activities. For example, an adaptive learning strategy could be to acquire practical knowledge about the world during early stages of development, and to divert this investment toward other efforts upon reaching adulthood, such as reproduction and subsistence (i.e., optimising an explore-exploit tradeoff; see Gopnik, 2020).

Second, environments are typically structured in ways that favour simple heuristics (Gigerenzer & Todd, 2001; Sloman & Fernbach, 2017). A forager, for example, could discern edible vs. poisonous berries with simple, locally relevant rules (e.g., discriminating based on colour, taste, or location) that make a complex botanical theory unnecessary for survival. Simple rules can be useful for a range of computationally complex tasks, such as predicting seasonal weather patterns and animal behaviours, or navigating social relationships (Gigerenzer, Hertwig, & Pachur, 2011). Nevertheless, complex and elaborate theories about these tasks, which might or might not be useful on a day-to-day basis, are well-documented in a variety of ethnoscientific domains across cultures (Albuquerque et al., 2015). Moreover, across a population, individual knowledge about these elaborate theories often varies (Kronenfeld, 2011), and might only be mastered by relatively few individuals in the population, i.e., experts (Berlin & Berlin, 2015; Reyes-García et al., 2009).

Finally, it is not clear how expertise relates to cultural transmission. Cultural evolutionary theorists often highlight trait variation and imitation of skills that involve easily observable and transmissible behaviours, such as boat making or food preparation (Boyd, Richerson, & Henrich, 2011; Henrich, 2016). The costs and benefits of adopting easily observable traits, however, can be difficult to evaluate. It can therefore be adaptive to adopt a "package" of transmissible traits that are either common in the population, or are exhibited by "successful" individuals (Henrich, 2016; Richerson & Boyd, 2005).

It is less obvious that *unobservable* and mostly *conceptual* knowledge, e.g., about plants, animals, or weather patterns, can be grouped with easily observable behaviours in a single overarching category of transmissible cultural traits (Morin, 2015; Read & Andersson, 2019). Assumptions about expertise, such as the scope for improving the competence of most individuals in the population on a task, might need to vary according to whether the skills and knowledge are easy to observe, such as motor skills, or more difficult to observe, such as conceptual knowledge, and how often the knowledge and skills are useful (Ericsson & Charness, 1994).

Further, if expertise requires an individual learning cost (e.g., time spent practicing, innovating, or experimenting to improve a skill), and socially learning from an expert is possible, then evolutionary models show that without additional benefits to the expert, populations with social learning gain no fitness advantages relative to those without it (Rogers, 1988). This suggests that expertise requires a fitness advantage to offset the costs of individual learning (Boyd & Richerson, 1995).

In short, why do some individuals invest more heavily in ethnoscientific knowledge than others? If a given knowledge domain is not obviously practical or useful on a day-to-day basis, how do experts apply their knowledge, if at all, to increase their inclusive fitness?

3.1.2 *Study aims: Investigating evolutionary theories of expertise in the ethnographic record*

In this study, which is largely exploratory, we consider multiple theoretical perspectives on knowledge and skill acquisition that might explain expertise as an evolutionary strategy, examine them in the ethnographic record, and then consider if our results warrant a new theory that is specific to expertise. Many previous cultural evolutionary theories have modeled skill acquisition and transmission in practical knowledge domains. These theories emphasise *imitation*, i.e., copying observable behaviours involving substantial motor activity, such as boat making (Boyd et al., 2011) and food preparation (Henrich, 2016).

We diverge from prior studies by emphasising *conceptual* knowledge, a consequence of our focus on ethnoscientific expertise. Ethnoscience in this study includes elaborate systems of knowledge, such as botany or medicine, where concepts are interrelated via rules and principles "concerning phenomena of the external world and of the human organism" (Human Relations Area Files World Cultures, 2021). These social or natural principles might (or might not) be used for practical applications with observable motor activity, such as bone-setting, weaving, or hunting. It is therefore inevitable that practical activities will emerge from our systematic search of ethnography. Our restricted search criteria, however, ensures that practical applications are secondary to the ethnoscientific knowledge on which we focus (discussed further in the Methods section).

We also make an important distinction between *products* of knowledge vs. *know-how*. *Products* refer to observable applications of knowledge, whereas *know-how* refers to the underlying cognitive system or process – sometimes easily inferred from behaviour and sometimes not – that reliably yields a desired product. Importantly, *products do not necessarily reveal know-how*. For example, a doctor might know how to diagnose and treat illness. The patient however, cannot gain the know-how used for her diagnosis and treatment by imitating the doctor. That is, if a skill requires complex conceptual knowledge, then observation is often insufficient to acquire that skill (Morin, 2015).

In order to systematically code ethnographic texts for variables that might explain how and why individuals would invest heavily in know-how (conceptual knowledge), we identify influential evolutionary theories of knowledge and skill acquisition. It is important to note that these theories were not necessarily formulated to explain the acquisition of ethnoscientific expertise or conceptual knowledge. We therefore take them as our starting point, operationalising each into five sets of overlapping variables, which we term our "theoretical models" (see the SI for extended supporting quotations and further discussion that support our operationalisations).

We evaluate the degree to which each theoretical model is supported by the ethnographic evidence on expertise. These theoretical models are best understood as theoretical *perspectives* based on "family resemblances", however, rather than as formal hypotheses. Our overarching aim is therefore not to simply support one model over the others but instead to start from existing ideas, assess the circumstances under which each model applies, and use exploratory methods to move toward a data-driven theory of conceptual expertise.

Cultural transmission model

Dual inheritance theorists characterise the human brain as a device for learning, storing, and transmitting cultural information (Muthukrishna, Doebeli, Chudek, & Henrich, 2018; Richerson & Boyd, 2005), and argue that social learning is strictly necessary to explain human evolutionary success (Boyd et al., 2011; Henrich, 2016). In the cultural transmission model, experts commit high levels of cultural knowledge to memory, and are a source of socially transmitted knowledge to others in the population (Boyd & Richerson, 1985), generally in exchange for a fitness benefit (Boyd et al., 2011; Henrich & Gil-White, 2001). Fitness benefits conferred to experts might include material resources, cooperative partnerships, or services from an apprentice or peer, all of which may contribute to reproductive success (Jiménez & Mesoudi, 2019; Price & Van Vugt, 2015).

The *cultural transmission model* also explains *how* skillful persons are identified: prestige is a cue of competence that allows others to selectively learn from, and direct freely conferred deference to, experts (Henrich & Gil-White, 2001; Henrich & McElreath, 2003). Prestige might include culturally-specific concepts, symbols, or other conspicuous indications of success (Boyd & Richerson, 1985; Henrich, Boyd, et al., 2001). For the *cultural transmission model*, experts do not have proprietary or secretive knowledge that they withhold from laypersons, but instead transmit their valuable knowledge based on proximity sought by acolytes, who somehow benefit experts in return. Importantly, valuable knowledge for the *cultural transmission model* should not only include products such as advice or assistance, but know-how that the expert possesses, such as plant knowledge or technological skills that acolytes can use in the future.

Cultural transmission model predictions include widely distributed knowledge addressing common, day-to-day problems (e.g., subsistence-related activities, technological skills); experts with reputations for efficacious solutions to those problems; and experts who share know-how with other experts or non-experts, often in the context of mentorship or apprenticeship. Additional predictions include prestigious and high-status experts, deference to experts, experts who have a reputation for generosity and/or are preferred social partners beyond their domains of expertise, and experts with influence beyond their domains of expertise (e.g., medicinal experts who also have political authority).

Proprietary knowledge model

Many services provided by experts, such as predictions, advice, or medical care, require underlying know-how that is not readily transmissible without effortful teaching and practice (Ericsson & Charness, 1994; Hagen & Garfield, 2019; Morin, 2015). In contrast to the *cultural transmission model*, which emphasises an adaptive capacity for culture and its attendant wide distribution of knowledge (e.g., Boyd et al., 2011), we formulated the proprietary knowledge model, which proposes that experts' conceptual knowledge is not readily transmissible, but restricted to specialists. A central idea for the *proprietary knowledge model* is that experts can use know-how to provide a valuable service or product to other people, who themselves do not possess solutions of their own, and who cannot subsequently transmit this learned information to others. A cost-effective strategy for addressing rare and consequential problems might be to consult a specialised expert in exchange for a complementary service or payment. According to the *proprietary knowledge model*, the value of an expert is determined by his or her relatively rare ability to provide a specific efficacious service (Tooby & Cosmides, 1996).

The commodities in a *biological market* of mutually beneficial partnerships (Hammerstein and Noe 2016) can include providing information (Bouhlel, Wu, Ilanaki, & Goldstone, 2018) in exchange for similarly valuable benefits (e.g., payments and continuing patronage to the expert). An expert's high value in this market requires that she is hard to replace (Tooby & Cosmides, 1996). Hence, according to the *proprietary knowledge model*, services (*products*) are readily shared, but the rare *know-how* used to generate shared outcomes is proprietary, difficult to reverse engineer, and difficult for non-experts to apply and achieve similar outcomes (Hagen & Garfield, 2019).

Proprietary knowledge model predictions include: experts' services successfully conferring some kind of benefit; experts having reputations for efficacy and gaining patronage based on efficacy; narrow specialisation in a domain-specific problem that is uncommon and serious when it arises; rare, secretive know-how employed in an opaque (i.e., not easily observable) process by which products are provided; and material resources received in return as payment.

Collaborative cognition model

The *collaborative cognition model* emphasises that knowledge and expertise are highly social. Activities among multiple specialist types are collaborative on this view, and each expert has complementary roles, insights, and areas of specialisation. Contrary to popular images of science, creativity, and innovations, the *collaborative cognition model* proposes that concepts are not improved by lone geniuses or individual experts, and rarely if ever emerge as fully formed ideas (Mercier & Sperber, 2017; Sloman & Fernbach, 2017). Instead, cognitive tasks are often distributed across multiple interdependent roles, allowing experts to invest heavily in some areas of expertise while relying on other experts for information in other areas, a division of cognitive labour (Heintz, 2004; Hutchins, 2000; Keil, 2003). According to the *collaborative cognition model*, a high level of interaction between cognitive, sociocultural, and ecological factors collectively shape concepts, theories, solutions to domain-specific problems, and even the questions that experts consider in the first place (Nersessian, 2010; Sperber, 1996).

Collaborative cognition model predictions include distributed expertise across multiple types of narrow specialist (i.e., a division of labour), collaboration among specialists that collectively produces more knowledge than each individual possesses, and knowledge (know-how) that is shared or exchanged among multiple experts.

Honest signalling model

Spence (1978) argued that candidates in a job market can honestly signal their general competence, which is otherwise opaque to employers, with credentials that are relatively less costly to acquire for those with greater general competence. In evolutionary biology, a similar argument suggests that costly traits reliably signal genetic quality in a mating market (Grafen, 1990; Penn & Számadó, 2020; Zahavi, 1975). Sexual selection based on costly signals of fitness is hypothesised to explain a number of human traits, such as male hunting behaviour and conspicuous meat sharing to gain mating opportunities (Smith & Bird, 2000). Abilities must not only be successfully broadcast, but typically gain traction in a given cultural milieu in the form of social standing, locally relevant indicators of success, and prestige (Hawkes & Bliege Bird, 2002; Winegard, Winegard, & Geary, 2018).

Applied to expertise, the honest signalling model proposes that displays of knowledge serve as a costly signal of genetic quality to prospective mates (i.e., that expertise is less costly to obtain for those with higher genetic quality). On this view, culture largely consists of conspicuous "courtship adaptations" (Geher, Camargo, & O'Rourke, 2008; Miller, 2011, 1999, p. 81), and creativity and intelligence are relevant underlying traits that are signalled by displays of expertise. This might not only include displays of erudition, however, but also proximate indicators of expert status, such as ornamentation, among other indications of prestige (Cheng and Tracy 2014).

Predictions based on the *honest signaling model* prioritise overt displays of knowledgeability and skill, status and prestige; a short-term mating market in which signals are produced; and experts' access to multiple mates. The *honest signaling model* refers specifically to signalling genetic quality to potential mates, and is not meant to represent a comprehensive model of the role of signalling in all forms of status competition. Hence, fitness indicators, such as culturally-relevant displays of expertise, should be difficult for those with low genetic quality to achieve. Because our data did not have measures of genetic quality, we looked for evidence that acquisition of expertise involved clear costs.

Mate provisioning model

Human social hierarchies and mate competition involve not only physical formidability, as seen in gorillas and chimpanzees, but also "prestige" – culturally-defined symbols of success that often involve valued skills and knowledge (Barkow, 1989; Maner & Case, 2016; Van Vugt & Smith, 2019). Humans also diverged from chimpanzees and gorillas in their shift toward strong male-female pair-bonding and increased paternal investment in offspring (Alger, Hooper, Cox, Stieglitz, & Kaplan, 2020; Kaplan, Hooper, & Gurven, 2009), sexual selection for which would have included individuals choosing mates based on their relatively high levels of resource access and provisioning behaviour (Buss, 1989; Gavrilets, 2012).

In contrast to the short-term mating strategy outlined in the *honest signaling model*, the *mate provisioning model* suggests that expertise is a means of competing for mates by increasing one's ability to provision their offspring either directly, or by controlling resource production (Barkow, Cosmides, & Tooby, 1992; Stewart-Williams & Thomas, 2013). That is, mates choose prestigious and high-skilled experts based on their prospects for long-term parental investment and mate provisioning (Barkow, 1989; Buss, 1992; Schmitt, 2008). Researchers have suggested similar hypotheses about sexually selected hunting behaviours among males who preferentially provision food to their kin (Buss, 1995; Hill & Hurtado, 1989).

Predictions based on the *mate provisioning model* include skill and knowledge acquisition involved in expertise that is best understood in terms of its practical applications, which are preferentially used to acquire resources for mates and offspring (Kaplan, Hill, Lancaster, & Hurtado, 2000). Hence, predictions based on the *mate provisioning model* include status and prestige, mate choice based on male provisioning prospects (e.g., reputations for generosity, commitment to offspring), actual evidence of investment toward offspring, and high levels of mate fidelity.

3.1.3 Similarities and differences among theoretical models

Although many of the predictions described here are specific to one theoretical model, some are compatible with multiple models. We refer to these predictions as model-*specific* and model-*generic*, respectively. Four of the five models (*cultural transmission model*, *proprietary knowledge model*, *mate provisioning model*, *honest signaling model*) are premised on a hierarchy among skill levels, and prestige is central to at least three of these (*cultural transmission model*, *mate provisioning model*, *honest signaling model*). The *cultural transmission model*, *proprietary knowledge model*, *mate provisioning model*, and *honest signaling model* emphasise fitness benefits to experts, but these models largely differ on how and why expertise is beneficial. This is especially clear, for example, in the mate access conferred for prestige described in sexual selection models (*honest signaling model* and *mate provisioning model*) vs. the deference and resource access in *cultural transmission model*. Resource access is common to the *mate provisioning model*, *cultural transmission model*, and *proprietary knowledge model*, but the latter two make no predictions about provisioning of those resources to mates.

The *proprietary knowledge model* sharply diverges from the *cultural transmission model* by focusing on shared products and secretive know-how, which might be conditionally shared for a direct benefit. The *proprietary knowledge model*, which emphasises *barriers* to knowledge transmission, would nevertheless require some transmission of knowledge systems from experts to novices, meaning that it is at least partially compatible with the *cultural transmission model*.

The *collaborative cognition model* is uniquely compatible with other models. Rather than providing a strictly evolutionary explanation for expertise, it emphasises the distributed and collaborative social structure that might underlie expertise at a group level, in addition to the competition inherent to the other four models.

3.2 Methods

To characterise ethnoscientific expertise and assess the level of cross-cultural support for each theoretical model, we used data from the electronic Human Relations Area Files (eHRAF). The eHRAF is a digitised database of over a million pages of primary ethnographic documents, spanning several centuries, from over 400 cultures around the world. We restricted our search to the Probability Sample Files, a stratified subset of 60 cultures in the eHRAF that includes one randomly selected culture from 60 geographically diverse areas (Naroll, 1967). All documents in the eHRAF are coded at the paragraph level using an Outline of Cultural Materials (OCM), a hierarchically organised coding scheme containing several hundred numeric codes that are assigned to a unique and specific topic (Murdock et al., 2006). Paragraphs usually relate to multiple topics and are therefore usually assigned multiple codes. For example, if a single paragraph explains a cultural theory about plants, animals, and disease, then the paragraph would be coded with OCM codes for "ethnobotany" (824), "ethnozoology" (825), and "theory of disease" (753).

We searched the Probability Sample Files for 68 OCM codes that could plausibly result in descriptions of *conceptual* knowledge in social or natural domains, such as ethnometeorology, ethnophysiology, and genealogy (see the SI for a complete list). We narrowed this search using six keywords that refer to highly knowledgeable experts in those domains, such as "expert*", "specialist*" and "practitioner*" (where the "*" is a wildcard that would match any suffix). We did not include OCM codes or keywords that referred to specific skills, such as woodworking or boatmaking. Focusing on knowledge about the social and natural world, we also did not include OCM codes relating to religious or spiritual leaders in our search terms (but did not exclude them or expertise in supernatural domains from our results). See the SI for our full search parameters. This search resulted in 1595 paragraphs from 483 documents.

3.2.1 Inclusion criteria for text records

Many OCM topics are quite broad, and some paragraphs did not contain any information that was relevant to ethnoscientific expertise. If a description was relevant to ethnoscientific expertise, then we included the contiguous set of paragraphs of which it was part, which we refer to as a "text record" henceforth. Because our primary aim was to collect text records about ethnoscientific expertise, we included text records from the ethnographic literature based on two key criteria, which we set out prior to searching: both (1) evidence of ethnoscientific knowledge, and (2) evidence of expertise. In this section, we clarify our inclusion criteria.

First, and for the purposes of including vs. excluding text, we defined *ethnoscientific knowledge* as conceptual systems where principles about the natural or social world are socially or individually acquired. Although knowledge can be usefully applied to a number of possible types of practical applications (e.g., curing/healing, certain crafts, hunting/trapping, conflict resolution, ethical quandaries), the OCM codes in our search prioritised the underlying conceptual theories that *can* be applied (rather than descriptions of applications themselves).

Second, as evidence of *expertise* we considered indications of within-group variation in knowledgeability that included descriptions of "experts", or individuals who were highly knowledgeable compared to others. If a text record described an expert individual or a specific group of experts, then it met this criterion. If a text record was vague about individual or within-group variation (e.g., "the Maasai are expert herders"), then it did not meet this criterion and was therefore excluded. Expert knowledge might be specific to a single domain such as plants, animals, meteorology, or social exchange, but it might also be general and include multiple distinct knowledge domains possessed by a single expert and/or multiple types of expert. See the discussion of our coded variables in the SI for details.

Practical skills such as hunting, herding, agriculture, or conflict resolution were not included in our search terms, but did appear in search results. If a conceptual knowledge domain was included in our search (e.g., ethnozoology) and was frequently linked to text records about a skill that was not included in our search (e.g., hunting), then we retained these records because they were an informative result about that knowledge domain being commonly applied to hunting, rather than a simple result of “hunting” being included in the search.

The final dataset contained 547 text records discussing ethnoscientific experts and specialists from 257 documents (e.g., books, articles) and 55 cultures.

3.2.2 Operationalising and coding evidence for our theoretical models

Each theoretical model was operationalised as a set of coded variables. We coded each text record on the presence or absence of evidence for each of the variables in our theoretical models, and its domain(s) of conceptual knowledge. Domains involved the conceptual knowledge in our search terms, as well as motor-skills and other additional domains found in our results (i.e., not included in our search terms). For example, for an ethnozoology expert with exceptional hunting skill, we coded "ethnozoology" and "hunting" as expertise domains despite only the former being included in our search terms.

We simplified the wide range of domains in our final dataset by additionally coding each domain of expertise in each text record on three non-mutually exclusive, high-level *domain types*: conceptual, motor skill-related, and/or medicinal domains. Because our inclusion criteria was based on the presence of ethnoscientific expertise, conceptual knowledge was included to some extent in each text record. Nevertheless, there was considerable variation in the extent to which text records described conceptual knowledge. A text record's domain of expertise was therefore coded as "conceptual" only if the domain *primarily* involved conceptual knowledge (the *conceptual* domain type refers to ethnoscientific conceptual domains, largely designated by the eHRAF OCM codes; see the SI for details) The distinction between conceptual vs. motor skills was motivated by how observable a skill might be: Motor skills are observable, whereas conceptual domains often are not. The medicinal domain was also included as a domain type because it was both recurrent in the literature and highly inclusive (e.g., herbalists, pharmaceutical experts, diviners and curing specialists). Importantly, these domain types often co-occurred in single text records. For example, experts with motor skills as boat makers, construction specialists, and woodworkers often had high levels of ethnobotanical knowledge, a conceptual domain.

See the SI for more details about the overlap among conceptual, motor, and medicinal domain types.

We coded each text record for presence/absence on each of the 42 variables operationalising our five theoretical models (described above and detailed in the SI). See figure 3.2.1 for a list of these variables and their relationships to each theoretical model. Specifically, for each variable and each text record, we coded 1 if there was evidence for the variable and 0 if there was no evidence for the variable. Some text records had evidence against certain variables. For these variables, we therefore created a complementary "anti-variable" indicating evidence against that variable (e.g., low status experts were coded as evidence against prestige, or "anti-prestige"). We term the set of anti-variables complementary to a theoretical model its "anti-model". We also included variables for age, sex, and case vs. cultural model. The latter indicated if a text record discussed specific individuals who were experts (cases) and/or a general description of domain experts in that culture (cultural models). Finally, we coded two additional *ad hoc* variables that struck the coders as important but were not part of our theoretical models: religious leaders and teaching among kin. The former characterised many experts. The latter was an important special case of the *cultural transmission model* variable *experts teaching others* (but kinship is not a feature of the *cultural transmission model*, so we did not include this variable in the *cultural transmission model*). See the SI for coding examples and other details.

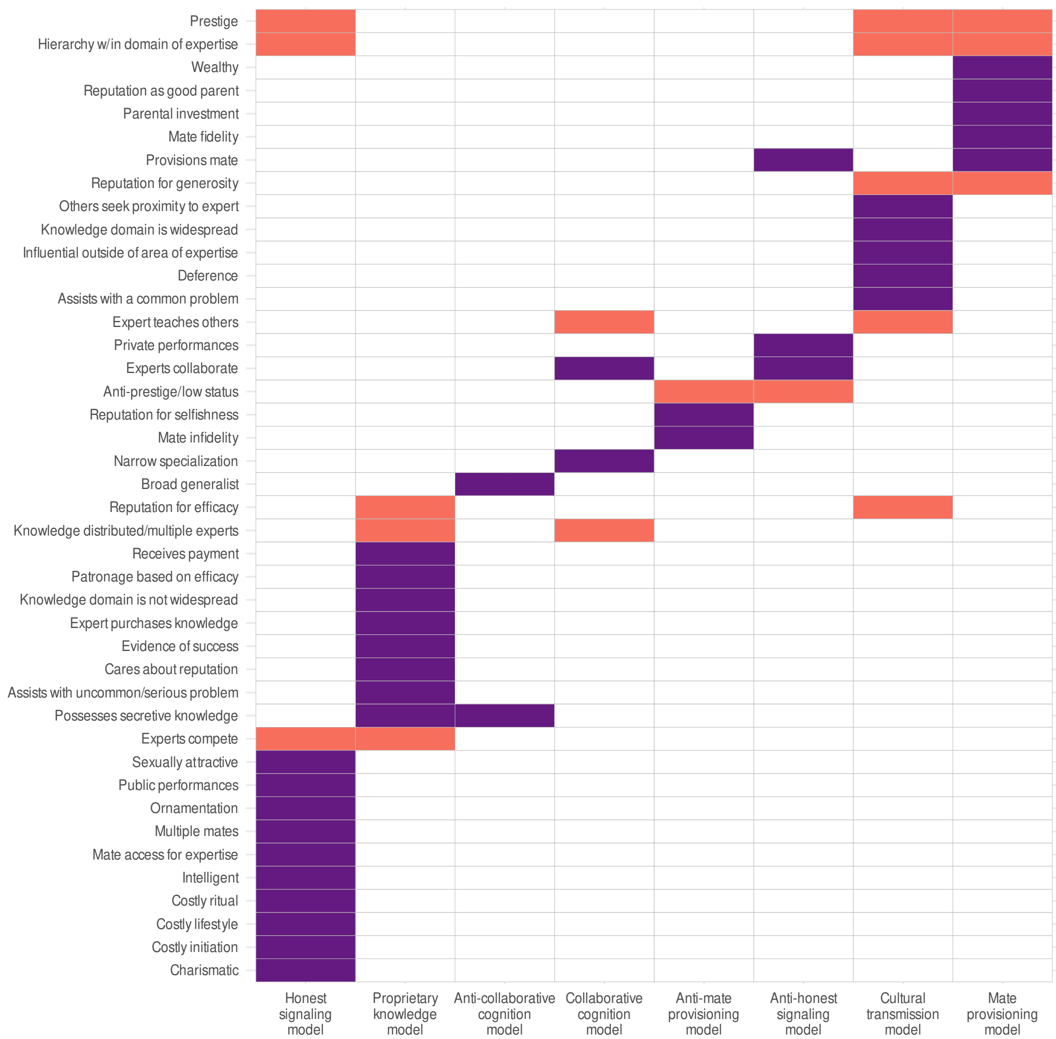

Figure 3.2.1: Coded variables corresponding to predictions outlined in our theoretical models. Variables are listed along the y-axis, and each theoretical model is listed with its opposing model along the x-axis. Purple cells indicate a variable that is unique to one theoretical model (specific), and orange cells indicate a variable that is general to multiple theoretical models (generic).

The first and second authors independently coded for presence/absence (1/0) of evidence for each variable on each text record. The second author was familiar with relevant theories but blind to specific hypotheses in this study, and the first author was not blind to the study hypotheses. Results of the independently coded datasets were a 88.1% match with a Cohen's kappa indicating moderate agreement ($k = 0.48$). See the SI for more details about interrater reliability. Afterward, both coders discussed and reconciled all disagreements to produce the coded dataset used in our analyses.

Finally, each of the Probability Sample Files cultures in our search was coded for geographic region and mode of subsistence, which we obtained from the eHRAF (shown in figure 4.2.1).

3.2.3 Statistical analyses

Our data comprised a 547 row by 42 column binary matrix of 0's and 1's, where each row was one text record and each column was one variable (0: no evidence; 1: evidence for). Each text record belonged to one culture (i.e., no text records discussed multiple cultures); thus, text records were nested within authors, who were nested within cultures.

Our first analytical goal was to explore which variables clustered together (i.e., variables for which evidence tended to co-occur in text records), as a means to assess the extent to which the structure of the data corresponded to our theoretical constructs. Our second analytical goal was to more formally assess the extent to which the data supported each theoretical model by determining the level of evidence for each variable (i.e., the mean of each column), the proportion of cultures with at least some evidence for each variable, and the total evidence for each model (as described in detail later). Our third analytical goal was to explore the extent to which the variables and each of the theoretical models were associated with three broad types of knowledge: medicinal, motor skills, and conceptual knowledge domains.

Goal 1: Exploring the structure in our dataset

To explore inherent structure in our entire binary data matrix, i.e., ignoring our *a priori* theoretical models, we used two different clustering methods.

In the first clustering method, we visualised the entire binary matrix with a heatmap (dark colour = 0, light colour = 1). We ordered the rows and columns, so that “similar” rows were adjacent, and “similar” columns were adjacent. Similarity between two row vectors or two column vectors was defined as the angle between the vectors when projected onto the first two principal components of the entire matrix, which approximates the correlation between the vectors. Specifically, the ordering was determined by a principal components analysis (PCA) angle seriation method (Hahsler et al., 2020).

To use row ordering as an example, this method conducts a PCA on the row vectors, projects each row vector onto the first two principal components, and then orders each row by the angle between the row vector and the first principal component (smallest to largest; see Friendly 2002). It then splits this ordering by the largest "jump" between adjacent angles (specifically, the absolute value of the difference between adjacent angles), and rearranges these two split orderings so that the largest jump is at the end of the entire ordering. Column ordering is similarly determined, but the PCA is instead conducted on the column vectors. The result is that similar rows (text records) and columns (variables) in the heatmap are adjacent (Friendly and Kwan 2002; Hahsler 2020).

The second clustering method is based on another measure of similarity among our variables. Here, we computed the square matrix of all pairwise binary distances between column vectors, where binary distance is defined as the proportion of element pairs (i.e., (0, 0), (0, 1), (1, 0), or (1, 1)) in which only one element = 1, amongst the pairs in which at least one element = 1. A binary distance = 0 therefore means that two variables both had evidence in exactly the same text records. A binary distance = 1 means that two variables never had evidence in the same text records. The resulting matrix can be conceptualised as an adjacency matrix, which defines a weighted graph G, where each vertex is a variable and each weighted edge is the distance between these variables.

We then computed the minimum spanning tree of this distance matrix, a subgraph of G in which every node is connected in a single path that minimises the total weighted path distance without creating any loops (i.e., with no closed paths) (Dijkstra, 1959; Prim, 1957; Zahn, 1971). As a result, only similar variables (the vertices) are connected to each other in the minimum spanning tree. We then identified "clusters" of variables by visual inspection of the minimum spanning tree, seeking groups of adjacent variables that were conceptually related. Given the subjectivity of cluster identification, we perform this step after completing the remaining goals.

Goal 2: Assessing how the evidence supports different theoretical perspectives

Each theoretical model was operationalised as a set of coded variables. These sets of variables overlapped to some degree, indicating overlap between the theoretical models. To assess each theoretical model, we determined the proportion of text records that supported each of its binary variables (i.e., the proportion of 1's). Because multiple text records often came from the same document, and multiple documents often reported on the same culture, the text records from an ethnographer who focused on, e.g., uncommon and serious medical problems, would have a misleadingly high proportion of evidence for the "uncommon and serious problem" variable. It was therefore necessary to account for the hierarchical structure of our data.

Specifically, we fit an intercept-only generalised linear mixed effects logistic regression model (GLMM) for each binary variable, with random intercepts for authors nested within cultures. We fit 42 models, one for each binary variable, using all 547 data points, to predict for each text record whether the variable was 0 or 1, adjusting for the structure of the data. The model structure for each variable's proportion of text record-level evidence was therefore as follows:

$$
\begin{aligned}
\mathrm{y}_i &\sim \mathrm{Binomial}(n = 1, \mathrm{prob}_{\mathrm{y}=1} = \widehat{P}) \\
\log\left[\frac{\hat{P}}{1-\hat{P}}\right] &= \alpha_{j[i],k[i]} \\
\alpha_j &\sim N\left(\mu_{\alpha_j}, \sigma^2_{\alpha_j}\right), \text{ for author:culture j} = 1, \ldots, \text{J} \\
\alpha_k &\sim N\left(\mu_{\alpha_k}, \sigma^2_{\alpha_k}\right), \text{ for culture k} = 1, \ldots, \text{K}
\end{aligned}
$$

where the value of y_i (and its 95% CI) represents the proportion of text records with evidence for a given variable i, adjusted for the hierarchical structure of the data.

To compare theoretical models, we computed a "total model score" as the proportion of evidence for the model in each text record. Specifically, we summed the model variables in each text record and divided by the number of variables. The "weight" of this value was the number of variables. For example, the *mate provisioning model* has 8 variables. The total score for this model in each text record was the sum of these variables in each text record, divided by 8 (with weight = 8). This proportion was the outcome variable. The mean proportion and its 95% CI were computed identically to the GLMM structure shown above. Theoretical models with a higher total model score were judged to have more support. (Note that the "anti" models, i.e., the models shown in figure 3.2.1, with variables that refuted its corresponding theoretical models, were analysed identically to the theoretical models.)

We also examined evidence for each variable at the culture level, i.e., the simple proportion of cultures with at least one text record supporting each variable, with 95% confidence intervals for the proportion computed with cluster bootstrapping (i.e., first resampling cultures, then resampling authors within cultures). We converted all proportions and their confidence intervals into percentages, which we reported as the variable's level of support.

Goal 3: Exploring how support for variables were associated with presence of domain types

At the text record level only, we explored the extent to which evidence for our three high-level domain types (conceptual, motor, and medicine) was associated with evidence for each of our 42 variables (e.g., prestige, teaching, secretive knowledge). Specifically, we fit three logistic regression models with our three high-level domain types as binary outcome variables and, in each model, our theoretical model variables as predictors. (Prior to fitting, we removed variables that were >95% zeros, i.e., for which there was almost no evidence; otherwise these variables had spuriously large estimates. See the SI for more details, and a discussion of our rationale and filtering process.) Because inclusion of many predictors risks overfitting, we used *elasticnet* regression (Friedman et al., 2021), a popular type of penalised regression that was developed for use in situations where the number of predictors, p is large relative to the number of observations, n (see SI for a brief description). We used the "lasso" penalty, which sets some coefficients to 0, with the non-zero coefficients representing the "best" predictors, given the limitations of the data. As in a standard logistic regression, the coefficients are log odds, which we transformed to odds ratios, i.e., the ratio of the odds that a text record has evidence for the outcome (domain type) if it has evidence for the predictor variable to the odds that it has evidence for the outcome if it does not have evidence for the predictor variable. This analysis will therefore identify three subsets of variables that are most closely associated with the conceptual, motor, and medicinal domains. Note that this model cannot include random effects (i.e., cannot adjust for the hierarchical structure in our data).

We then assessed the association of our five theoretical models with the three domain types as follows. First, we computed text record-level model scores as the proportion of evidence for each model in each text record. For example, the *collaborative cognition model* comprised four variables. If a text record had evidence for all four *collaborative cognition model* variables, its text record-level *collaborative cognition model* model score was 1; if it had evidence for two *collaborative cognition model* variables, its *collaborative cognition model* score was 0.5. We computed text record-level model scores similarly for the other four theoretical models.

We then fit three generalised linear mixed effects logistic regression models, each predicting the presence/absence of evidence for one domain type (medicinal, motor, and conceptual) as a function of the five text record-level model scores. Similar to the GLMM described above, we included random intercepts for authors nested within cultures. The estimated coefficients of these three models would then represent the association between the evidence for each theoretical model in each text record with the evidence for the domain type in each text record.

All data and analysis code are available at:

https://github.com/alightner/conceptualExpertsHRAF.

3.3 Results

The dataset contained 547 text records, and we found evidence supporting one or more variables from our theoretical models in 528 (97%) of these records. Each text record had an average of 5 variables coded as present, with 95% of text records containing evidence for 10 or fewer variables (median was 4 present per text record, $SD = 3.3$, min = 1, max = 25). The geographic distribution of the cultures in this sample, along with their subsistence strategy and number of text records, are shown in figure 4.2.1. We did not find evidence for ethnoscientific expertise in 5 of the 60 cultures in the Probability Sample Files. Text records per culture ranged from 1 to 46 with a median of 7. In total, our text records included 115 cases describing specific experts and 473 cultural models, i.e., general descriptions of experts. Publication dates of the 257 documents from which the text records came ranged from 1704 to 2000, with 99% of documents published during the 20th century (median year was 1968). See the SI for details and text analyses.

Sex was unknown in 55% of all text records. Of the 45% of text records that identified at least one sex, 82% included males (37% of all text records), 42% included females (19% of all text records), 22% included both males and females within the same text (10% of all text records), and 15% described specialist roles that were exclusive to males and/or females (7% of all text records). (About 2% of all text records described exclusively male experts, and about 2% described exclusively female experts.) Individuals pursuing expertise in ethnoscientific domains were described as older or elderly adults in 13% of all text records, whereas 5% described younger adults and 4% described children or adolescents. Age was unknown in 86% of our text records (for age categories, the percentages in each category and the percentages of uninformative records add to values greater than 100, because some text records described experts in multiple age categories within the same record).

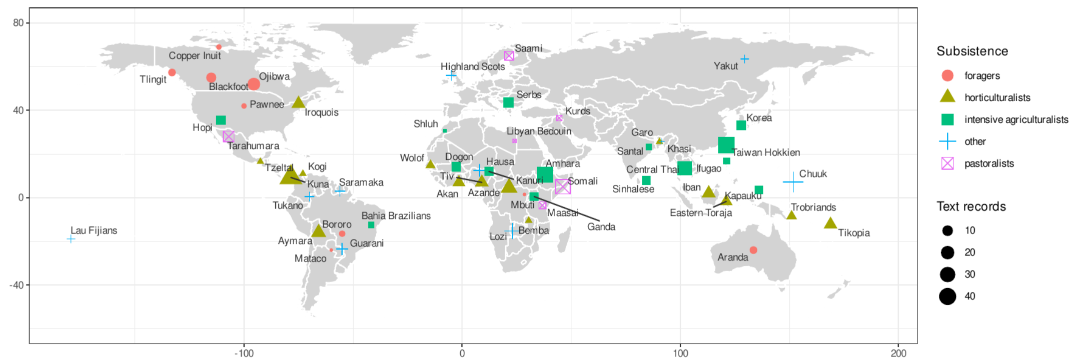

Figure 3.3.2: Geographic region of each culture included in our dataset. Colours and shapes indicate subsistence strategy for each cultural group, and sizes indicate the number of text records for each culture in our dataset.

3.3.1 Exploring structure in the data matrix

We visualised our dataset with a heatmap, ordering the rows and columns using the PCA angle seriation method (Hahsler et al., 2020). See figure 3.3.3. The heatmap revealed that there was considerable evidence for some variables (top) and much less evidence for others (bottom). The seriation method also shows two partially overlapping clusters among our well-supported variables. In the left cluster of text records, expertise includes hierarchies in knowledge or skill level, widespread knowledge, assistance with common problems or activities, and experts who teach other people their skill. In the right cluster of text records, expertise includes assistance with uncommon and serious problems, patronage based on efficacious services provided by experts, and evidence of success in an expert's task domain. These clusters of text records are somewhat interpretable as primarily relating to the *cultural transmission model* (left) and the *proprietary knowledge model* (right), although it is worth noting that they overlap with each other, and the left cluster is diffuse and includes high levels of support in a number of columns that are not specific to the *cultural transmission model*. Also, the partial overlap between these clusters hinges, in part, on reputations for efficacy and distributed experts among multiple experts. The latter, which was well-supported in both of these clusters, was central to the *collaborative cognition model*.

3.3.2 Knowledge domains and types of skill

Our search for ethnoscientific experts yielded a variety of knowledge and skill domains, many of which were not included in our search query. Among the conceptual knowledge domains that we included in our search, ethnomedical specialists, largely resulting from our search for theories of disease, were the most common. Expertise in ethnobotany, ethnozoology, ethnopsychology, and healing injuries were also relatively common, and frequently co-occurred in text records describing medicinal specialists. However, some knowledge or skill domains that we did *not* include in our search query reliably co-occurred with domains that we did include. Text records describing

Figure 3.3.3: Heatmap visualising the coded dataset based on presence (light cells) vs. absence (dark cells) of evidence for each variable in each text record. For readability, the dataset shown here is transposed, i.e., each row represents a variable and each column represents a single text record. Rows and columns were ordered using the PCA angle seriation method. See text for details.

medicinal specialists, for example, often included descriptions of divination, which was not specified in our search terms. See figure 3.3.4.

Some domains tended to co-occur more frequently than others: Medicine, ethnobotany, and ethnozoology often co-occurred, for example, forming a "cluster", but medicine, ethnopsychology, and divination also frequently co-occurred, forming a different "cluster." Social expertise, an inclusive category motivated by the ethnosociology OCM code (e.g., conflict resolution, intergroup relations), similarly clustered with traditional domains, such as mythology and norms of behaviour, and with traditional history and law. Skills relating to a culture's subsistence strategy (not included in our search query) clustered with ethnozoology, ethnobotany, and ethnometeorology, and often described use of knowledge to improve subsistence outcomes (e.g., ethnozoology among hunter-gatherers, ethnobotany among agriculturalists, and ethnometeorology among pastoralists and horticulturalists; see figure 3.3.4).

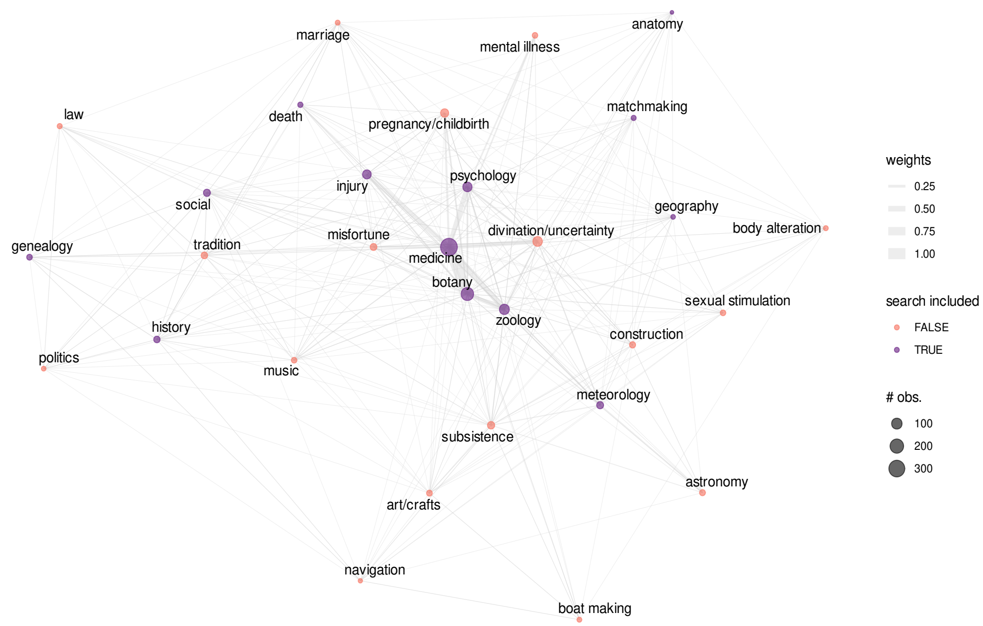

Figure 3.3.4: Graph representing commonly occurring domains of knowledge and skill that occurred in text records in our dataset. Vertices indicate domains that occurred in at least ten text records, and colours indicate whether or not the domain was included in our original search query. Each edge indicates a pair of domains co-occurred in at least one text record, and widths reflect the frequency with which each pair co-occurred.

3.3.3 Theoretical model results at the text record and culture levels

Support for each variable was determined by the percentage of text records containing evidence for it (text record level support), and the percentage of cultures containing at least one text record with evidence for each of the same variables (culture level support). Each "total model score" was the percentage of text record level support across all variables defining a model. (See the Methods section for details.) As indicated in figures 3.2.1 and 3.3.5, some variables were consistent with multiple theoretical models, and were therefore included in multiple total model scores. As we also show in figure 3.2.1 and the Methods section, some text records contained evidence that explicitly refuted a theoretical model, which we coded as an anti-model. Anti-models were analyzed identically to the other theoretical models.

Based on the total model scores, the *collaborative cognition model* received the highest level of support at the text record level (25.6%) but it also had considerable evidence against it (13.1%). The *proprietary knowledge model* and *cultural transmission model* were both relatively well-supported and made largely distinct predictions, indicating mixed support for each (*proprietary knowledge model*: 19.4%, *cultural transmission model*: 14.5%). Although the *honest signaling model* and *mate provisioning model* received similar but relatively low levels of support (*honest signaling model*: 6.6%, *mate provisioning model*: 6.2%), evidence against the *honest signal-*

ing model and *mate provisioning model* was also relatively low (anti-*honest signaling model*: 6%, anti-*mate provisioning model*: 1.5%). See figure 3.3.5 for text record level support, culture level support, and total model scores. At the culture level, we found no meaningful variation in model scores by geographic region or subsistence strategy. See the SI for details.

3.3.4 Exploring associations between the variables and conceptual, medicinal, and motor domains

At the text record level, we fit three elasticnet logistic regression models to explore which model variables in figure 3.3.3 (as predictors) were associated with evidence for each of our three high-level domain types (as outcomes), i.e., medicinal domains, conceptual domains (e.g., ethnobotany, ethnometeorology, genealogy), and motor skill-related domains (e.g., construction, boat making, art/crafts).

The coefficients of each of our three elasticnet regression models are shown in figure 3.3.6. The elasticnet regression models showed two key results. First, evidence of experts assisting with routine or common problems was strongly associated with individuals working in motor skill-related domains, such as woodworking, crafting, and subsistence. (To a much lesser extent, motor skill-related domains were also positively associated with some uncommon and serious problems, such as bone-setting after an injury.) Second, medicinal domains were positively associated with assistance with

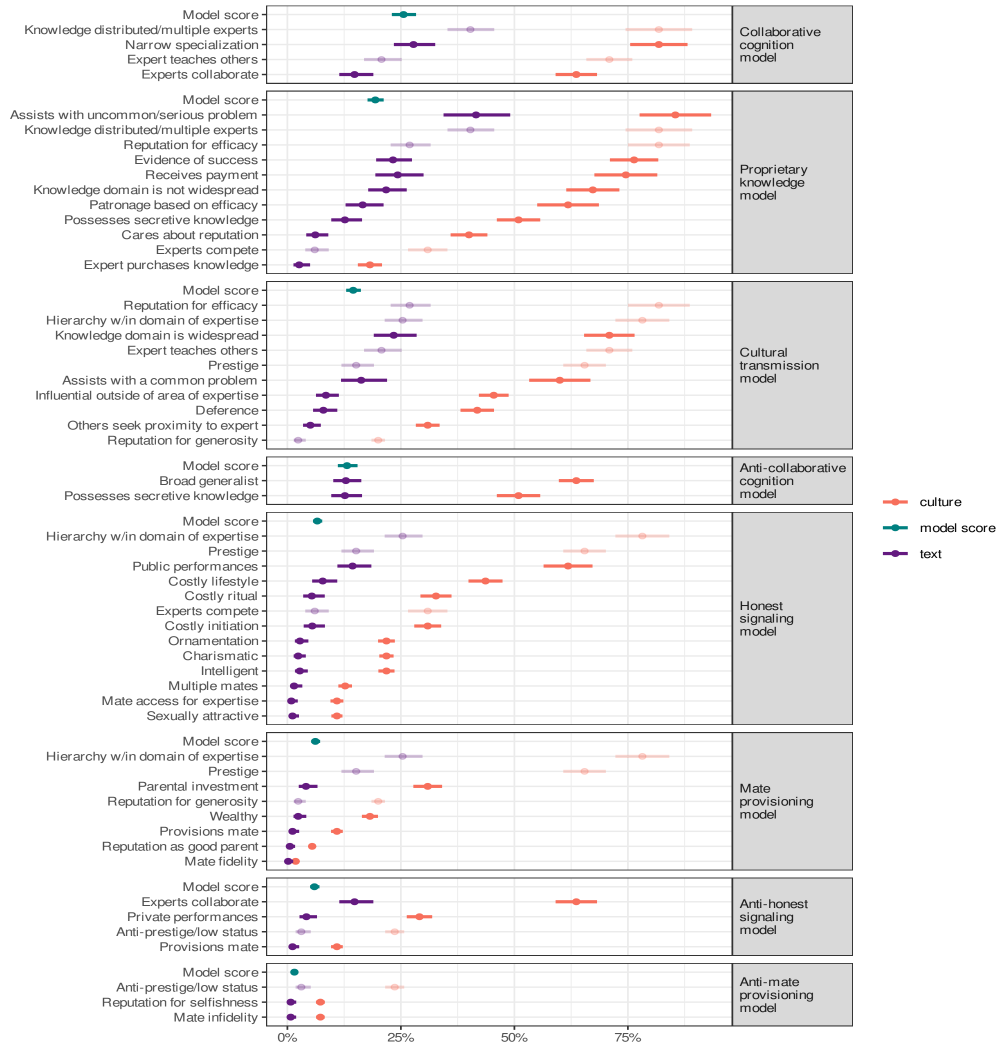

Figure 3.3.5: Support for each variable, faceted by model. Points represent the percentage of evidence for variables, and colours indicate whether that percentage is at the level of text, culture, or total model score. Solid colours indicate variables specific to models, whereas faded colours indicate variables included in more than one model. Error bars are 95% confidence intervals.

uncommon and serious problems, and positively associated with highly specialised knowledge among multiple types of expert. Medicinal domains were negatively associated with widespread or readily accessible knowledge, and in contrast with motor skills, medicine was also negatively associated with assistance with common problems. A handful of variables were weakly positively or negatively associated with conceptual domains, which frequently overlapped with medicinal domains and, to a lesser extent, motor skill-related domains (figure 3.3.4). However, no clear pattern emerged with conceptual domains as the outcome variable (figure 3.3.6).

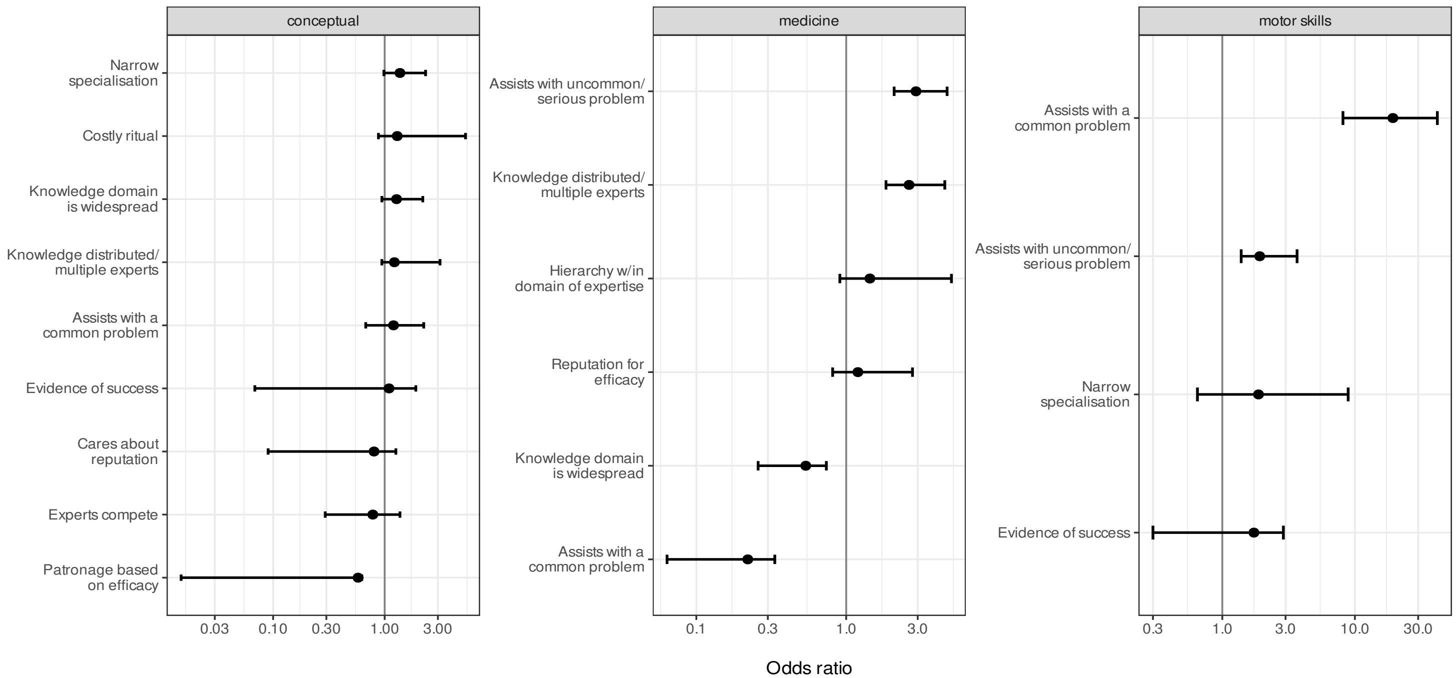

Figure 3.3.6: Coefficients for the "best predictors" of each domain type in our three elasticnet logistic regression models. Each facet shows the coefficients of each regression model. Each domain type, shown in the facet labels, was the outcome variable, and each variable along the y-axes was a best predictor in its regression model (i.e., had a non-zero coefficient). Error bars are 95% confidence intervals. Note that each x-axis is log-scaled.

3.3.5 *Exploring associations between the theoretical models and conceptual, medicinal, and motor domains*

To assess associations of our five theoretical models with each of the three domains, we first computed text record-level models scores for each of our five theoretical models to determine how well each text record supported each model (see Methods section). We then fit three separate generalised linear mixed effects logistic regression models, with domain types as outcomes and text record-level model scores (*collaborative cognition model*, *cultural transmission model*, *proprietary knowledge model*, *honest signaling model*, and *mate provisioning model*) as predictors. The results of these regression models showed that the *cultural transmission model* was positively associated with motor skill-related domains and negatively associated with medicinal domains, whereas the *proprietary knowledge model* was positively associated with medicinal domains (figure 3.3.7).

3.3.6 *Minimum spanning tree: Exploring structure among the variables*

In our minimum spanning tree, variable clusters only partially mapped onto our *a priori* theoretical models. See figure 3.3.8. Specifically, we found a variable cluster that we characterise as a "market for specialists", which includes two subclusters:

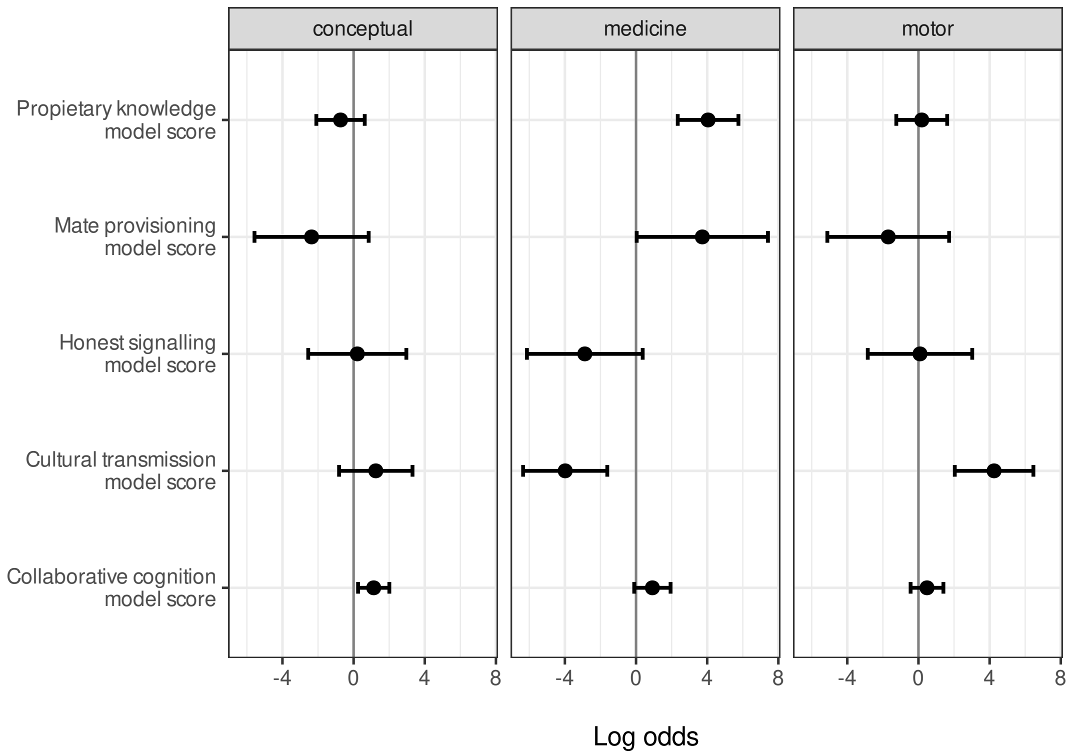

Figure 3.3.7: Regression coefficients for three generalised linear mixed effects logistic regression models of each domain type (conceptual, medicine, motor) as a function of theoretical model scores at the text record level. Theoretical model names are listed along the y-axis, and domain types are shown in the facet labels. Estimates are reported in log odds, and are shown on the x-axis. Error bars are 95% confidence intervals.

efficacious services and knowledge restrictions relevant to the *proprietary knowledge model*. The variables in this cluster had high levels of evidence across text records (indicated by the size of the nodes).

A second cluster included experts with prestige, deference, reputations for generosity, influence and skill outside of one's area of expertise (i.e., "broad generalists"), and expert competition. We interpret this cluster, which also had high levels of evidence across text records, as support for the prestige and "information goods" theories associated with the *cultural transmission model* (Henrich & Gil-White, 2001).

Further, we found variable clusters that resembled aspects of the *honest signaling model* and *mate provisioning model*, although the levels of evidence across text records was relatively low. A final cluster appeared to relate largely to shamans and low status occupational specialisations. See the SI for details and examples of text records supporting this interpretation.

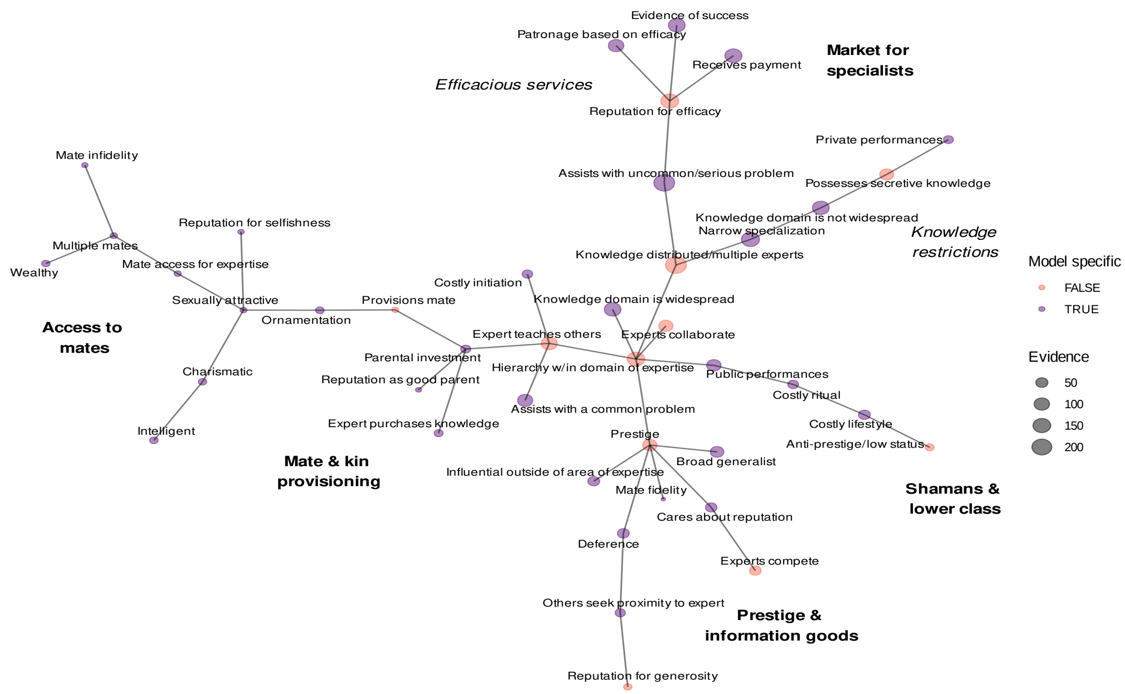

Figure 3.3.8: Minimum spanning tree of the variable binary distance matrix. Vertices represent variables, vertex sizes correspond to levels of text record support for each variable, and vertex colours to whether or not the variable is model specific vs. model generic. Edge lengths represent binary distances between variables.

We re-ran all of the foregoing analyses separately by sex to explore possible sex-specific patterns. We found no major sex-specific patterns, except that three variables – prestige, public performances, and narrow specialisation – were associated with evidence for male experts. See the SI for a more detailed analysis of sex differences.

3.4 Discussion

In this study, we considered the extent to which multiple evolutionary perspectives on knowledge and skill acquisition explain ethnoscientific expertise, and whether our exploratory results would suggest a new theory of expertise.

Ethnoscientific experts were skilled in a variety of conceptual domains, with medicinal expertise being especially common. Although we restricted our search query and post-search filtering to only include text records describing ethnoscientific expertise, these text records also frequently included discussion of multiple knowledge and skill domains, conceptual and/or motor skill-related, such as boat making, woodworking, subsistence, and construction (figure 3.3.4).

Our analyses were generally supportive of three theoretical models developed from the existing literature on the acquisition of knowledge and skill: the collaborative cognition model, the proprietary knowledge model, and the *cultural transmission model*. The *proprietary knowledge model* and *cultural transmission model* make some contrasting predictions, however, and the anti-*collaborative cognition model* (evidence against *collaborative cognition model*) also received a moderate level of support. The *collaborative cognition model*, *proprietary knowledge model*, and *cultural transmission model* therefore received mixed support overall. We found similarly mixed support for the *honest signalling model* and *mate provisioning model*, but in general there was much less evidence in the text records for these models, and for their counterparts (anti-*honest signaling model* and anti-*mate provisioning model*) (figure 3.3.5). The mixed support for our *a priori* models indicates that reformulation is in order.

3.4.1 Toward a data-driven theory of expertise

Our exploratory analyses revealed factors that were associated with greater or lesser support for the three models with greatest support overall: the *collaborative cognition model*, *proprietary knowledge model*, and *cultural transmission model*. Here, we distill these insights as a first step toward the development of a more general theory of ethnoscientific expertise.

Our first exploratory analysis revealed two clusters of text records associated with two clusters of variables. The upper left quadrant of the heatmap (figure 3.3.3) mostly involved text records that discussed hierarchies of experts that assisted with common problems in widespread knowledge domains, who had prestige, and taught others.

This cluster included support for many *cultural transmission model* variables, among others. The upper right quadrant, on the other hand, mostly involved text records that discussed experts who *assist with serious, uncommon problems* and who were *patronised based on their efficacy*. This cluster included support for many *proprietary knowledge model* variables. There was considerable overlap between these clusters, however, which hinged on high levels of support in each cluster for the presence of experts with *reputations for efficacious services*, *narrow specialisation*, and *distributed knowledge among multiple experts*. Distributed knowledge and narrow specialisation were motivated by the *collaborative cognition model*, and their support is consistent with the idea that distributed and complementary social structures are key factors for both widely transmitted knowledge and proprietary knowledge. The *collaborative cognition model*, in other words, seems to serve as a bridge between the *proprietary knowledge model* and *cultural transmission model*.

In the text records, knowledge domains and their characteristics (e.g., hidden and conceptual vs. observable and motor skill-related) varied considerably. Nevertheless, the two foregoing clusters seemed to be distinguished by an emphasis on motor-skills (left cluster) vs medicinal skills (right cluster). We therefore categorised specific expertise domains in each text record (figure 3.3.4) into more general domain types: motor skills, medicinal knowledge, and/or our ethnoscientific domains that were primarily conceptual knowledge.

Our elasticnet regression models found that evidence supporting the *cultural transmission model* and *proprietary knowledge model* was largely conditional on these domain types (figures 3.3.6 and 3.3.7). Specifically, two variables associated with the *proprietary knowledge model* (*assists with uncommon and serious problems* and *distributed knowledge across multiple experts*) were positively associated with medicine, whereas two variables associated with evidence for the *cultural transmission model* (and against the *proprietary knowledge model*) – *knowledge domain that is widespread* and *assists with common and routine problems* – were negatively associated with medicinal domains. Evidence for assistance with common problems (from the *cultural transmission model*), such as subsistence and construction, was strongly associated with motor skill-related domains. Assistance with uncommon and serious problems was also associated with motor skill-related domains (albeit to a much lesser extent), but these text records involved bone-setting and similar types of injury healing (see figure 3.3.6).

Aggregating text record-level evidence for each variable into total model scores showed a similar trend: Support for the *cultural transmission model* was positively associated with expertise in motor skill-related domains, whereas support for the *proprietary knowledge model* was positively associated with expertise in medicinal domains (figure 3.3.7). In general, medicinal domains were occasionally linked to motor skill-related domains, such as injury healing, but they were far more often linked to conceptual and non-motor skill-related domains, such as botany, psychology, and, more surprisingly, divination during times of uncertainty (figure 3.3.4).

Our finer-grained exploratory analysis of structure in our data matrix, using a graph-based clustering method (minimum spanning tree), further clarified the relationship between the *proprietary knowledge model*, *collaborative cognition model*, and *cultural transmission model* seen in our heatmap. In the minimum spanning tree, our variables clustered in ways that largely, but not completely, corresponded to our theoretical models (figure 3.3.8). A large and relatively well-supported cluster contained associations among prestige, deference, reputations for generosity, and high competence outside of one's area of expertise (termed "broad generalists"). We interpreted this cluster as support for the "prestige and information goods" theories associated with the *cultural transmission model* (Henrich & Gil-White, 2001). A separate cluster, which was also well-supported, resembled what we call a "market for specialists", which itself included two subclusters: efficacious services and knowledge restrictions that are relevant to the *proprietary knowledge model*.

Social dimensions of expertise, some part of the *collaborative cognition model*, served as "hubs" linking the *cultural transmission model* and *proprietary knowledge model* clusters together: distributed expertise among multiple complementary expert roles and knowledge and skill hierarchies were each situated between the *market for specialists* and *prestige and information goods* clusters. Collaboration among experts was directly adjacent to these hubs, and occurred more frequently than competition overall (competitive experts in 8% of text records vs. collaborative experts in 15%).

The *skill level hierarchy* hub of the minimum spanning tree also connected the branches that largely corresponded to the *honest signaling model* and *mate provisioning model*. These are labelled as "access to mates" and "mate and kin provisioning" in figure 3.3.8, respectively, and are difficult to draw inferences from given the low levels of evidence for their constituent variables.

Interestingly, a separate cluster that our theoretical models did not anticipate appeared to relate largely to shamans and low status occupational specialisations. (See the SI for details about how we arrived at this interpretation.) Although this particular cluster consisted of low levels of support, ethnoscientific experts were also religious or spiritual leaders, such as priests or shamans, in 19% of all of our text records. Future research will further address this trend by investigating how religious leadership and ethnoscientific expertise might share a common evolutionary explanation (Lightner, Heckelsmiller, and Hagen in prep; see also Garfield et al., 2020).

We now focus on the major *market specialists* and *prestige and information goods* branches, and their linking hubs, to more thoroughly evaluate their theoretical implications and interrelationships, in light of the domain specificity revealed by our exploratory analyses.

3.4.2 A market for specialists

The *proprietary knowledge model* was more associated with ethnomedical specialists who were consulted during a crisis, sometimes using divination (figure 3.3.4), whereas the *cultural transmission model* was associated with observable motor skills, knowledge that is widely distributed in lesser forms among the population (beyond the experts), and commonly occurring problems (figures 3.3.3, 3.3.6, and 3.3.7).

If a problem is rare but serious, then for the average individual, the cost of learning to resolve it might be greater than the cost of paying a specialist to do so, if and when that problem arises. Outsourcing uncommon but serious problems creates a demand for solutions, and thus, a market niche for specialising in those solutions. Specialised knowledge can therefore allow some individuals to gain a fitness advantage (e.g., prestige, material resources, beneficial partnerships) in exchange for their services, or *products* (Hammerstein & Noë, 2016; Price & Van Vugt, 2015; Sugiyama & Sugiyama, 2003; Tooby & Cosmides, 1996), what Hagen & Garfield (2019) refer to as computational services. If the market value of those products is undermined by sharing the underlying know-how used to generate them, then a beneficial strategy for specialists would be to keep their knowledge hidden, or proprietary.

This creates an apparent contradiction: The existence of cumulative cultural knowledge in *any* type of domain, proprietary or not, presupposes transmitted knowledge (Legare, 2017; Tennie, Call, & Tomasello, 2009). That is, cultural evolution literature correctly emphasises that transmitted knowledge is imperative for cumulative culture (Boyd & Richerson, 1996; Boyd et al., 2011; cf. Pinker, 2010). As our results clarify, however, it would be a mistake to conclude that transmitted and proprietary knowledge are at loggerheads, or that evidence for the *proprietary knowledge model* is evidence against the *cultural transmission model* (and vice versa). Instead, as we argue next, the relative importance of the *cultural transmission model* and *proprietary knowledge model* depends on properties of an expert's task domain.

3.4.3 The relationship between transmitted and proprietary knowledge

Under the *cultural transmission model*, there is one type of social transmission: a larger pool of naive individuals observes a smaller pool of skilled individuals, perhaps in exchange for deference, thus acquiring their skills. Under the *proprietary knowledge model*, in contrast, there are two types of "transmission": First, there are the services (products) that a few experts provide to a large pool of customers in exchange for some kind of payment, e.g., doctors' diagnoses and treatments to patients. This does not result in much, if any increase in specialised knowledge by customers (e.g., patients do not gradually become doctors). Second, experts expend considerable effort training a small pool of future experts (again, perhaps in exchange for some kind of much larger payment or inclusive fitness benefit). Indeed, consistent with the *cultural transmission model*, experts were also teachers in 21% of our text records, and this was closely related to assistance with common problems (figures 3 and 6). Of these observations, however, 11% involved purchased knowledge, and 37% appeared to involve teaching among kin. These constraints on social learning are amenable to a variety of interpretations, but in any case they are consistent with the *proprietary knowledge model* proposal that know-how is a valuable resource, and might not be unconditionally shared. Questions about the roles of payment and nepotism in parting with valuable know-how can be explored in future research, but these findings do suggest that in practice, a spectrum of expertise lies between the *cultural transmission model* and *proprietary knowledge model*.

Although the *proprietary knowledge model* does not rule out transmission, a possible concern about its constraints on transmission is knowledge loss, undermining the scope for cumulative culture. Task domains supported with the *proprietary knowledge model* are not commonly encountered, which by definition means that they are sampled rarely and provide fewer opportunities to learn (Strimling, Enquist, & Eriksson, 2009). For example, Reyes-García et al. (2013) found that medicinal knowledge was susceptible to knowledge loss among Tsimane forager-horticulturalists over time, whereas motor skill-related domains such as boat making and construction tended to either remain consistent or increase over time.

However, there are reasons to doubt that this concern is general to all types of skill domains. While much focus in cultural evolutionary theory is on behavioural copying, it is worth making explicit *how* knowledge in a particular domain is transmitted. One key difference between conceptual and motor skill-related domains is the degree to which information is public vs. private. Many motor skill-related domains, such as technological tasks, are achieved through specific, well-defined action sequences that can be observed and copied with high fidelity, even when underlying know-how is causally opaque (Flynn & Smith, 2012). In contrast, conceptual knowledge comprises mental representations, some of which are more easily and reliably constructed than others (Boyer, 1998; Sperber, 1996). Learning tools, such as ostensive communication, intuitive analogies, and mnemonic devices, are available means for communicating conceptual knowledge, but these rely on reconstructive processes rather than high fidelity copying (Acerbi & Mesoudi, 2015; Morin, 2016).

Our study suggests that among experts, a tendency to broadly vs. conditionally share knowledge depends strongly on the type of knowledge/skill domain, i.e., common problems that are solved by acquiring motor skills, vs. rare and serious problems that are solved by acquiring conceptual knowledge. Future research can investigate how high market value of services might be associated with proprietary knowledge that is reluctantly shared or exchanged for a benefit (but see Lewis, 2015). A relevant factor for choosing whether or not to share knowledge might also be its scope for monopolising valuable services. An alternative hypothesis about knowledge loss, consistent with our account here, might be that some socioecological changes (e.g., market integration, developing clinics and infrastructure) introduce novel or expanded markets of knowledgeable specialists, on whom individuals can rely for efficient and efficacious solutions in a given domain (Salali et al., 2020).

3.4.4 The distribution of cognitive labour

A central feature of the *collaborative cognition model*, which bridged the *cultural transmission model* and *proprietary knowledge model*, is a distribution of cognitive labour: Multiple experts have elaborate but incomplete knowledge about their own domains of expertise, and rely on others to share knowledge about similarly partial expertise in complementary areas (Heintz, 2004; Keil, 2003). An economic exchange of ideas, on this view, enables cumulative cultural knowledge among highly interdependent specialists, permitting mutually beneficial increases in group-level knowledge. This might suggest that for specialists in conceptual domains, the market value of know-how is based on its rarity. Specialists can therefore use their comparative advantage to beneficially trade their (otherwise proprietary) innovations for other innovations outside of their areas of expertise (Tooby & Cosmides, 1996).

On the other hand, the market dynamic described here at least partially resembles existing perspectives on group size and cultural innovations, where a larger number of specialists exchange know-how with each other and improve their overall scope for innovation (Henrich, Boyd, et al., 2016; cf. Vaesen, Collard, Cosgrove, & Roebroeks, 2016). Some empirical evidence has supported a relationship between group size and cultural innovations (Derex, Beugin, Godelle, & Raymond, 2013; Kline & Boyd, 2010), but these might be general to non-cumulative cultural copying, so long as the task at hand is sufficiently easy to copy (e.g., Ashton, Thornton, & Ridley, 2019).

Future research should therefore be vigilant about the different dynamics of cumulative culture in motor domains, which are relatively easy to copy with high fidelity, vs. conceptual domains, which are not. In conceptual domains, cumulative culture might resemble the evolution of scientific concepts, i.e., old ideas used to generate new ones, with lower demands on transmission fidelity and higher demands on sufficiently building up their underlying intuitions (Carey, 2011; Heintz, 2013; Wimsatt & Griesemer, 2007). Culture is complex, and when explaining its accumulation it is likely that one size does not fit all.

It is also worth noting that the *collaborative cognition model* does not necessarily represent "pure collaboration" among experts. Instead, it is compatible with the coexistence of collaboration and competition, both of which are compatible with the *proprietary knowledge model* and *cultural transmission model.* (The *cultural transmission model* even clustered with competition among experts in figure 3.3.8.) Indeed, a more restrictive version of the *collaborative cognition model* might have attenuated its emphasis on collaborative expertise, e.g., by including argumentation to gain influence in discourse (Mercier & Heintz, 2014; Mercier & Sperber, 2017), or by emphasising the role of prestige as an incentive for competition among specialists. In small-scale societies, prestige and general competence might be linked to transmitted knowledge and some mix of collaboration and competition: For example, traits that are frequently associated with elected leadership – such as intelligence, high quality decision-making, prosociality, and mentorship (Garfield & Hagen, 2020; Garfield, Hubbard, & Hagen, 2019) – reflect key aspects of the *cultural transmission model*, *proprietary knowledge model*, and *collaborative cognition model*. Conversely, more specialised competences often emerge as societies and markets scale up in complexity (Cockburn, Crabtree, Kobti, Kohler, & Bocinsky, 2013; Johnson, 1982). This increased complexity can, for some historical or ecological reason, also lay groundwork for a mix of collaboration and competition among prestigious groups of specialists, e.g., as seen in the shift from general medical practitioners toward widespread medical specialisation in nineteenth-century Paris (Weisz, 2003).

Open questions therefore remain about how competition among experts with proprietary knowledge is balanced against collaboration among experts, especially when they have complementary areas of knowledge. Do individual interests overlap as a consequence of mutually beneficial epistemic partnerships? What benefits calibrate otherwise conflicting interests, e.g., among apprentices and their acolytes, or possibly among leaders and followers more generally? These questions can be investigated in future research.

3.4.5 Limitations and caveats

Our source ethnographies varied in their theoretical commitments and aims. Some were broadly descriptive, but most focused on specific subjects other than expertise, and few shared our theoretical questions. Our search strategy also relied heavily on eHRAF OCM codes. Our sample is therefore not random, but is biased toward the subjects drawing the attention of ethnographers in our dataset, and the paragraph coding schemes used by HRAF staff. This suggests that our sample and its analyses are representative of ethnographic writings about expertise, rather than direct observations of expertise.

Relatedly, an absence of evidence in this study should not be interpreted as evidence of absence. Ethnographers often emphasise the immediately relevant aspects of expertise, such as applications of knowledge, learning, social roles as experts, and consequences of being highly knowledgeable. This might account for the high levels of support among the *collaborative cognition model*, *proprietary knowledge model*, and *cultural transmission model* compared to the *honest signaling model* and *mate provi-*

sioning model, especially if mating, parenting, and resource flows are less observable for, or deemed irrelevant by, the ethnographers. A similar caveat should be applied to the large number of religious practitioners in our results (19% of text records); ethnoscientific concepts might be mistakenly seen as supernatural, when subject matter is abstract or involves invisible entities (Gottlieb, 2004).

The abstract nature of conceptual knowledge also complicated matters. It is difficult to measure and characterise the distribution of knowledge in a population. Compared to direct empirical observations, which themselves face formidable challenges (Kronenfeld, 2011), ethnographic studies are especially imprecise. Drawing inferences from ethnographic texts, especially the relatively short ones in our study, involves a further and inevitable lack of precision. Different variables in our coding scheme have different levels of overlap with each other, they might vary in their inclusiveness and specificity, and they are coded based on multiple levels of interpretation. We attempted to minimise these limitations by using two independent coders and reconciling coding differences afterward. Nevertheless, our data were filtered through judgments made not only by an ethnographer (Sperber, 1985), but also by our own interpretations of how the text records related to our coding scheme.

3.4.6 Conclusion

In this study, we investigated the extent to which five mutually compatible evolutionary theories of knowledge and skill acquisition could account for ethnoscientific expertise, using 547 ethnographic text records from 55 geographically diverse societies. We found high levels of support for the collaborative cognition model, the *proprietary knowledge model*, and the *cultural transmission model*, and low levels of support for the *honest signalling model* and the *mate provisioning model*. Our exploratory analyses revealed that the *proprietary knowledge model* was associated with medicinal knowledge, which was largely conceptual and involved solving rare and serious problems for clients. Conversely, the *cultural transmission model* was associated with motor skill-related knowledge, which involved solving common, everyday problems, such as subsistence and construction. Support for each of these theoretical models was often linked to support for the *collaborative cognition model*, which was broadly supported across knowledge domains. While many evolutionary theories imply competition among experts, our results suggest that collaboration among experts, who share know-how and/or services, is also important.

Taken together, our results suggest that, rather than applying a single theoretical framework across multiple cultural domains, cultural evolutionary theories about ethnoscientific expertise should explicitly focus on the private and conceptual vs. public and observable nature of knowledge and skill domains, and their applications to common vs. rare problems.

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Research Transparency and Reproducibility

All data and code are available at:

https://github.com/alightner/conceptualExpertsHRAF.

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CHAPTER 4. ETHNOMEDICAL SPECIALISTS AND THEIR SUPERNATURAL THEORIES OF DISEASE

4.1 Introduction

In his seminal work on comparative religion, Frazer (1890) considered shamans and other religious practitioners in small-scale societies to be performance artists without serious regard for scientific knowledge, notably stating that for them "magic is always an art, never a science" (p. 34). These individuals, who we refer to as *religious specialists*, invoke the supernatural while healing illnesses and performing divination rituals (Winkelman and White 1987; Eliade, Trask, and Doniger 2004). In the anthropological literature, "religion" is a family resemblance category referring to traditions that deal with activities such as ritual techniques for diagnosing the unknown, and "supernatural" concepts such as spirits, souls, and witchcraft (Needham 1975). In traditional societies, most religious specialists deal with practical problems such as health, illness, crop failures, or natural disasters (Peoples, Duda, and Marlowe 2016; Boyer 2020).

In practical task domains that can involve high stakes and uncertainty, such as medicine, it is unclear why specialists should use "religious" methods, particularly if using “scientific” ones would be a more effective strategy. This is especially puzzling for evolutionary theorists: What advantages, if any, could religious specialists gain by relying on religious methods for healing? And conversely, why should laypersons find religious methods convincing and/or pay costs to religious specialists as patrons? We address these questions by focusing specifically on specialists who deal with health, medicine, and illnesses.

4.1.1 A standard account: The subjective appeal of magical healing

An influential evolutionary explanation of religious specialization focuses on the origins of “magical thinking” as a cognitive byproduct. According to this view, human cognition is susceptible to supernatural beliefs and superstitious behaviors, which themselves are evolutionary byproducts of adaptive error management strategies: When an outcome is uncertain and false negatives are costly, adaptive strategies can include over-attributing agency to non-agents (Guthrie 1995) and spuriously inferring causes that appear “superstitious” to more knowledgeable observers (Foster and Kokko 2009). More generally, humans’ adaptive capacities for reasoning about other minds, material artifacts, physical processes, and biological kinds might make “religious” ideas cognitively appealing (Kelemen 2004; Boyer and Bergstrom 2008).

Most proponents of this view also argue that cognitive byproducts alone are insufficient for religion to gain traction, because the space of possible religious ideas vastly outweighs the space of those that culturally evolve in reality to become sacred, socially sanctioned religious ideas (Atran 2002). A complete evolutionary account of religion therefore requires an explanation of the social origins of religious institutions, in addition to its cognitive origins (Norenzayan 2015).

Explanations that complement the cognitive byproduct account focus on the social benefits of participating in religion, such as improved within-group cooperation, that offset the potential costs of participating in rituals or observing taboos (Wilson 2010; Chwe 2013). Religious specialists sometimes play a coordinative leadership role by publicly performing rituals, facilitating the spread of some religious beliefs over others by giving them "rehearsal time" at the social group level (Dennett 2006). These rituals are often costly, and one possible reason for religious specialists to gain traction is based on the subjective appeal of their displays to laypersons, which might attract the attention of admiration of potential followers (credibility enhancing displays; Henrich 2009; Singh 2018). The displays made by religious specialists, and the behaviors they inspire among religious followers, can provide societies with real benefits, such as improved between-group competitiveness (Norenzayan 2015), improvements to the local ecology (Purzycki 2016), social bonding, and/or ingroup signals of cooperative intent (Sosis and Alcorta 2003).

Convincing displays of supernatural ability?

Magical thinking about uncertain and high-stakes phenomena makes laypersons susceptible to exploitation, providing an opportunity for aspiring religious specialists. For serious yet rare events whose causes are opaque, such as many illnesses, laypersons could benefit by gambling on the advice of knowledgeable, trustworthy sources of information or aid (Morin 2015; Lightner and Hagen 2021). Religious specialists, on the other hand, could gain an advantage by using "plausible-seeming magical practices" that pander to intuitions about invisible and malevolent agents, with whom the specialist can negotiate to treat the illness. On this view, the religious specialist can gain prestige and patronage because the effectiveness of a magical practice is difficult to evaluate and/or prone to confirmation bias (Strimling, Enquist, and Eriksson 2009; Singh 2018).

Religious specialization might therefore represent a reliably-occurring, culturally evolved opportunity for adapting to people's intuitions and convincing laypersons that the specialist can influence otherwise unpredictable and high-stakes outcomes (Singh 2018). Professionalizing this opportunity can (and often does) involve religious specialists who not only convince others of their supernatural abilities, such as healing, but also gain deference through fears of their abilities to impose harms and/or resources through patronage (Singh 2021).

Exploitation of cognitive byproducts fails to explain some important phenomena:

Why do the areas of religious specialization so frequently relate to healing, e.g., compared to other unpredictable and high-stakes outcomes? And more importantly, if religious specialists are performers who use culturally evolved myths and customs that "hack our psychologies and placate our anxieties" (Singh 2018:17), then why should laypersons settle for the "religious" healer if a "scientific" one could be more reliable?

4.1.2 An alternative account: Religion, ethnomedicine, and a market for useful services

A mutually compatible explanation for religious specialization is that the "religious" healer *is* the "scientific" healer, and that patronage from laypersons is based on the actual efficacy of a specialist's treatments.[3] We refer to this idea as the *efficacious healing* hypothesis. People everywhere use folk scientific knowledge to make causal inferences and navigate uncertainty (Sperber, Premack, and Premack 1995; Szollosi and Newell 2020), and traditional knowledge systems are widely interpreted as providing useful, practical solutions for recurring challenges in a given socioecological environment (e.g., Glowacki 2020; Rappaport 1968; Steward 1972; Lansing and Kremer 1993).

[3] We use "efficacy", like the standard definition in medicine, to refer to the effectiveness of a treatment method in obtaining its desired outcome.

In many societies, local specialists master elaborate systems of culturally evolved knowledge that require costly investments of time, resources, and opportunity costs (Lightner, Heckelsmiller, and Hagen 2021). Cross-culturally, medicine is one of the most common domains of folk scientific knowledge (Erickson 2007; Singer and Erickson 2011), and most adults in traditional and small-scale societies have at least some knowledge of medicinal plants and health-related practices, i.e., *ethnomedical knowledge* (Conklin 1980; Medin and Atran 2004; Lozada, Ladio, and Weigandt 2006). Nevertheless, even these societies typically have individuals who specialize in efficacious, culturally evolved strategies for alleviating locally salient diseases (Berlin and Berlin 2015). We refer to these individuals, whose extensive medicinal knowledge can include herbal medicines, animal venoms, and human physiology, as *ethnomedical specialists*.

A market for efficacious ethnomedical specialists

Much research has focused on the cognitive, social, and ecological factors behind scientific knowledge (Carruthers, Stich, and Siegal 2002; Heintz 2007; Nersessian 2010; Thagard 2019), but the relationship between specialists and laypersons is less clear, particularly among ethnomedical specialists. What benefits, if any, do ethnomedical specialists provide to laypersons in traditional societies, and what benefits do the specialists gain in return?

People might favor knowledgeable ethnomedical specialists because they provide valuable services when stakes are high, especially for know-how that is inefficient to learn individually. If a service resolves a sufficiently uncommon and serious problem, such as an unlikely but deadly illness, then knowing how to diagnose and heal the illness can favor a market for specialized knowledge: for the average individual, the cost of mastering these skills might be greater than the cost of paying a specialist to do so, if and when the serious event arises. Ethnomedical specialists can therefore improve their own prospects by professionalizing an opportunity to provide valuable knowledge-based services, such as efficacious healing techniques, to their clients in exchange for benefits, such as payments or prestige. Clients do not necessarily learn the skills or knowledge underlying the service – patients who receive diagnosis and treatment do not thereby become doctors – but they might evaluate specialists based on individual-level feedback when they are recipients of specialists' services. We refer to this idea, which builds on the work of many others, as the *market for specialists* hypothesis (see, e.g., Hagen and Garfield 2019; Tooby and Cosmides 1996; Sugiyama and Sugiyama 2004).

Another view of the specialist-layperson relationship is that it is akin to mentorship. On this view, which we refer to as the *mentorship* hypothesis, experts possess valuable skills, and laypersons exchange deference for proximity so as to better acquire the skills for themselves (Boyd, Richerson, and Henrich 2011). Laypersons are not patrons *per se*, but are acolytes who can use ecologically rational cues to determine who to learn from: People might decide based on prestige (Henrich and Gil-White 2001) and/or who others are copying (Henrich and Boyd 1998).

Is ethnomedicine "religious"?

The extent to which ethnomedical specialists resemble religious specialists is unclear. Historically, traditional scientific knowledge systems in Western and non-Western societies have included intuitive humoral and sympathetic concepts, e.g., among ancient Greeks, Quetzi Mayan, Ayurvedic, and Amharic Debtera medical knowledge systems (Young 1975; Atran and Medin 2008; Jaiswal and Williams 2016). To the modern Western observer, traditional ethnomedical concepts about infection, for example, might be easily interpreted as "religious" or "supernatural" based on their resemblances to spirits or magical contagion (Gottlieb 2004).

Conversely, religious healers such as shamans and priests employ esoteric and supernatural concepts in their practices, the medicinal and/or psychological benefits of which might help explain the evolution of religious ritual (Winkelman 1990; McClenon 1997). In at least some cases, they also display evidence of technical expertise in diagnosing and effectively curing illnesses with herbs (Andritzky 1989; Blackwell and Purzycki 2018).

We refer to the idea that ethnomedical specialists are also religious specialists (and vice versa) as the *religiosity* hypothesis. If "religious" specialists are also the "scientific" ethnomedical specialists, however, then how can we explain why they use supernatural theories of disease instead of naturalistic theories? Should laypersons weigh the relative importance of more "scientific" specialists vs. more "religious" ones?

A misleading distinction between science and religion

Social sciences have long assumed that practical and scientific concerns vs. religious ones are distinct aspects of both culture and psychology (e.g., James 1902; Frazer 1890; Weber 1920), and have largely developed their evolutionary theories of science separately from their evolutionary theories of religion.

This separation between scientific and religious practices has been carried forward to modern theories about distinct types of cognition (Shenhav, Rand, and Greene 2012; Funk and Alper 2015; Uzarevic and Coleman 2020), or at least of two separate positions on a continuum where religion is developmentally "natural" and science is not (McCauley 2013). This separation of religion, which seems intuitive, vs. science, which does not, might appear patently obvious and only motivate questions about *how* religion and science relate to each other (for a range of perspectives, see Barbour 1966; Draper 2009; Gould 2011; Coyne 2016).

Although scientific and religious *institutions* have a long and complex history of political and ideological cooperation and conflict among Western societies, the distinction between scientific and religious *knowledge* is relatively recent. Influential Western scientists, including Newton, Boyle, Hooke, and Kepler, were deeply religious and viewed much of their work as supplying evidence for a divine and transcendent creator (Gillispie 1996). The term "scientist" itself was not widespread until after the British Association's William Whewell coined it around 1834 as a suitable replacement for the term "natural philosopher". The term was meant to imply specialized commitments to creating knowledge (*scientia*, in Latin), analogous to the artist's commitment to creating art (Snyder 2012).

It is therefore not obvious that a distinction between "science" and "religion" is useful for analyzing beliefs and institutions in most non-Western societies. The modern Western institutional separation of science and religion might misleadingly lead theorists to carry this separation over into their evolutionary perspectives of cognition (Boyer 2018; Sperber 2018). In small-scale societies, anthropologists have documented uses of magic and religion for practical tasks involving high-stakes risk and uncertainty (Malinowski 1932; Evans-Pritchard 1940), often integrating *natural* and *supernatural* concepts into unified explanatory frameworks (Legare et al. 2012; Tucker et al. 2015).[4] In a classic example, Zande farmers understand the natural causes of unfortunate granary collapses (termites), but particular *occurrences* of these collapses demand supernatural explanation (witchcraft) (Evans-Pritchard and Gillies 1976).

[4]While *supernatural* is arguably an ethnocentric concept (see Sperber 2018), it is nevertheless central to defining religious belief systems in the existing literature. Indeed, this objection is an empirical claim, rather than an assumption, which we test in the present study.

At cognitive and behavioral levels, Westerners also integrate “scientific” and “religious” concepts by resorting to ritual in times of high-stakes uncertainty (Gmelch 1971), appearing to use magical thinking in experiments (Rozin, Millman, and Nemeroff 1986), and merging natural and supernatural explanations for life, death, and disease (Legare et al. 2012).

Mental models about abstract and “supernatural” phenomena

The alternative account, involving a market for efficacious healers, therefore hypothesizes that “science” and “religion”, while nominally distinct institutions among Western societies, are products of a cognitively integrated system whose evolved function is to acquire, exchange, and apply locally relevant social and ecological knowledge. Many anthropologists argue that religion should not be seen as a unitary phenomenon, nor that most societies have had “religions” in a useful sense of the term. Instead, small-scale societies, in which religion is not a hegemonic institution, have a variety of ideas, practices, and institutions that are described to varying degrees as “religious” in a loose and interpretive sense (Bloch 2008; Sperber 2018; Boyer 2020). As a culturally specific system for gaining practical knowledge (Heintz 2004), “science” might or might not include “religious” concepts.

It is unclear that cross-cultural and evolutionary perspectives of scientific knowledge should exclude religious belief, and vice versa. Applied to ethnomedicine, the cognitive function of “supernatural” thinking about theories of disease might be to mentally model and make inferences about rare or abstract phenomena whose causes are unobservable (e.g., infection, mental illness, probability, counterfactuals) instead of a separate "religious" style of thinking.

4.1.3 Study aims and hypotheses

In a two-part study, we assessed the foregoing hypotheses about the roles of religiosity, efficacy, and knowledge specialization among ethnomedical specialists and their potential patrons. Study 1 was a cross-cultural study of ethnographic data from the electronic Human Relations Area Files (eHRAF), and study 2 was a field study with Tanzanian Maasai pastoralists.

In study 1, we assessed levels of evidence in cross-cultural data for attributes supporting the roles of *religiosity*, *efficacy*, *market specialization*, and *mentorship* among ethnomedical specialists. We exclusively searched the eHRAF for examples of ethnomedical specialists rather than religious specialists, meaning that any resulting ethnographic examples of religious specialists, efficacious healers, or prestigious mentors were not a consequence of our search query, but a consequence of their association with ethnomedical specialists in the ethnographic record.

In study 2, we investigated the criteria that patrons use to select among ethnomedical specialists, and their cultural models of medical treatments. Specifically, we interviewed 84 Tanzanian Maasai pastoralists about who they would favor among local medicinal specialists in the region if they were seriously ill and why. We also assessed cognitive models of disease by asking participants to detail their explanations for how a medicine for a common ailment works, and we introduce qualitative data from interviews with two local Maasai ethnomedical specialists and a traditional religious specialist. These interviews were conducted in a population undergoing a cultural and economic transition from pure cattle-based subsistence and trade, and toward a more Christian and cash-based market economy (Hodgson 2005).

4.2 Study 1: Cross-cultural data

We used cross-cultural data from the eHRAF to investigate the hypotheses that ethnomedical specialists are *religious*, offer *efficacious* treatments, compete for patrons in a *specialized market*, and are prestigious *mentors* who teach acolytes. We focused exclusively on ethnographic descriptions of ethnomedical specialists (i.e., without attempting to search for religious specialists), so we compared the extent to which each of these hypotheses, which were not part of our search terms, were supported by ethnographic evidence.

We also conducted extensive exploratory analyses at the text record level and the culture level. For example, we considered the correlates of supernatural theories of disease, religiosity, and acculturation, with acculturation interpreted as an "expansion" of pre-existing markets for ethnomedical specialists (e.g., via the introduction of infrastructure, hospitals and clinics, and/or foreign medicinal practices).

4.2.1 Methods

We searched for ethnographic data about ethnomedical specialists from the eHRAF, a digitized database of primary ethnographic documents from over 400 cultures around the world. We restricted our search to the Probability Sample Files (PSF), a stratified subset of 60 cultures in the eHRAF that includes one randomly selected culture from 60 geographically diverse areas (Naroll 1967). Documents in the eHRAF are coded at the paragraph level using an Outline of Cultural Materials (OCM) hierarchically organized coding scheme, containing several hundred numeric codes assigned to unique and specific topics (Murdock et al. 2006).

Previously, in a study of ethnoscientific expertise (Lightner et al. 2021), we searched the PSF for 68 OCM codes that could plausibly result in descriptions of expertise in conceptual, folk scientific knowledge domains, such as ethnobotany, ethnometeorology, and theories of disease. We narrowed this search using six keywords that refer to highly knowledgeable experts in those domains, such as "expert*", "specialist*", and "practitioner*".[5] We did not include any OCM codes or search terms corresponding to religious topics. See the supplementary information (SI) for a more in depth summary of our search protocol, which produced 547 text records in total.

Whereas Lightner et al. (2021) broadly investigated the social characteristics of knowledge specialists that might explain knowledge specialization as an evolutionary strategy, and did not focus on their religious or supernatural qualities, here we restricted our investigation to *ethnomedical specialists*, resulting in 341 text records describing specialists with ethnomedical expertise. We included the 42 coded variables from Lightner et al. (2021) that characterized the knowledge domains and attributes (e.g., uses of plant knowledge) and social attributes (e.g., prestige) of ethnomedical specialists. We added 16 variables that characterized religious and supernatural dimensions of ethnomedical specialization, variables that would conceivably be important to patrons, such as the benefits and costs provided and imposed by specialists, and variables that indicated acculturation. This produced a total of 58 variables. See the SI for examples illustrating the text record coding procedure.

Our resulting dataset represented ethnomedical specialists in 47 cultures, whose geographic distribution and subsistence strategies are shown in figure 4.2.1. Our 58 variables allowed us to assess the extent to which ethnomedical specialists were *religious*, provided *efficacious services*, engaged in a *specialized market* for payment

[5]The "*" is a wildcard that would match any suffix.

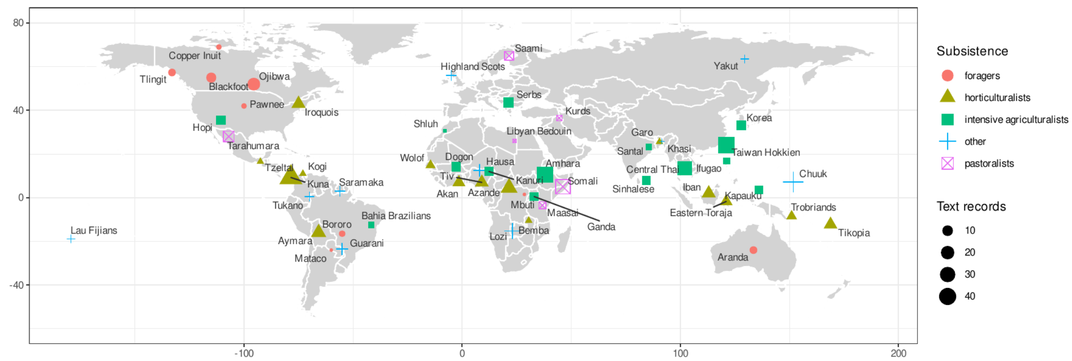

Figure 4.2.1: Geographic region of each culture included in our dataset. Colours and shapes indicate subsistence strategy for each cultural group, and sizes indicate the number of text records for each culture in our dataset.

and patronage, and participated in *mentorship* as prestigious teachers. Similar to the variables in Lightner et al. (2021), many of these variables related to knowledge attributes and social attributes. See figure 4.2.2 for our coded variables and their corresponding attributes and hypotheses.

ADL and CH independently coded each text record for presence/absence (1/0) on each of our 58 variables, which generated a 85.5% match with a Cohen's kappa indicating moderate agreement ($k = 0.49$). Although most variables represented the presence or absence of evidence for a variable, in a few cases, it was feasible to code variables with evidence against one of our coded variables. We coded on variables for *prestige* and *specialist confers benefits*, for example, but we also coded on variables for *low status*, or "anti-prestige", and *specialist imposes costs*. See the SI for more

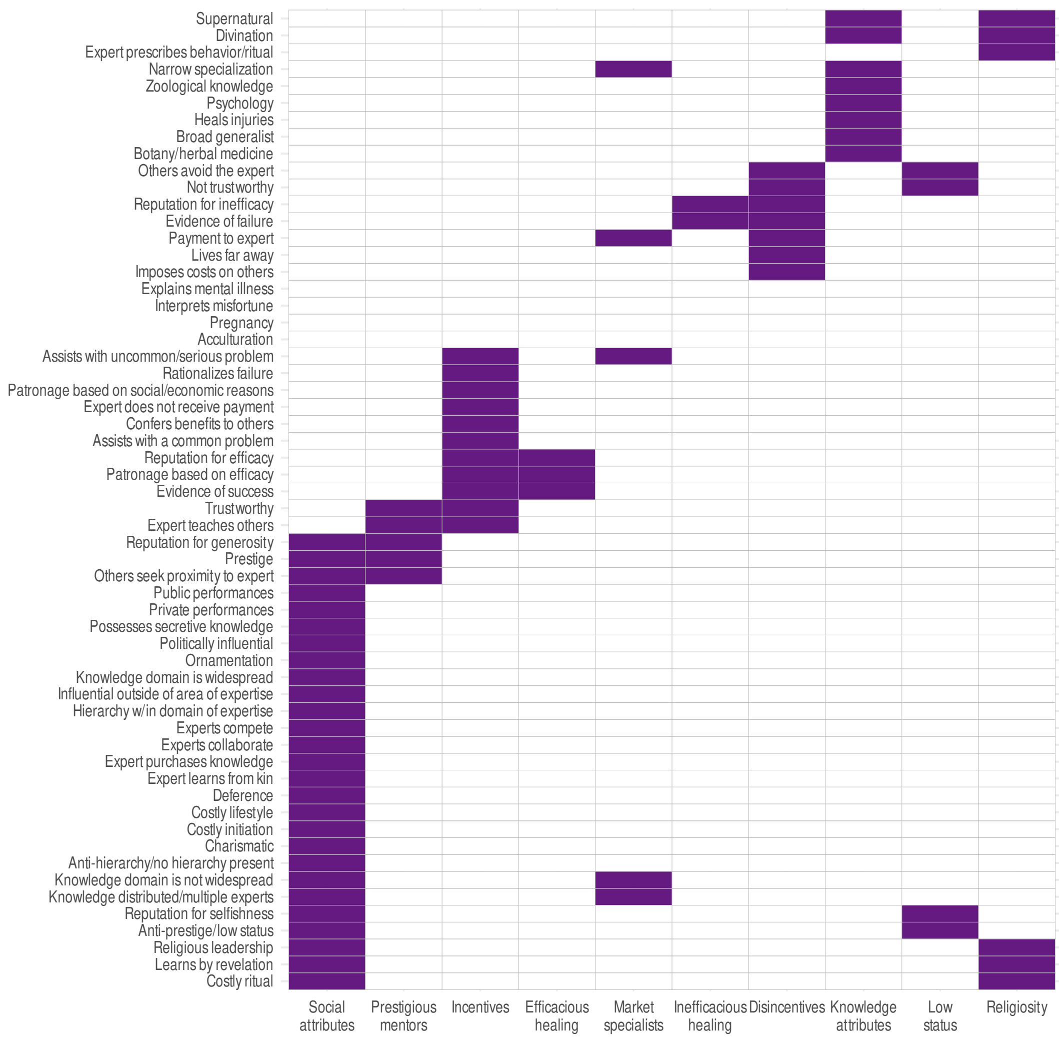

Figure 4.2.2: Coded variables about ethnomedical specialists are listed along the y-axis. The relevance of each variable to each hypothesis, and whether it is a social or knowledge attribute, is listed with its opposing model along the x-axis. Filled cells indicate which variables are included in each hypothesis and/or type of attribute.

details about interrater reliability. Afterward, ADL and CH discussed and reconciled all disagreements to produce the coded dataset used in our analyses.

Although most of our analyses were at the text record level, we were also interested in analyses at the culture level. We used the Standard Cross Cultural Sample (SCCS) to acquire variables at the culture level. The SCCS contained 44 of the 47 cultures in our eHRAF dataset, so text records from 3 cultures were excluded from analyses using the SCCS data.[6]

Statistical analyses

Our dataset comprised a 341 row by 58 column binary matrix, where each row represented one text record on ethnomedical specialists, and each column represented one coded variable (0=no evidence, 1=evidence). We analyzed this matrix in four ways. First, we computed the proportion of text records that provided evidence for each variable. Second, we grouped variables representing each hypothesis, and computed the mean proportion of evidence for each hypothesis (which we termed its *total score*). Third, we used hierarchical and penalized (elasticnet) regression models to determine the association of supernatural and religious concepts with other dimensions of ethnomedical specialization, the association of supernatural and religious concepts

[6]The eHRAF data is our primary dataset of coded data from ethnographic text records about ethnomedical specialists, and should not be confused for the SCCS dataset that we used for this particular cross-cultural analysis. All references to "the data" or "the dataset" in Study 1 should therefore be assumed to be the eHRAF dataset, unless it is specified as the SCCS dataset.

with culture-level factors, such as continental region, mode of subsistence, and cultural complexity (using variables obtained from separate SCCS data, and a principal components analysis (PCA) of these variables; Kirby et al. 2016), and the association of acculturation with dimensions of ethnomedical specialization. Finally, to examine structure in our entire data matrix, i.e., to determine which groups of variables tended to have evidence in the same text records and therefore might indicate important abstractions about ethnomedical specialization, we used a network clustering technique known as a minimum spanning tree (MST), in which only similar variables (the vertices) are connected to each other. We then identified "clusters" of variables by visual inspection of the MST, seeking groups of adjacent variables that were conceptually related. For a full description of our statistical analyses, see the SI. We also provide all data and R code: `https://github.com/alightner/ethnomedicine-magic`.

4.2.2 Results

The text record level evidence for each of the 58 coded variables, which we broadly characterize as knowledge and social attributes, are shown in figure 4.2.3. We found high levels of evidence for supernatural theories of disease, uses of botanical knowledge, and narrow specialization. Text records frequently described multiple specialists who were distributed among separate roles with complementary specializations, often with collaborative relationships. In some cases, ethnomedical specialists were situated in a hierarchy with prestige, and engaged in public performances. Sometimes knowledge was clearly restricted to the specialists – in some of these cases the knowledge was intentionally kept secret – and sometimes the specialists were simply more knowledgeable and/or skilled compared to others in their society (figure 4.2.3A).

Most ethnomedical specialists (74%) used at least some "supernatural" concepts, such as witches, spirits, or deities. Some ethnomedical specialists had religious leadership roles (24%) and/or performed divination rituals during times of uncertainty (13%). When we grouped our variables according to hypotheses, their total scores showed relatively high levels of evidence for a market for specialists, efficacious healing, and religiosity. We found relatively less evidence for and against mentorship, and for inefficacious healing practices. See figure 4.2.3B.

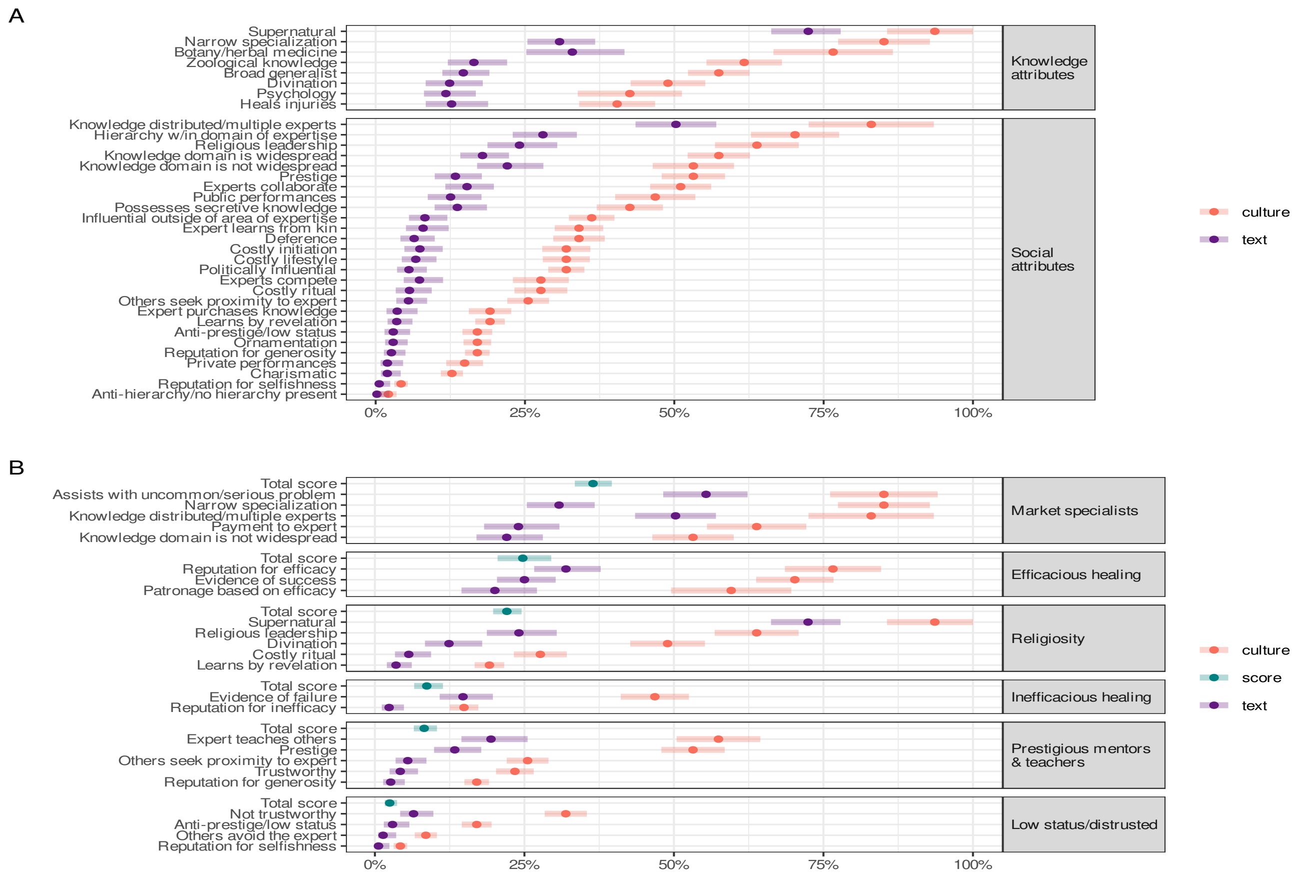

Figure 4.2.3: Percentage of text records (purple) and cultures (orange) with evidence for each variable.

Religion and the supernatural among ethnomedical specialists

The elasticnet regression model with religion scores for each text record as the outcome variable showed that variables most positively associated with evidence for religion were ethnospecialists assisting with uncommon and serious problems, imposing costs on others, specializing in theories of psychology, and possessing secretive knowledge. Religious ethnomedical specialists were also positively associated with multiple specialists whose knowledge was distributed across multiple roles. Predictors that were most negatively associated with evidence for religion were acculturation, purchased knowledge, and healing injuries (figure 4.2.4A). Neither regional variation nor subsistence strategy were associated with substantial variation in religion scores at the culture level (figures 4.2.5A and 4.2.5B).

The elasticnet regression model with presence/absence of supernatural theories in each text record as the outcome variable showed that the supernatural was positively associated with divination, costly rituals and initiation processes, and religious leadership. This model also showed that the supernatural was negatively associated with acculturation and evidence of success in their healing practices. See figure 4.2.4B. At the culture level, ethnomedical specialists' uses of the supernatural did not systematically vary by region or subsistence strategy, although intensive agriculturalists appeared to have less evidence for supernatural healing compared to horticulturalists (figures 4.2.5C and 4.2.5D).

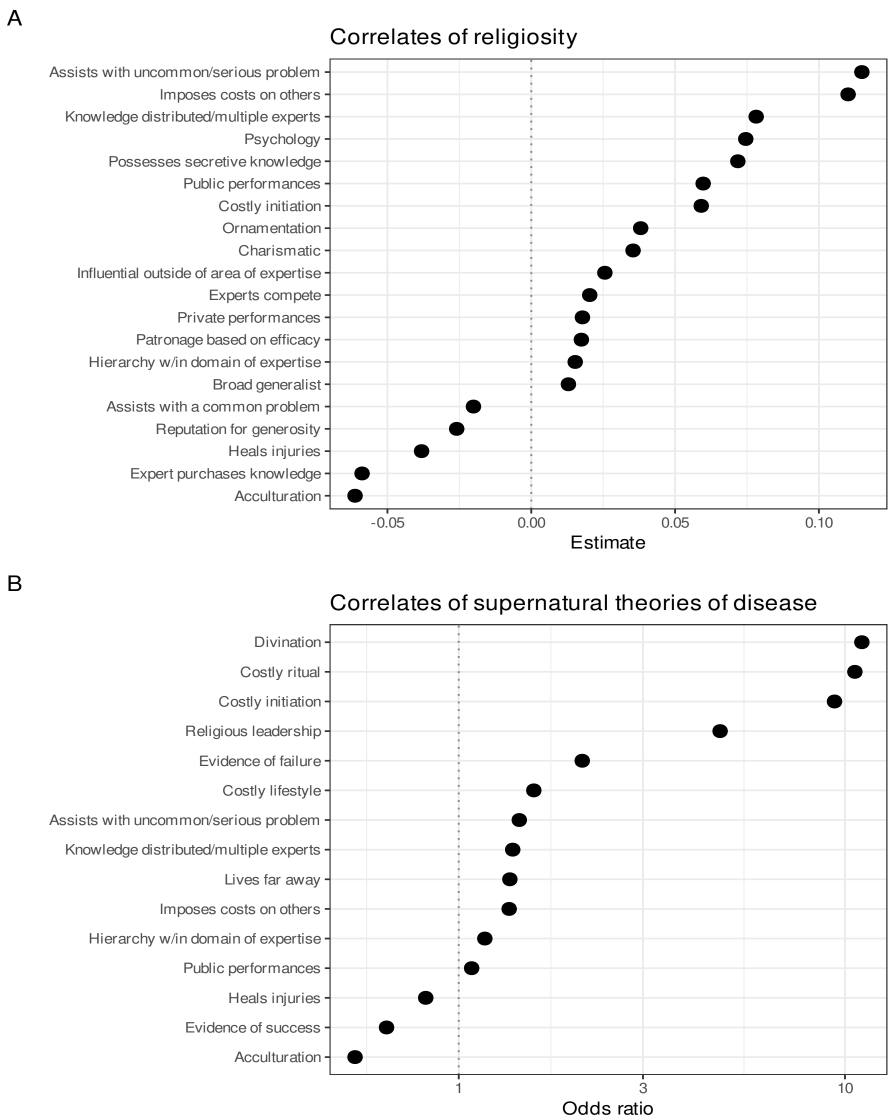

Figure 4.2.4: Coefficients from the elasticnet model of religiosity (A) and supernatural theories of disease (B).

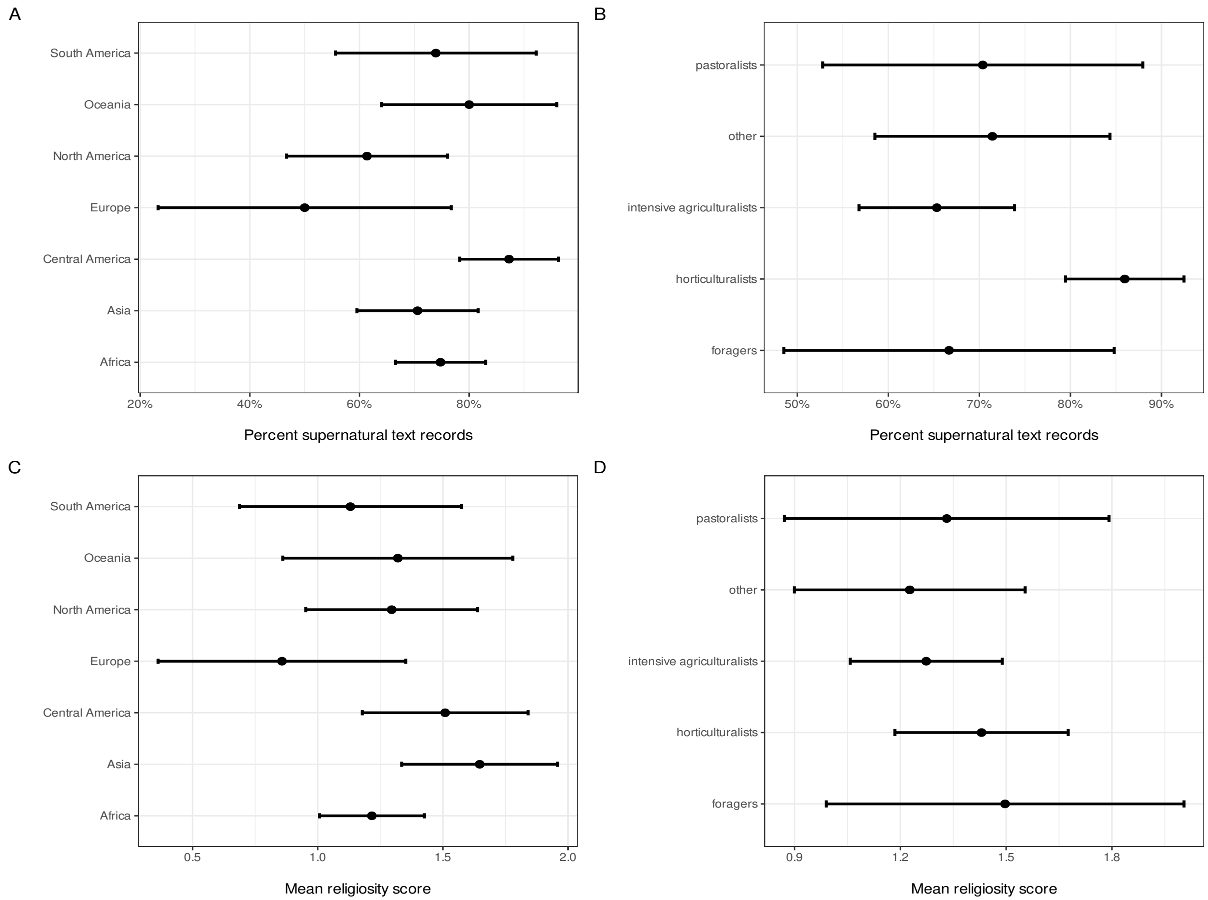

Figure 4.2.5: Estimated marginal means of religiosity scores by region (A) and subsistence strategy (B), and of the proportion of supernatural theories of disease by geographic region (C) and subsistence strategy (D).

Supernatural theories of disease are about the uncertain and the unobservable

Ethnomedical specialists often specialized in specific knowledge or skill domains, which included conceptual, ethnoscientific domains such as plant and animal knowledge. Supernatural theories of disease were more frequent in domains that are unobservable and uncertain, such as divination, misfortune, uncertainty, and psychology, and less frequent in domains involving some observable motor activity, such as physical injuries and childbirth (figure 4.2.6).

The first two components of a PCA of the 186 cultures in the SCCS data (see the SI) were interpretable as "culture complexity and scale" (PC1) and "pathogen stress and proximity to the equator" (PC2). See figure 4.2.7. We plotted the PC1 and PC2 values of the 44 cultures that were also in our eHRAF sample of ethnomedical specialists (3 cultures were not included in the SCCS). The eHRAF cultures that were higher on PC2 (i.e., higher pathogen stress, closer to the equator) appeared to account for many of the above-average proportions of text records with supernatural theories of disease (figure 4.2.8), a pattern supported by a regression model of the supernatural variable as a function of PC1 and PC2, in which PC2 is a significant predictor of supernatural but PC1 is not (see the SI for details and caveats).

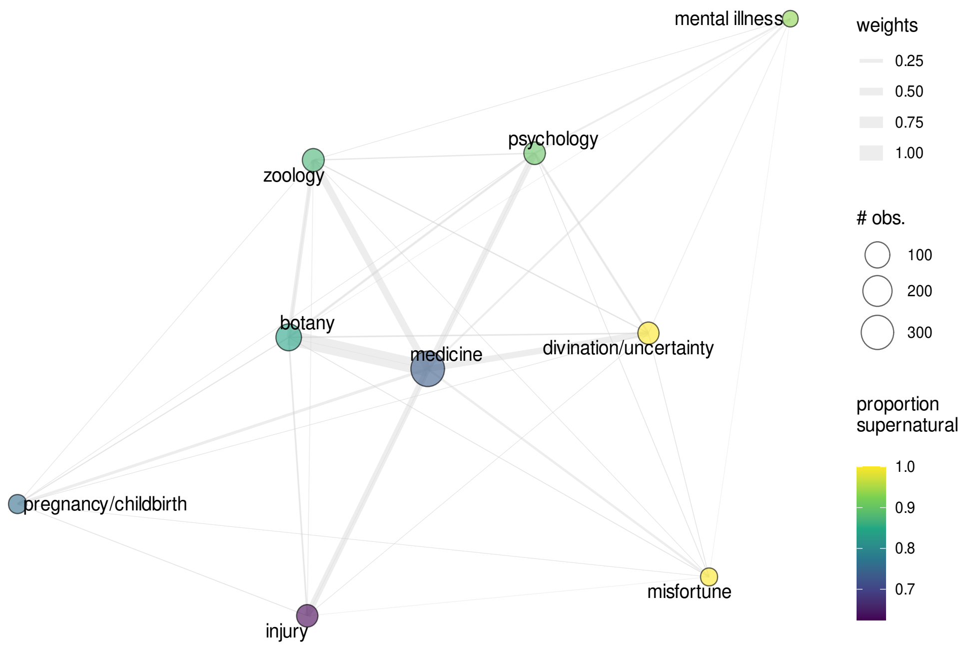

Figure 4.2.6: Graph representing commonly occurring domains of knowledge and skill that co-occurred with medicinal knowledge in text records in our dataset. Vertices indicate domains that occurred in at least ten text records, and vertex size corresponds to the number of text records including that domain. Vertex colors indicate the proportion of supernatural theories of disease that was associated with each knowledge domain. Each edge indicates that a pair of domains co-occurred, and widths indicate the frequency of each pair.

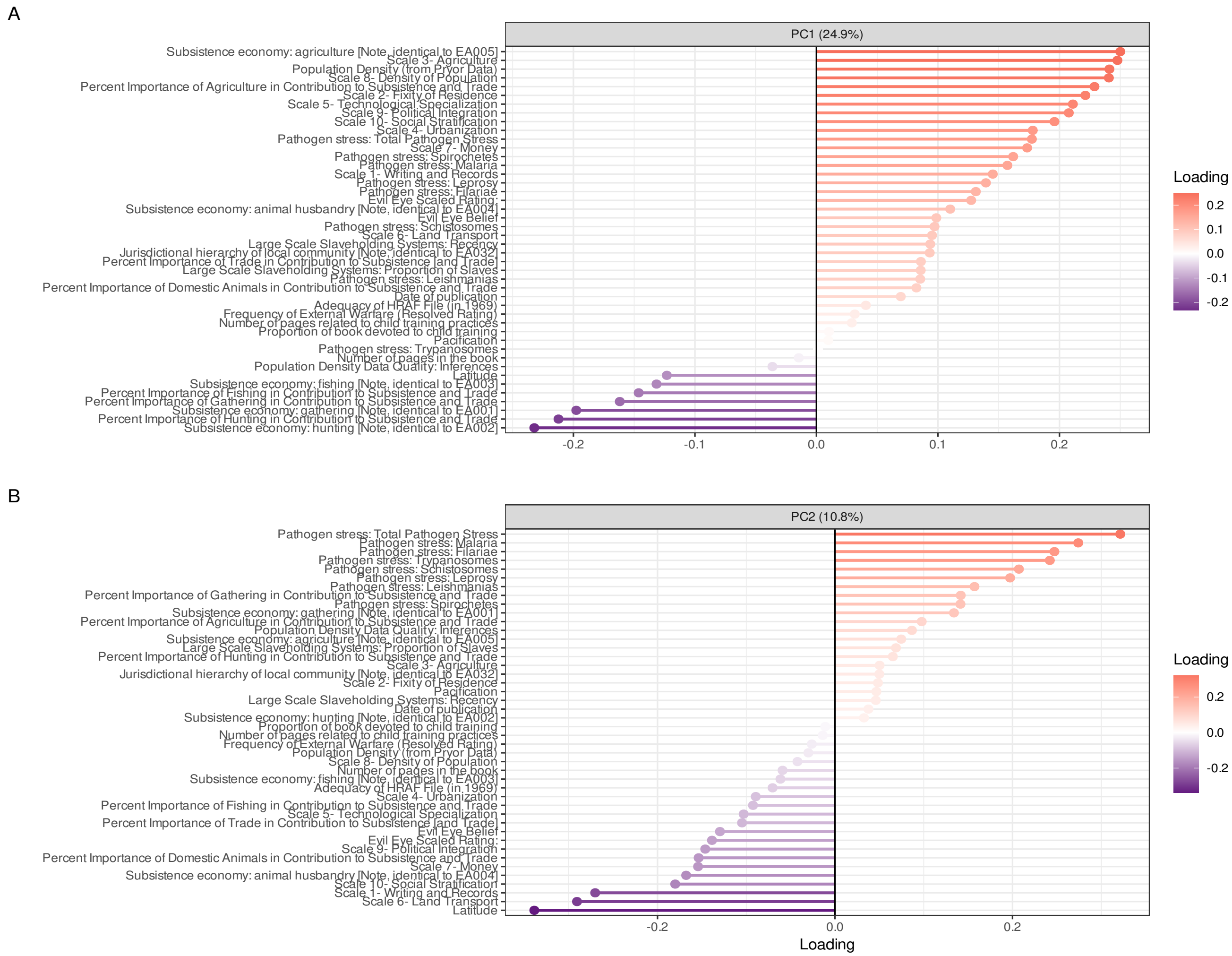

Figure 4.2.7: PCA loadings on the first two principal components in the SCCS dataset. See text for details.

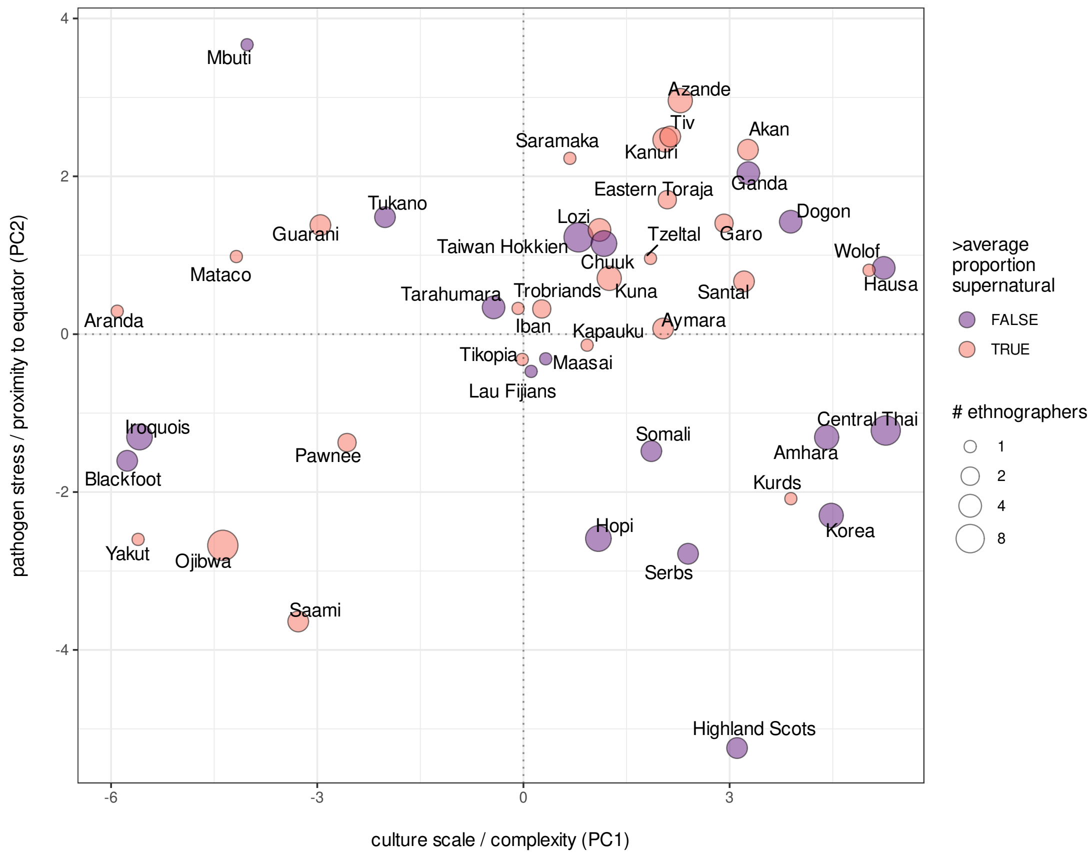

Figure 4.2.8: PC1 and PC2 values for each of the 44 eHRAF cultures that were in our study and the SCCS. Colors indicate whether each culture had an above average proportion of supernatural theories of disease, and point sizes indicate the number of ethnographers who contributed texts about a culture.

Incentives and disincentives for patrons and acolytes

We found substantial evidence for the "market for specialists" variables and some evidence for the "prestigious mentors" variables (figure 4.2.3B). Here, we investigate the social relationships among ethnomedical specialists and laypersons as potential patrons and/or acolytes. Incentives for patrons and acolytes to favor ethnomedical specialists were more common than disincentives, and specialists often possessed rare and valuable knowledge (figure 4.2.9). Modeling pairs of incentives and their opposing variables – which were often disincentives – suggested that ethnomedical specialists usually conferred benefits to others, gained patronage based on their reputations for efficacy, assisted with uncommon and serious problems, were more often successful at healing than they were unsuccessful, and rarely offered their services for free. There was modest evidence for teaching. Evidence for trustworthy vs. untrustworthy specialists was about evenly split (figure 4.2.9).

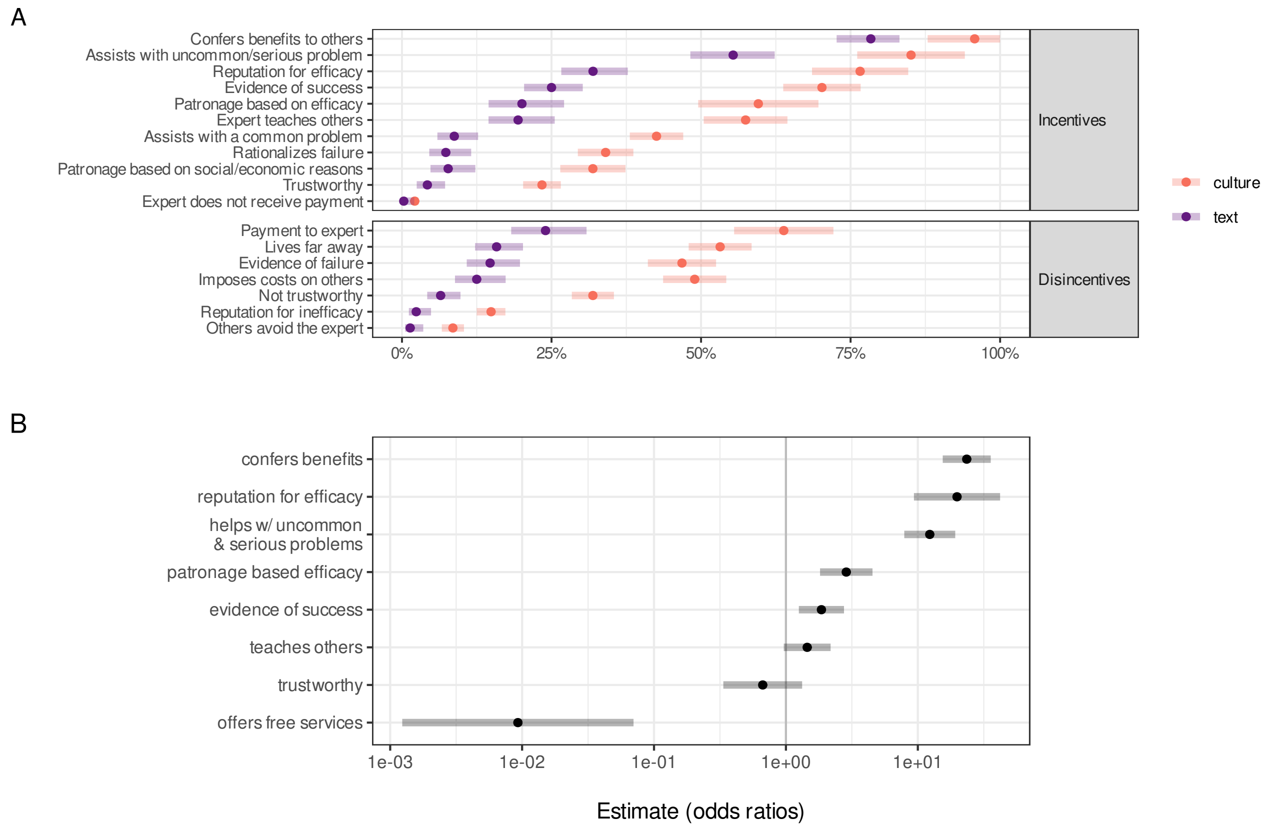

Figure 4.2.9: A: Support for incentives and disincentives associated with ethnomedical specialists in our eHRAF data sample. B: Logistic regression coefficients among models of presence of evidence for vs. against each of the incentives for favoring ethnomedical specialists. Error bars in both plots are +/- 2 SE.

Acculturation and market expansion

Acculturation was our proxy for expanding markets for ethnomedical specialists, and was positively associated with variables relevant to efficacious services, such as patronage based on efficacy, specialists with a reputation for efficacy, evidence of success and failure, and specialists conferring benefits to patrons. Acculturation was negatively associated with rare knowledge and variables relevant to religion, such as specialists prescribing ritual behaviors and supernatural theories of disease (figure 4.2.10).

Classifying ethnomedical specialists based on structure in the entire data matrix

Our MST revealed three branches of similar variables, which we interpreted as a taxonomy of three broad types of ethnomedical specialists: the "efficacious healer", the "feared diviner", and the "prestigious teacher" (figure 4.2.11). These interpretations are based on the variables within each of the three branches, which also contain informative sub-branches comprising similar variables. These three broad types of ethnomedical specialist are equally close to two central nodes at the root of our entire taxonomy: *supernatural* theories of disease and *religious leadership*.

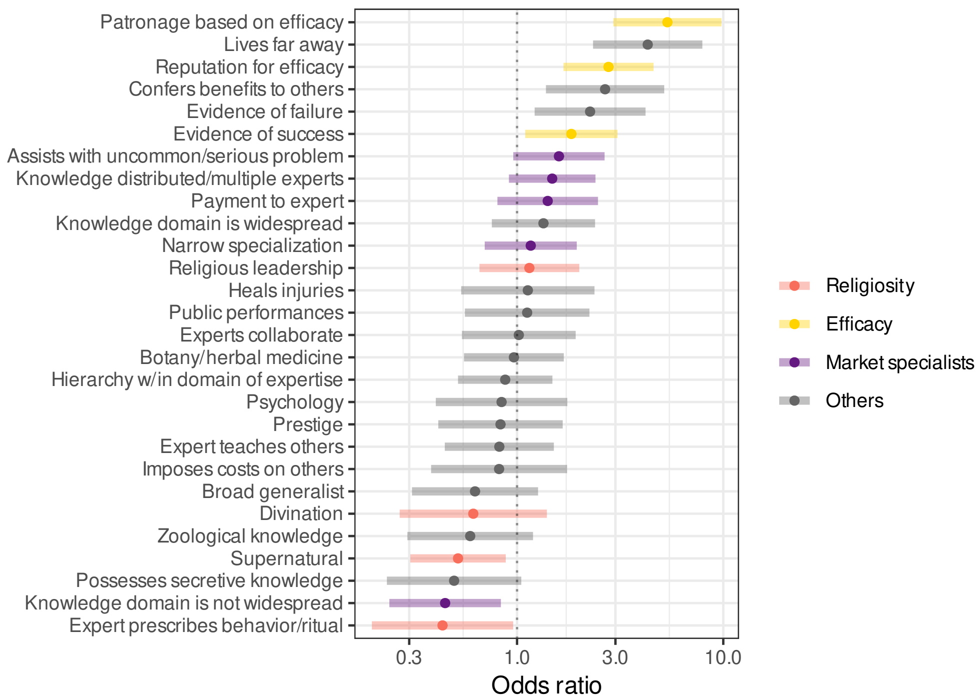

Figure 4.2.10: Fixed effects of acculturation on the proportion of text record evidence for each of the variables that had at least 10% support. Acculturation was the predictor in each GLMM and each variable listed along the y-axis was an outcome. Estimates on the log-scaled x-axis are reported as odds ratios. Error bars are +/- 2 SE, and colors indicate religious variables or specialized services.

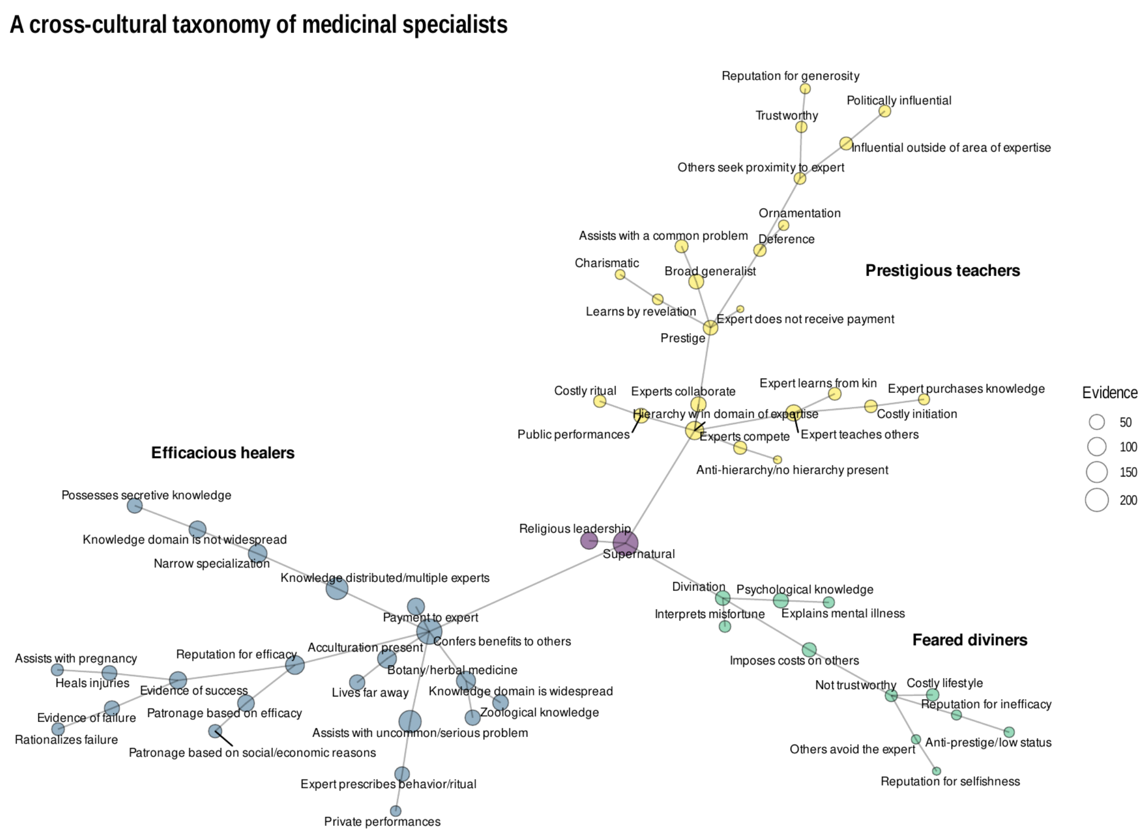

Figure 4.2.11: Minimum spanning tree of our dataset about ethnomedical specialists. Vertices represent variables, and sizes correspond to levels of text record evidence for each variable. See text for details.

4.2.3 Discussion of Study 1

Ethnomedical specialists were frequently sources of valuable knowledge, and provided efficacious treatments for specific, uncommon and serious illnesses. Although our search terms for eHRAF texts deliberately did not include religious topics, ethnomedical specialization nevertheless was frequently described as a "religious" occupation (figures 4.2.3 and 4.2.4). Specialists were often formal or semi-formal religious leaders such as priests and shamans, and in fewer cases, held politically influential roles. Most specialists across cultures, regardless of region or subsistence strategy, invoked "supernatural" concepts in their theories of disease, such as witches, spirits, or deities, and many also performed "religious" behaviors, such as costly rituals and divination during times of uncertainty (figures 4.2.4 and 4.2.5).

We found that supernatural theories of disease were more common among ethnomedical specialists who deal with conceptual knowledge about unobservable phenomena, such as interpreting mental illnesses or providing herbal remedies for infections, and were less common among those who deal with observable phenomena, such as childbirth and physical injuries (e.g., bone-setting and wound mending) (figure 4.2.6). Our PCA of the SCCS data found PC1 indexed culture complexity and scale, and PC2 indexed pathogen stress and proximity to the equator. Among cultures with higher pathogen stress (high PC2 values) – and therefore higher chances of serious illnesses due to infection – we saw a higher prevalence of supernatural theories of disease (figures 4.2.7 and 4.2.8). We caution that pathogen stress and proximity to the equator are highly confounded with many other relevant factors, such as money-based economies and agricultural intensification (the latter two also loaded on PC2).

As high levels of support for the "market for specialists" hypothesis suggested, many ethnomedical specialists served a practical function in their societies, regardless of their "religiosity" (figure 4.2.3). Incentives for favoring an ethnomedical specialist generally outweighed the disincentives, which were usually payments rendered for healing or teaching. Markets for specialists seemed to intensify with acculturation, which was positively associated with variables relating to efficacy, and negatively associated with supernatural theories of disease (figure 4.2.10). Acculturation, as coded by the OCM scheme and our coding protocol, often referred to a presence of Western medicine, such as nearby hospitals and clinics. Services were frequently for uncommon and serious illnesses, rather than common or everyday health issues (figure 4.2.9). We speculate that it is more efficient for laypersons to outsource sufficiently uncommon and serious problems to specialists rather than individually or socially learn solutions themselves (see also Hagen and Garfield 2019; Sugiyama and Sugiyama 2004).

We and others have argued that religion is at least partly an epiphenomenon of science, and the distinction between the two in Western cultures is primarily institutional (e.g., Sperber 2018; Boyer 2020). That is, supernatural concepts about "religious" entities vs. invisible forces invoked by "scientific" folk theories might share common cognitive characteristics (similar to the continuity hypothesis; Carruthers et al. 2002, p. 74). In our data, abstract essences such as bodily humors were not themselves coded as "supernatural", but they frequently co-occurred with the descriptions of spirits, ghosts, or other invisible agents that were. Indeed, Western folk scientific concepts about "germs" often resemble sympathetic magic or agentive thinking (Siegal 2002; Gottlieb 2004), and folk psychological concepts often invoke hidden invisible forces such as "souls".

We also found patterns that were not obviously explainable by efficacious or "scientific" healing practices: supernatural theories of disease were associated with religiosity, divination, evidence of failure, and costly rituals. This seems to suggest that at least some religious specialists in our data do not conform to our hypotheses about efficacious healing or a market for specialists.

The MST in figure 4.2.11 suggested a taxonomy, with three types of ethnomedical specialists emerging from structure in the data. We refer to the largest and most well-supported branch on this taxonomy as the "efficacious healers", the attributes of which are unified by *conferring benefits to others* and *receiving payment* at their root. Consistent with the market for specialists hypothesis, sub-branches included variables relevant to patronage, efficacious healing, and narrow specialists with rare and valuable knowledge (Tooby and Cosmides 1996).

The most diverse branch was “prestigious teachers”, sub-branches of which generally conformed to the “mentorship hypothesis” (and many of the prestigious mentors emphasized in literature on social learning biases and cultural transmission, e.g., Richerson and Boyd 2005), along with prosocial and trustworthy leaders (Garfield, Hubbard, and Hagen 2019), and charismatic and prestigious shamans (Singh 2018). Perhaps unsurprising among ethnomedical specialists, we found less evidence for this branch compared to the “efficacious healers”; in a cross-cultural study of 55 traditional societies, Lightner et al. (2021) found that apprenticeships, mentorships, and other forms of social learning were associated with experts who were skillful in everyday tasks with easily observable motor skills, such as toolmaking and food preparation.

A third type, the “feared diviners”, interpreted misfortune and psychological phenomena, and were characterized by traits that conflicted with our hypotheses about efficacious “scientific” healers, such as costly lifestyles, low status, and distrust among the laypersons who they might harm (Singh 2021).

Further supporting our conclusions about the centrality of supernatural concepts and “religious” specialization in medicine, these three types of ethnomedical specialists were unified by their mutual associations with religious leadership and supernatural theories of disease, central nodes in the MST.

4.3 Study 2: Maasai field data

In Study 2 among Tanzanian Maasai pastoralists, we focused on the criteria that patrons use to select among ethnomedical specialists when they become seriously ill, such as efficacy, religious identity, and/or interpersonal trust, and their cultural models of medical treatments.

The population we examined is currently undergoing substantial cultural and economic transitions that resemble the "acculturation" of Study 1, including relatively recent introductions of hospitals, clinics, and Christian churches. Additionally, we analyzed the extent to which Christianity predicted agreement in the statement that science and religion can conflict with each other, and how individuals' cultural models of how a medical treatment works compared to that of a local ethnomedical specialist. We primarily interviewed laypersons, but also include qualitative data from interviews with three ethnomedical specialists, one of whom also plays a traditional religious role in Maasai culture.

4.3.1 Methods

Fieldwork occurred in Monduli Juu highlands of northern Tanzania in a Kisongo Maasai village near two market integrated towns, each with shops, weekly markets, churches, and clinics. We conducted semi-structured interviews with key informants and a focus group, allowing us to identify local ethnomedical specialists during preliminary stages of fieldwork, and to establish the widespread perceptions about the hospitals and clinics, the church, and the traditional religious healer (the *laibon*) among the community. Key informants included Christian and non-Christian ("traditional") community leaders, locally salient ethnomedical specialists, and one of the several laibon healers in the region.

We conducted structured and semi-structured interviews with 84 Maasai adults in Monduli Juu (35% female) about their religious beliefs, trustworthiness of local religious figures, and on whom they rely to help them with a serious illness. To assess the criteria patrons use to select a specialist for medical assistance with a serious illness, we asked participants to list their first, second, and third ranked choices, the second and third choices assuming their condition did not improve. Responses to each of the foregoing questions were categorized as family, friends, a laibon (traditional healer), a church leader, a clinic/hospital, or themselves. We followed this with a series of questions about participants' religious identities; who they rely on most for spiritual advice; whether or not they trust the local church leadership, laibon healers, and doctors working at the clinic; and how frequently they attend church services.

To address the question of science and religion as separate or competing ideologies, we asked participants whether or not scientific ideas ever conflicted with their religious beliefs. If they confirmed that it did, we asked them to provide an example.

Finally, to examine the recurring abstract and/or "supernatural" features of ethnomedical explanations, we asked a subset of 58 participants to identify a common herbal medicinal treatment that they were knowledgeable about, and to explain how it worked against illness. We coded presence/absence of the following response features: *don't know*, *conditions* under which one should take the medicine (e.g., when a person feels chills), *substances* (e.g., blood, vomit), *essences* (e.g., illness is "driven out" by expelling a substance), *heat* (e.g., hot tea reducing chills in the body), *anatomy* and/or *physiology* (e.g., citing body parts and organs such as the stomach or kidneys, and/or describing how they interact with the medicine), *preparation* steps required for the medicine, whether or not it requires assistance from a *hospital or specialist*, citing *belief* that it works, and citing that *prayer* helps it work.

Participants were paid 10,000 TZS (about $4.35) for their participation, and all protocols and survey materials were approved by Washington State University IRB and the Tanzanian Commission for Science and Technology (COSTECH) prior to data collection.

4.3.2 Results of semi-structured surveys and field observations

Maasai often have extensive practical knowledge about herbal remedies for common ailments (Heckelsmiller 2015; Roulette et al. 2018). Traditionally, the inexplicable and/or serious illnesses had been brought to the laibon, who plays a role as a healer and diviner in times of uncertainty (Spencer 2004).

More recently in Monduli, missionaries have had collaborative relationships with local community leaders, who have worked toward developing schools, churches, and privately funded clinics. Many clinics are run by physicians affiliated with missionary organizations, and are reputed as the most efficacious available option. Christianity has also seen a relatively recent uptick among locals in the area (Hodgson 2005), a departure from the traditional religious system in which the laibon healer is a trusted source of medical, social, and spiritual advice (Fratkin 2011).

Religious specialists: The traditional laibon healer and the Christian church

The laibon healers, who possess medicinal knowledge learned during apprenticeships with their fathers, still maintain regular clientele for serious illnesses. Laibon healers can only be males from a specific clan, and although they treat illnesses with tinctures and herbs, their knowledge and the contents of their medicines are inherited secrets. The laibon routinely charges a fee for his services. If he cannot help improve an illness then he might refer his client to another laibon or ethnomedical specialist in the region or, in more recent times, to a local clinic.

The laibon is also a diviner who practices clairvoyance. He uses an oracle horn to cast stones and interpret their configurations to guide him while preparing his medicines, gaining insight from *Engai*, the Maasai God. Although Engai has been described as an agent, similar in some ways to monotheistic gods (Hodgson 2005), the laibon likened *Engai* to "oxygen" during our interview, explaining that *Engai* is a "mind" in the sense that it represents the totality of knowledge.

The participants we interviewed were generally split in their perspectives on the laibon. For some, the laibon can help a person with serious illnesses, but also with bad luck, spiritual quandaries, or lost items. Many know one or more laibon healers through long-standing family friendships, and cite his importance to Maasai traditions. Others, however, distrust the laibon, considering him to be dishonest and insisting that the traditional reliance on him has been replaced by doctors and churches. A few participants were ambivalent, stating that the laibon is untrustworthy but nevertheless can help people when they need it.

Missionaries and church leaders were viewed in a similarly polarizing way. Some people noted that church leaders, local or otherwise, give people moral and spiritual guidance, pray for people to heal when they are ill, and give people hope in times of need. Others see the church as a business, using deceptive practices to collect money and resources. Some also noted that they have had little-to-no contact with, or interest in, the churches in the area.

The doctors employed at clinics were described in neutral to positive terms, with many interviewees stating that local clinicians are highly knowledgeable, trained, and experienced. Some described the trustworthiness and efficacy of clinicians in terms of their past experiences at clinics, where a doctor helped them improve after a serious illness or injury. Others were unsure what to believe about clinicians because they never went to the clinic, and preferred the laibon healers, friends, and the local ethnomedical specialists with whom they were familiar.

Ethnomedical specialists in Monduli Juu

The overwhelming consensus among key informants was that most clinics are the safe option for treating serious illnesses. In the rural areas of Monduli Juu, however, where fieldwork occurred, clinic access is often restricted by costs and travel distances, so friends, family, laibon healers, and ethnomedical specialists represent more personal and convenient options. We interviewed two reputable ethnomedical specialists, a younger man nicknamed Daktari Samuel (DS) and a respected older woman named Koko Nasari (KN). ("Daktari" is Swahili for "doctor" and "Koko" is Maa, roughly translating to "grandmother". "Samuel" and "Nasari" are pseudonyms.) DS and KN are both locally recognized experts in diagnosing specific illnesses in which they specialize, with DS focusing on herbal remedies for infections and "systemic" illnesses, such as cholesterol problems, and KN focusing on injuries and children's health. DS is a local botanical expert who sells herbal medicines, which he grows and procures, for cash. KN treats muscular and gastric pains and general malaise (*ngongu*, or "evil eye") with massage, bloodletting, tooth extraction, and minor surgeries, sometimes in exchange for small payments. Similar to the laibon, each acquired their medicinal knowledge from parents and grandparents, but unlike the laibon they do not have formal and traditional titles. Instead, they gain their reputations through popular recognition of useful medicinal knowledge. For most participants, their salient social roles are as trusted friends or family members.

4.3.3 Results of the structured survey

In our sample, 61% of participants were Christian and 39% were traditional believers. Most participants (86%) did not see science and religion as conflicting under any circumstances. While a few did agree that scientific and religious ideas might sometimes conflict (14%), all of these participants were Christians. See the SI for examples given by these participants.

Participants overwhelmingly preferred to use the clinic in cases of serious illness. Many also preferred to use either friends, family, or religious specialists, such as the laibon and, in some cases, healing through prayer with church leaders. Religious options tended to be chosen mostly when other options failed. Although there was no strong religious disparity among those preferring the clinic as a first or second option, Christians tended to report that they would default to either the church or themselves if the clinic failed, or would not know to whom they should turn. (It is worth noting that help from church leaders often consisted of prayer and counsel rather than medicine.) Conversely, traditional believers often reported that they would turn to friends, family, or a laibon if the clinic failed. Some participants reported that they would seek a laibon first and a clinic second, and these were exclusively traditional (non-Christian) believers. More broadly, while Christians avoided the laibon and favored the church, and traditional believers avoided the church and favored the laibon, both Christians and traditional believers alike reported that they would often favor the clinic when serious diseases arise. See figure C.40.

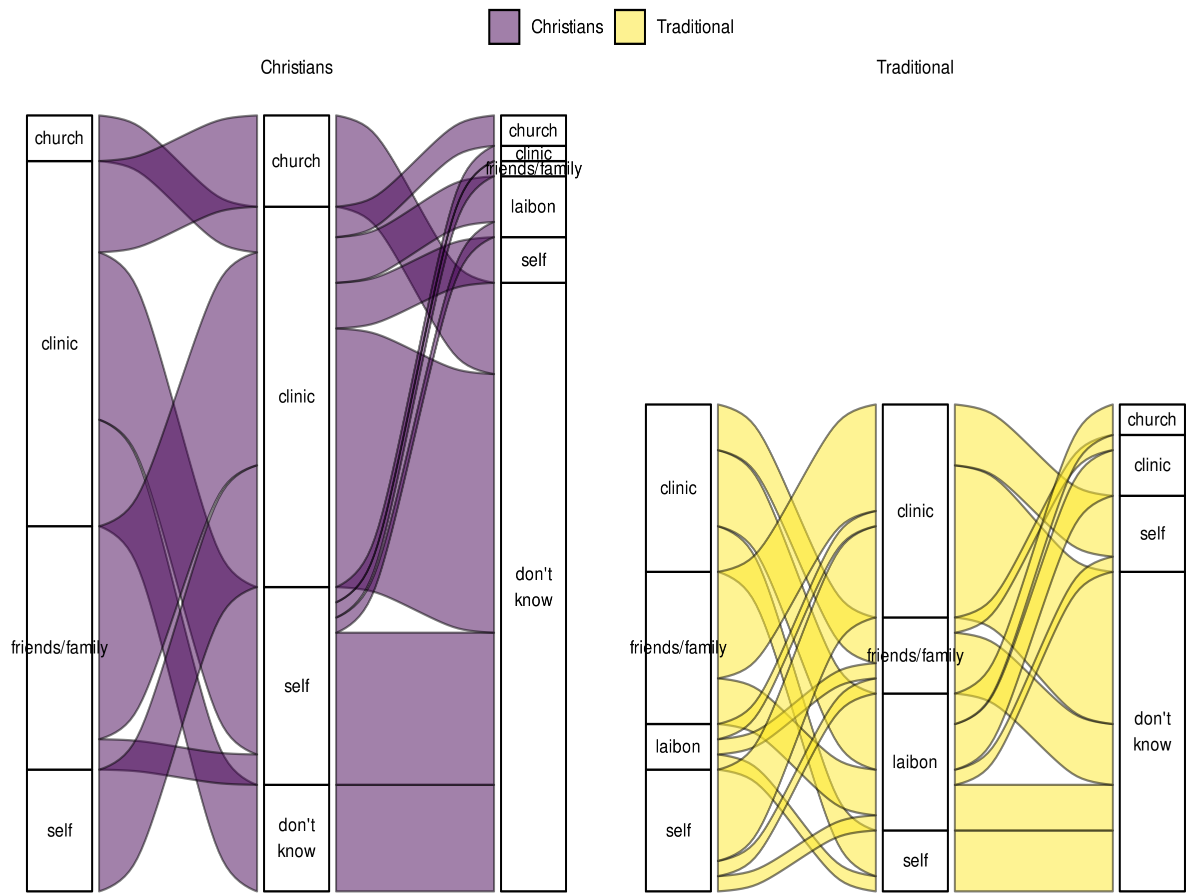

Figure 4.3.12: Alluvial plot of the proportions of participants who identified different types of specialists as their first (left) to third (right) choices to help them in the case of serious illness.

We conducted a PCA on the results of our surveys about interpersonal trust, spiritual advice during times of uncertainty, and patronage for serious illnesses, which revealed that participants did not sharply distinguish trust in medical advice from trust in other domains, and that these response patterns were at least partly split along lines of religious identity. Traditional believers were more likely to rely on the laibon for a serious illness, to personally trust the laibon, and to rely on him for spiritual advice. On the other hand, Christians were more associated with trusting church leadership, relying on elders for spiritual advice, attending church services, and soliciting help from the clinic for serious illnesses (figure 4.3.13).

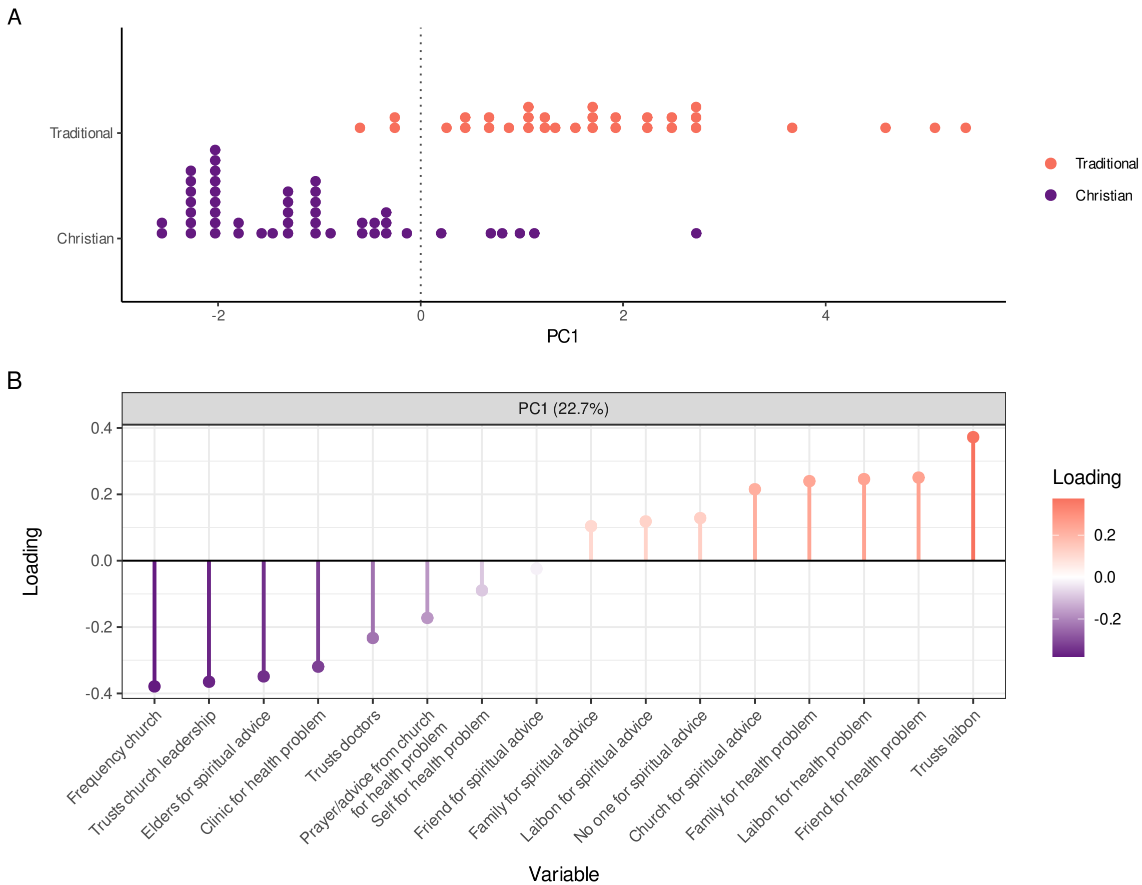

Figure 4.3.13: Variation among traditional and Christian participants on PC1, reflecting trust in the laibon healer vs. church and elders. See text for details.

Explanations of how herbal medicines work

We asked a subset of 58 participants to identify and explain how a common herbal medicinal treatment works. Their explanations largely fell into three groups: participants either (1) stated that they did not know how it worked, but only *that* it worked (which we term "don't know"); (2) stated that they only knew the conditions under which one should take it while listing the steps to prepare the medicine, and/or citing "belief" that it works or that they pray it will work (which we term "how-to"); and (3) explained the mechanisms in terms of substances, essences, heat, and/or anatomy and physiology (which we term "mechanistic"). See figure 4.3.14 and the SI for PCA results.

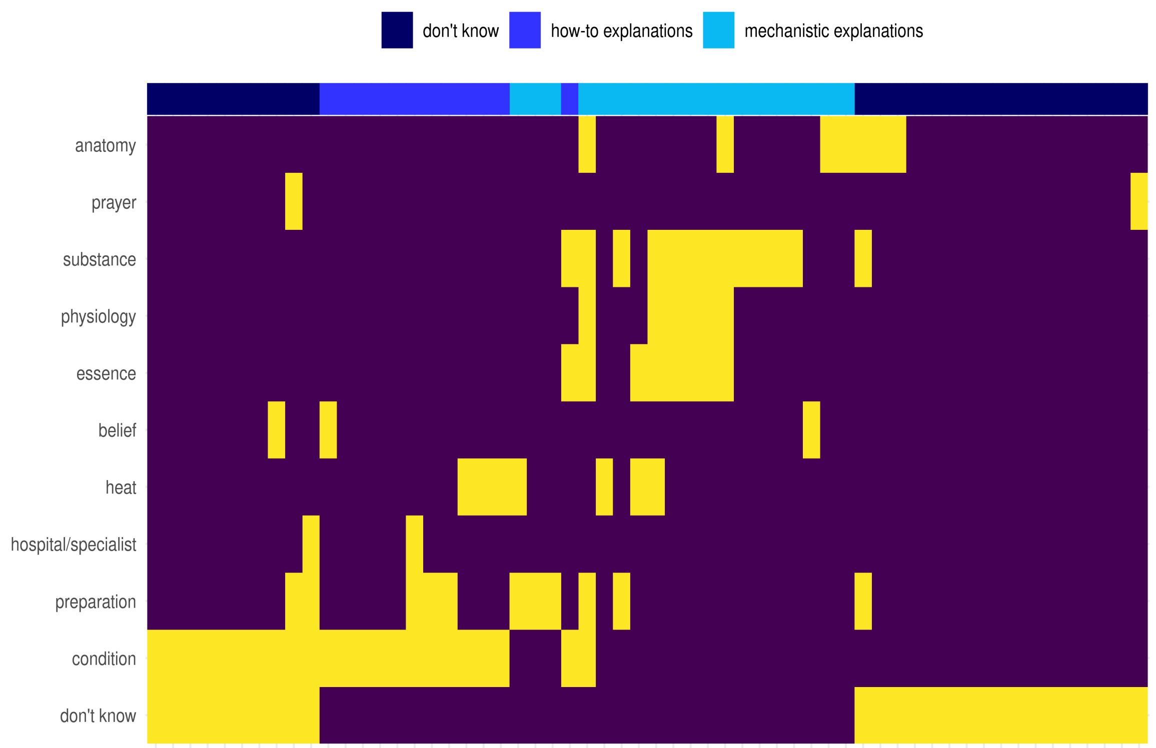

Figure 4.3.14: Explanations of how common herbal medicines work. Each column is one participant. Each row is a feature that was present in (yellow) or absent from (purple) each participant explanation. Rows and columns were ordered using the PCA angle seriation method.

4.3.4 *Discussion of Study 2*

Our survey of Tanzanian Maasai pastoralists, in a setting where cultural and economic changes include recent influxes of Christianity and clinics ("acculturation"), had two primary goals.

Our first goal was to investigate the criteria that patrons use to select an ethnomedical specialist when they become seriously ill (e.g., efficacy, interpersonal trust, religious identity). Most participants preferred to use the clinic when seriously ill, which was described as the most efficacious option among most key informants and participants. Participants who trusted the doctors from clinics largely cited their past experiences with treatment, despite their generally impersonal relationships with the doctors who work there. Others preferred to rely on friends, family, and religious leaders who they personally trusted, and who, in contrast to the clinics and hospitals, were conveniently nearby. Preferences for the clinic appeared to be mostly independent of religious affiliation, but religious identity became relevant if a non-religious option, such as the clinic, were to fail (figure C.40.

These results elaborate on the "patronage" variables of Study 1 (based on efficacy vs. socioeconomic considerations): although expected efficacy from ethnomedical specialists was important, this preference was at least partly constrained by social considerations, such as religious identity and trustworthiness (figure 4.3.13), and by economic considerations, such as distance traveled, cost, and accessibility.

Christians often commented that they distrusted the laibon, avoided him, and believed that he deceives people for financial gain. In this way, the Christian perspective of the laibon resembled the “feared diviner” of Study 1. On the other hand, traditional believers, who trusted the laibon as an “efficacious healer”, similarly viewed the local church leadership as untrustworthy. The causal relationship between religious identity and participants’ response patterns remains unclear, and future research can further explore whether religious beliefs motivate a preference for some specialists over others, or actual benefits from some specialists are motivating religious commitments to their belief system.

A key idea for the “market for specialists” hypothesis is that specialists possess useful knowledge about uncommon and serious illnesses, the value of which is based on the specialist being irreplaceable (Tooby and Cosmides 1996). An example of this would be medical treatments that are “proprietary”, or secretive knowledge (figure 4.2.11). Our qualitative data showed mixed support for this. Consistent with proprietary knowledge, the laibon, a traditionally preferred specialist for treating inexplicable and serious illnesses, declined to explain how he understood his medicines to work, and explained that his knowledge was an inherited family secret. On the other hand, DS and KN openly explained at least some of their treatment methods to clients and interviewers, and nevertheless made livelihoods using their skills.

Our second goal was to investigate the extent to which "religious" ideas were distinct from "scientific" ones. We found that science vs. religion was a largely unintuitive distinction for most Maasai participants, and that the few who recognized the distinction (14%) were exclusively Christians who were able to give specific and familiar examples, such as "sometimes scientists say there is no god, which I disagree with" (see the SI for details).

When we asked laypersons and specialists to explain how medicines worked to heal the body, those who attempted to explain the underlying processes almost uniformly responded in terms of abstract forces that were not "religious" – with the exception of a few people saying that they would pray for an improved condition (figure 4.3.14). Instead, common illnesses were explainable in abstract terms that do not clearly resemble the "supernatural", and although religious behaviors (e.g., prayer) were sometimes advocated as potentially helpful for the medicines' effectiveness, they were rarely invoked as a component of its explanation (Tucker et al. 2015). More serious illnesses were associated with patronage to a clinic or specialist rather than self-care.

The main exception to this pattern was the "religious" laibon healer, who used clairvoyance from *Engai* and divination with an oracle horn, to deal with inexplicable illnesses. Nevertheless, the laibon's description of Engai as an ethereal force whose "mental" properties are akin to a totality of knowledge might suggest that the "supernatural" concept of Engai is simply an abstract metaphor (see also Evans-Pritchard

1953). Future research could therefore benefit from questioning the extent to which "religious" concepts that appear patently supernatural (e.g., Engai, or "god", as an agent) are, in fact, at least partly overlapping with abstract but naturalistic metaphors (e.g., Engai, or an "ethereal force", representing the totality of knowledge).

4.4 General Discussion

Influential models of cultural evolution emphasize the transmission of important skills, such as tool manufacture or food preparation, that are frequently used by most members of the population (Boyd et al. 2011; Henrich 2016). This view corresponds to one of the three main branches of our MST, the "prestigious teachers" (figure 4.2.11). Yet the ethnographic record is replete with descriptions of knowledge specialists, such as shamans and healers, who have proprietary knowledge that they use to solve uncommon and serious problems, such as illnesses. An individual's expected benefit of mastering solutions to rare problems might be low: By definition, the problem might rarely or never arise, and building and maintaining expertise can be costly. In a large population, rare and serious problems will nevertheless occur to someone, so there will be demand for knowledge specialists who can solve those problems (Sugiyama and Sugiyama 2004).

As studies 1 and 2 suggest, ethnomedical specialists often provide practical solutions to unobservable and uncertain problems for payments (see also Lightner et al. (2021)), and clients largely base their patronage on efficacious outcomes (figures 4.2.9A and C.40). Indeed, we sometimes even observed clients deferring to specialists they did not necessarily trust (figure 4.2.9B). Ethnomedical specialists can benefit by gaining a clientele that is willing to exchange payment for services such as diagnoses and treatments, whereas clients benefit by outsourcing these tasks instead of acquiring expertise of their own (Hagen and Garfield 2019). This view corresponds to a second major branch of our MST, the "efficacious healers" (figure 4.2.11).

This is not to suggest that other considerations are unimportant, such as prestige, social norms, and convenience (which we referred to as socioeconomic factors; see figure 4.2.3). On the contrary, Maasai participants often preferred nearby family and friends over clinics for treating illnesses, and preferences for religious figures were aligned with religious beliefs and trustworthiness (figure 4.3.13). We also saw support for this pluralistic approach to client preferences among specialists in the ethnographic data, where clients would primarily select a specialist based on their efficacy, among other socioeconomic considerations (figure 4.2.9).

These points echo an important caveat about markets, namely, that transaction costs (e.g., energetic requirements, information scarcity) constrain efficient market dynamics (North 1990; Ensminger 1992). Such considerations might help understand why some Maasai participants often preferred family and religious figures over clinicians that they never met, and why we saw a similar trend in the ethnographic data.

4.4.1 Religious and non-religious ethnomedical specialists

Specialized knowledge typically comprises a combination of what Western scholars would characterize as "scientific" and "supernatural" or "religious" concepts. One view of the religious and supernatural services provided by specialists is that they are credible displays that serve to convince observers that the specialists can control unobservable forces (Henrich 2009; Singh 2018). This view corresponds to a third branch of our MST, the "feared diviners" (figure 4.2.11).

Nevertheless, ethnomedical specialists ("efficacious healers") were often "religious", and the "supernatural" and "religious leader" nodes were equally close to each of the three major branches of the MST (figure 4.2.11). One possible interpretation of these results is that religiosity somehow benefit the client. Shamans and similar healers routinely dispense herbal medicines with accompanying rituals, and these rituals might serve supplementary social functions (Winkelman 2010) or even enhance the efficacy of the substances consumed by a client. Shamans often assist with ailments that are accompanied by psychological stress and its associated symptoms, which are amenable to placebo-effect treatment (McClenon 1997; Sosis 2007). Indeed, this is consistent with findings in study 1, where specialists sometimes used costly and religious rituals, and study 2, where prayer and religious figures were important parts of dealing with serious illness.

Another possibility is that a specialist's "supernatural" concepts represent folk intuitions about unobservable or abstract scientific kinds, such as germs, life, chance, or minds (Siegal 2002; Gottlieb 2004; Howell 2012). For example, although modern medicine has delivered incredibly detailed and rigorous bodies of knowledge about viruses and bacteria, Western educated laypersons nevertheless tend to possess vague concepts of disease-causing agents that might appear magical or superstitious (Rozin et al. 1986; Keil et al. 1999; Legare et al. 2012). This is consistent with the idea that categorization of the "supernatural" vs. the "natural" requires interpretation by ethnographers and readers, which are built from a culturally contingent (often Western) framework (Sperber 1985) that is based on an *a priori* separation of science and religion.

According to this view, "religious" and "supernatural" are not only polythetic terms, but arguably ethnocentric descriptions of a variety of unrelated phenomena (Engler and Miller 2004; Bloch 2008; Schilbrack 2010; Sperber 2018). How, for example, should bodily humors, spiritual essences, or magical contagion be disentangled from Western folk theories about life, consciousness, or transmissible illnesses? In the text records in study 1, "natural" concepts, e.g., about plants, animals, and physical injuries, frequently co-occurred with supernatural ones (supernatural+natural: 49%, supernatural only 25%, natural only 21%). In study 2, a separation of science and religion was only observed among Christians, i.e., those who were familiar with this institutional conflict that is arguably idiosyncratic among Western societies.

4.4.2 How does acculturation impact a market for specialists?

When markets for specialists expand to accommodate new ideas that did not traditionally exist (acculturation), both studies suggested a higher frequency of patronage based on efficacy, and a lower frequency of reliance on supernatural knowledge and/or religious specialists (figures 4.2.10 and C.40).

For clients, we interpret these outcomes as a result of an expanded market for specialists: more options beget a more competitive market. All else equal, clients can "shop around" for more efficacious specialists with proven track records and reliable bodies of knowledge, such as clinic-trained physicians. A specialist's value is largely based on how rare, consequential, and hard-to-replace that specialist's services are (Tooby and Cosmides 1996), so acculturation linked to newly efficacious alternatives (e.g., clinics) can undermine the high market share that an ethnomedical specialist might have traditionally had, prior to acculturation.

4.4.3 Limitations

Our study has some important limitations. In study 1, data are based on ethnographic descriptions, so absence of evidence should not be interpreted as evidence of absence. Ethnographers often write about subjects they deem relevant for their own purposes, which did not generally align with our own questions. Moreover, our very critique of the distinction between supernatural vs. natural concepts was linked to a methodological challenge in study 1, i.e., we lacked precise definitional principles for interpreting supernatural descriptions. To address this, ADL and CH carefully and independently coded each text record before deliberating about each discrepancy thereafter. (See the SI for coding details.)

In studies 1 and 2, we presented our hypotheses and tests with a working assumption that specialists have high levels of knowledge compared to clients. There is some truth to this assumption, especially where medicinal knowledge is kept secret (Lightner et al. 2021), but expertise is often distributed among multiple specialists with varying levels of knowledge and types of specialization, i.e., a division of cognitive labor (Hutchins 2000; Keil 2003; Heintz 2013). For example, it is unclear whether or not a Maasai participant's group of neighbors and family members, who we interpret as the convenient option, are collectively more knowledgeable about a local illness than a single laibon or local physician. These friends and family were often not explicitly identified by participants in figure C.40, and might have even included more "informal" ethnomedical specialists.

Finally, preferences in study 2 were clearly aligned with participants' religious beliefs and trust in religious figures, but the causal direction of these relationships are less clear. Do culturally transmitted beliefs about trusting the laibon and adhering to traditional Maasai religion lead to a preference for the laibon as a healer? Or rather, do these preferences mostly arise from incentives derived from past and beneficial experiences with the laibon resolving practical problems, leading religious commitments to follow? Our findings are consistent with the latter, but the notion that these religious alternatives are solely based on efficacy, rather than norms, prestige, or trust, is a strong claim that our study cannot make. Credibility-enhancing displays, and exploitation more generally, probably play a role in explaining supernatural concepts in ethnomedicine. This broader question about the ideational vs. material nature of culture is pervasive in anthropology (McGee and Warms 2003).

4.5 Conclusion

This study investigated the extent to which ethnomedical specialists provide "religious" medicinal services to laypersons in traditional, non-Western societies, and why laypersons find such approaches convincing. Using cross-cultural data from the eHRAF (study 1) and field data among Tanzanian Maasai pastoralists (study 2), we tested the hypothesis that ethnomedical specialists are “religious” specialists who possess efficacious knowledge about uncommon and serious illnesses. We found that ethnomedical specialists are frequently religious figures who use “supernatural” concepts while fulfilling a practical and specialized service for their clients. Levels of evidence for supernatural theories of disease increased with pathogen stress, proximity to the equator, and lower reliance on market economies, and were more associated with infections and mental illness compared to physical injuries and childbirth. We therefore hypothesize that “religious” beliefs among traditional healers might often, but not always, represent abstract thinking about rare phenomena whose causes are unobservable, rather than a separate “religious” style of thinking. Our cross-cultural data revealed a taxonomy of ethnomedical specialists, suggesting that while some religious figures who assist with medical problems, such as shamans, might be “feared diviners” or “prestigious mentors”, many are “efficacious healers” who possess technical knowledge allowing them to exchange efficacious services to clients for various forms of payment.

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Availability of data and materials

All data, code, and supplementary materials are available at: https://github.com/alightner/ethnomedicine-magic.

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CHAPTER 5. CONCLUSION

Anthropologists have increasingly focused on the nuances and the points of tension vs. reconciliation among different evolutionary approaches to explaining culture (Acerbi & Mesoudi, 2015; Buskell, Enquist, & Jansson, 2019). At the outset of this dissertation, I identified two separate sources of tension in the literature: Humans' reliance on cultural learning vs. epistemic vigilance, and, using supernatural beliefs as an example, broadly transmitted beliefs (e.g., religious institutions) vs. pragmatic specialists and their services to clients.

This dissertation advances these existing discussions about cultural knowledge by: (1) testing theories of trust among learners among Tanzanian Maasai pastoralists, (2) testing theoretical perspectives of expertise and knowledge specialization across 55 cultures in a variety of conceptual knowledge domains, and (3) exploring the criteria by which clients judged healing specialists and their supernatural theories of disease among 47 cultures.

The theme that emerged from the three studies in this dissertation is that although humans may rely on the benefits of cultural knowledge, possibly investing heavily in acquiring more cultural knowledge (i.e., expertise) than most, they do so in ways that are conditional on their personal incentives. That is, knowledge does not always appear to be freely broadcasted, as previous models have assumed (e.g., Boyd, Richerson, & Henrich, 2011; Enquist, Strimling, Eriksson, Laland, & Sjostrand, 2010; Rendell, Fogarty, & Laland, 2010; Rogers, 1988), but instead, knowledge frequently involves a mutually beneficial exchange of services and – in some cases – valuable know-how.

We also identified that, in many cases, (1) clients care about effectively gaining a personal benefit from a specialists' know-how, and are willing to pay material resources in exchange for that benefit; (2) specialists frequently do not teach clients their knowledge in the course of conferring a service or benefit, and often refuse to do so; and (3) specialists frequently engage in a collaborative cognitive division of labor when it is beneficial to do so.

These results collectively suggest a synthesis that will inform questions for future research. To what extent can knowledge acquisition and sharing continue to mirror, and possibly be absorbed by, the abundance of existing theories about the evolution of cooperation, where material resources are acquired and contributed at a cost and shared with others? Further, how might we characterize the supernatural beliefs that are built into this knowledge exchange as utilitarian explanations under uncertainty, rather than as frivolous or "religious" beliefs?

To the first question, Lightner et al. (in preparation) build on Lightner et al. (2021a), and expand on previous models of social learning (Boyd & Richerson, 1995; Rogers, 1988), by modeling the conditions under which specialists and clients are mutually beneficial and highly competitive evolutionary strategies. To the second question, building on Lightner et al. (2021b), Lightner and Hagen (in preparation) propose that supernatural explanations might, in many cases, reflect useful falsehoods that constitute underfitted but predictive explanatory models for navigating rare and hidden phenomena, such as infections and natural disasters.

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APPENDIX

A Supplementary information for Chapter 2: *Acculturation and market integration are associated with greater trust among Tanzanian Maasai pastoralists*

A.1 Freelists on nkanyit *as a prestige concept*

Semi-structured and key informant interviews described a person with high levels of *nkanyit* as an honorable and prudent elder who leads his community by example, caring for his many cattle, wives, and children. Composite salience scores (S) were computed by normalizing the total weighted salience (WS).

Weighted salience of each item i, mentioned by a given participant j, was computed as $WS_{i,j} = \sum_i^k \frac{r_i}{k}$, where r_i is the inverted rank of the item listed and k is the number of items listed by participant j. Note that to simplify the notation, participant j is not specified in the right-hand side of the equation, though $WS_{i,j}$ was computed per item per participant.

Composite salience was then determined by normalizing total weighted salience across participants, such that $S = \sum_j^n \frac{WS_j}{n}$. Here, n is the total sample size of the freelisting interview sample ($n = 57$). Thus, composite salience S reflects a statistic relating to how high-ranking (salient) *and* how frequently mentioned a given item is across freelists in an interviewed sample. See Quinlan (2018) for more information with examples.

Composite salience scores showed that the most important contributors to gaining nkanyit include, in descending order of importance, large cattle numbers (0.52), having and caring for a large family (0.46), being respectful to others (0.25), having good moral character (0.14), being helpful to others (0.13), and being knowledgeable, e.g., by giving good advice, being educated, and/or being intelligent (0.12). See table S1 for a full table.

A.2 Complete vignette text

The following vignette texts were used in our structured interviews, initially by A.D.L. with the assistance of a Maasai translator, who was either assistant 1 (from the southern area) or, in some cases, assistant 2 (from the northern area).

Prestige condition

Suppose that you are speaking with another person (*anya lomon*[7]), who is also from the Eluwai community. This person tells you about a place outside of the village, about a day's walk from here, where you should take your livestock for grazing because

[7]This is sometimes translated to English speakers as "exchanging news", but the literal Maa translation is "eating words". *Anya lomon* appears to be compulsive and frequent, somewhat ritualistic, and follows a consistent question-answer format with a heavy use of phatic sounds from the listener. It is therefore easy for participants to imagine this type of scenario, as it refers to a common and important method for staying informed on a daily basis.

Table A.1: Composite salience scores for freelisted domains, mentioned in response to a interview questions about how a person gains nkanyit.

coded domain	composite salience
has cattle or wealth	0.52
family	0.46
gives respect	0.25
has good character	0.14
helps others	0.13
has knowledge or education	0.12
religious	0.05
good standing in community	0.05
is an elder	0.03
resolves conflicts	0.02

there is plenty of grass and water available over there. This person advising you is a person you know, because he is someone in your community who has a lot of *nkanyit*.

(On a scale of 1-10)[8], how much do you believe this person? (*trust outcomes*)

[8]This was mainly used by A.D.L., but was abandoned during most of the interviews conducted by the local research assistants. Coded trust outcomes were established prior to entering or analyzing data, based on our experiences communicating this scale to participants. See the following section for more information.

If you were considering following this person's advice, would you need to travel there yourself to see if they were telling the truth? (*fact-checking outcomes*)

Experience condition

Suppose that you are speaking with another person (*anya lomon*), who is also from the Eluwai community. This person tells you about a place outside of the village, about a day's walk from here, where you should take your livestock for grazing because there is plenty of grass and water available over there. This person advising you is a person you know, because he is someone you have known from personal experience to be very knowledgeable.

(On a scale of 1-10), how much do you believe this person? (*trust outcomes*)

If you were considering following this person's advice, would you need to travel there yourself to see if they were telling the truth? (*fact-checking outcomes*)

A.3 Coding our outcome variable

Trust outcomes were coded on a three-point scale (1 = completely trust, 0.5 = somewhat trust, 0 = does not trust). Fact-checking outcomes were measured as simple yes/no responses (1 = yes, 0 = no).

Coding trust outcomes onto a three-point scale was motivated strictly by a challenge in the data collection process, and we documented this prior to analyzing data in our preregistration osf.io/5p7ut. Trust outcomes were initially, for most interviews conducted by A.D.L., on a scale of 1-10. Most participants found scales of 1-10 very unintuitive, so A.D.L. used a carefully measured visual aid on cardstock, allowing participants to point to a location on the scale.

Participants, however, found this visual scale to be much more intuitive when A.D.L. evoked three salient reference points: left means no trust at all, middle means some trust, and right means complete trust. Many participants had ignored the scale completely and simply answered "yes, completely" or "no, not at all". The two local assistants framed the same question by exclusively using these three salient reference points as options, asking participants if they had complete trust, some trust, or no trust in the advice given (which they recorded as 10, 5, and 1, respectively).

It therefore made sense to code responses onto a three-point scale, because it not only more accurately reflects the data collection process used by each interviewer, but also the way that most participants interpreted the question about "how much" they trusted the advice. Responses on a scale of 1-10 appeared to be routinely thought about with respect to their closeness/distance to/from 1, 5, and 10 in interviews with A.D.L. The three-point scale we coded responses onto were 0, 0.5, 1, and responses to A.D.L. were converted by dividing the 1-10 scale into increments of 3, according to the following rule: $i < 4 \rightarrow 0$, $4 \leq i < 7 \rightarrow 0.5$, and $i \leq 7 \rightarrow 1$.

In effect, this means that for the participants interviewed by A.D.L., people who pointed closest to the middle of the line were assigned the middle value on a 3-point scale, whereas people who pointed closest to one of the extremes were assigned their corresponding values on that same scale. More straightforwardly, responses collected by the two local research assistants were converted as 1 (not at all trusting) was assigned to 0, 5 (somewhat trusting) assigned to 0.5, and 10 (completely trusting) assigned to 1.

Although this decision was based solely on constraints on our data collection method, we investigate the question of if and how this might have substantially affected our results in a section below. (It did not, as we will show in the following sections.)

A.4 Confirmatory analyses

In the main article text, under Confirmatory analyses (Results section), we included a single effects plot showing our supported predictions for trust outcomes in the RIM. Here, we include effects plots from the PBM (figure S1) and fact-checking outcomes for the RIM (figure S2), which did not show a statistically significant effect conforming to our predictions.

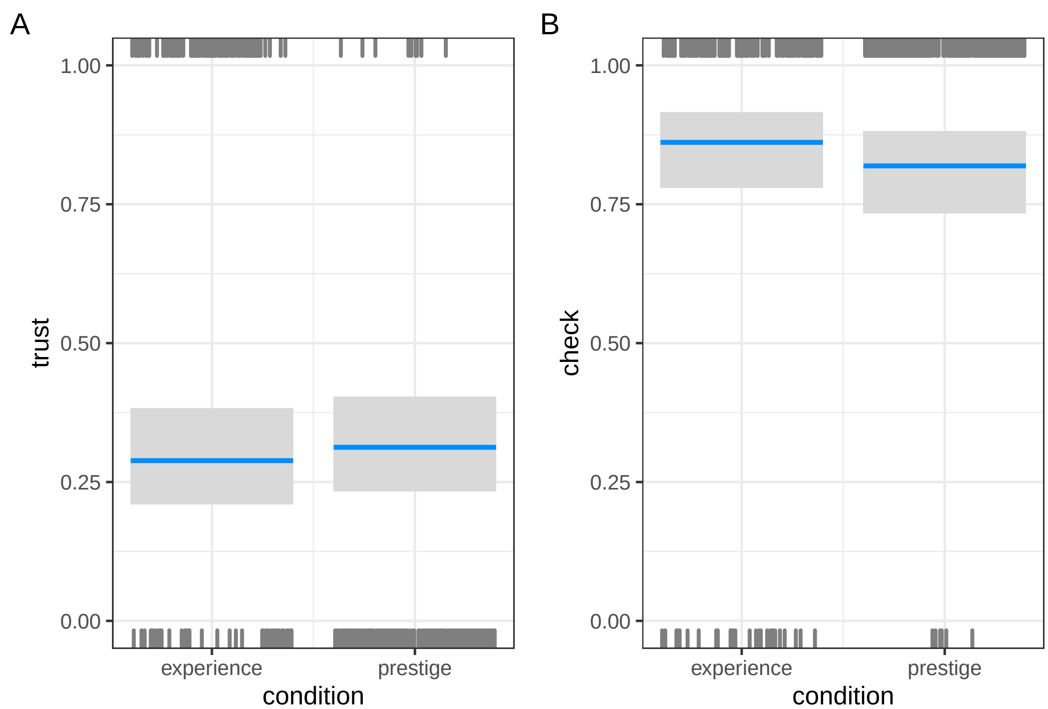

Figure A.1: Logistic regression model for PBM predictors on trust outcomes (A) and fact-checking outcomes (B). Model coefficients are shown in table 2 (columns 1 and 4) of the main article.

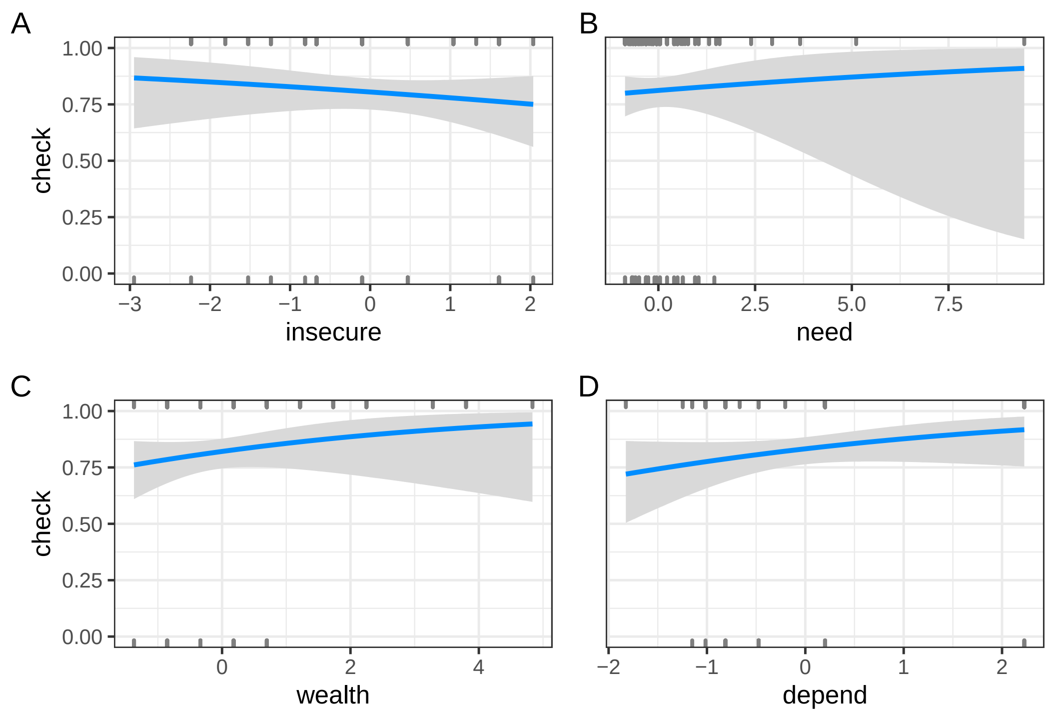

Figure A.2: Logistic regression models for RIM predictors on fact-checking outcomes. Model coefficients are in table 2 (column 5) of the main article.

AICc model selection

For trust outcomes, model selection using weighted AICc showed that the RIM had better performance than the PBM and the PBM+RIM. For fact-checking outcomes, PBM had slightly better performance than the RIM and PBM+RIM, although it is worth emphasizing: *none* of these models showed a statistically significant effect for fact-checking outcomes, and a larger number of parameters in RIM accounts for its underperformance here. Furthermore, model comparisons in our confirmatory analysis, while conforming to our preregistration, involves only 216 out of 225 observations in each model, after complete cases. We therefore re-evaluate the PBM, RIM, and PBM+RIM in the exploratory analyses below, using multiple imputation to make use of the full dataset. See table S2.

Table A.2: Model comparison of logistic regression models used in our confirmatory analyses, using AICc scores and weights as our selection criteria to compare models with trust outcomes (left) and fact-checking outcomes (right).

	trust models	K	AICc	Delta_AICc	ModelLik	AICcWt	LL	Cum.Wt
2	RIM	5	198.85	0.00	1.00	0.44	-94.26	0.44
3	PBM+RIM	6	199.34	0.49	0.78	0.34	-93.44	0.78
1	PBM	2	200.19	1.34	0.51	0.22	-98.06	1.00

check models	K	AICc	Delta_AICc	ModelLik	AICcWt	LL	Cum.Wt
PBM	2	171.65	0.00	1.00	0.56	-83.79	0.56
RIM	5	173.22	1.57	0.46	0.26	-81.45	0.82
PBM+RIM	6	173.96	2.31	0.31	0.18	-80.75	1.00

Re-analyzing confirmatory predictions after questioning our decisions

To stay consistent with our preregistration, we (1) used logistic regression on proportional outcomes, rather than ordered logistic regression on our three-point scale, and (2) transformed trust outcomes into that three-point scale, based on confusion among participants about judging on scales of 1-10. Here, we re-analyze the data to address the question of if and how either of these decisions might have affected the results on our trust outcomes.

Did logistic regression on proportional trust outcomes affect the results?

First, we re-ran trust models using an ordered logistic regression and found similar effects in each of our models in the main text, which, based on our preregistration, used logistic regression on proportional outcomes. In other words, analyzing our data using logistic regression on proportional outcomes (which we did in the main text) vs. ordered logistic regression (which now do here) did not substantially change our results in the confirmatory analyses, nor in the exploratory analyses. See table S3, and figures S3 and S4 for results of the ordered logistic regression based on ranked categorical responses.

Did coding trust outcomes onto a three-point scale affect the results?

Second, we re-ran trust models using the ten-point scale that some participants initially tried to respond with, when A.D.L. was present to explain it to them. Trust

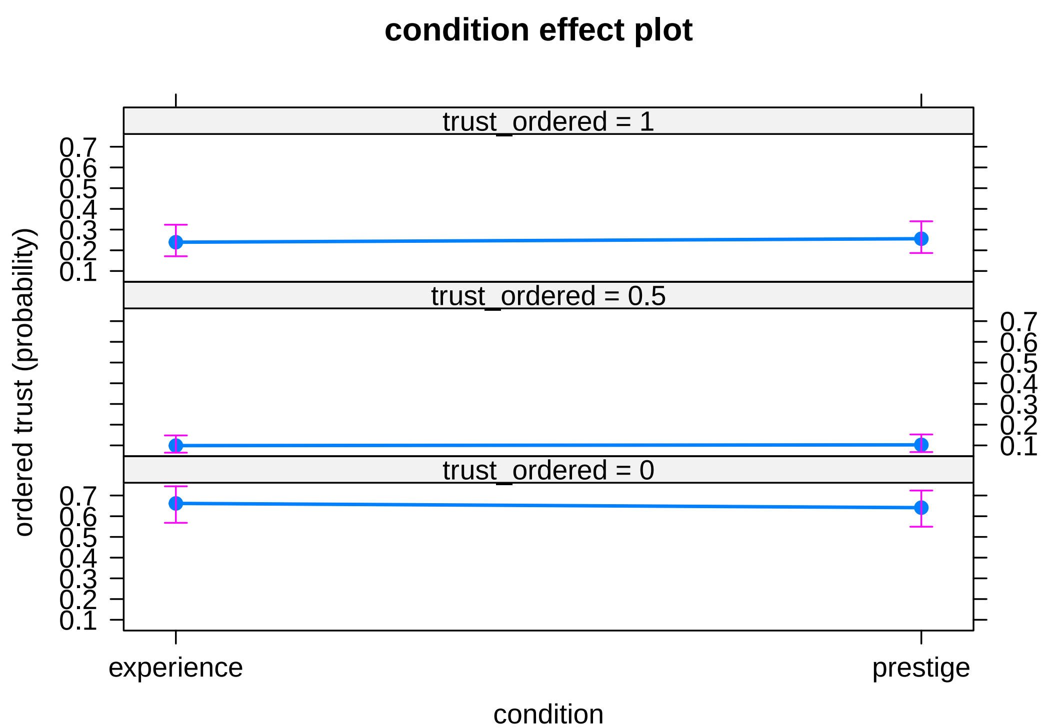

Figure A.3: Effects plot for PBM using ordered logistic regression with trust outcomes on a categorical three-point scale.

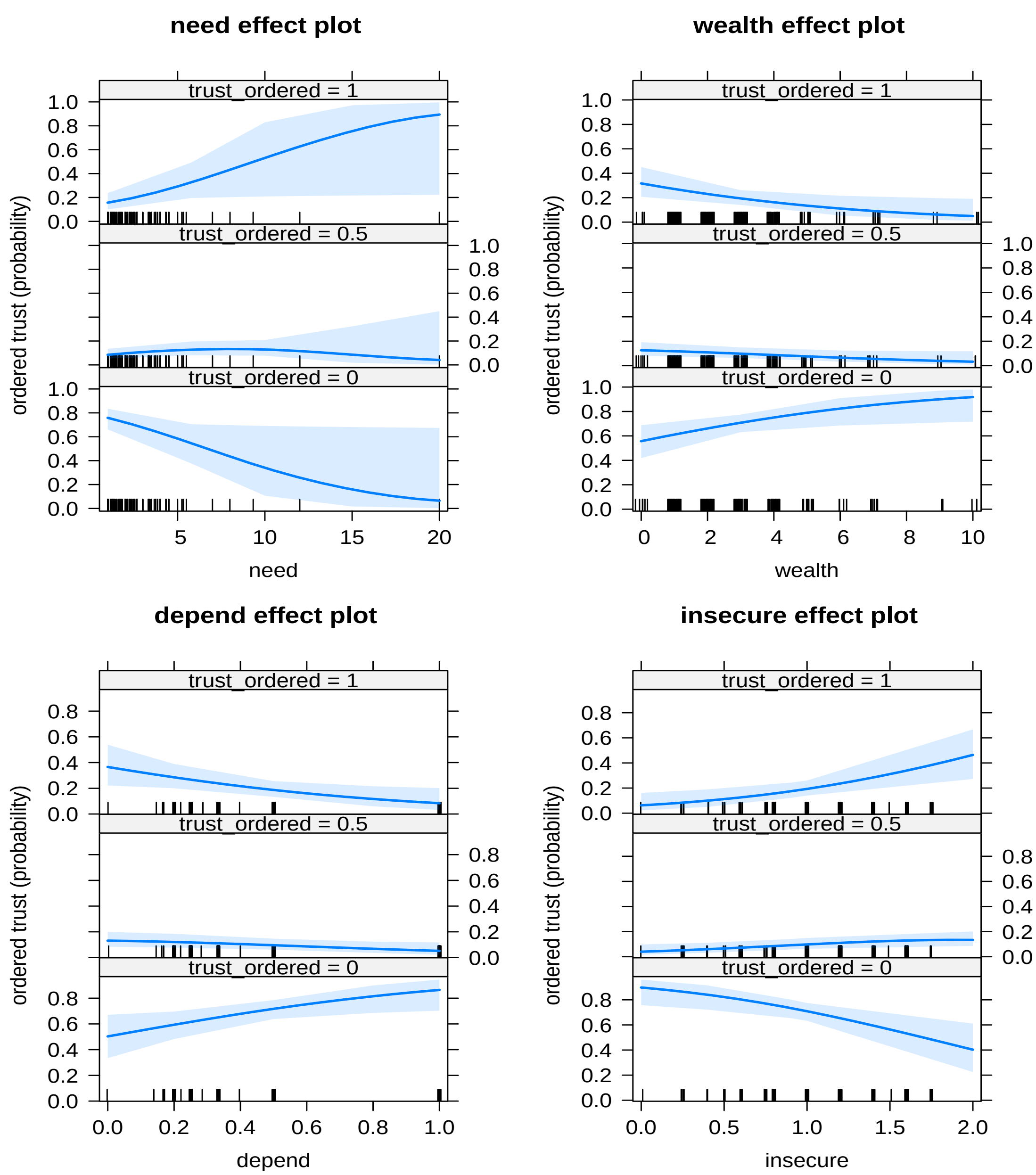

Figure A.4: Effects plot for RIM using ordered logistic regression with trust outcomes on a categorical three-point scale.

Table A.3: Ordered logistic regression models for trust outcomes (on an ordered three-point scale), based on condition (PBM, column 1), and on scaled measures of household food insecurity, need, wealth, and dependence on livestock as a source of subsistence (RIM, column 2).

	Dependent variable:	
	trust_ordered	
	(1)	(2)
conditionprestige	0.090	
	(0.279)	
need		0.201^{*}
		(0.100)
wealth		-0.219^{*}
		(0.097)
depend		-1.840^{*}
		(0.792)
insecure		1.285^{**}
		(0.449)
Note:	*p<0.05; **p<0.01; ***p<0.001	

outcomes based our initial data collection (i.e., some participants attempting to respond on a ten-point scale, but preferring the more intuitive three-point scale[9]) only involved recoding of 18% of all data points (as described here in sect. 3). The ten-point scale outcomes were strongly correlated with those in our coded three-point scale, which were used in our main results ($r = 0.98$, $p = 6 \times 10^{-155}$). Our re-analysis shows that the inclusion of the ten-point scale responses largely does not affect our results, although in the RIM, effects of our proxy measures of household wealth and need are slightly weakened in particular. See figures S5 and S6 for effects plots, and table S4 for regression coefficients and statistics.

A.5 Regional variation in responses

Responses in PC1 (figure 2, main article) appeared to be a regional acculturation variable that was low in the northern region and high in the southern region. Similarly, responses in the northern vs. southern regions varied on trust outcomes (north: 1 = 51%, 0.5 = 24%, 0 = 25%; south: 1 = 7.8%, 0.5 = 1.4%, 0 = 86%) and fact-checking outcomes (north: 1 = 69%, 0 = 31%; south: 1 = 92%, 0 = 8%). For a mosaic plot visualizing this large regional disparity, see figure S7.

[9]See section 3 in this document for a detailed description of the original measurement methods and how the ten-point scale was coded into the three-point scale for trust outcomes.

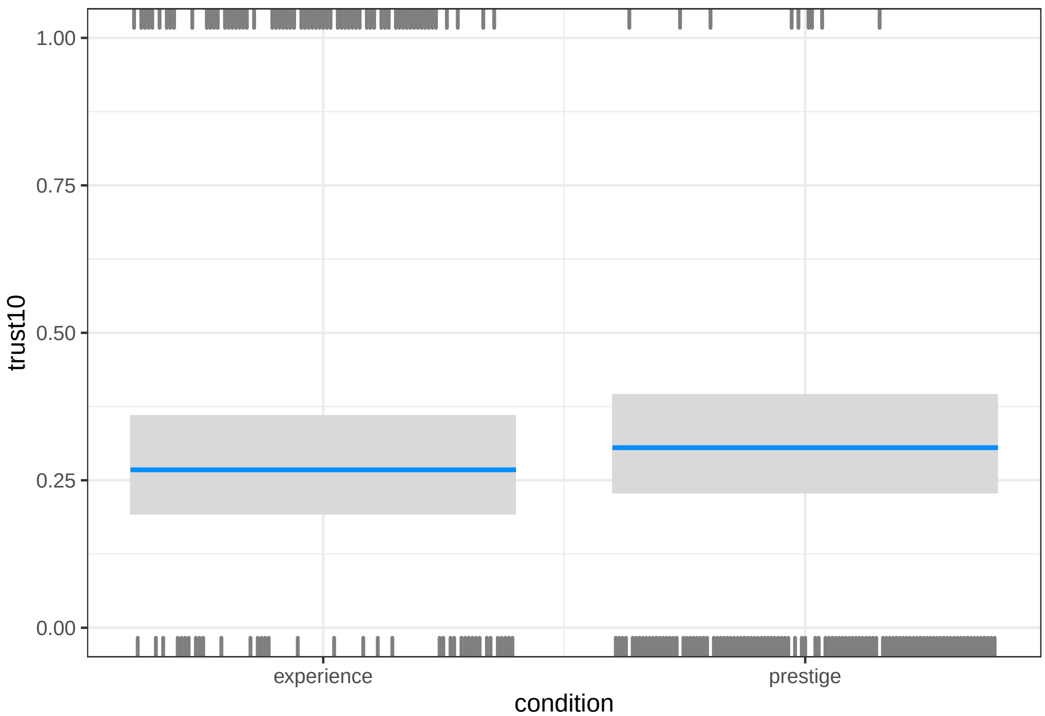

Figure A.5: Effects plot for PBM using logistic regression with trust outcomes, using our initial use of a ten-point scale for trust outcomes (prior to coding onto three-point scale).

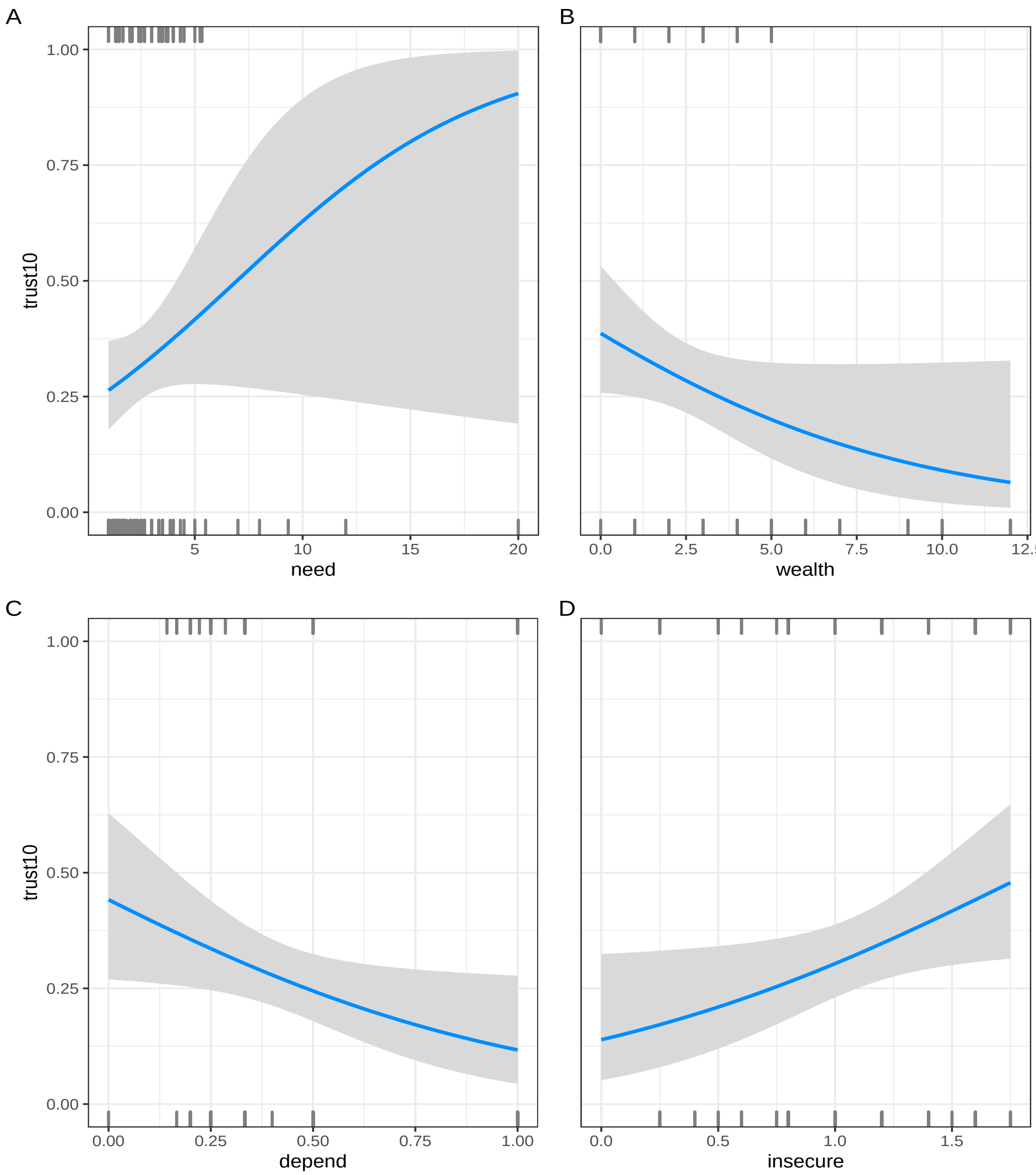

Figure A.6: Effects plot for RIM using logistic regression with trust outcomes, using our initial use of a ten-point scale for trust outcomes (prior to coding onto three-point scale).

Table A.4: Logistic regression models for trust outcomes, including the ten-point scale used unsuccessfully in some our sample, based on condition (PBM, column 1), and on scaled measures of household food insecurity, need, wealth, and dependence on livestock as a source of subsistence (RIM, column 2).

	Dependent variable:	
	trust10	
	(1)	(2)
conditionprestige	0.184	
	(0.301)	
need		0.173
		(0.108)
wealth		−0.185
		(0.101)
depend		−1.787*
		(0.855)
insecure		0.992*
		(0.472)
Constant	−1.006***	−1.228
	(0.220)	(0.755)
Note:	*p<0.05; **p<0.01; ***p<0.001	

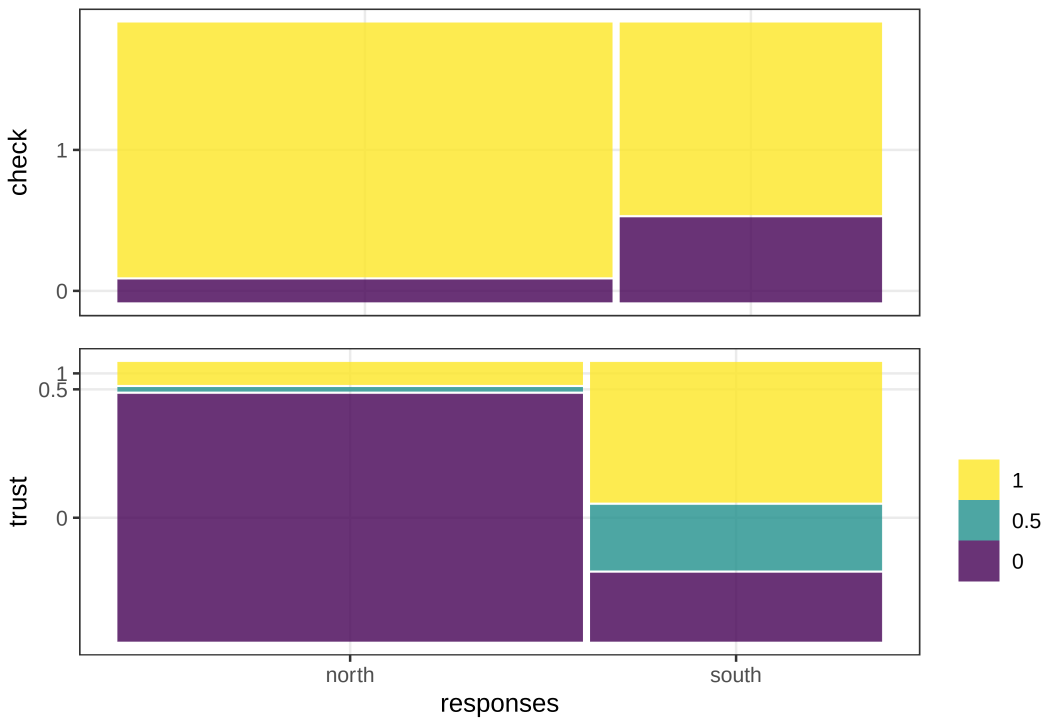

Figure A.7: Mosaic plot showing response counts for each trust outcomes (lower) and fact-checking outcomes (upper) by region (colors).

Regional differences vs. interviewer differences

As discussed in our limitations (see Discussion section in the main text), it is possible that northern vs. southern regions were somehow a consequence of different interviewers, rather than of true regional differences. As we also claim in the main text, however, we doubt this for at least two reasons.

First, A.D.L. and assistant 1 separately collected data in the southern region, and their results within this region were similar overall. Second, important regional differences, which were included in our PC1 acculturation variable, also included relatively straightforward and objective survey items that were unlikely to result from an interviewer effect. These included roof material, solar panels, and number of wives.[10] We address each of these two claims here.

Including an interviewer term in our southern regression models

Within our southern region data, we do not find a substantial interviewer effect on trust outcomes (figure S8) and fact-checking outcomes (figure S9). We also do not generally find interviewer effects in the southern region data when including an interviewer term in the confirmatory and exploratory models, although fact-checking outcomes might be a slight exception in some cases – see table S5. Overall, we do not

[10]It is also worth emphasizing that interviewers 1 and 2 are both highly experienced in administering scientific research, and are both local and respected adults. Each interviewer was trained directly by A.D.L. in the survey, communicated with him when they had questions, and practiced administering the survey by translating for A.D.L. prior to administering the survey independently.

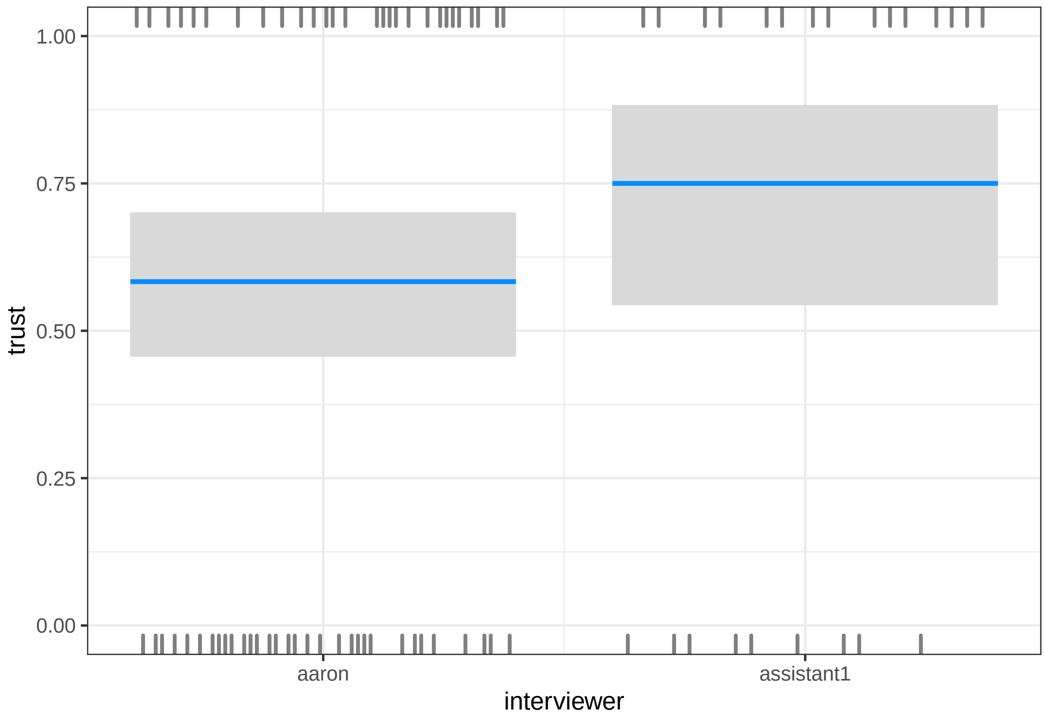

Figure A.8: Effects plot using logistic regression to model trust outcomes as a function of interviewer in the southern region.

find a strong interviewer effect on trust and fact-checking outcomes in the southern region, suggesting that data were not collected differently by A.D.L. and interviewer 1.

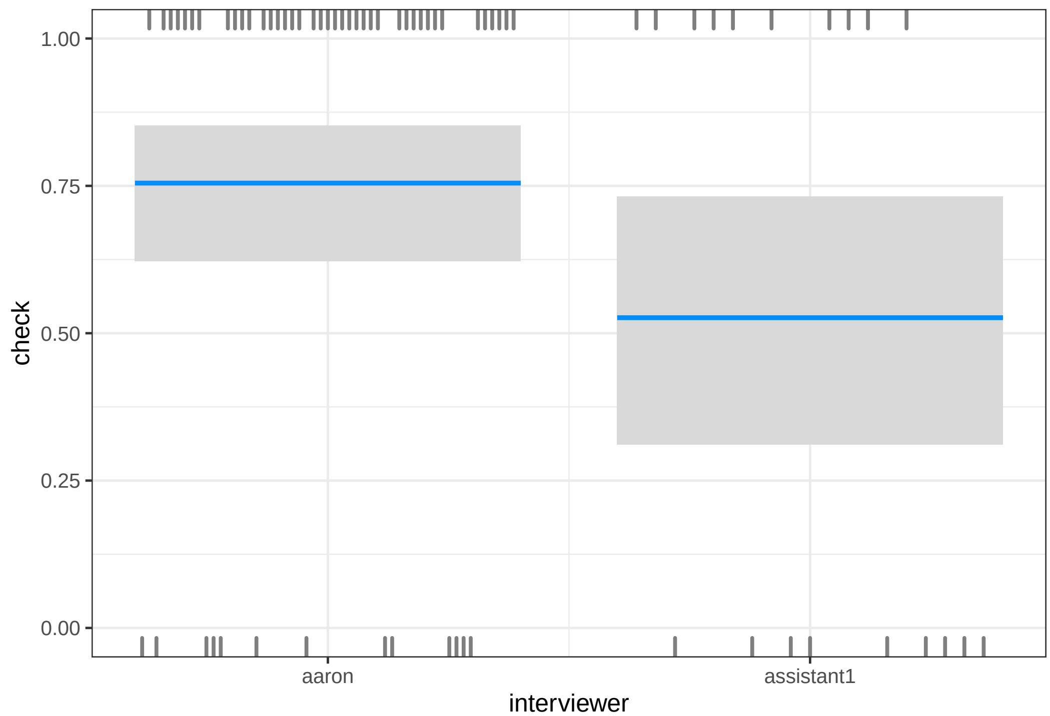

Figure A.9: Effects plot using logistic regression to model fact-checking outcomes as a function of interviewer in the southern region.

Table A.5: Logistic regression models for trust outcomes and fact-checking outcomes in the southern region, with interviewer term included in each model. Columns 1 and 6 correspond to the effects plots in figures S8 and S9, and the remaining columns correspond to our confirmatory results (PBM, RIM, PBM+RIM) and key exploratory result (PC1).

	Dependent variable:									
	trust					check				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
conditionprestige		−0.40		−0.36			−0.19		−0.42	
		(0.47)		(0.52)			(0.53)		(0.61)	
insecure			0.15	0.12				−0.01	−0.03	
			(0.24)	(0.25)				(0.29)	(0.29)	
need			0.04	0.04				0.75	0.80	
			(0.25)	(0.25)				(0.60)	(0.62)	
wealth			−0.30	−0.31				−0.06	−0.09	
			(0.25)	(0.25)				(0.30)	(0.30)	
depend			0.08	0.11				−0.002	0.04	
			(0.28)	(0.28)				(0.39)	(0.39)	
pc1					0.20					−0.13
					(0.44)					(0.51)
interviewerassistant1	0.76	0.77	0.57	0.56	0.82	−1.02	−1.03	−0.79	−0.85	−1.05
	(0.54)	(0.54)	(0.58)	(0.58)	(0.55)	(0.56)	(0.56)	(0.62)	(0.63)	(0.57)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Consistent regional differences on straightforward and objective measures

A remaining test for a possible interviewer effect is whether or not the most straightforward and objective observational data also vary by region. The key here is to analyze measures that are not likely subject to interviewer effects. Suppose, for example, that trust outcomes vary by region (which they do, as shown in figure S7), but measures requiring little-to-no participant input do not. This would be consistent with the idea that response variation was a result of different interviewers. Now suppose, in contrast, the regional differences that are easy to measure and do not likely involve interviewer effects *also* vary by region. This would be consistent with the idea that these differences, like other variables in PC1 (acculturation), result from true regional differences. Here, we consider three observational measures that are extremely unlikely to result from interviewer effects: presence/absence of a metal roof, presence/absence of a solar panel, and number of wives in the household.

When comparing differences in roof material by region, an especially stark and plainly observable difference by region is in roof material, a reliable proxy measure for cash wealth and market access. The proportion of southern participants owning a metal roof is 40%, in contrast to the 0% of northern participants owning a metal roof. Crucially, this is both unsurprising and consistent with our key findings in the main text: metal roof construction does not only require cash and access to purchased materials in town, but also requires sufficient infrastructure (i.e., road access) to transport the materials to a household for construction. As A.D.L. observed during fieldwork, transporting such materials is challenging but doable in the southern region, but virtually impossible in the northern region.

Similarly, we see a higher proportion of solar panel ownership among southern participants, which was 41%, in contrast to the 16% among northern participants (Fisher's exact test: $OR = 3.6$, $p = 8.5 \times 10^{-5}$). This regional trend is consistent with our key findings in the main text because solar panel ownership is another useful proxy indicator of cash wealth: not only are they purchased, but as key informants mentioned, they usually involve monthly (cash) payments to a rental company that owns the panel. These are typically installed on the (metal or grass) roof, and are not constrained by transportation requirements like metal roofs are. Lastly, in the more traditional/less market integrated northern region, we also saw more wives per household (north: 2.6, south: 1.8; Wilcoxon rank sum test: $W = 7009.5$, $p = 0.0015$), which is also consistent with the key results in our exploratory analyses.

These trends are each consistent with the main findings of our study, and are much less likely to result from interviewer differences than from regional differences in market access, cash wealth, and possibly broader social and cultural differences (which we discuss further in the main text; see Discussion section).

A.6 Exploratory analyses with multiple imputation

Exploratory analyses used the mice package (van Buuren 2020) to conduct multiple imputation, pooling results from five imputed datasets. Here, we show a walk-through of variable selection and quality checks on the multiple imputed datasets. This section includes a follow-up on our confirmatory analyses, which we included in the exploratory analyses after imputation, finding similar results to those in our preregistered confirmatory analysis. We show our selection procedure for variable inclusion here.[11] After selecting our quantitative variables for inclusion (53 variables), we were left with a remaining dataset with 1.8% of all observations missing.

Selecting variables for inclusion

Many questions in our survey contained missing data. Some questions contained very large amounts of missing data, particularly on certain items for which A.D.L. needed to be present (e.g., to guide follow up questions). All quantitative variables in our dataset were initially considered candidates for inclusion in our exploratory analyses, which involved PCA and model comparisons. Both of these analyses required complete cases, which we addressed with multiple imputation (see details in the next section). We first needed to select a subset of our candidate variables missing

[11] Note that our final sample used in the exploratory analyses, *after* multiple imputation, was 216 observations, because we did not impute outcomes variables (which each had a few missing cases)

only a few observations, along with a non-arbitrary way of defining "a few". As an initial heuristic, we considered $< 10\%$ missing data per column (about 23 missing observations, maximum) to be ideal.

Plotting the number of missing observations per candidate variable, we looked for a large gap in number of missing observations that might suggest a low cutoff, roughly optimizing our tradeoff between maximizing variable inclusion and minimizing numbers of missing observations. See figure S10. Notice two things about this figure. First, variable names along the y-axis are not relevant to our decision process to include vs. exclude, so they are not labeled here (if anything, knowing variable names here would have possibly biased this procedure). Second, there is a large gap on the dot chart between the blue variables and the red variables. The maximum number of missing observations in the blue variables is 10, and the next largest number of missing observations (i.e., minimum number of missing observations in the red variables) is 21. Hence, we used 10 missing observations as our threshold for inclusion in the multiple imputation.

PC1 variation between imputed datasets

To check for possible variation in our PCA results on our multiple imputed datasets, we analyzed PC1 outcomes between the five imputed datasets. Specifically, we investigated the pointwise standard deviation on PC1 between datasets. (Note that these are standard deviations computed from 5 observations, which are

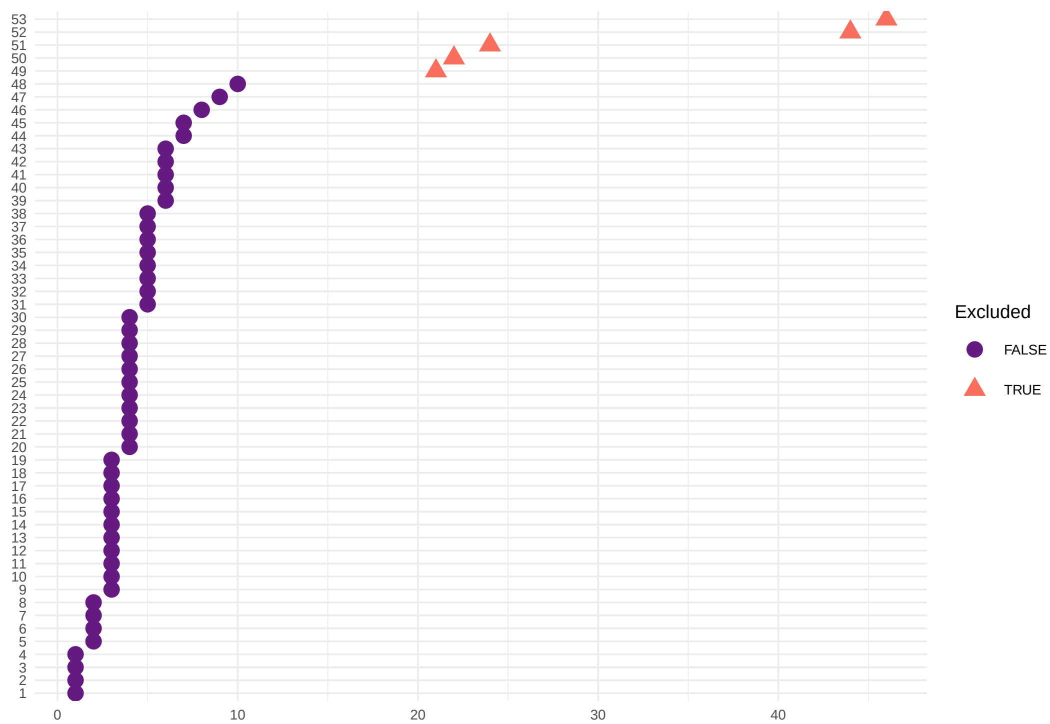

Figure A.10: Dot plot showing number of missing observations (x-axis) for quantitative variables containing 1 or more missing observations, which were considered for inclusion in multiple imputation and PCA (y-axis). Blue dots correspond to variables we included, with 10 or fewer missing observations. Red dots correspond to variables we excluded, with more than 10 missing observations.

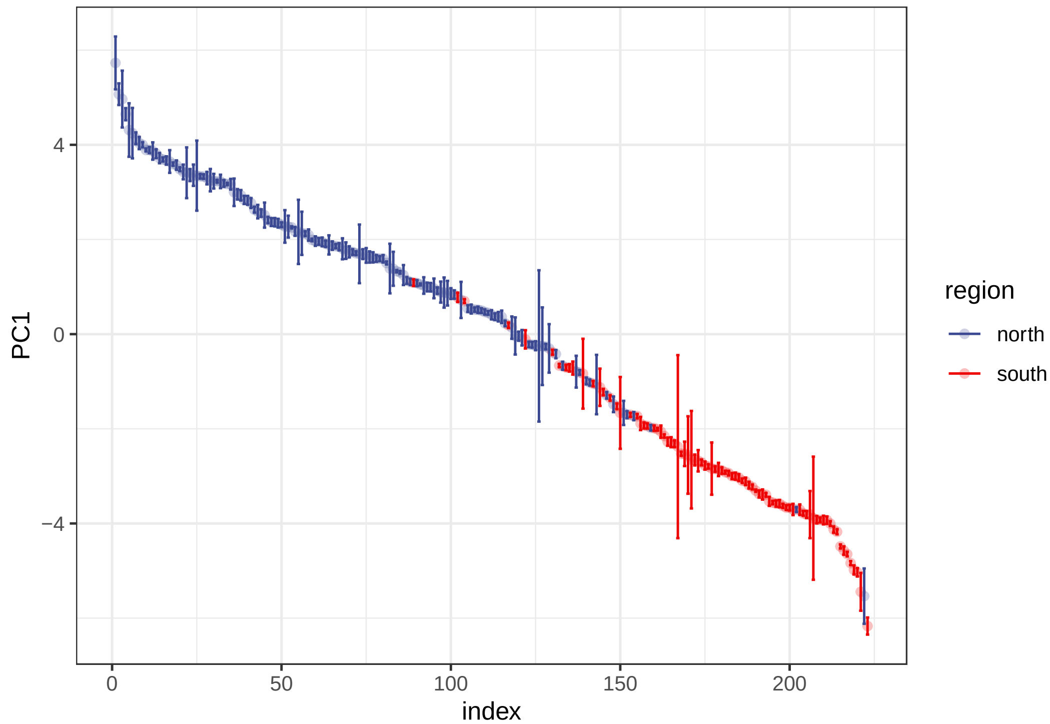

Figure A.11: Ordered PC1 outcomes for each participant in five imputed datasets. Points are mean PC1 outcomes between imputations, error bars are +/- 2 standard deviations, and colors are region.

susceptible to some noise.) See figure S11.

AICc tables for each imputed dataset

Results from our model selection were largely consistent across imputations, though with a few minor exceptions. See table S6 for model selection based on trust outcomes, and table S7 for model selection based on fact-checking outcomes. Note that our confirmatory results here do not substantially change after imputing the data and re-analyzing the PBM, RIM, and PBM+RIM. Recall that MI refers to our *a priori* measure of market integration, whereas EMI refers to our cluster found in the hierarchical cluster analysis discussed in the main text (e.g., figure 5 in the article). The model with acculturation (PC1), which reflects covariation among many variables beyond MI, had the best performance of all.

Model estimates before and after pooling

Each of the models in our AICc model comparison above were individually analyzed prior to pooling results. Pooled results are shown in the coefficients plot (figure 6) of the main article text, and statistics are report here (table S8). Each of these pooled results conform closely to the results from each individual imputed dataset, which we report individually here for trust and fact-checking outcomes. See tables S9-S18.

Table A.6: Model comparison of logistic regression models using AICc scores and weights as our selection criteria to compare models (trust outcomes). Each refers to a separate imputed dataset.

Modnames	K	AICc	Delta_AICc	ModelLik	AICcWt	LL	Cum.Wt
pc1	2	212.48	0.00	1.00	0.56	-104.21	0.56
pc1_pbm	3	212.98	0.50	0.78	0.44	-103.43	1.00
EMI	2	226.06	13.57	0.00	0.00	-111.00	1.00
hclust	3	227.67	15.19	0.00	0.00	-110.78	1.00
MI	2	228.28	15.80	0.00	0.00	-112.11	1.00
dep	2	241.38	28.90	0.00	0.00	-118.66	1.00
ETB	2	246.47	33.99	0.00	0.00	-121.21	1.00
RIM	5	246.48	34.00	0.00	0.00	-118.10	1.00
PBM_RIM	6	247.30	34.82	0.00	0.00	-117.45	1.00
PBM	2	249.42	36.94	0.00	0.00	-122.68	1.00
pc1	2	210.94	0.00	1.00	0.56	-103.44	0.56
pc1_pbm	3	211.42	0.48	0.79	0.44	-102.65	1.00
MI	2	223.35	12.41	0.00	0.00	-109.65	1.00
EMI	2	224.34	13.40	0.00	0.00	-110.14	1.00
hclust	3	226.04	15.10	0.00	0.00	-109.96	1.00
dep	2	240.77	29.83	0.00	0.00	-118.36	1.00
RIM	5	244.97	34.03	0.00	0.00	-117.34	1.00
PBM_RIM	6	245.80	34.87	0.00	0.00	-116.70	1.00
ETB	2	246.54	35.60	0.00	0.00	-121.24	1.00
PBM	2	249.42	38.48	0.00	0.00	-122.68	1.00
pc1	2	211.01	0.00	1.00	0.57	-103.48	0.57
pc1_pbm	3	211.58	0.57	0.75	0.43	-102.73	1.00
EMI	2	225.76	14.75	0.00	0.00	-110.85	1.00
MI	2	226.30	15.29	0.00	0.00	-111.12	1.00
hclust	3	227.40	16.40	0.00	0.00	-110.65	1.00
dep	2	239.93	28.93	0.00	0.00	-117.94	1.00
RIM	5	244.62	33.61	0.00	0.00	-117.17	1.00
PBM_RIM	6	245.39	34.38	0.00	0.00	-116.49	1.00
ETB	2	246.42	35.41	0.00	0.00	-121.18	1.00
PBM	2	249.42	38.41	0.00	0.00	-122.68	1.00
pc1	2	211.31	0.00	1.00	0.56	-103.63	0.56
pc1_pbm	3	211.80	0.49	0.78	0.44	-102.84	1.00
EMI	2	225.74	14.43	0.00	0.00	-110.84	1.00
MI	2	226.86	15.55	0.00	0.00	-111.40	1.00
hclust	3	227.26	15.95	0.00	0.00	-110.58	1.00
dep	2	239.23	27.92	0.00	0.00	-117.59	1.00
RIM	5	243.29	31.98	0.00	0.00	-116.50	1.00
PBM_RIM	6	243.90	32.59	0.00	0.00	-115.75	1.00
ETB	2	246.16	34.85	0.00	0.00	-121.05	1.00
PBM	2	249.42	38.11	0.00	0.00	-122.68	1.00
pc1	2	211.41	0.00	1.00	0.56	-103.68	0.56
pc1_pbm	3	211.88	0.47	0.79	0.44	-102.88	1.00
EMI	2	225.06	13.65	0.00	0.00	-110.50	1.00
MI	2	225.73	14.32	0.00	0.00	-110.84	1.00
hclust	3	226.62	15.21	0.00	0.00	-110.25	1.00
dep	2	239.93	28.52	0.00	0.00	-117.94	1.00
RIM	5	244.70	33.30	0.00	0.00	-117.21	1.00
PBM_RIM	6	245.44	34.03	0.00	0.00	-116.52	1.00
ETB	2	246.14	34.73	0.00	0.00	-121.04	1.00
PBM	2	249.42	38.01	0.00	0.00	-122.68	1.00

Table A.7: Model comparison of logistic regression models using AICc scores and weights as our selection criteria to compare models (fact-checking outcomes). Each refers to a separate imputed dataset.

Modnames	K	AICc	Delta_AICc	ModelLik	AICcWt	LL	Cum.Wt
pc1	2	173.24	0.00	1.00	0.43	-84.59	0.43
pc1_pbm	3	173.84	0.60	0.74	0.32	-83.86	0.75
MI	2	175.51	2.27	0.32	0.14	-85.72	0.89
EMI	2	177.32	4.08	0.13	0.06	-86.63	0.95
hclust	3	178.06	4.82	0.09	0.04	-85.97	0.99
dep	2	182.23	8.99	0.01	0.00	-89.09	0.99
ETB	2	182.32	9.08	0.01	0.00	-89.13	1.00
PBM	2	184.65	11.41	0.00	0.00	-90.29	1.00
RIM	5	185.21	11.97	0.00	0.00	-87.45	1.00
PBM_RIM	6	185.84	12.60	0.00	0.00	-86.71	1.00
pc1	2	173.43	0.00	1.00	0.42	-84.69	0.42
pc1_pbm	3	174.04	0.61	0.74	0.31	-83.96	0.72
MI	2	175.07	1.64	0.44	0.18	-85.51	0.91
EMI	2	177.83	4.39	0.11	0.05	-86.88	0.95
hclust	3	178.55	5.12	0.08	0.03	-86.21	0.99
dep	2	182.14	8.71	0.01	0.01	-89.04	0.99
ETB	2	182.37	8.93	0.01	0.00	-89.15	1.00
PBM	2	184.65	11.21	0.00	0.00	-90.29	1.00
RIM	5	185.25	11.81	0.00	0.00	-87.47	1.00
PBM_RIM	6	185.91	12.48	0.00	0.00	-86.74	1.00
pc1	2	173.11	0.00	1.00	0.46	-84.52	0.46
pc1_pbm	3	173.75	0.64	0.73	0.33	-83.81	0.79
MI	2	175.78	2.68	0.26	0.12	-85.86	0.91
EMI	2	177.83	4.73	0.09	0.04	-86.89	0.96
hclust	3	178.58	5.47	0.06	0.03	-86.23	0.99
dep	2	181.95	8.84	0.01	0.01	-88.94	0.99
ETB	2	182.35	9.24	0.01	0.00	-89.14	1.00
PBM	2	184.65	11.54	0.00	0.00	-90.29	1.00
RIM	5	185.20	12.09	0.00	0.00	-87.45	1.00
PBM_RIM	6	185.83	12.73	0.00	0.00	-86.71	1.00
pc1	2	173.40	0.00	1.00	0.46	-84.67	0.46
pc1_pbm	3	174.02	0.62	0.73	0.33	-83.95	0.79
MI	2	176.00	2.60	0.27	0.12	-85.97	0.91
EMI	2	178.23	4.83	0.09	0.04	-87.09	0.95
hclust	3	178.75	5.35	0.07	0.03	-86.31	0.98
ETB	2	182.09	8.69	0.01	0.01	-89.02	0.99
dep	2	182.10	8.70	0.01	0.01	-89.02	1.00
PBM	2	184.65	11.25	0.00	0.00	-90.29	1.00
RIM	5	184.89	11.49	0.00	0.00	-87.29	1.00
PBM_RIM	6	185.51	12.11	0.00	0.00	-86.55	1.00
pc1	2	173.95	0.00	1.00	0.40	-84.95	0.40
pc1_pbm	3	174.60	0.64	0.73	0.29	-84.24	0.68
MI	2	175.52	1.56	0.46	0.18	-85.73	0.87
EMI	2	177.53	3.57	0.17	0.07	-86.74	0.93
hclust	3	178.12	4.17	0.12	0.05	-86.00	0.98
dep	2	182.00	8.04	0.02	0.01	-88.97	0.99
ETB	2	182.08	8.13	0.02	0.01	-89.01	1.00
PBM	2	184.65	10.69	0.00	0.00	-90.29	1.00
RIM	5	185.13	11.17	0.00	0.00	-87.41	1.00
PBM_RIM	6	185.79	11.83	0.00	0.00	-86.68	1.00

Table A.8: Pooled estimates for each model in our exploratory analysis after multiple imputation. Regression coefficient, within- and between- imputation variance, total variance, and standard error (SE) are reported here.

outcome	model	predictor	est	within	between	total	SE
trust	pc1	pc1	-1.22	0.04	0	0.04	0.19
trust	pc1__pbm	pc1	-1.24	0.04	0	0.04	0.20
trust	pc1__pbm	condition	0.39	0.12	0	0.12	0.34
trust	mi	MI	0.89	0.03	0	0.03	0.17
trust	dep	depend	-0.59	0.04	0	0.04	0.20
trust	pbm	condition	0.11	0.09	0	0.09	0.30
trust	rim	insecure	0.41	0.03	0	0.03	0.16
trust	rim	need	0.44	0.04	0	0.05	0.21
trust	rim	depend	-0.51	0.04	0	0.05	0.21
trust	rim	wealth	-0.33	0.04	0	0.04	0.19
trust	pbm__rim	condition	0.25	0.11	0	0.11	0.33
trust	pbm__rim	insecure	0.41	0.03	0	0.03	0.16
trust	pbm__rim	need	0.41	0.04	0	0.05	0.21
trust	pbm__rim	depend	-0.54	0.05	0	0.05	0.22
trust	pbm__rim	wealth	-0.32	0.04	0	0.04	0.19
trust	EMI__ETB	EMI	1.05	0.04	0	0.04	0.20
trust	EMI__ETB	ETB	-0.13	0.08	0	0.08	0.28
trust	EMI	EMI	1.07	0.04	0	0.04	0.19
trust	ETB	ETB	-0.47	0.08	0	0.08	0.28
check	pc1	pc1	0.68	0.04	0	0.04	0.20
check	pc1__pbm	pc1	0.70	0.04	0	0.04	0.20
check	pc1__pbm	condition	-0.47	0.16	0	0.16	0.40
check	mi	MI	-0.60	0.04	0	0.04	0.20
check	dep	depend	0.41	0.06	0	0.06	0.25
check	pbm	condition	-0.32	0.15	0	0.15	0.38
check	rim	insecure	-0.23	0.04	0	0.04	0.19
check	rim	need	0.06	0.04	0	0.04	0.20
check	rim	depend	0.38	0.07	0	0.07	0.26
check	rim	wealth	0.25	0.05	0	0.05	0.23
check	pbm__rim	condition	-0.49	0.16	0	0.16	0.40
check	pbm__rim	insecure	-0.23	0.04	0	0.04	0.19
check	pbm__rim	need	0.09	0.05	0	0.05	0.21
check	pbm__rim	depend	0.45	0.07	0	0.07	0.27
check	pbm__rim	wealth	0.23	0.06	0	0.06	0.24
check	EMI__ETB	EMI	-0.45	0.03	0	0.04	0.19
check	EMI__ETB	ETB	0.38	0.15	0	0.15	0.39
check	EMI	EMI	-0.50	0.03	0	0.03	0.18
check	ETB	ETB	0.57	0.17	0	0.17	0.41

Table A.9: Imputed dataset 1. Logistic regression models for trust outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	trust									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	-1.22^{***}	-1.23^{***}								
	(0.19)	(0.19)								
conditionprestige		0.39						0.11		0.24
		(0.34)						(0.30)		(0.33)
MI			0.85^{***}							
			(0.17)							
EMI				1.06^{***}	1.04^{***}					
				(0.19)	(0.20)					
ETB					-0.13				-0.47	
					(0.28)				(0.29)	
insecure							0.42^{**}			0.42^{**}
							(0.16)			(0.16)
need							0.44^{*}			0.41
							(0.21)			(0.21)
depend						-0.56^{**}	-0.47^{*}			-0.51^{*}
						(0.20)	(0.20)			(0.21)
wealth							-0.31			-0.30
							(0.19)			(0.19)
Note:							$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$			

Table A.10: Imputed dataset 1. Logistic regression models for fact-checking outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	check									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	0.68^{***}	0.70^{***}								
	(0.20)	(0.20)								
conditionprestige		−0.48						−0.32		−0.49
		(0.40)						(0.38)		(0.40)
MI			-0.61^{**}							
			(0.20)							
EMI				-0.51^{**}	-0.46^{*}					
				(0.18)	(0.19)					
ETB					0.37				0.57	
					(0.40)				(0.42)	
insecure							−0.23			−0.23
							(0.19)			(0.19)
need							0.06			0.09
							(0.20)			(0.22)
depend						0.39	0.37			0.44
						(0.24)	(0.25)			(0.27)
wealth							0.25			0.24
							(0.23)			(0.24)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Table A.11: Imputed dataset 2. Logistic regression models for trust outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	trust									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	-1.22^{***}	-1.24^{***}								
	(0.19)	(0.19)								
conditionprestige		0.39						0.11		0.24
		(0.34)						(0.30)		(0.33)
MI			0.93^{***}							
			(0.17)							
EMI				1.09^{***}	1.07^{***}					
				(0.19)	(0.20)					
ETB					-0.11				-0.45	
					(0.28)				(0.28)	
insecure							0.41^{**}			0.41^{**}
							(0.16)			(0.16)
need							0.44^{*}			0.41
							(0.21)			(0.21)
depend						-0.58^{**}	-0.49^{*}			-0.53^{*}
						(0.20)	(0.21)			(0.22)
wealth							-0.35			-0.35
							(0.19)			(0.19)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Table A.12: Imputed dataset 2. Logistic regression models for fact-checking outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	check									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	0.67***	0.69***								
	(0.20)	(0.20)								
conditionprestige		−0.48						−0.32		−0.48
		(0.40)						(0.38)		(0.40)
MI			−0.62**							
			(0.20)							
EMI				−0.50**	−0.45*					
				(0.18)	(0.19)					
ETB					0.37				0.55	
					(0.39)				(0.41)	
insecure							−0.23			−0.23
							(0.19)			(0.19)
need							0.07			0.10
							(0.20)			(0.21)
depend						0.40	0.38			0.45
						(0.24)	(0.26)			(0.27)
wealth							0.24			0.23
							(0.23)			(0.23)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Table A.13: Imputed dataset 3. Logistic regression models for trust outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	trust									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	-1.23^{***}	-1.24^{***}								
	(0.19)	(0.20)								
conditionprestige		0.38						0.11		0.24
		(0.34)						(0.30)		(0.33)
MI			0.88^{***}							
			(0.17)							
EMI				1.06^{***}	1.04^{***}					
				(0.19)	(0.20)					
ETB					-0.12				-0.47	
					(0.28)				(0.28)	
insecure							0.41^{**}			0.41^{**}
							(0.16)			(0.16)
need							0.47^{*}			0.44^{*}
							(0.21)			(0.21)
depend						-0.59^{**}	-0.49^{*}			-0.53^{*}
						(0.20)	(0.21)			(0.22)
wealth							-0.36			-0.35
							(0.19)			(0.19)

Note: *p<0.05; **p<0.01; ***p<0.001

Table A.14: Imputed dataset 3. Logistic regression models for fact-checking outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	check									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	0.69***	0.71***								
	(0.20)	(0.20)								
conditionprestige		−0.47						−0.32		−0.48
		(0.40)						(0.38)		(0.40)
MI			−0.60**							
			(0.20)							
EMI				−0.49**	−0.45*					
				(0.18)	(0.19)					
ETB					0.36				0.55	
					(0.38)				(0.40)	
insecure							−0.23			−0.23
							(0.19)			(0.19)
need							0.04			0.07
							(0.19)			(0.20)
depend						0.42	0.39			0.46
						(0.25)	(0.26)			(0.27)
wealth							0.24			0.23
							(0.23)			(0.23)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Table A.15: Imputed dataset 4. Logistic regression models for trust outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	trust									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	-1.23^{***}	-1.24^{***}								
	(0.19)	(0.20)								
conditionprestige		0.40						0.11		0.27
		(0.34)						(0.30)		(0.33)
MI			0.89^{***}							
			(0.17)							
EMI				1.08^{***}	1.06^{***}					
				(0.19)	(0.20)					
ETB					-0.14				-0.49	
					(0.28)				(0.28)	
insecure							0.40^{*}			0.40^{*}
							(0.16)			(0.16)
need							0.40			0.37
							(0.20)			(0.20)
depend						-0.63^{**}	-0.55^{**}			-0.59^{**}
						(0.20)	(0.21)			(0.22)
wealth							-0.29			-0.29
							(0.19)			(0.19)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Table A.16: Imputed dataset 4. Logistic regression models for fact-checking outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	check									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	0.68^{***}	0.70^{***}								
	(0.20)	(0.20)								
conditionprestige		-0.47						-0.32		-0.49
		(0.40)						(0.38)		(0.40)
MI			-0.59^{**}							
			(0.20)							
EMI				-0.48^{**}	-0.43^{*}					
				(0.18)	(0.19)					
ETB					0.40				0.58	
					(0.40)				(0.41)	
insecure							-0.23			-0.22
							(0.19)			(0.19)
need							0.09			0.12
							(0.21)			(0.22)
depend						0.41	0.39			0.46
						(0.25)	(0.26)			(0.27)
wealth							0.27			0.25
							(0.23)			(0.24)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Table A.17: Imputed dataset 5. Logistic regression models for trust outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	trust									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	-1.23^{***}	-1.25^{***}								
	(0.20)	(0.20)								
conditionprestige		0.40						0.11		0.25
		(0.34)						(0.30)		(0.33)
MI			0.91^{***}							
			(0.17)							
EMI				1.09^{***}	1.06^{***}					
				(0.19)	(0.20)					
ETB					-0.14				-0.49	
					(0.28)				(0.28)	
insecure							0.41^{**}			0.42^{**}
							(0.16)			(0.16)
need							0.46^{*}			0.44^{*}
							(0.21)			(0.21)
depend						-0.60^{**}	-0.52^{*}			-0.55^{*}
						(0.20)	(0.21)			(0.22)
wealth							-0.35			-0.34
							(0.19)			(0.19)
Note:							*p<0.05; **p<0.01; ***p<0.001			

Table A.18: Imputed dataset 5. Logistic regression models for fact-checking outcomes based on exploratory models (MI, EMI, ETB, EMI+ETB, and dependence on livestock only), and on confirmatory models (after imputation; condition, and scaled measures of household food insecurity, need, wealth, and dependence on livestock).

	Dependent variable:									
	check									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
pc1	0.66**	0.68***								
	(0.20)	(0.20)								
conditionprestige		−0.47						−0.32		−0.48
		(0.40)						(0.38)		(0.40)
MI			−0.61**							
			(0.20)							
EMI				−0.51**	−0.45*					
				(0.18)	(0.19)					
ETB					0.39				0.58	
					(0.39)				(0.41)	
insecure							−0.23			−0.23
							(0.19)			(0.19)
need							0.04			0.07
							(0.19)			(0.21)
depend						0.41	0.38			0.45
						(0.25)	(0.26)			(0.27)
wealth							0.25			0.23
							(0.23)			(0.23)
Note:	*p<0.05; **p<0.01; ***p<0.001									

A.7 Material and ideational culture clusters

In our results, both in the exploratory analyses and in the AICc tables shown above, we separated variables belonging to ideational (TB, or *traditional beliefs*) and material categories (MI, EMI, denoting *market integration* and *empirical market integration*,[12] respectively). Variables in each category were all included in our PCA, and therefore comprise subsets of the PCA variables (i.e., loading on PC1, the *acculturation* variable; figure 2 in the main text).

It is worth exploring here, in more detail, interrelationships among these covariates of PC1 (acculturation). Specifically, missionization and education are often thought to be largely responsible for the fact that Maasai values and norms are largely shifting away from traditional beliefs (TB). There was a roughly equal split among Christians (51%) vs. traditional Maasai believers (49%) across regions, but it is difficult to keep Christianity *completely* separate from the changing material conditions (MI); missionization, along with non-government organizations funded from Western sources (often Christian), has emphasized an increasing focus on educational development, infrastructure among the villages such as Eluwai, and contributed an influx of cash

[12]To re-emphasize here, as we discuss in the main text results, *empirical market integration* refers to the market integration variable that resulted from our hierarchical clustering analysis. We distinguish this from the *market integration* variable, which, as discussed in our main methods section, was constructed prior to our exploratory analyses based on proxy measures of cash wealth/reliance and market purchases for subsistence.

and resources in the area.

Variation in trust outcomes for each cluster as predictor

Comparing the models in our exploratory analysis to each other, and to the confirmatory models, we showed that market integration and empirical market integration each predicted higher trust (market integration: $\beta = 0.87$, $SE = 0.34$; empirical market integration: $\beta = 1.1$, $SE = 0.39$) and lower fact-checking (market integration: $\beta =$ -0.59, $SE = 0.39$; empirical market integration: $\beta =$ -0.5, $SE = 0.37$), whereas traditional beliefs weakly predicted lower trust ($\beta =$ -0.46, $SE = 0.56$) and higher fact-checking ($\beta = 0.56$, $SE = 0.83$). These effects were larger those in the RIM, but neither were as large as the effect of acculturation (trust: $\beta = 1.2$, $SE = 0.4$; check: $\beta =$ -0.67, $SE = 0.42$).

Correlations among clusters and other predictors

Here, we show how market integration, empirical market integration, traditional beliefs, and other aspects of acculturation (PC1), along with outcome variables, are correlated with each other. In general, (an *a priori* measure of) market integration was higher in the southern region (mean = 0.84) than in the northern region (mean = -0.51; $t = 12.8$, $p = 6 \times 10^{-27}$). Market integration and empirical market integration each strongly correlated with acculturation (market integration: $r = 0.72$, empirical market integration: $r =$ -0.82), and traditional beliefs moderately correlated with acculturation ($r = 0.25$). Market integration, empirical market integration, and traditional beliefs were similarly intercorrelated. Although Christianity weakly correlated with market integration ($r = 0.17$) and empirical market integration ($r = 0.23$), it was not correlated with traditional beliefs (r = -0.04). This seems to suggest that acculturation is largely driven by market integration, but less driven by traditional beliefs, and, more interestingly, Christianity is largely *independent* of changes in market integration, traditional beliefs, and acculturation.

It is worth noting, however, that our traditional beliefs cluster was partially driven by variation in herd sizes, a clearly material domain. As shown in the main text, these were collapsed into a single cluster strictly as a result of our hierarchical clustering analysis. This leads to the compelling question of why was this material domain so tightly linked to variation in our ideational variables. The answer could be relevant either to traditional beliefs and values, or to locational differences relative to the market and towns near the southern region, specifically as a consequence of more private land and less available grazing land.

Correlation matrix

We reported that market integration and empirical market integration were strongly associated with acculturation, traditional beliefs was moderately associated with acculturation, and that market integration, empirical market integration, and traditional beliefs were similarly intercorrelated with each other. We also noted that

Christianity weakly correlated with market integration and empirical market integration, but it was not correlated with traditional beliefs. See figure S12 for a correlation matrix showing these associations. Note that although traditional beliefs and Christianity were not correlated with each other, each of these variables weakly to moderately correlated with other variables listed here, including acculturation. It is also worth pointing out that out of their covariates, the strongest associations for each Christianity and traditional beliefs were seen with acculturation.

A.8 Sex differences in the PCA

We found little-to-no meaningful sex differences in the PCA results. Specifically, PC1 values were not systematically different among males and females, but it is worth noting that the variance and skew on PC2 were higher for males than they were for females (figure S13). This is unsurprising, as we interpreted PC2 as largely corresponding to certain aspects of wealth (e.g., number of wives) and household size (see figure 2 in main text), which in Maasai culture, vary among males much more than they do among females (see also Spencer 1965).

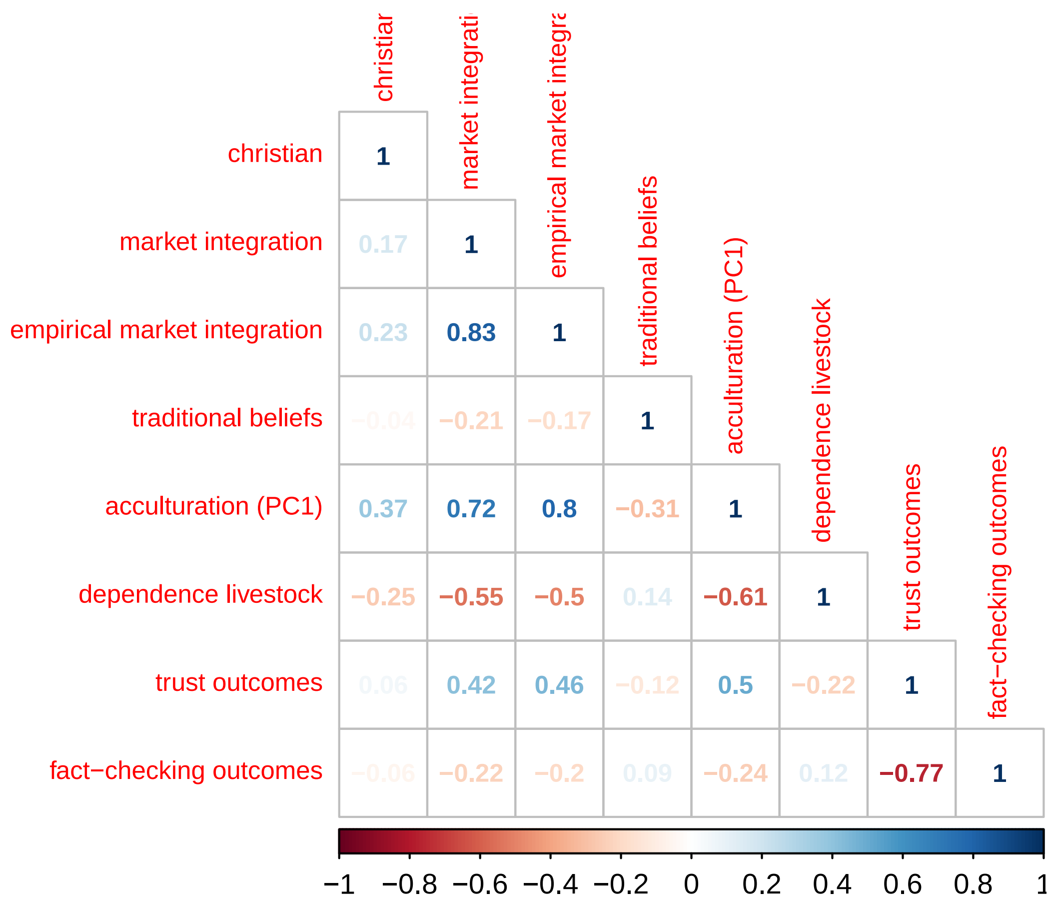

Figure A.12: Correlation matrix for Christianity, market integration (both a priori, MI and empirically driven MI, EMI), traditional beliefs (ETB), PC1, dependence on livestock, and trust and fact-checking outcomes.

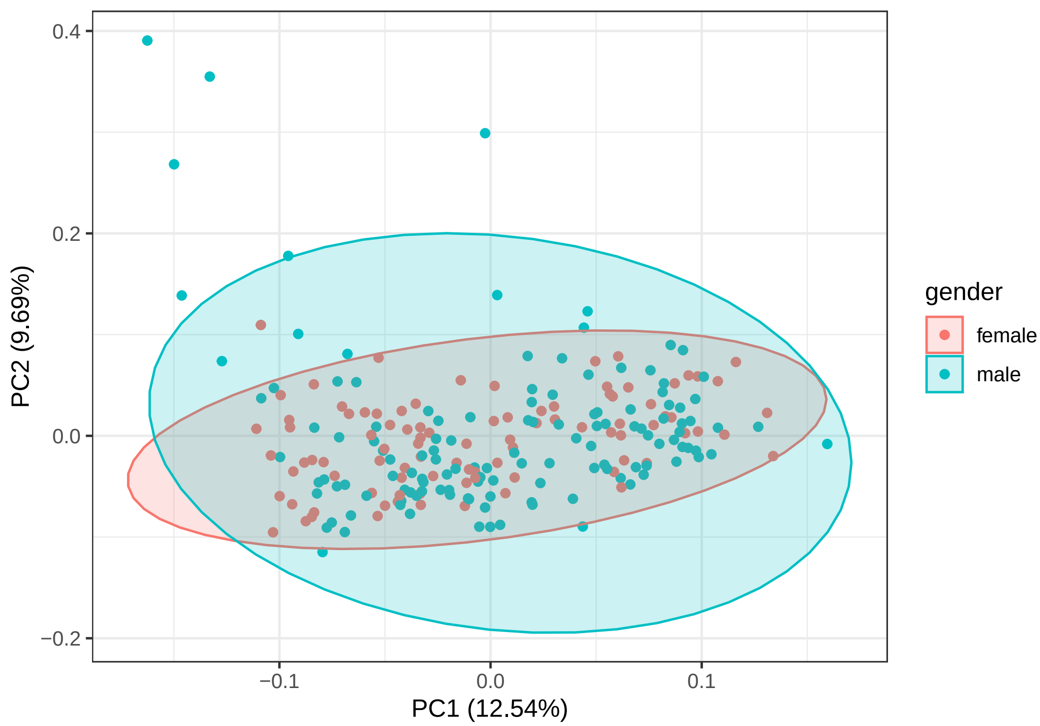

Figure A.13: Biplot of PCA results from the exploratory analysis, with participant sex indicated by color. Similar to our main results, we interpreted PC1 as relating to acculturation and PC2 as relating to household size.

B Supplementary Information for Chapter 3: *Ethnoscientific expertise in 55 traditional societies*

B.1 Operationalizing our theoretical models

In this section, we discuss how we operationalized our theoretical models in more detail, including quotations from key references that motivate the inclusion of our model predictions. All of the variables in our coding scheme are associated with, and based on, these predictions and their associated references.

Cultural transmission model

The cultural transmission model emphasizes the social transmission of knowledge as an indispensible core feature of human evolution. Coded variables supporting and clearly distinguishing the cultural transmission model from others include evidence of experts having relatively high skill in an ability which is, in some form, common knowledge and a solution of a common or day-to-day problem. Others include prestigious and high status experts; reputations for efficacious solutions to certain problems; same-sex deference; experts who have reputations for generosity and/or are preferred social partners beyond their domains of expertise; experts who share knowledge ("know-how") with other experts and/or non-experts, often in the context of mentorship or apprenticeship; experts with influence on others beyond their domain of expertise.

The cultural transmission model emphasizes two closely related ideas from dual inheritance theory, namely, the cultural niche hypothesis and the cumulative cultural brain hypothesis. The Cultural and Cumulative Cultural Brain Hypotheses of Muthukrishna, Doebeli, Chudek, & Henrich (2018) is defined as: "[T]he idea that brains have been selected for their ability to store and manage information via some combination of individual (asocial) or social learning. That is, we develop the idea that bigger brains have evolved for more learning and better learning" (p. 1). Muthukrishna et al. formally model these hypotheses and discuss them in more detail:

> "In contrast to competing explanation, the key message of the Cultural Brain Hypothesis (CBH) is that brains are primarily for the acquisition, storage and management of adaptive knowledge and that this adaptive knowledge can be acquired via asocial or social learning. Social learners flourish in an environment filled with knowledge (such as those found in larger groups and those that descend from smarter ancestors), whereas asocial learners flourish in environments where knowledge is socially scarce, or expensive but obtainable through individual efforts. ... The Cumulative Cultural Brain Hypothesis posits that these very same processes can, under very specific circumstances, lead to the realm of cumulative cultural evolution. These circumstances include when transmission fidelity is sufficiently high, reproductive skew is in a Goldilocks' zone close to monogamy (or equally, there is some, but not too much

> individual-level selection), effective asocial learning has already evolved, and the ecology offers sufficient rewards for adaptive knowledge" (p. 29).

Citing Boyd and Richerson (1995), Muthukrishna et al. go on to state:

> "Our model supports both arguments [by Boyd and Richerson] showing that only high fidelity social learning gives rise to cumulative cultural evolution and that the parameter range to enter this realm expands if social learning is more common. In our model, cumulative cultural evolution exerts a selection pressure for larger brains that, in turn, allows more culture to accumulate. Prior research has identified many mechanisms, such as teaching, imitation, and theory of mind, underlying high fidelity transmission and cumulative cultural evolution" (p. 30).

This is closely related to, and clearly summarized in, the cultural niche hypothesis, which is an alternative to the cognitive niche hypothesis favored in response to Pinker (2010) by Boyd, Richerson, & Henrich (2011):

> "We suggest, instead, that our uniquely developed ability to learn from others is absolutely crucial for human ecological success. This capacity enables humans to gradually accumulate information across generations and develop well-adapted tools, beliefs, and practices that no individual could invest on their own" (p. 10919).

A key feature of the cultural niche hypothesis, Boyd et al. conclude, is that "cultural evolution operating over generations has gradually accumulated and recombined adaptive elements, eventually creating adaptive packages beyond the causal understanding of the individuals who use them" (p. 10923).

In other words, even experts are not highly knowledgeable in a task domain that others lack; rather, they are highly skilled relative to others, but knowledge is widely disseminated via long, intergenerational transmission chains, often via imitation, in the population. This assumption is more clearly featured in Henrich (2004), which makes a number of assumptions about expertise that are consistent with the cultural transmission model:

> "This evidence [of human social learning], from both field and laboratory studies, shows that humans possess a psychological propensity to pay attention to, and attempt to imitate, particularly skillful, successful and/or prestigious individuals. A tendency to orient one's social learning attention toward particularly skillful individuals ("cultural models") creates a selective force in cultural transmission that may, under some circumstances, generate cumulative adaptation" (p. 200).

This quotation, in context, leads up to his model in which discrete, transmittable skills are characterized by a quantitative measure of how skillful a person is, and naive learners must copying this skill from more skillful experts in attempts to copy with varying degrees of resulting success (which is usually lower than the skill level of an expert). These skills "might involve such things as net-manufacturing preferences. . . , spear-throwing techniques, fishhook material selection, canoe-building techniques, bone-tool craft, and medicinal plant knowledge" (p. 200).

Key aspects of this model, which shed light on the relevant assumptions of imitation according to the cultural transmission model, include the parameterization Henrich (2004) uses of the distribution of skill levels in the population. Specifically, he uses a Gumbel distribution of skill levels to model imperfect imitation, such that experts are on the high-valued end of the distribution. The skew is modeled by α, and the dispersion is modeled by β:

> "If something is easy to imitate and people vary little in the inferences they make during the imitation process, then both α and β will be small – for perfect replication α and $\beta = 0$. If something is hard to imitate, but people tend to make the same kinds of mistakes, then α will be large, and β small. If something is difficult to accurately imitate, and people make wildly different inferences/mistakes, then α and β will both be large. If people generally make fairly accurate inferences in learning something, but sometimes diverge wildly in their efforts, α will be small and β large" (p. 201).

The α parameter represents, in other words, the assumption that inferences made by social learners "are biased so that the behaviors acquired by copiers are, on average, less skilled than that of their model", whereas β reflects the assumption that they "are noisy, so that copiers never accurately replicate the [skill] value of their model" (p. 201). The resulting tradeoff (figure 2 in the Henrich [2004] paper) highlights the resulting necessity of transmission: as the ratio $\frac{\alpha}{\beta}$ increases (i.e., imitation is uniformly difficult and mistakes have low variation), the required population size for maintaining cumulative adaptive evolution – in contrast to maladaptive skill/knowledge loss – sharply increases. As Henrich (2004) describes it:

> "To get an intuitive sense of what is going on here, consider what happens if each learner picks only one person (N=1) and attempts to copy his skills. Under these conditions, learners would, on average, select only a model of average skill to copy, and thus would obtain a worse-than-average set of skills (assuming copies tend to be worse than the original). However, if learners can pick two models and learn from whichever of the two is the most skilled, then learners will (on average) learn from a better-than-average model, but they will still suffer the losses from imperfect inference and imitation. . . . Cultural learning becomes cumulatively adaptive when the effect of having a larger set of models from which to pick the most skilled exceeds the losses from imperfect copying" (p. 203).

This necessity of knowledge dissemination and its relevance to expertise is reinforced even more clearly by Kline and Boyd (2010):

> "[S]ocial learning is subject to error, and since errors will usually degrade complex adaptive traits, most 'pupils' will not attain the level of expertise of their 'teachers'. In this way, inaccurate learning creates a 'treadmill' of cultural loss, against which learners must constantly work to maintain the current level of expertise. This process is counteracted by the ability of individuals to learn selectively from expert practitioners, so that cumulative cultural adaptation happens when a rare pupil surpasses his/her teachers (Henrich 2004, 2006). Learners in larger populations have access to a larger pool of experts, making such improvements likely."

Note from an earlier quotation by Henrich (2004) that imitation chains are not the only challenge associated with social learning; another key aspect of this perspective is the question of *how* a highly skillful person is identified. Success and prestige are crucial solutions to this problem (Henrich and Gil-White 2001; Henrich and McElreath 2003). Thus, a key aspect of the cultural transmission model is its predictions about prestige. High levels of prestige is featured in most theoretical models of expertise. The cultural transmission model, however, characterizes it differently from the sexual selection models (honest signaling and mate provisioning) by conceptualizing it as a cue of competence. This is clearly stated, for example, in Henrich et al. (2001):

> “A substantial amount of cross-cultural ethnography (e.g., Dove 1993; Hammel 1964; Rogers 1995; Moore 1957) and laboratory psychology (for a summary, see Gil-White and Henrich 1999) suggests that humans everywhere possess a tendency to copy prestigious individuals, i.e., those who receive the most displays of respect/deference from others. This mechanism embodies two shortcut heuristics. First, by preferentially copying a”bundle” of cultural traits from prestigious individuals (prestige correlates with skill/knowledge and often wealth) copiers can rapidly acquire a repertoire of fitness-enhancing or success-oriented traits (i.e., better-than-average solutions to the problems of life). Second, rather than gradually learning via individual experience who the most successful, knowledgeable, or skillful individuals are, copiers rely on honest ethological and sociolinguistic signals of respect that other individuals display toward such high status individuals” (p. 345)

Predictions about prestige, particularly relating to its role in social learning (i.e., its relevance to the cultural transmission model) are conveniently summarized in Jiminez and Mesoudi (2019), and include: “skilled/knowledgeable individuals are prestigious”; “older individuals tend to be more prestigious than younger ones”; “generous individuals tend to be prestigious”; “knowledgeable/skillful/prestigious individuals receive freely conferred deference”; “people seek proximity to knowledgeable/skillful/prestigious individuals"; "people preferentially copy knowledgeable/skillful individuals"; and "prestigious individuals are influential/copied, even beyond their domain of expertise" (p. 3; see table 1 in the Jiminez and Mesoudi paper). Expanding on the rationale for including generosity with prestige, Jiminez and Mesoudi state:

> "Generosity has also been linked to prestige... in experiments (e.g., Flynn et al. 2006; Halevy et al. 2012; Hardy and Van Vugt, 2006; Willer, 2009) and ethnographic observations (e.g., Konečná and Urlacher, 2017; Price, 2003; Radcliffe-Brown, 1964). Because prestigious individuals tend to be both competent and generous (Cheng and Tracy, 2014; Cheng et al. 2010; Henrich, 2016), at least towards members of their ingroup, generosity can be used as a proxy for competence. According to [Henrich and Gil-White], this link is probably due to the fact that providing public goods is an excellent way to signal competence and, therefore, to receive further deference, which might be translated into fitness gains."

Proprietary knowledge model

The proprietary knowledge model focuses on the idea that know-how used by experts can allow them to provide extremely valuable services to other people. In contrast to the focus on cultural transmission in the foregoing section, this model proposes that experts' conceptual knowledge is restricted to specialists because it adds value to those specialists' services. Coded variables supporting and clearly distinguishing the proprietary knowledge model from others include expertise that is distributed among multiple experts; knowledge that is not widespread, or is rare, in a population; secretive and esoteric knowledge; assistance with uncommon and serious problems; evidence of successfully providing assistance; reputations for, and patronage based, efficacious services; and receiving payment for knowledge or services.

This model expands on existing ideas in the resource sharing and cooperation literature, where a person gains value from the services that s/he can provide that are difficult to replace.

Tooby and Cosmides (1996) argued that adaptations associated with reciprocal altruism are insufficient for dealing with uncommon and serious problems, such as health risks, because there are no profits to be gained by investing in someone unlikely to be able to reciprocate in the future. Thus, a better strategy would become "irreplaceable":

> "Consider X's choice between two potential objects of investment, Y and Z. Each helps X in different ways; the magnitude of the benefits Z delivers are higher than the magnitude of the benefits that Y delivers, but the types of benefits that Y supplies can be supplied by no one else locally. Consider the alternative payoffs when one or the other enters a crisis and requires help. Extending 'credit' to a person in crisis may easily have

> a negative payoff if the *kind* of benefits that she customarily delivers could be easily supplied by others. ... A 'replaceable' person would have been extremely vulnerable to desertion. In contrast, extending credit has a higher payoff if the person who is currently in trouble customarily delivers types of benefits...that would be difficult to obtain in her absence. Selection should favour decision rules that cause X to exhibit loyalty to Y to the extent that Y is irreplaceably valuable to X. In other words, Y's associates will invest far more in rescuing her than they would if she lacked these unique distinguishing properties (Tooby & Cosmides 1984, 1989). Y may be helped, and Z abandoned even though the benefits Z delivers are greater" (p. 133).

Extrapolating from the Tooby and Cosmides paper and their own work, Sugiyama and Scalise Sugiyama (2003) note that Gurven (2000), in his "signaling generosity" model, shows that food exchanges among disabled individuals are largely driven by need. Sugiyama and Scalise Sugiyama go on to note, however, that these benefits can go beyond material resources to *services*, stating:

> "These include foraging and technological expertise, political savvy, medical aid, and alliance partnership in warfare (Sugiyama 1996; Sugiyama and Chacon 2000). Benefits that can be provided by one individual but not by others (or less well by others) are expected to be especially valued

> (Sugiyama and Chacon 2000; Tooby and Cosmides 1996). *Social niche specialization* (i.e., the cultivation of recognized, useful roles within the social group) is thus one hypothesized outcome of the selection pressure exerted by health risk, yielding interlacing networks of cooperative endeavors encompassing numerous benefit classes" (p. 169-170).

More broadly, services might straightforwardly maximize inclusive fitness (e.g., alarm calls among closely related social animals). For humans, these services – which are central to the proprietary knowledge model – are what give know-how its "market value". A key idea here is pseudoreciprocity, a cooperative strategy driven by byproduct benefits conferred by one's own self-interested actions (Connor 1986). This is likely to evolve in a wide range of species and domains, and Tooby and Cosmides (1996) apply it to friendship:

> "Behaviours that are not undertaken as intentional acts of altruism often have side-effects that are beneficial to others – what economists call positive externalities. Some potential associates exude more positive externalities than others. For a knowledge-generating and knowledge intensive species such as ours, such situations abound. Someone who is a better wayfinder, game locator, tool-maker, or who speaks neighbouring dialects is a better associate, independent of the intentional altruistic acts she might direct toward you. Similarly, there are an entire array of joint re-

> turns that come about through coordinated action, such as group hunting or joint problem-solving. Individuals may vary in their value as friends and associates because they contribute to the general success, or because their attributes mesh especially well with yours or with other members of your cooperative unit" (p. 137).

They go on to argue that if these scenarios were relevant for selection, then one should "be motivated to cultivate specialized skills, attributes, and habitual activities that increase their relative irreplaceability", and "preferentially seek, cultivate, or maintain social associations. . . where their package of valued attributes is most indispensible, because what they can offer is what others differentially lack" (p. 170).

Applied to know-how associated with a valuable service, "increasing their relative irreplaceability" is, by definition, guaranteed by possessing a service that is not widely disseminated in the population (i.e., cannot be replaced by someone else).

In some ways, the focus on individual cognition in this model might be seen as a counterargument against the cultural transmission model. Indeed, Pinker (2010) notes:

> "Given the undeniable practical advantages of reasoning, cooperation, and communication, it seems superfluous, when explaining the evolution of human mental mechanisms, to assign a primary role to macromutations,

> exaptation, runaway sexual selection, group selection, memetics, complexity theory, cultural evolution (other than what we call 'history'), or gene-culture coevolution (other than the commonplace that the products of an organisms's behavior are part of its selective environment)" (p. 8996).

It is not obvious how contradictory these positions ought to be, but this is a separate issue from our aim in this section, which is supplementing our motivation for the proprietary knowledge model. Nevertheless, because this quotation was from a publication eliciting the critical Boyd et al. (2011) reply (cited in the cultural transmission model in the section above), these models are clearly distinct.

Collaborative cognition model

The collaborative cognition model suggests that knowledge and expertise are a highly social and collaborative activity among multiple experts with complementary roles, insights, and areas of specialization. Variables supporting the social cognition model include distributed expertise across multiple types of specialist, each with narrow specialization; collaboration among experts to collectively produce more knowledge than each individual possesses; and knowledge ("know-how") shared among multiple experts.

Hutchins (1995) characterized the distributed cognition onboard a Naval ship in his seminal ethnography, which informs much of the later work that we operationalize in the social cognition model. His descriptions of the collaborative workings of the ship and its navigational capabilities describe an elaborate division of labor that is greater than its parts:

> "None of the component cognitive abilities has been amplified by the use of any of the tools. Rather, each tool presents the task to the user as a different sort of cognitive problem requiring a different set of cognitive abilities or a different organization of the same set of abilities" (p. 154).

Examples of this dynamic between social relationships and cognition as interdependent components of knowledge have been applied by cognitive of science researchers studying science and scientific concepts. Nersessian (2008) illustrates this in her book about this very subject, emphasizing that the questions scientists think to address ("problem situations") are, themselves, defined by the ongoing discourse defined by social context:

> "Novel concepts arise from attempts to solve specific problems, using the conceptual, analytical, and material resources provided by the cognitive-social-cultural context in which they are created. They are located within 'problem situations'. So, to understand creativity, it must be located not in the act but in these problem-solving processes' (p. ix).

More recently, similar views have been described by cognitive scientists (e.g., Sloman and Fernbach 2017) expanding on the notion that knowledge is a group activity, and that individuals are prone to varying levels of the so-called "illusion of explanatory depth". This idea, relevant to the social cognition model, is referenced in Keil (2003):

> "In the philosophy of science it has become evident that scientific explanations are often much shallower and less complete than they might seem to the outsider. ... As outsiders we are often surprised at how interdependent scientists are on the expertise of others that have come before them and work elsewhere; but even with such dependencies, most individual scientists usually do know quite deep causal patterns in local domains" (p. 368).

In many ways, the social cognition model is similar to the cultural transmission model and should be viewed as a complementary to, rather than competing with, the cultural transmission model. However, we keep these two models distinct because the social cognition model makes no assumptions about the compulsory sharing of information. For example, Boyd et al. (2011, p. 10921) explicitly take issue with and diverge from the following attempt to incorporate focus on both cognitive capacities and cultural transmission by Barrett, Cosmides, & Tooby (2007):

> "Cognitive mechanisms underlying cultural transmission coevolved with improvisational intelligence, distributing the costs of the acquisition of

> nonrivalrous information over a much greater number of individuals, and allowing its cost to be amortized over a much greater number of advantageous events and generations. Unlike other species, cultural transmission in humans results in a ratchet-like accumulation of knowledge" (p. 244).

Similarly, Heintz (2013) cites Wimsatt and Griesemer (2007) while diverging only in the details from the cultural transmission model:

> "The cumulative aspect of cultural evolution has been used by proponents of dual inheritance theory to argue that transmission of cultural knowledge, rather than mere reaction of populations to the specifics of their habitats, was the factor that could account for cultural phenomena (Richerson and Boyd 2005). An image that easily comes to mind is one of piling up: during cultural evolution, humans pile up new ideas, traditions, and know-how. There is certainly some trust in this image. However, I would argue that Wimsatt and Griesemer's terms of 'scaffolding' and 'generative entrenchment' better grasp a central aspect of cumulative cultural evolution (Wimsatt and Griesemer 2007). The notion of 'generative entrenchment' suggests that faithful transmission is not a necessary characteristic of cumulative cultural evolution. Rather, old ideas are used in the generation of new ideas, and this is why they are stabilized. Old ideas are stabilized in time especially when they have become the basis of

> other widespread ideas and practices – they become entrenched" (p. 211).

Heintz goes on to expand on conceptual changes over developmental and generational timeframes, emphasizing the importance of distributed specialization:

> "[T]he distribution of cognitive labor enables people to become more knowledgeable in specific domains and ignorant in other domains that are covered by others. Economic exchange permits people to remain ignorant in certain domains and invest their cognitive resources in others. As a consequence, the group as a whole is more knowledgeable than when all members of the group know the same basic survival knowledge" (p. 211).

Honest signaling model

The honest signaling model emphasizes short-term mating, gaining relatively higher levels of access to multiple mates, and signaling fitness. The variables that most clearly support the honest signaling model, and distinguish it from the others, include competition among experts; prestigious or high status experts; public performances conducted by experts; costly displays by experts, either in their initiation rites, lifestyles, and/or rituals; experts who are described as highly charismatic, intelligent, and/or sexually attractive; and relatively high levels of mate access (e.g., multiple mates).

The honest signaling model is largely motivated by the idea that "human culture is mainly a set of adaptations for courtship" (Miller 1999, p. 72). On this view, expertise is a signal, the value of which creates a "within-species arms race that plays out within rather than across lifespans" (Winegard, Winegard, & Geary 2017, p. 45). Miller (2001) clearly outlines his perspective in a way that not only emphasizes competition for mates, but distinguishes it from the mate provisioning model that we also operationalized in this study:

> "In modern market economies people put a high value on wealth indicators during courtship . . . David Buss has amassed a lot of evidence that human females across many cultures tend to prefer males who have high social status, good income, ambition, intelligence, and energy–contrary to the views of some cultural anthropologists, who assume that people vary capriciously in their sexual preferences across different cultures. He interpreted this as evidence that women evolved to prefer good providers who could support their families by acquiring and defending resources I respect his data enormously, but disagree with his interpretation.
>
> The traits women prefer are certainly correlated with male abilities to provide material benefits, but they are also correlated with heritable fitness. If the same traits can work both as fitness indicators and as wealth indicators, so much the better. The problem comes when we try to project wealth indicators back into a Pleistocene past when money did not ex-

> ist, when status did not imply wealth, and when bands did not stay in one place long enough to defend piles of resources. Ancestral women may have preferred intelligent, energetic men for their ability to hunt more effectively and provide their children with more meat. But I would suggest it was much more important that intelligent men tended to produce intelligent, energetic children more likely to survive and reproduce, whether or not their father stayed around. In other words, I think evolutionary psychology has put too much emphasis on male resources instead of male fitness in explaining women's sexual preferences" (p. 210-211).

Although a highly sexually dimorphic runaway brain model is rejected in Miller (2001), his alternative mutual mate choice model nevertheless "emphasizes how sexual ornaments advertise each sex's fitness to the other sex – a function of mate choice that may stretch back to the origins of sexual reproduction itself" (p. 98). In other words, experts can be expected to use evidence of their creativity and intelligence to acquire mates, such that productivity "should increase rapidly after puberty, peak at young adulthood when sexual competition is greatest, and gradually decline over adult life as parenting eclipses courtship" (Miller 1999, p. 81).

Miller (2001) often uses competition among artists to illustrate his arguments. For example, he describes Hollywood as a failure "from a military point of view", going on to state: "Its avoidance of physical conflict allows it to amass, quietly and discreetly, enormous resources and expertise to produce ever more impressive shows" (p. 154). Here is another example in which Miller (2000) applies these ideas to competition among artists:

> "It evolved through sexual selection to serve the same courtship functions as almost all other examples of organic beauty and complex behavioral signals observable in nature. Such ornamentation often evolves as a reliable, costly indicator of the signaler's good health, good brain, and good genes. This leads to the further proposal that many design features of art function as indicators of the artist's virtuosity, creativity, intelligence, conscientiousness, and other important heritable mental and physical traits" (p. 25).

As demonstrated by these quotations, costly and ostentatious signals of ability, typically in a courtship context, are an important part of the honest signaling model. These courtship displays are "costly, conspicuous displays of cognitive prowess in language, music, art, and humor... [and] may be thought of as reflecting a person's overall genetic quality" (Geher, Camargo, & O'Rourke 2008). Winegard et al. (2017) favors, at least to some extent, the public and costly signaling aspects of the honest signaling model in helping explain the evolution of expertise:

> "We believe that expertise (or elite performance) often, but not always,

> functions as a costly signal of some desirable underlying trait (Miller 2001; Winegard, Winegard, & Geary 2014). Consider these features of expert performance that make it a good candidate for a costly signal: (1) expect performance is often broadcast publicly; (2) there are enormous individual differences in the domains in which people care about expert performance (music, sports, art), making for obvious rankings between competitors or performers; (3) performances are generally ritualized or organized in such a way that they can be assessed, also facilitating ranking of performers; and (4) expertise is difficult to achieve and quite rare, meaning it is costly and that it relies upon unique constellations of underlying traits and large amounts of leisure time. These traits may consist of, but are not limited to, conscientiousness, athleticism, intelligence, the size of one's social network, and ambition (Hawkes & Bliege Bird 2002; McAndrew 2002; Miller 2001)" (p. 44-45).

Their citation of Hawkes and Bliege Bird (2002) is in reference to a discussion of the "show-off hypothesis" of male hunting, i.e., the idea that hunting skill is a sexually selected signal of ability. Hawkes and Bliege Bird (2002) argue that costly signals can range in the benefits that they provide, shortly after citing Veblen (1899) on conspicuous consumption and Zahavi (1975) on handicapped signaling:

> "Costly signals are enormously variable. One important dimension of

> variation is between signals that provide little but information and those that provide benefits to the audience in addition to information. For example, when a display consists of providing feasts, others gain from participating in the feast. By signaling in this way, the show-off provides something besides information about a hidden quality to the audience" (p. 58).

With respect to skills and their displays, Hawkes and Bliege Bird (2002) go on to emphasize "broadcast effectiveness", i.e., that "signals must be detected effectively by appropriate recipients". They then argue that:

> "Signals designed to acquire or maintain higher social standing in a group should be directed to the group at large; other more specialized signals may be directed to smaller subsets of the population. Signalers competing for popular prestige should seek to gain a larger and larger share of the advertising market. They gain a larger share by providing more of what the viewers want to see or consume than the competition provides. The provisioning of collective goods may serve the purpose of reaching a wide audience better. Both competition among signalers and audience preference for particular signals can play a role in shaping the display" (p. 65).

Mate provisioning model

The mate provisioning model is based on the idea that high standing based on skill is sexually selected, but in contrast to the honest signaling model, it emphasizes long-term mating strategies, parental investment, and a preference for resource access. The variables that support and most clearly distinguish the mate provisioning model are prestigious or high status experts; reputations for generosity, commitment to parenting, and mate fidelity; and instances of mate provisioning and/or investment in offspring.

A clear statement of the mate provisioning model is outlined in summary after a discussion of his arguments in previous works, and similar works of others on prestige and parental investment, in which Barkow (1992, p. 635) states:

> "Thus, I have in effect hypothesized that (a) human beings tend to strive for higher relative standing and this striving usually takes the form of seeking control over surplus production or over the means of production; (b) human beings everywhere tend to be nepotistic; (c) the view of social exchange algorithms presented by Cosmides and Tooby (1989, this volume) is essentially correct; and (d) both cross-culturally and historically, surplus production is associated with differences in social rank in all cases, and with social stratification in most. If any of these four hypotheses is inaccurate, then the entire argument must fall."

As suggested in the honest signaling model, the mate provisioning model is more consistent with human mating in the sense of Buss (1989), which he characterizes based on his reading of Trivers (1972):

> "Males may provide mates with food, find or defend territories, defend the female against aggressors, and feed and protect the young. Human males may also provide opportunities for learning, they may transfer status, power, or resources, and they may aid their offspring in forming reciprocal alliances. These forms of male investment, when provided, tend to decrease the investment disparities between males and females. ... In species with male parental investment, such as *Homo sapiens* (Alexander & Noonan 1979), females should seek to mate with males who have the ability and willingness to provide resources related to parental investment such as food, shelter, territory, and protection. ... The hypothesis that females will mate preferentially with males bearing greater gifts, holding better territories, or displaying higher rank has been confirmed empirically in many nonhuman species (Calder 1976; Lack 1940; Trivers 1985; see also Betzig et al. 1988)" (p. 2).

This view of human mating is also summarized in Buss (1992):

> "The female tendency to favor high-status males is only one part of the

> constellation of evaluative mechanisms expected to underlie mate choice in women. Selection should also have favored mechanisms in females designed to detect and prefer males who were willing to convert status and ability into paternal assistance. . . . All else equal, therefore women should find men who demonstrate the willingness to devote time and resources to a chosen female and her offspring more attractive than men who do not" (p. 272).

The mate provisioning model therefore emphasizes human mating as a long-term investment strategy rather than a short-term one, a framing explicitly used by Schmitt (2010). He concludes that "among humans, many men invest heavily in their children, teaching them social skills, emotionally nurturing them, and investing both resources and prestige in them" (p. 57). The rationale for a strategy in which individuals seek status, but maintain high mate provisioning plus parental investment, is clarified from an evolutionary perspective by Gavrilets (2012) in his model of pairbonding in human evolution:

> "Top-ranked males can easily beat out or chase away the low-ranked males and steal the paternity, making the investment of low-ranked males in production wasteful. However, after females start developing preference for being provisioned, the low-ranked males' investments start to pay off. In the model presented here, male provisioning and female faithfulness co-

> evolve in a self-reinforcing manner. At the end, except for a very small proportion of the top-ranked individuals, males invest exclusively in provisioning females who have evolved very high fidelity to their mates" (p. 4-5).

Note from the foregoing quotation that mate fidelity and self-imposed "reproductive ceilings" are not a limitation, but a feature of the mate provisioning model. This is also explicitly featured in Stewart-Williams and Thomas (2013):

> "As brain size increased in the hominin lineage, our young became progressively more dependent and the childhood period became progressively longer. As a result, pair bonding and male parental care became central elements in our reproductive repertoire. This dramatically reduced the discrepancy in the maximum number of offspring that men versus women could produce. Although in principle a man could impregnate hundreds of women every year, in practice the reproductive ceiling for even the most attractive men was almost always much lower" (p. 138).

B.2 Description of our search query

We collected text records from the electronic Human Relations Area Files World Cultures database while intentionally targeting those that reflect some kind of "scientific expertise" in the ethnographic literature. Inclusion was therefore based on descriptions of expertise in a potentially relevant conceptual knowledge domains, which we describe in the main text. Our exact search query, i.e., the set of OCM codes and search terms that generated our initial results, was:

((Cultures = (Any Culture)) AND (((Subjects = (‘173’ OR ‘278’ OR ‘571’ OR ‘577’ OR ‘578’ OR ‘581’ OR ‘582’ OR ‘583’ OR ‘584’ OR ‘751’ OR ‘752’ OR ‘753’ OR ‘757’ OR ‘758’ OR ‘759’ OR ‘761’ OR ‘802’ OR ‘803’ OR ‘804’ OR ‘805’ OR ‘810’ OR ‘811’ OR ‘812’ OR ‘813’ OR ‘814’ OR ‘815’ OR ‘816’ OR ‘820’ OR ‘821’ OR ‘822’ OR ‘823’ OR ‘824’ OR ‘825’ OR ‘826’ OR ‘827’ OR ‘828’ OR ‘829’ OR ‘830’ OR ‘831’ OR ‘832’ OR ‘833’ OR ‘834’ OR ‘835’ OR ‘836’ OR ‘837’ OR ‘838’ OR ‘839’ OR ‘840’ OR ‘841’ OR ‘842’ OR ‘843’ OR ‘844’ OR ‘845’ OR ‘846’ OR ‘847’ OR ‘848’ OR ‘860’ OR ‘861’ OR ‘862’ OR ‘863’ OR ‘864’ OR ‘865’ OR ‘866’ OR ‘867’ OR ‘868’ OR ‘869’ OR ‘875’ OR ‘877’)) AND (Text = (knowledgeable OR expert* OR proficient* OR skilled OR specialist* OR practitioner*)))))))

The initial results from the entire eHRAF database found 5734 paragraphs in 1901 documents in 311 cultures, and filtering Probability Sample Files (PSF) found 1595 paragraphs in 483 documents in 60 cultures. ADL read, contextualized, and filtered these remaining 1595 paragraphs to determine whether or not they were appropriate examples of ethnoscientific expertise, i.e., requiring high levels of culturally specific conceptual knowledge about the social and/or natural world. Text records that were included consisted of the focal paragraph from the results, and a contiguous set of paragraphs that provided context necessary for understanding the paragraph that turned up in the results.

Inclusion criteria

The *a priori* justification for including text records was based on whether or not some kind of "[ethno]scientific" expertise was described. We defined scientific domains in this context as conceptual domains where knowledge is ultimately acquired though observation, testing, and/or learning about natural and/or social principles, which in turn result in developing theories, either over the life course or via cumulative culture, that could potentially be usefully applied to a number of possible types of tasks or applications (e.g., crafts, healing, hunting, trapping, conflict resolution, or ethical quandaries). These applications are referred to and distinguished as "products" in our main text, and their underlying conceptual theories are similarly referred to as "know-how". Crucially, we were searching for knowledge that is not specific to any particular use, but uses might recur because they are relevant to certain types of knowledge. For example, it is unsurprising that plant knowledge (ethnobotany) is frequently relevant to medicine, despite its potential uses in basket weaving. Similarly, animal knowledge (ethnozoology) is useful to hunting and trapping, but might not be limited to these activities alone. In other words, knowledge might be "for something", but what that "something" is not the topic being queried. Rather, it is high levels of investment in the underlying knowledge (expertise) that are our outcomes of interest.

B.3 Complete description of our coding scheme

Each text record was coded by two independent coders (ADL and CH) for each variable in our coding scheme, as described in the main text. Note that some variables in our dataset are evidence against variables in our coding scheme.

Categorical variables are indicated in the descriptions, and were coded as presence/absence for each category as a separate column/variable in our data matrix. This meant that multiple categories could be present in a single text record. For example, if male and female experts were both present in a text record, then we coded presence for both males and females.

Here are our coded variables and a brief description of each:

Text ID: Provides a unique key id number corresponding to a text record, citation, and OCM codes.

Case/model: Does the text record describe a specific case about an expert, a cultural model of expertise, or both? (*Categorical:* Case, model, both)

Age: How old are the experts described? (*Categorical:* Child/adolescent, Adult, Older adult/elderly)

Sex: What is the sex of the experts described? (*Categorical:* Male, female, either/both present)

Costly lifestyle: Does being an expert entail some kind of costly lifestyle, where the expert must fulfill certain obligations on a regular basis, making his/her life substantially more difficult than it would be otherwise?

Costly ritual: When applying his/her expertise (e.g., to perform a service, teaching), does the expert perform some kind of ritual (can be either public or private) in which s/he takes on some kind of cost, e.g., in the form of fitness, money, resources, pain, or risk?

Costly initiation: Does the expert perform some kind of initiation rite, in which s/he takes on some kind of cost (e.g., in the form of fitness, money, resources, pain, or risk) as a condition of being considered an expert by other people?

Expert teaches others: Do experts teach other people what they know? Does becoming an expert entail some kind of apprenticeship, mentorship, assistantship, or knowledge sharing, for example? The expert is described sharing his "know-how" (knowledge or skills) with others, which might or might not be exchanged for something else.

Expert purchases knowledge: Experts conferred a benefit to another expert in exchange for acquiring their knowledge/skill from another person.

Public performance: The expert demonstrates his/her abilities in a public setting, perhaps involving some kind of performance that is visible to others.

Private performance: The expert demonstrates his/her abilities or provides services to others in a private setting.

Experts compete: If multiple experts exist, then they are described as having a competitive relationship with each other.

Experts collaborate: If multiple experts exist, then they are described collaborating or as having a collaborative relationship with each other.

Distributed knowledge among multiple experts: If multiple experts exist, then their expertise is distributed across different roles or types of expertise, which do not strongly overlap with each other.

Hierachy within the domain of expertise: If multiple experts exist, then their expertise involves a hierarchical structure *among the experts* within a given domain, either in seniority among experts or level of skill. (This is not a reference to prestige in the broader community; it is strictly within-domain structure among experts, e.g., senior vs. novice specialists.)

Sexually attractive: The expert is described as being sexually attractive.

Charismatic: The expert is described as being charismatic.

Intelligent: The expert is described as, or has a reputation for being, intelligent.

Multiple mates: The expert has multiple mates.

Deference: People (non-experts or novices) are described as deferring to the expert by displaying signs of respect. (For example, this might include deferring to someone by paying them a respectful greeting, but would *not* include people simply deferring to a medical expert for medical advice.)

Prestige: The expert is considered prestigious, high status, and/or is well-respected in the community. This might include people who are generally paid more attention than others, but is distinct from reputation for efficacy (see below).

Others seek proximity to expert: Is the expert a preferred social partner (e.g., friend, coworker), or frequently/preferentially sought out for advice? Do people (non-experts) seek proximity to the expert, including for reasons that are not directly to the benefits or traditions relating directly to their domain of expertise?

Generosity: Is the expert generous, or does s/he have a reputation for being generous?

Mate fidelity: Does the expert have a mate who gives him/her exclusive sexual access? (Note: this one mostly comes up when violations/evidence against arise. It can include involuntary examples, such as cheating on partners, and voluntary ones, such as wife sharing among experts.)

Reputation as good parent: The expert has a reputation for being a good parent.

Parental investment: The expert is described conferring some kind of benefit to his/her offspring.

Provisions mate: The expert is described conferring some kind of benefit to his/her mate.

Narrow specialization: An expert or experts is/are described as having a narrowly specialized knowledge in their domain of expertise.

Broad generalist: An expert or experts is/are described as having a broad range of general knowledge, such as multiple domains of expertise (e.g., medicine, geography, and meteorology) or multiple unrelated specialties in a domain of expertise (herbal medicine, bone-setting, and childbirth).

Influential outside of area of expertise: The expert has influence over other people in domains outside of his/her domain of expertise. (Examples might include political influence, if the expert's domain is not related to politics, or trusted with medical advice if the expert's domain is not related to medicine.)

Evidence success: Evidence is documented by the ethnographer or his informant describing the expert as applying his/her knowledge or skill for a patron, and successfully bringing about an intended and/or desired outcome.

Secretive knowledge: An expert or experts is/are secretive about their knowledge or skills ("know-how"), and attempt to keep it hidden from (e.g., uninitiated) non-experts.

Assists with an uncommon and serious problem: Does the expert have patronage or clientele for their applied knowledge and/or services based on an uncommon and serious problem that arises for the patron (which the expert might be able to help with)?

Receives payment: Does the expert receive money or other material resources (e.g., gift or payment) for his/her applied knowledge and/or services?

Access to mates: Does the expert receive mates or sexual favors for his/her applied knowledge and/or services?

Patronage based on efficacy: Does the expert have patronage or a clientele for their applied knowledge and/or services based on an apparent expectation that the expert will bring about desired and/or beneficial outcomes for the patron? (Instead of costs, familiarity, or tradition, for example.)

Cares about reputation: The expert cares about his/her reputation and takes measures to present himself/herself in a positive and self-serving way.

Reputation for efficacy: The expert has a reputation for applying his/her knowledge in a way that can bring about desirable results for other people.

Possesses widely distributed knowledge: While the expert is highly knowledgeable in his/her domain (by definition), other "non-experts" in the community also tend to be fairly knowledgeable in the same domain.

Ornamentation: The expert wears some kind of ornamentation or body alteration that symbolizes to others his/her special status as an expert.

B.4 Examples of our coded variables

In this section, we include examples of text that would be coded as supportive for each variable in this study. Note that some of these might be multiply coded, i.e., some text records would also constitute evidence for additional variables, in addition to the variables for which they are illustrative examples.

Possesses secretive knowledge

> The secret language follows the grammatical patterns of standard Trukese, but it is laced with cryptic distortions. Secret words, altered regular words, regular words with special meanings, and esoteric metaphors make this language incomprehensible to those who speak only standard Trukese. Masters of strategy use this language among themselves and in speeches at formal meetings. It is also the medium in which they preserve "significant history" (wuruwo), that is, history that justifies claims to valuables.

Parental investment

> Knowledge of this kind is freely applied to the curing of a lineage mate or other close relative as a personal favor. Any one else, however, must pay in advance. The patient brings goods to the specialist and requests his aid. When cured, he is further obligated to the practioner and makes him a present. Such knowledge, then, not only has practical social value, but through its application can provide other forms of wealth for the specialist. To this knowledge, too, the specialist's children and lineage mates have a claim. Without their permission, he may not teach it to another unless

he receives compensation for it. For if the specialist teaches someone else, he dissipates the monopoly his heirs will someday enjoy and lowers their future earning power.

Costly initiation

Offers of help soon give way to competition as the established students come to regard him as a rival for the master's personal instruction and encouragement. To be the master's favorite means rapid advancement through the curriculum and a seat at his table. Without his patronship, a student is committed to years of physical misery, scraping to meet his subsistence needs, and paying his "tuition" in arduous and humbling ways, by gathering wood for the master's fire, tilling his garden, and washing the feet of the master and his visitors.

Assists with uncommon/serious problem

The ng'aka, therefore, is employed where a malady or misfortune is caused by something mysterious and inexplicable to ordinary people. He is consulted only on the advice of a diviner though… he may himself be the diviner.

Hierarchy w/in domain of expertise

Most adult men know something about the curing of minor ailments, but very few know how to cure serious illness. There is a graded series of curing techniques and only the most widely known shamans know all of them. Shamans are thus ranked according to their knowledge and abilities. Their powers are founded upon their knowledge of myths. Most adult men know a considerable number of myths but shamans differ from the rest in two respects: first, they know more myths, and secondly, they know and understand the esoteric meaning behind them.

Assists with a common problem

Wood for building purposes is felled when one comes across a suitable tree in the forest. ... Carpenters keep wood stored at home. Some men are so interested in woodwork that they cannot make any conversation except about wood. An old man in Utsjoki called Tor'te-t seähtsi ("Uncle Spinning Wheel") had gathered so much wood in his home that he could hardly find room enough to sleep in. Boats and sleds require the longest time to prepare, but making a spinning wheel requires the greatest skill. Specialists in making spinning wheels have been known in Utsjoki since at least the middle of the previous century.

Broad generalist

A few people are experts in several different forms of special knowledge; some know one kind, and some know only fragments of one kind. Although everyone knows that many kinds of special knowledge exists, any particular type is important because few others share it.

Charismatic

Another reason why the Toradja are set on the treatment with kajoe sina by a Mohammedan is because he combines with his work all sorts of mysterious things, which are impressive. With great ostentation the medical expert pronounces a magic formula over the pot, and if the sick person recovers, then he ascribes this more to the power of this formula than to the effect of the medicine.

Reputation for efficacy

When a somewhat more complicated disease develops, one has recourse to the known herbal specialists. These specialists... have become known for their general skill or perhaps for success in treating special diseases.

Receives payment

The patient pays the doctor a fee, usually tobacco and some common article, but one person charges a fee of $5.00 per treatment.

Knowledge domain is not widespread

> There are types of special knowledge relating to medicine and curing, house and canoe construction, navigation, sorcery, divination, and fighting. In general, only older people have special knowledge. . . . Not everyone in the older generations possesses special knowledge. It is carefully guarded from outsiders and can only be learned from a close kinsman, or purchased at considerable expense from a non-kinsmen.

Deference

> There are types of special knowledge relating to medicine and curing, house and canoe construction, navigation, sorcery, divination, and fighting. In general, only older people have special knowledge. . . . Not everyone in the older generations possesses special knowledge. It is carefully guarded from outsiders and can only be learned from a close kinsman, or purchased at considerable expense from a non-kinsmen.

Knowledge domain is widespread

> Laymen have little difficulty in selecting an appropriate kind of wogeysa , since the ailments treated by each category of wogeysa are characterized by unambiguous syndromes which are easily identified by laymen.

Costly lifestyle

The agamiy exposes himself to certain dangers in the performance of this therapy. Because he must remove a pathogenic substance through the medium of the sickman's blood, there is the danger that, should any of the blood enter his own mouth, the agamiy may himself fall ill with the ailment he is treating. In addition, contact with this blood threatens those chronic ailments from which the sickman suffers (such as the rheumatoid pains associated with kitin, syphilis).

Public performances

The wabeno was a highly honoured public official, in a sense, for he was the servant of his community, even though he was entitled to charge a fee for his services. Since his prestige depended partly on his popularity he generally gave a public feast and dance whenever a patient paid for the remedy that dispelled his sickness, or a hunter offered fitting compensation for the medicine that had delivered the game into his hands.

Costly ritual

At intervals in the dances one of the medicine-men might drum and dance alone around the fire, then, stooping, pick up from the embers a hot stone; or he might dip his fingers into a boiling cauldron, extract a piece of meat, and swallow it without evidence of pain. Some Indians say that he derived these powers from the medicines he rubbed on his hands, and that although he neither ate nor drank for four days and four nights previously, his strength remained totally unimpaired.

Knowledge distributed/multiple experts

Knowledge of magic and privileged access to spirits is distributed among four categories of people: herbalists, ecclesiastics, shamans, and debtera. Most herbalists incorporate some magic into their recipes. The rural herbalist is usually a farmer, indistinguishable from his fellows except for his curing. He is known to his public by his ability to treat a specific, named ailment, and his professional title indicates only his disease name specialty and his degree of proficiency, e.g., “expert curer for body ulcers.” Few herbalists offer therapies for more than three or four ailments.

Influential outside of area of expertise

Throughout these years, the intellectuals, as literati associated with the court (and often the court itself: some of Thailand’s greatest poets and dramatists were kings) helped maintain, develop, and glorify this civilization, but not change it radically.

Evidence of success

Besides the priestess, in each village there are several men and women about whom it is known that for certain indispositions they are familiar with a remedy that has already been applied with success many times. Such a person is then asked to come to try his skill on the sick person.

Experts collaborate

Every tagañ owns a recipe for an unguent, and the medicaments used in it are kept a professional secret. However, not all tagañs have recipes for kusil prophylaxis. Without the latter, a tagañ who wishes to treat compound fractures must obtain the services of an herbalist whose specialty is the treatment of kusil.

Experts compete

In their social role, midwives felt personal but not group solidarity. A solid bond existed between an older midwife and the particular younger one to whom he or she had given training and magic. . . . The expert who brought mother and baby through before the deposed midwives glowed inwardly with pride and skill and satisfaction that the magic of his particular teacher had proved effective. The sharpness of the competition reverberated through the words, "I pushed the other midwives down." Community standing or "face" was not lost by an unsuccessful case because of the midwives' fundamental role as helpers only, their faith in their own experiences, and again, the conviction that the course of childbirth was merit-determined.

Reputation for generosity

These first abinet [esoteric skill] are generally gifts from student friends . . . Among these companions favors are expected to be freely given and no formal accounting is made. Beyond this circle all students are implicitly rivals (towdaderiy). Another source of abinet at this time is some older, more knowledgeable student. Here, the relationship between donor and recipient is framed as an exchange between a patron (radat) and his client (taraj), a customary dyad contrasting power with dependency, and generosity with deference. The new boy appeals that he is abject and threatened by mortal dangers; the donor, by his gift, publicly asserts a status difference which sets him off from novices in general.

Intelligent

Certain natives, served by a good memory and a livelier intelligence, took an interest in these traditions and legends to the extent of learning those of neighboring families and even of neighboring kingdoms and little by little acquired a reputation as specialists in these matters.

Multiple mates

First, by being a powerful ritual specialist, Roberto had political influence and social prestige in society. Therefore, he could claim a woman in exchange for his ritual services. Secondly, he knew well that Eulalia was the only child of an old, widowed and remarried man in the headwaters area of the Goya stream ... Alberto, who indeed cared for Eulalia as for a proper sister, was indebted to Roberto and dependent upon his ritual services. So they could do nothing but accept the marriage. In this way, Roberto took Eulalia as his second wife and became one of the few polygynous men in the territory.

Narrow specialization

Aymara medicine is highly specialízed, and consequently has a great many different categories of practitioners. ... It is probably safe to say that no other primitive group known to modern ethnology has such a rich specialization among practitioners of native medicine.

Ornamentation

> As soon as possible, the patient's family presents the principal specialist with a string of multi-colored glass beads, which he places around his neck for the ceremony to follow … The multi-colored bead necklaces are frequently worn by snake medicine men even when they are not working on a case, and serve as identity badges.

Prestige

> In fishing, especially deep-sea fishing, and in some other crafts, knowledge of the technical processes and of the associated ritual is unequally distributed. … One effect of the possession of such knowledge lacking in others is the opportunity of enlarging one's resources. This is done by resort to fishing banks not commonly known, or use of a special technique at times when the fish refuse all others; or, in the case of a craftsman, by more prompt replacement of his implements, or by gaining goods in payment for his work for others; or to a small extent by the securing of a material return for the imparting of his knowledge to others. Important as an inducement to the acquisition of such personal knowledge, however, is the prestige that it obtains.

Private performances

> There is no particular moment that is better than any other for infor-

mal conversation about genealogies, except that people are most likely to want to discuss genealogy when they are contemplating a marriage, considering litigation that involves genealogical claims, or asking for financial assistance or political support on grounds of kinship. The conversation usually occurs inside the hut or room of the person whose genealogy is being discussed. The occasion is quite private, and other griots are not likely to attend.

Provisions mate

When, as a result of a different political structure, Ogobara was no longer "canton chief", the village secretary was obliged to look for other occupations. He went to Bandiagara and in the hospital there began a course in male nursing. He lives there in the family house and provides for his two wives and his children who have stayed with Ogobara's family in Sanga.

Mate access for expertise

Most of the bridewealth and other marriage expenses are waived and the girl is given to the husband by those having authority over her marriage dispensation rights ... A man may wish to express his gratitude to a mallam for supernatural aid having to do with medicine, prayers, or divination used by the practitioner for the benefit of the group bestowing the girl. In the same way, most individuals having power to bestow a girl would hesitate before refusing the request of a mallam because of the general awe in which he and his supernatural powers are held in the public eye.

Wealthy

The ideal type [of specialist] is a person of respectfulness, bravery, and strong thought who also controls abundant valuables.

Sexually attractive

Some experts may use the DixBo'ne [ritual object] on their own account, in which case they become irresistible to all women in the village. Informant mentioned the name of an individual who was an exceedingly successful love expert on his own account.

Others seek proximity to expert

If the professor wants to discourse on the domain of a particular spirit residing in the jungle, he will do so, and on his own time. If he wants to collect medicines one day, the student may follow along. And if he decides to pass on some esoteric information about the plants being gathered – or if he decides not to – that is the way things will happen.

Expert teaches others

> When a young Kuna becomes a disciple of an experienced curing specialist he places himself in a thoroughly submissive position with regard to his teacher. Once the branch of knowledge he wishes to learn has been decided upon and fixed, the specialist controls the manner in which instruction proceeds, the sequence in which all knowledge is passed out, and the topics to be discussed during each session ... When learning proper begins, the student characteristically listens attentively to a short portion of a chant several times, then is told to repeat it. When he has mastered this task adequately, another piece of the chant is given to him in the same fashion, and he repeats it. On and on it goes until the entire chant has been learned. As the student progresses and demonstrates his capacity for learning he is given information or symbols and their underlying meanings, commentaries on the nature of curing and disease in general, and instruction in accompanying ritual. Such information is conveyed to the student either by demonstration or verbally.

B.5 Coding our domains into domain types

Text records were categorized on a large number of knowledge and skill domains, as shown in network of coded domains in the main text. We assigned most of these domains, particularly those which were sufficiently informative to allow us to adhere to our assignment criteria (see below), to a specific domain type.

Conceptual domains types ($N = 322$, 58.9% of text records; referred to as conceptual domains, henceforth) were largely designated by the OCM codes in the eHRAF referred to as "ethnoscience", described as "ideas about nature and people". Some conceptual domains were frequently associated with these designated codes, and were agreed upon by both coders (ADL and CH) based on their tendency to involve mostly private and mental processes remaining opaque to others. Conceptual domains included ethnobotany, ethnopsychology, ethnometeorology, ethnozoology, traditional history, astronomy, genealogy, life and death, ethnogeography, ethnoanatomy, mathematics/measures, physiology, philosophy, ethnocosmology, ethnophysics, divination and uncertainty, interpreting misfortune, and literature.

Motor skill-related domain types ($N = 156$, 28.5% of text records; referred to as motor domains, henceforth) were agreed upon by both coders (ADL and CH). The general criteria for this domain type was that it necessarily involved some kind of behavior (i.e., motor activity) that was observable to other people, and was relatively transparent compared to primarily private and mental processes, such as plant knowledge or medical diagnoses. Motor domains included subsistence, art/crafts, boat making, body alteration, woodworking, food preparation, construction, navigation, warfare, music, dancing, fighting, dentistry, and injury.

Medicine ($N = 341$, 62.3% of text records) was its own large and overarching domain type, which linked to many conceptual domains (shown in the domain network, in the main text). In general, medicine was more often linked to conceptual domains than motor domains (57.8% vs. 47.4%, respectively), but the difference between these associations was not exceptionally large because conceptual domains were often co-present with motor domains (58.3% of conceptual cases included motor domains). Further, injury was highly linked to medicine but routinely involved motor skills, such as massage and bone-setting.

In sum, each *domain* was assigned to a unique *domain type*: conceptual, motor, or medicine. However, because each text record typically described (and was coded on) multiple domains, each text record often had multiple domain types. For example, if a medical specialist was described as using private, conceptual plant knowledge to prepare a medicine, then this text record would be coded on "medicine" and "ethnobotany" domains, and assigned "medicine" and "conceptual" domain types. If a hunter was described as using animal knowledge to improve his prospects on a hunting expedition, then this text record would be coded on "ethnozoology" and "subsistence" domains, and "conceptual" and "motor" domain types. See figures B.14 through B.16 for agreement plots indicating the proportion of overlap among each pair of domain types.

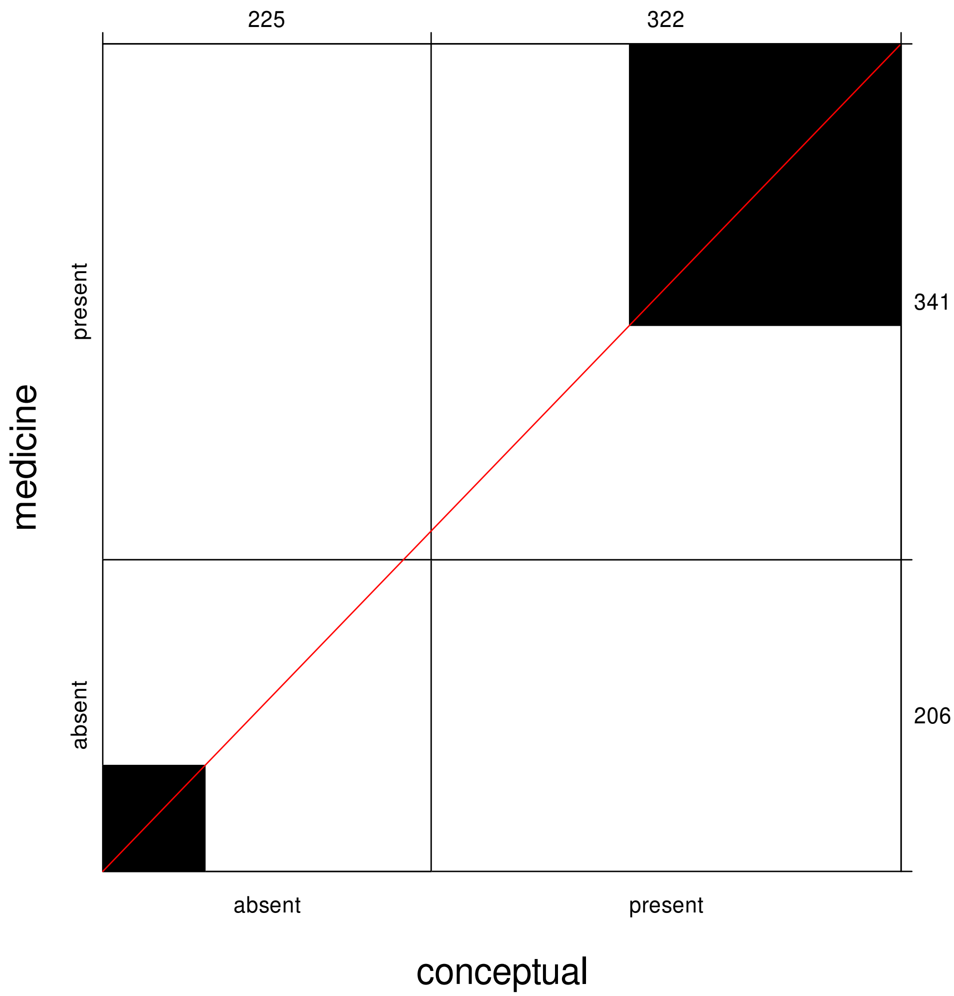

Figure B.14: Agreement plot showing the proportions of presence/absence of conceptual and medicinal domain types, and their levels of overlap, among each of our text records. The dark spaces represent the proportion of overlap (agreement) for the presence and absence these domain types.

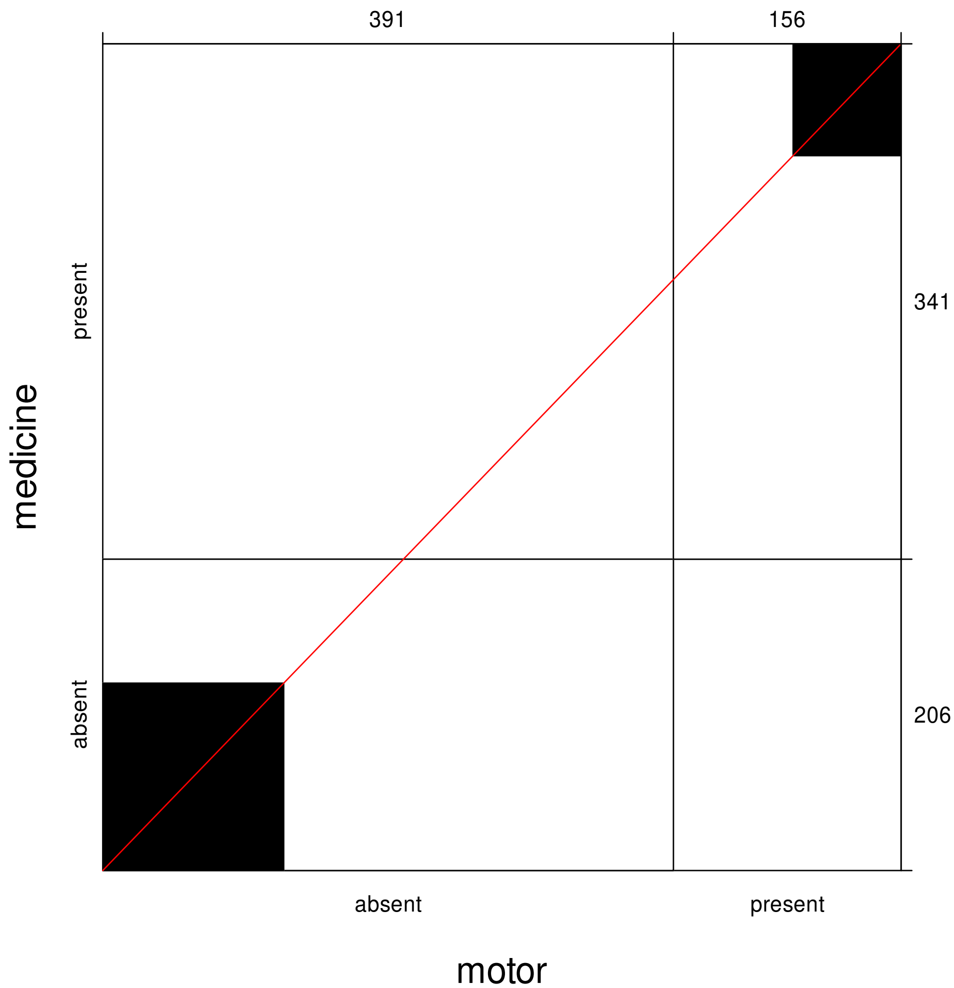

Figure B.15: Agreement plot showing the proportions of presence/absence of motor and medicinal domain types, and their levels of overlap, among each of our text records. The dark spaces represent the proportion of overlap (agreement) for the presence and absence these domain types.

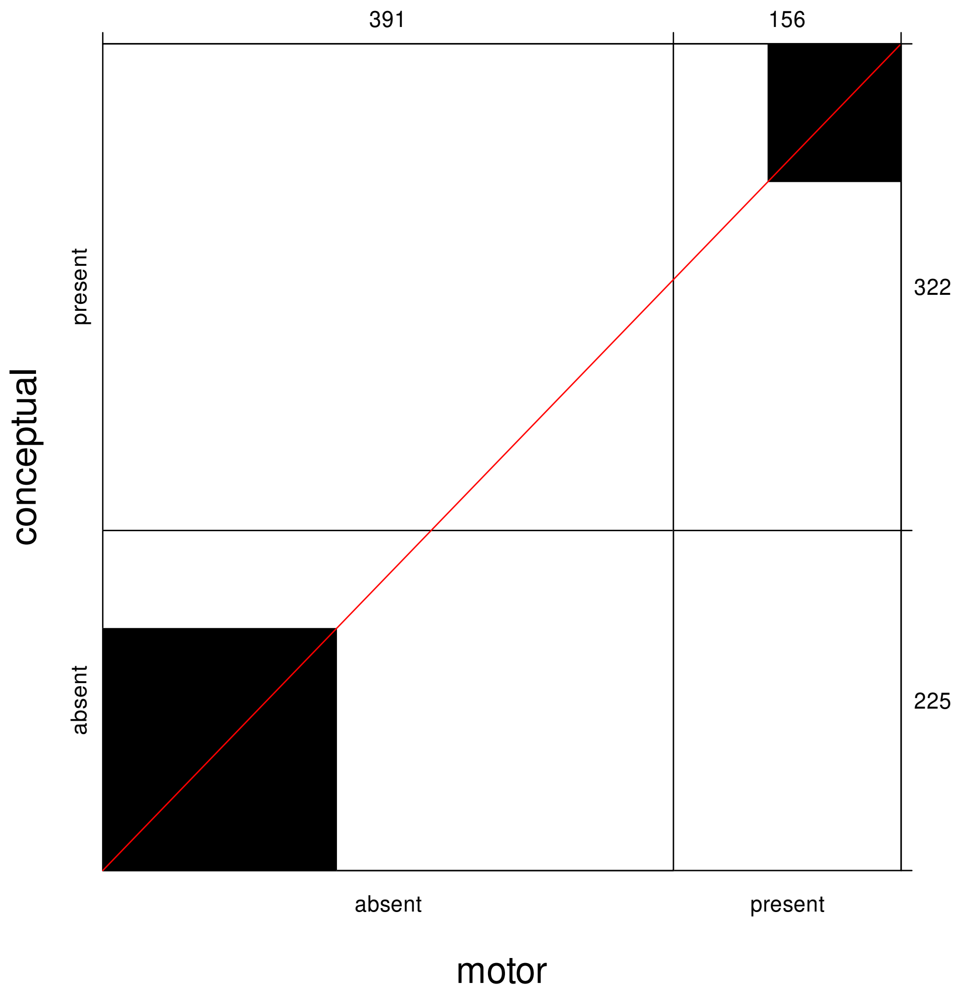

Figure B.16: Agreement plot showing the proportions of presence/absence of conceptual and motor domain types, and their levels of overlap, among each of our text records. The dark spaces represent the proportion of overlap (agreement) for the presence and absence these domain types.

B.6 Interrater reliability

Our dataset was coded independently, using the coding scheme described above, by the first author (AL) and second author (CH) on this study. After the independent coding phase, we checked the interrater reliability and reported these as percentage agreement in our data matrix and Cohen's kappa in the main text. An agreement plot visualizes our level of agreement, prior to reconciling the differences in our codes (figure C.39). After the independent coding and interrater reliability analysis, ADL and CH went through each disagreement of each text record and agreed on how they should be reconciled.

B.7 Explanation of the elasticnet regression model

Here, we briefly describe the elasticnet regression model. Standard regression models are fit by minimizing an objective function. In ordinary least squares regression the objective function is the residual sum of squares (RSS), and in logistic regression it is the negative log-likelihood, $-loglik(\beta)$. Penalized regression models instead minimizes the objective function plus a penalty term based on the magnitude of the coefficient vector. For linear regression this is:

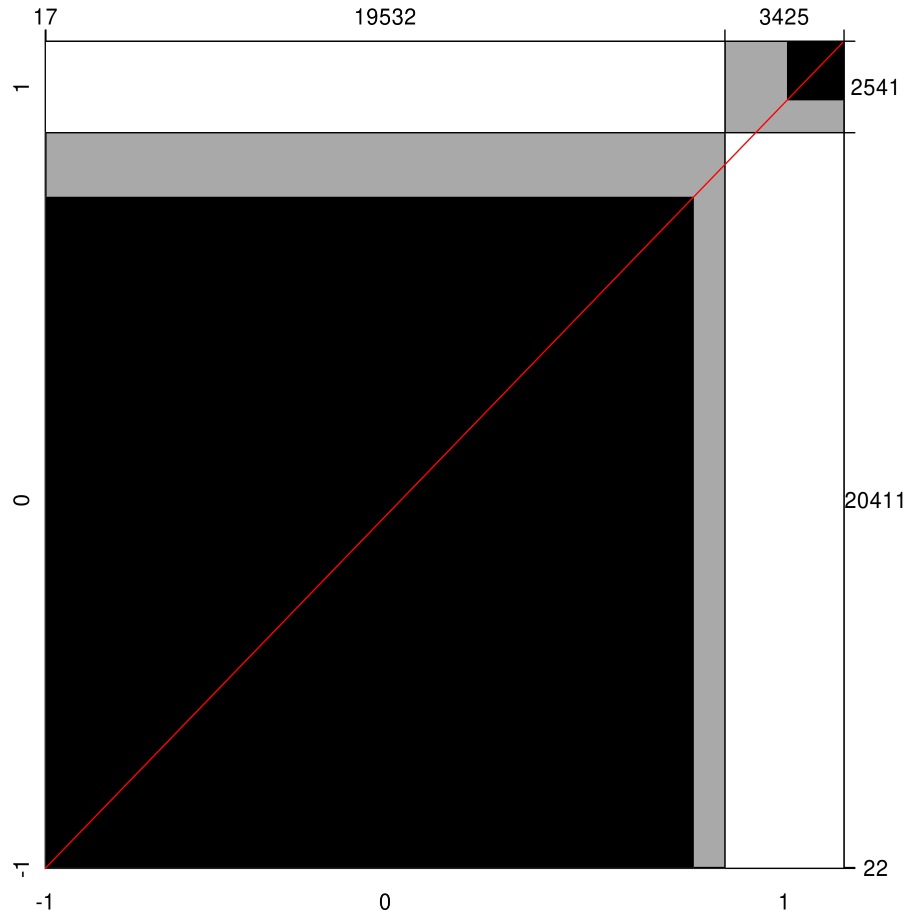

Figure B.17: Agreement plot showing the proportions of agreement between the two independent coders (ADL and CH). The dark spaces represent the proportion of agreement for the presence and absence of all aggregated variables in the entire dataset, and the gray spaces represent the proportions of disagreement for presence and absence.

$$\frac{1}{2}RSS/n + \lambda * penalty$$

and for logistic regression:

$$-loglik(\beta)/n + \lambda * penalty$$

There are two popular forms of penalized regression: ridge regression and lasso regression. For ridge regression the penalty is $||\beta||_2^2 = \sum_{j=1}^{p} \beta_j^2$, where the β_j are the regression coefficients, and for lasso regression the penalty is $||\beta||_1 = \sum_{j=1}^{p} |\beta_j|$. When $\lambda = 0$, this reduces to the standard estimation. As $\lambda \to \infty$, the coefficients β_j are "shrunk" to 0. Thus, when λ is small, the βs are relatively unrestricted, which can result in a good fit to the current sample (low bias), but a poor fit on future samples (high variance); roughly, the model will tend to be over-fitted. When λ is large, the βs tend to shrink toward 0, which reduces fit on the current sample (high bias), but results in a more stable fit across samples (low variance); roughly, the model will tend to be under-fitted. The optimal value of λ is typically found by minimizing cross-validation error.

With the lasso penalty, some coefficients might be set to 0, i.e., dropped from the model, which aids interpretation, but when variables are correlated, the lasso might drop some that are genuinely related to the outcome. In ridge regression, in contrast, the coefficients of correlated variables are shrunk to similar values; although the coefficients of some predictors might be very small, all predictors are retained in the model, which can make interpretation difficult.

Elastic net regression combines the advantages of ridge and lasso penalties using an additional tuning parameter α, $0 \leq \alpha \leq 1$:

$$penalty = (1 - \alpha)/2||\beta||_2^2 + \alpha||\beta||_1.$$

Thus, $\alpha = 0$ is the ridge penalty and $\alpha = 1$ is the lasso penalty. With intermediate values of α, there is a 'grouping' effect in which strongly correlated variables tend to enter or leave the model together (i.e., have their coefficients set to 0).

In the main text, we used elastic net regression to fit a logistic regression model of each domain type (conceptual, motor, medicine) as functions of our other coded (binary) variables. Following standard procedure, we used 10-fold cross-validation to find the optimum value of λ, i.e., the one that minimized cross-validation error.

B.8 Filtering extremely sparse variables in our elasticnet regression

When we included all of the variables from our theoretical models in the elasticnet regression models, extremely sparse variables were prone to spurious and extremely large associations in a few cases. For example, the “mate fidelity” variable was only supported in one text record, and that text record also involved a specialist with medicinal knowledge (which was an outcome variable of one of our elasticnet regression models). Strictly speaking, presence of this variable was associated with medicinal domains, but with an extremely large regression coefficient and standard error. Although ridge regression is generally suitable for fitting models with many sparse predictor variables, exceptionally sparse predictors are nevertheless prone to large regression coefficients, with similarly large standard errors, that dominate and overshadow results among other (less sparse) predictor variables. Associations based on sparser predictors are not only theoretically uninteresting (because they are more likely to reflect noise than a signal in the data), but they create a practical problem when plotting them next to smaller regression coefficients with smaller standard errors.

We therefore chose to filter extremely sparse variables in our elasticnet regression. To do so, we filtered predictor variables that had evidence present in less than 5% of all text records in the dataset, which is a sum of about 26. Hence, because each variable consists of 1’s and 0’s, we included variables with a sum of at least 26 as predictors in the elasticnet regressions. These variables, along with those that were excluded due to insufficient evidence, are shown in figure B.18.

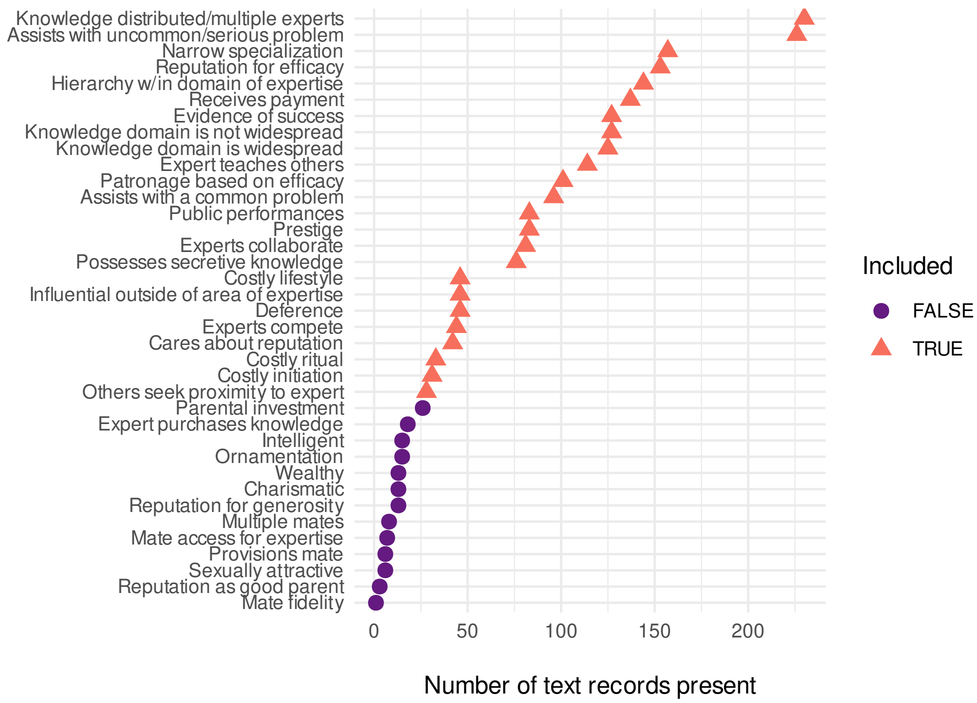

Figure B.18: Dot chart showing the number of text records present for each variable in our theoretical models. The total number of text records present in each variable is shown along the x-axis, and colors and shapes correspond to whether or not this number was greater than or equal to 5% of the number of observations (rows) in our dataset. If they were, then they were included in our elasticnet regression.

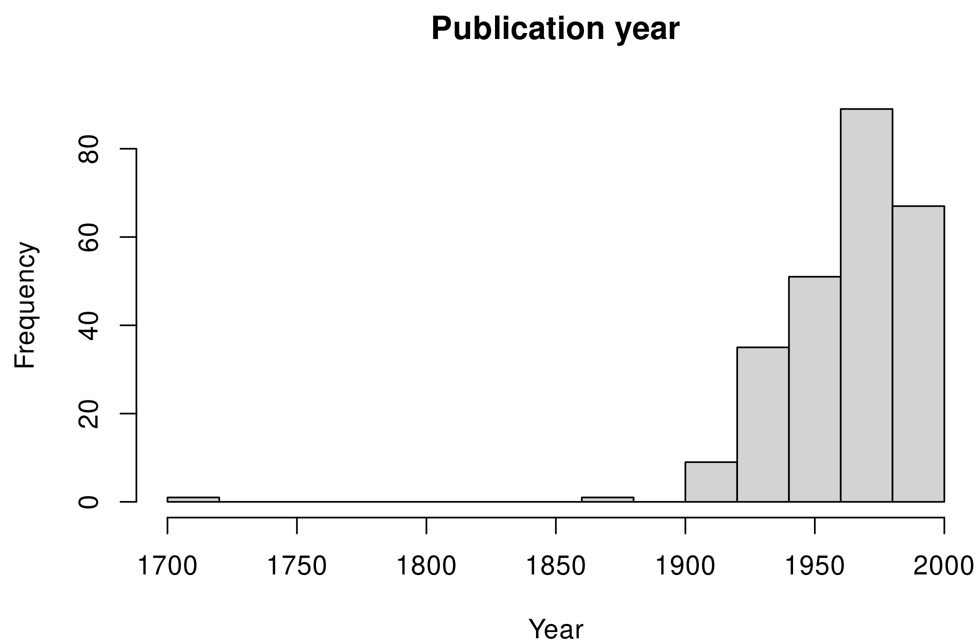

Figure B.19: Histogram showing the number of text records by year in our entire dataset.

B.9 Publication dates

The dates of publication for our ethnographic sources were mostly in the 20th century, though a few were in the 19th century and one was in the 18th century. We report key statistics about the publication dates and basic characteristics, but we show the distribution of publication dates here, both in the aggregate (figure B.19) and in the 20th century only (figure B.20).

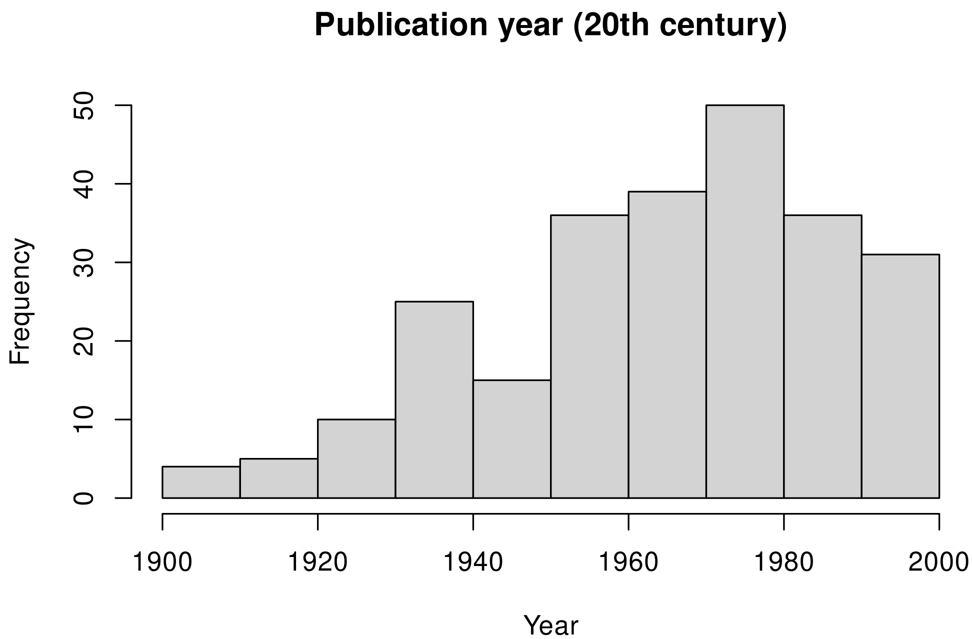

Figure B.20: Histogram showing a closer look at the number of text records by year, among the publications that were from the 20th century only.

B.10 Analyzing the raw text in our dataset

To analyze our text record data for additional insights, we created a document term matrix of all of raw text in our dataset. This involves compiling all unique and lemmatized word types (e.g., “ran”, “running”, “runs” would all be collapsed into a single lemmatization of “run”) and removes stop words, such as “a”, “and”, and “the”. (Text records were generally short: after lemmatizing each word, text records ranged in unique word counts from 9 to 684, with a mean of 108, standard deviation of 87, and median of 80.) The resulting document term matrix is a large and sparse data matrix, where each row is a unique text record ID, each column is a unique and lemmatized word that occurred at least once in our dataset, and each element is the number of times that a lemmatized word occurred in a given text record. Our document term matrix dimensions were 547 by 9325.

We then compiled the level of support for each theoretical model in each text record. In a lasso regression, which is designed for penalizing exceptionally large numbers of predictor variables, we used the word frequencies of our 9325 lemmatized words in our document term matrix as predictors of model support for each theoretical model (our outcomes variables). In other words, this analysis asks what types of words tend to be associated with text records that are supportive of each model. In our results, many of the predictive words were noisy or culturally specific, but

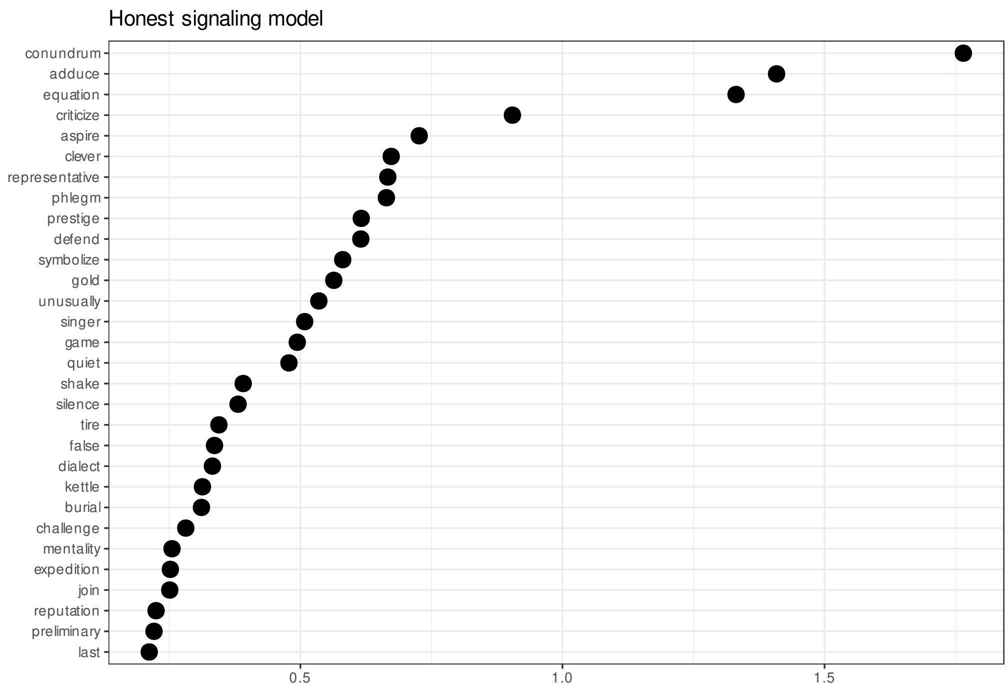

Figure B.21: Lasso regression coefficients for lemmatized words in our document term matrix, which were predictive of support for the honest signaling model in each text record.

many appeared to correspond to model predictions, validating our models and their relevance to the coded texts. See figures B.21 through B.25 for results.

B.11 Raw count data for each variable

Although these values are shown in the main text as proportions of each variable, we include counts of support for each variable in our coding scheme in the table below

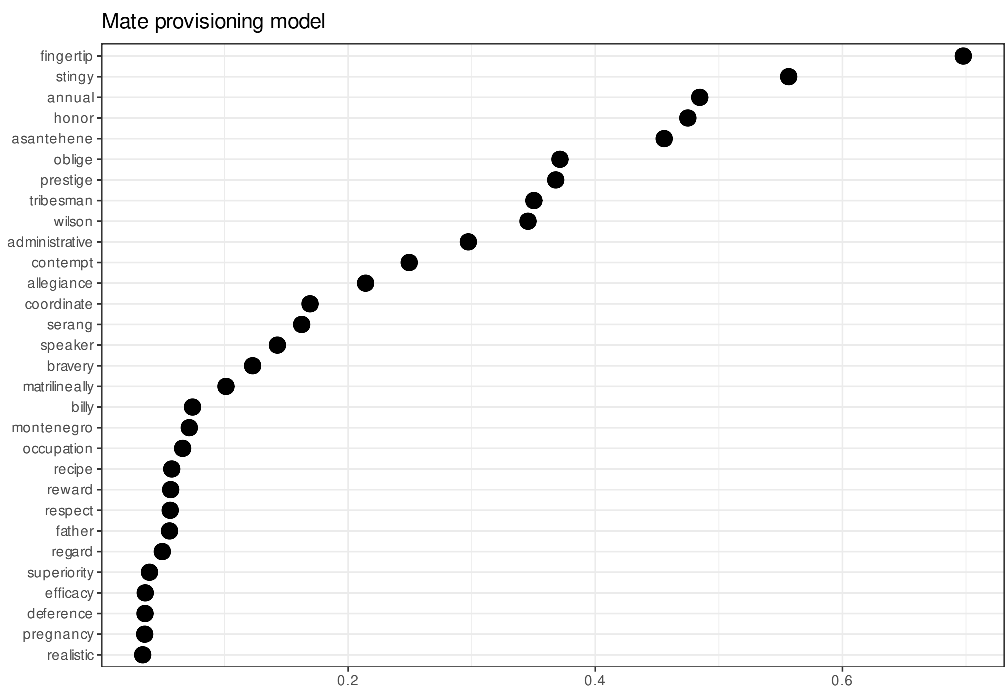

Figure B.22: Lasso regression coefficients for lemmatized words in our document term matrix, which were predictive of support for the mate provisioning model in each text record.

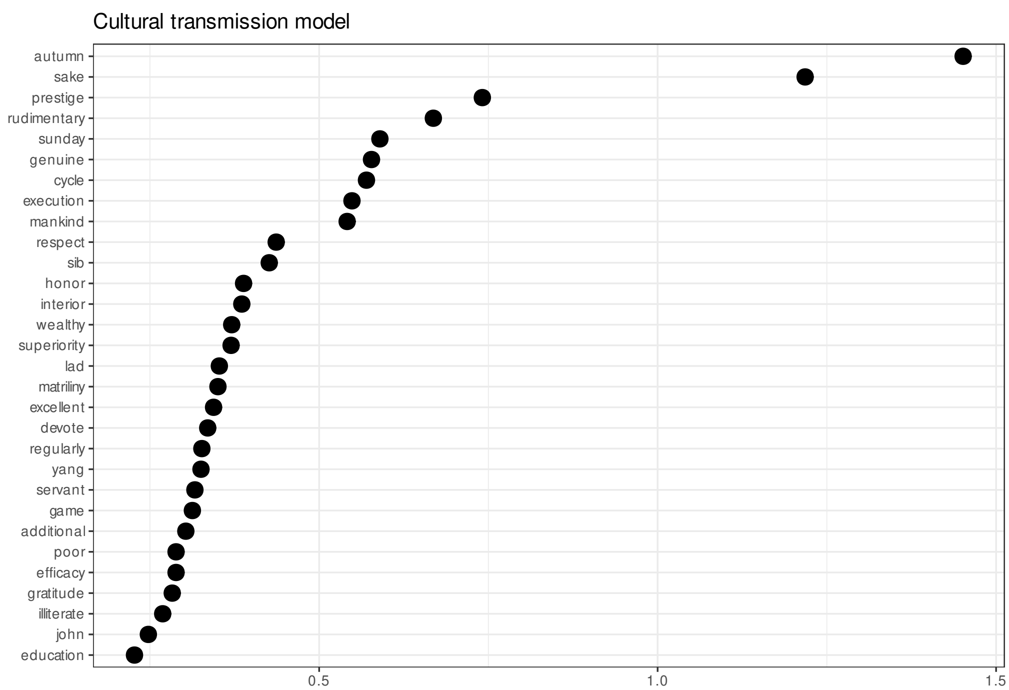

Figure B.23: Lasso regression coefficients for lemmatized words in our document term matrix, which were predictive of support for the cultural transmission model in each text record.

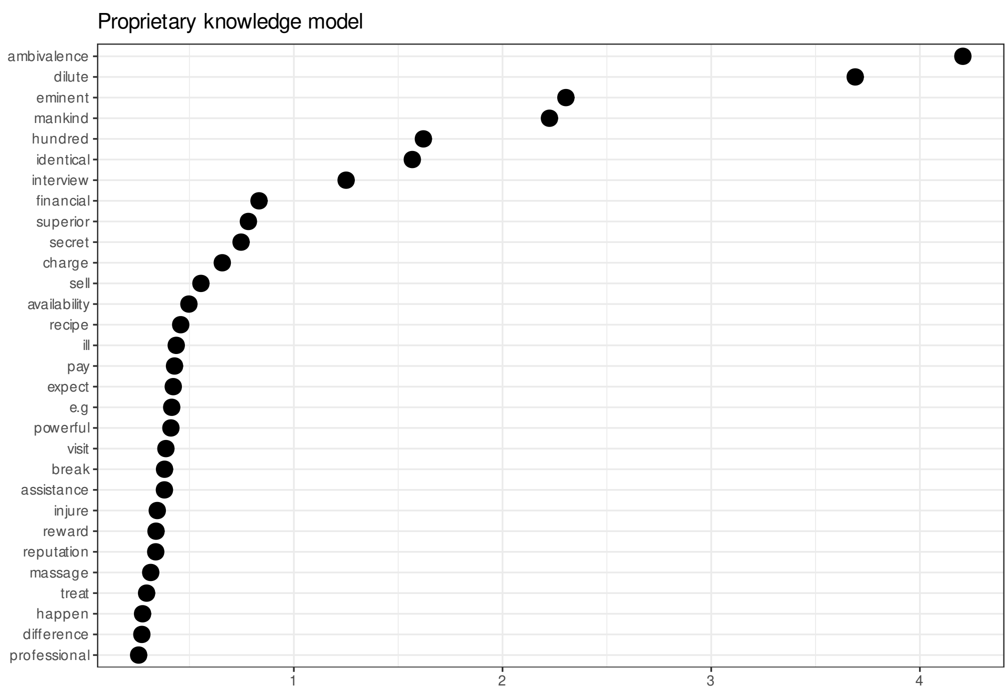

Figure B.24: Lasso regression coefficients for lemmatized words in our document term matrix, which were predictive of support for the proprietary knowledge model in each text record.

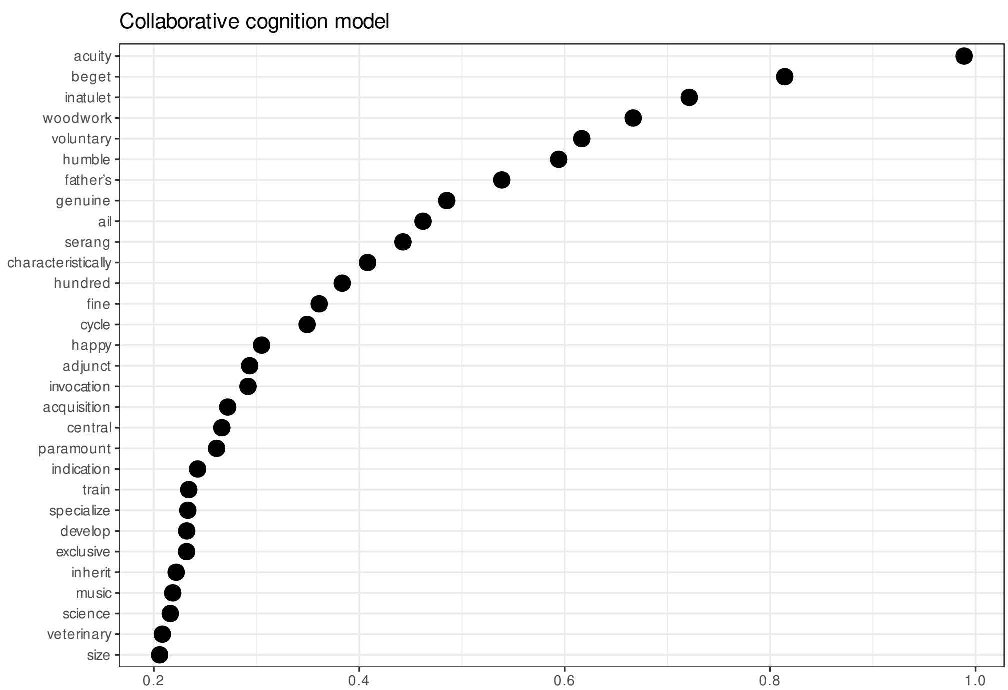

Figure B.25: Lasso regression coefficients for lemmatized words in our document term matrix, which were predictive of support for the collaborative cognition model in each text record.

Table B.19: Number of text records coded as supporting each variable included in our coding scheme are shown here, and plotted in the main text.

Variable	Evidence	Variable	Evidence
Knowledge distributed/multiple experts	230	Assists with uncommon/serious problem	226
Narrow specialization	157	Reputation for efficacy	153
Hierarchy w/in domain of expertise	144	Receives payment	137
Knowledge domain is not widespread	127	Evidence of success	127
Knowledge domain is widespread	125	Expert teaches others	114
Patronage based on efficacy	101	Assists with a common problem	96
Prestige	83	Public performances	83
Experts collaborate	81	Possesses secretive knowledge	76
Broad generalist	69	Deference	46
Influential outside of area of expertise	46	Costly lifestyle	46
Experts compete	44	Cares about reputation	42
Costly ritual	33	Costly initiation	31
Others seek proximity to expert	28	Private performances	26
Parental investment	26	Expert purchases knowledge	18
Anti-prestige/low status	17	Ornamentation	15
Intelligent	15	Reputation for generosity	13
Charismatic	13	Wealthy	13
Multiple mates	8	Mate access for expertise	7
Sexually attractive	6	Provisions mate	6
Reputation for selfishness	4	Mate infidelity	4

for each variable in our theoretical models.

B.12 Shamans and lower class individuals in our spanning tree results

In the minimum spanning tree in main text, we found a variable cluster that did not resemble any of our theoretical models, which we referred to as "shamans and lower class". This label was determined by further investigation of the text records that were associated with support for the variables in the cluster (e.g., low status, anti-charasmatic individuals).

Examples of shamans and other spiritual figures in this cluster

Some of the specialists linked to this cluster were shamans, witchdoctors, and medicine-men who were disliked, distrusted, and/or avoided by members of the community. (We used "shamans" as shorthand in the main text, despite the nuance that this term and other religious/spiritual leadership terms actually entail.) Here are three examples of texts supporting this aspect of our interpretation.

Example #1:

> The love magic specialist makes many of the objects described in the preceding section: love dolls, tied and buried statuettes, flower insects, corpse oil, amulets and charms, Montra and Khaatha, and sacralized cosmetics. . . . A majority of the specialists are males of lower status and income who are literate but not well educated. Most specialists know some Pali and Sanskrit words. They are consulted and paid by their customers, but

they are not publicly and permanently respected. They are considered disgusting and are avoided by the majority of people in the society.

Example #2:

One also finds, as in all other Buddhist lands, bonzesses living together in convents not far from the pagodas where they are forbidden to reside. Like the bonzes, they are supposed to remain continent during their stay in the bonzeries, and the penalty of death awaits those who give birth to children. For this reason, it is maintained, they are greatly skilled in the infamous art of abortion. Their morals have the reputation of being abominable.

Example #3:

As they [the laymen] see it, the debtera begins his career as an ordinary farmer-priest, who performs in the mass in his natal parish. He is no different from his fellow priests, except for a weakness in his character which makes him unable to keep within the proscriptions of the priestly life. Eventually, it leads him to commit a serious moral offense (badal), after which he can no longer perform the mass. Most often, it is adultery that spoils the priest's identity. The theft of church tithes is another frequently mentioned act. Once discovered, he finds it impossible to continue his life

> in the parish. He is filled with shame; he is scorned by kinfolk and neighbors; and he loses his usufruct to church lands. But how is such a man to support himself once he has left the parish? Since his only resources now are his ability to read and write Amharic and Ge'ez (the language of the church) and his knowledge of the liturgy, he takes up a solitary wandering life as a debtera. His flawed nature gives him no peace, however, and he progresses from sin to sin until at last he seals his perdition by seeking the help of demons. At this point, he begins his career as a great magician, sorcerer, and healer.

Examples of low status occupations in this cluster

Others in this cluster were people in low status roles, but were not described as shamans or other spiritual figures. These were generally individuals who were either born into a lower strata of society, or were specializing in skill domains that were, themselves, considered demeaning or associated with a lower class. Here are three examples of texts supporting this aspect of our interpretation.

Example #1:

> Few herbalists claim to master this method fully. It is generally believed that the method is mostly used by those endogamous social groups who are descendants of slaves or who are outcasts. The baxaari, whom I have mentioned, is such a group, but in every Southern Somali village

> there are groups or individuals with a corresponding social position. Just like the baxaari such people may have an inferior social position and be feared for their magical skills, although they are often only talked about as dhiryaqaan, "the one who knows about herbs" ... We should note here, then, that there is some connection between the lower levels of society and knowledge of medical plants. This does not imply that the plants as such are seen as belonging to these groups, nor that using plants for curative purposes is defiling, only that certain socially peripheral groups are often believed to be particularly skilled in handling them.

Example #2:

> Wagoosh also taught Rogers's family how to market snakeroot by escorting his mother to town to exchange it for a "goodly supply of groceries." After that, he and his family "dug snake root every day, making several trips to town with it—so we always had a good supply of edibles." Snakeroot had become a significant source of income, and the Anishinaabeg learned how to get the best price for it. Some observers regarded collecting snakeroot and ginseng (Panax quinquefolius L.) as a demeaning way to make a living.

Example #3:

> The other important akombo performed for women with child is called the

akombo swende. It is an act for the expulsion of evil and the transference of it into the body of a scape-goat. It is always performed by a male slave who must always disappear immediately afterwards.

B.13 Culture level support for each model

We analyzed model scores by three culture-level characteristics: Geographic region, subsistence strategy, and cultural complexity. We did not find any variation in levels of support (model score) by any of these predictors, suggesting consistent levels of evidence for each model cross-culturally. See figure B.26 for model scores by geographic region, and figure B.27 for model scores by subsistence strategy.

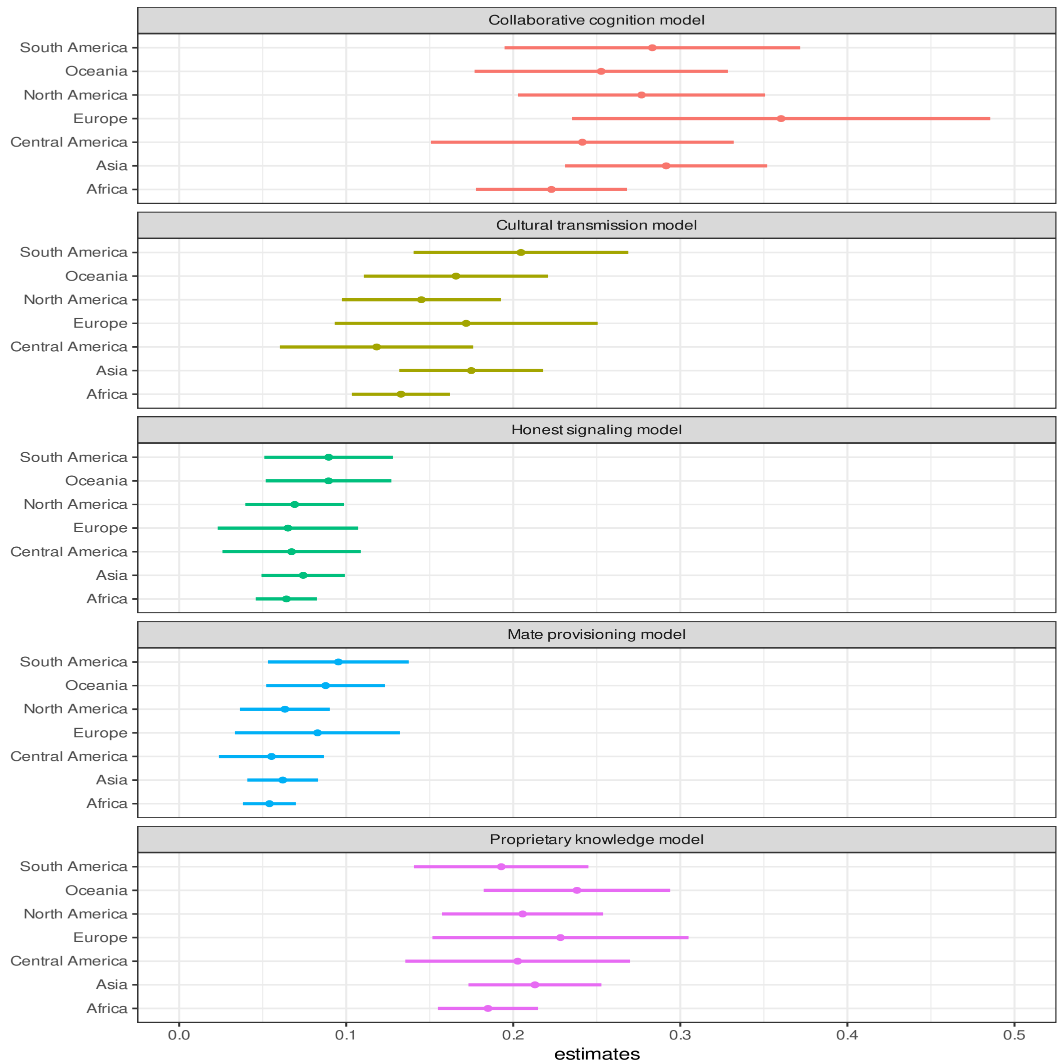

Figure B.26: Culture level support for each model score by geographic region, computed as estimated margin means of the generalized linear mixed model estimates. Error bars are 95% confidence intervals.

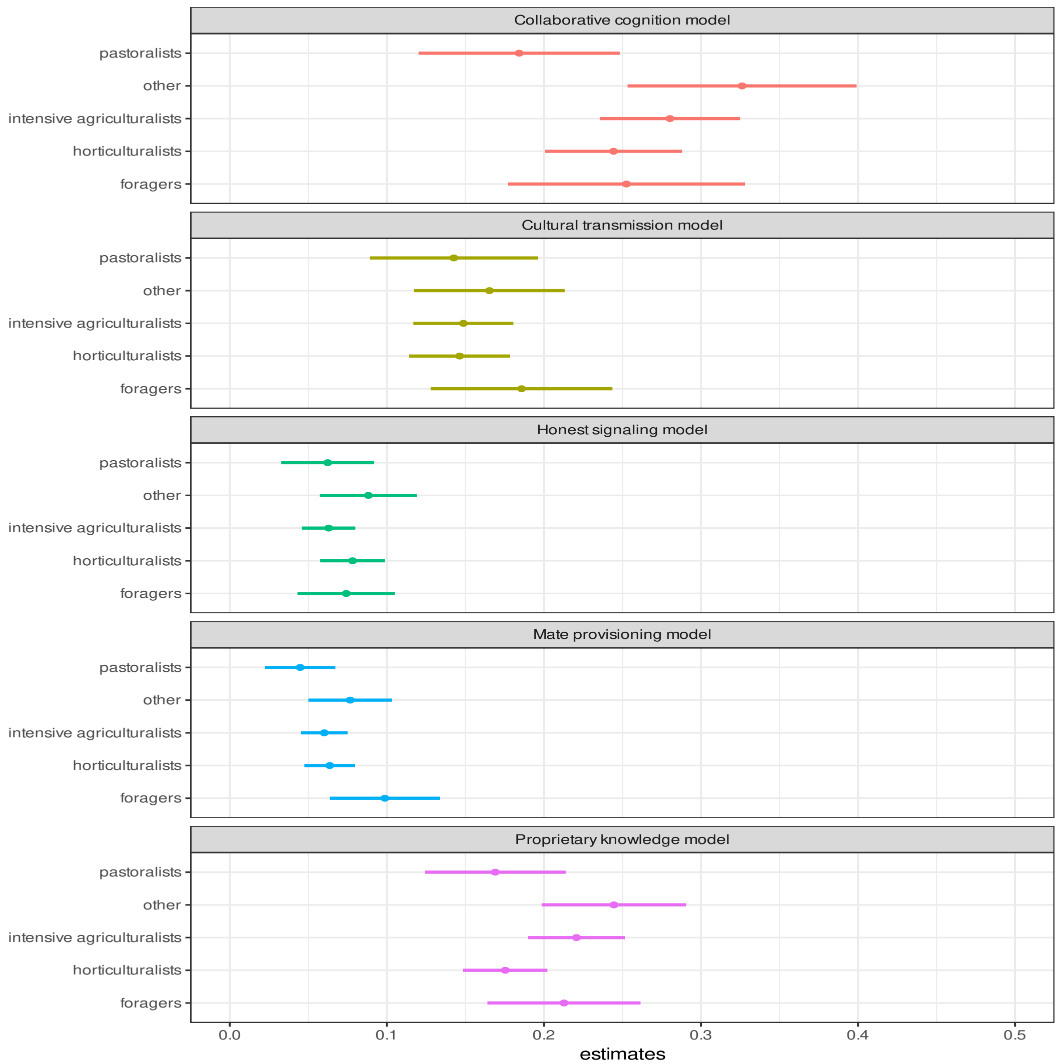

Figure B.27: Culture level support for each model score by type of subsistence strategy, computed as estimated margin means of the generalized linear mixed model estimates. Error bars are 95% confidence intervals.

B.14 Analysis of sex differences

In this section, we analyze our data to address the possibility of sex-specific patterns. We report the relative levels of evidence of males and females in the main results, but, as we show in this section, sex-specific trends were less clear. At the text record level, and to broadly analyze how our coded variables might be associated with the presence of males and the presence of females, we used two separate ridge regression models. (See our explanation of this method in the elasticnet regression section above.) The outcome variable in one regression model was presence of males, and the outcome variable in the other regression model was presence of females. Males were generally more positively associated with prestige, public performances, and narrow specialization (figures B.28 and B.29), but we did not find any meaningful associations among females (figures B.30 and B.31).

Replicating the heatmap from the main results (i.e., seriating rows and columns with PCA angle), annotating each text record to show the presence of males (figure B.32) and the presence of females (figure B.33) does not show any clear patterns. Females do appear to be slightly clustered into the rightmost section of the right cluster in figure B.33, which is associated with uncommon and serious problems (e.g., medicine, illness). It is difficult to make strong inferences from the high female presence here, however, because these particular text records substantially overlap

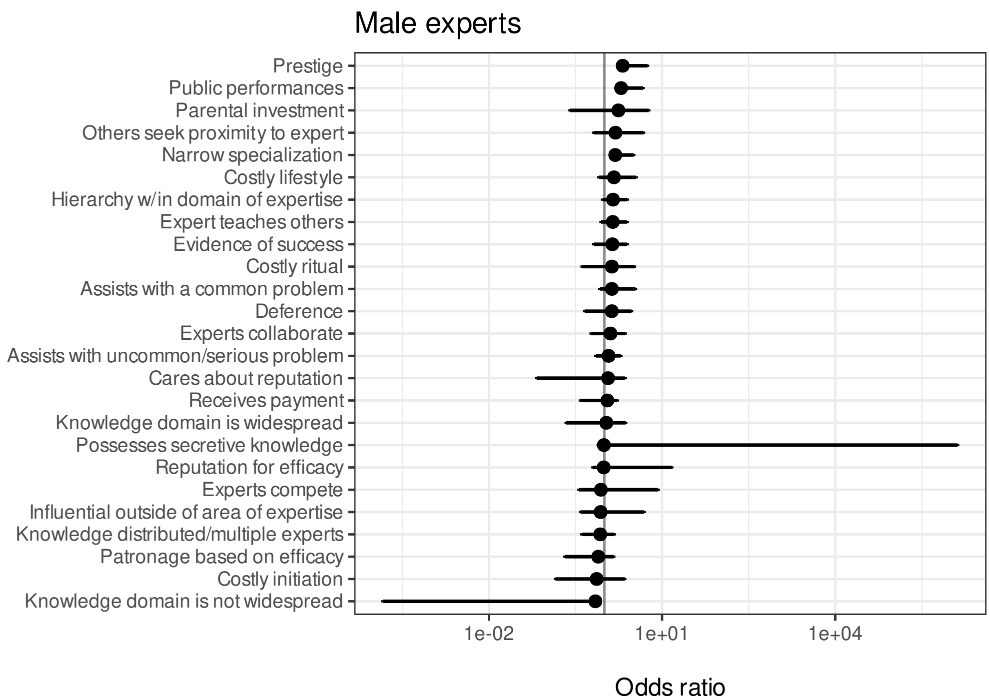

Figure B.28: Ridge regression model of variables predicting evidence for males at the text record level. Regression coefficients are reported as odds ratios along the x-axis, and error bars are 95% confidence intervals. Note that the x-axis is log-scaled. This figure includes all variables that were included in the regression model for males, listed along the y-axis.

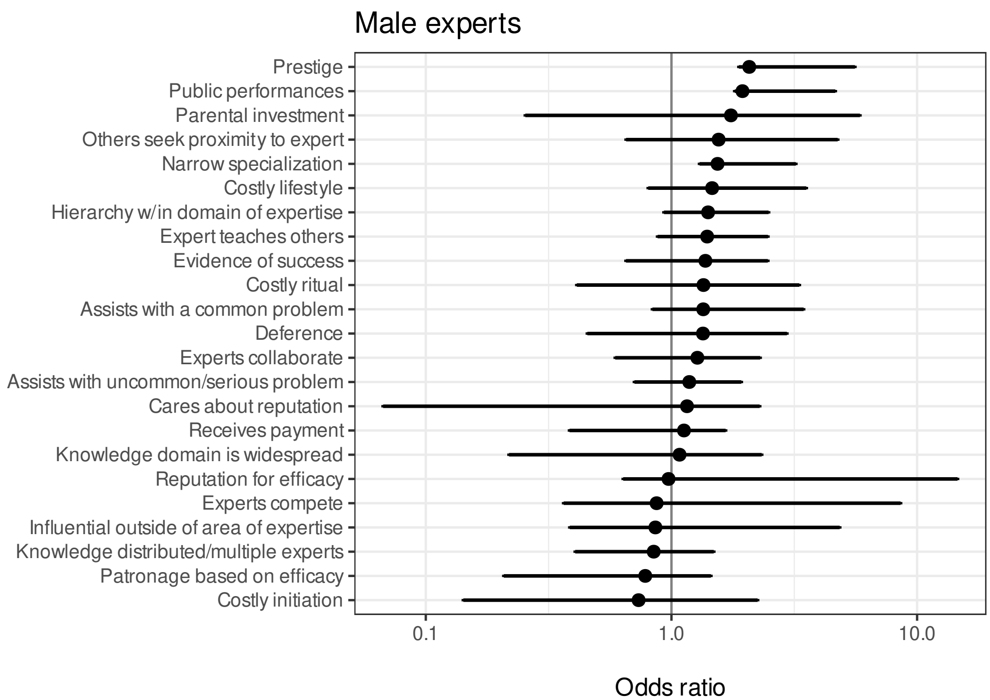

Figure B.29: Ridge regression model of variables predicting evidence for males at the text record level. Regression coefficients are reported as odds ratios along the x-axis, and error bars are 95% confidence intervals. Note that the x-axis is log-scaled. This figure replicates the previous figure, but removes variables with extremely large CI's to make our results more interpretable.

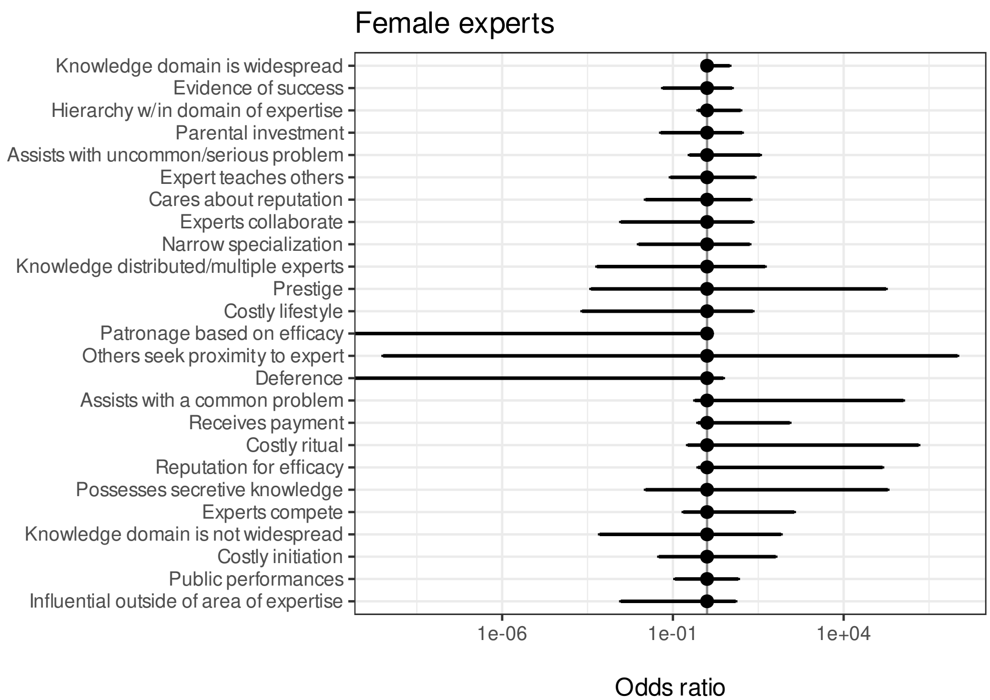

Figure B.30: Ridge regression model of variables predicting evidence for females at the text record level. Regression coefficients are reported as odds ratios along the x-axis, and error bars are 95% confidence intervals. Note that the x-axis is log-scaled. This figure includes all variables that were included in the regression model for females, listed along the y-axis.

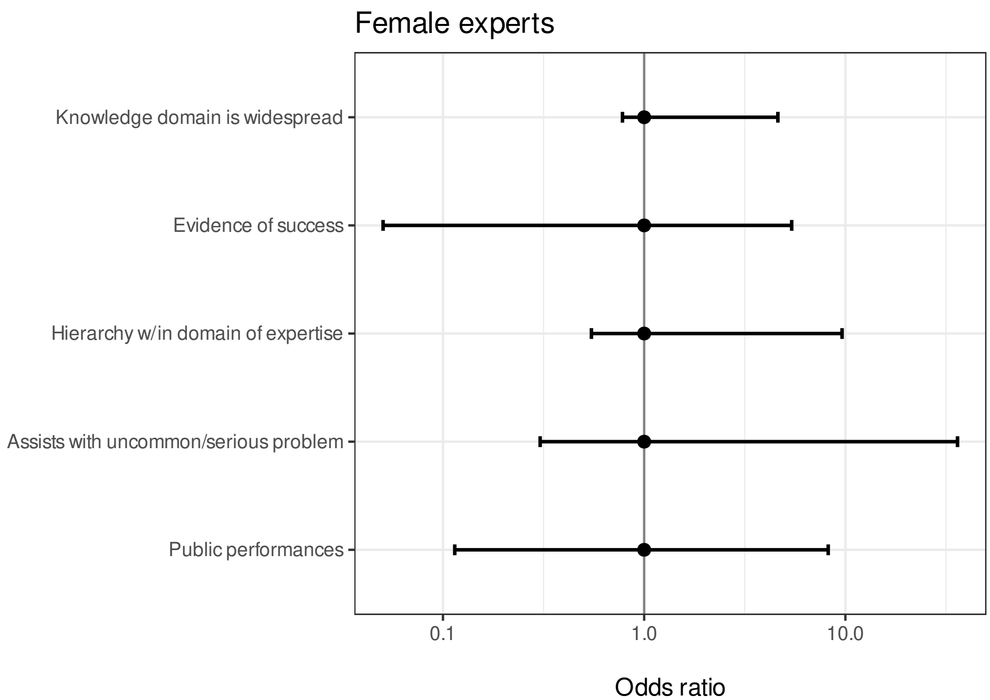

Figure B.31: Ridge regression model of variables predicting evidence for females at the text record level. Regression coefficients are reported as odds ratios along the x-axis, and error bars are 95% confidence intervals. Note that the x-axis is log-scaled. This figure replicates the previous figure, but removes variables with extremely large CI's to make our results more interpretable.

with the left cluster.

To further investigate sex-specific patterns, we recreated the heatmap using sex-specific data matrices (i.e., a "male" data matrix of *only* text records with males present, and a "female" data matrix of *only* text records with females present), we see trends in each that are similar to the heatmap based on our aggregated dataset (in the main text). See figures B.34 and B.35.[13] These trends, especially in the female data matrix, are coarser-grained compared to the original heatmap from the main results. This is because the number of female-present text records ($N = 102$) was lower than the number of male-present text records ($N = 201$) and both were far lower than the number of text records in the entire data matrix from our original heatmap ($N = 547$).

Another key exploratory analysis from our results was the minimum spanning tree (MST). We therefore replicated this analysis using the female data matrix (figure B.36) and the male data matrix (figure B.37). For females, we saw little-to-no interpretable clustering among the variables, although it is worth noting that assistance with uncommon and serious problems appears to be important to female experts in general. (This is consistent with the suggestive result in the heatmap in figure B.35 that females were generally clustered into the uncommon and serious

[13]Notice that the clusters are "flipped" to the bottom of these heatmaps, compared to the heatmap in our main results. This is a result of the PCA angle seriation method, and the position of these clusters on the heatmap is arbitrary. The key result to notice is that *which variables* that are clustering together remains largely in tact.

Figure B.32: Heatmap visualizing the coded dataset based on presence (light cells) vs. absence (dark cells) of evidence for each variable in each text record. For readability, the dataset shown here is transposed, i.e., each row represents a variable and each column represents a single text record. Rows and columns are ordered using the PCA angle seriation method, as shown in the main text. The annotated uppermost row indicates which text records have male experts present (light blue cells).

Figure B.33: Heatmap visualizing the coded dataset based on presence (light cells) vs. absence (dark cells) of evidence for each variable in each text record. For readability, the dataset shown here is transposed, i.e., each row represents a variable and each column represents a single text record. Rows and columns are ordered using the PCA angle seriation method, as shown in the main text. The annotated uppermost row indicates which text records have female experts present (light blue cells).

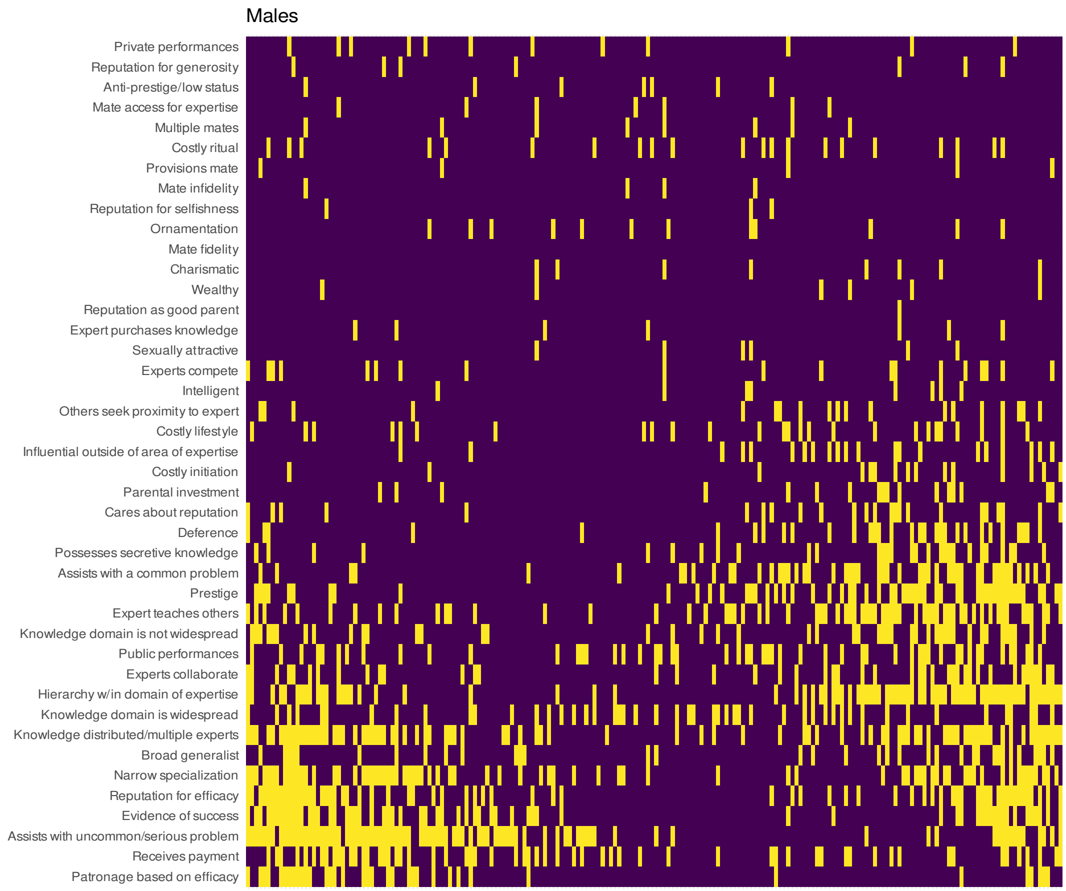

Figure B.34: Heatmap visualizing the coded dataset among only text records with male experts present, based on presence (light cells) vs. absence (dark cells) of evidence for each variable in each text record. For readability, the dataset shown here is transposed, i.e., each row represents a variable and each column represents a single text record. Rows and columns are ordered using the PCA angle seriation method, as shown in the main text.

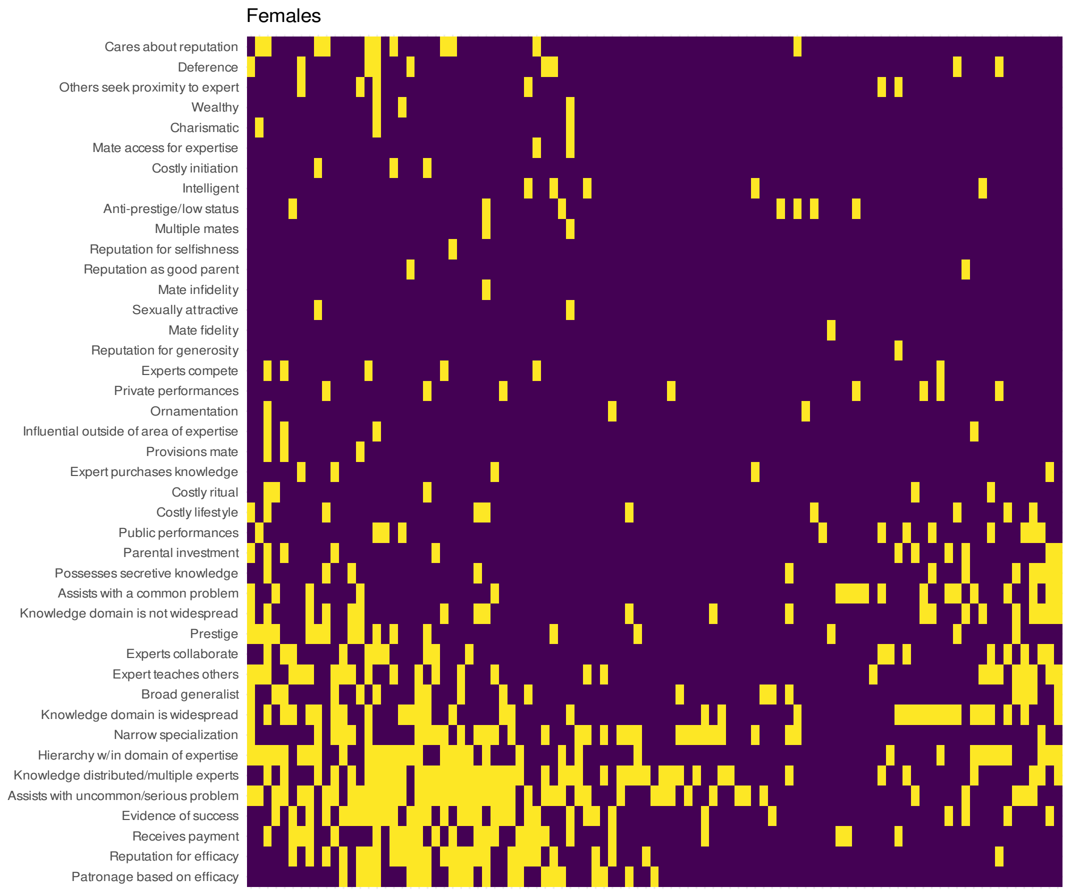

Figure B.35: Heatmap visualizing the coded dataset among only text records with male experts present, based on presence (light cells) vs. absence (dark cells) of evidence for each variable in each text record. For readability, the dataset shown here is transposed, i.e., each row represents a variable and each column represents a single text record. Rows and columns are ordered using the PCA angle seriation method, as shown in the main text.

problems cluster, and the observation that most females – about 55% of text records with females present – are associated with medicinal domains). For males, hierarchies within a given domain of expertise, prestige, and teaching were important variables. This is generally consistent with the key results of this section from figure B.29, i.e., that males are generally more associated with prestige. Interestingly, the uppermost cluster of figure B.37 suggests some coherent male support for variables in the mate provisioning model, but the scarcity of evidence for these variables overall makes this a more speculative findings.

Figure B.36: Minimum spanning tree of the variable binary distance matrix for text records with females present. See text for details.

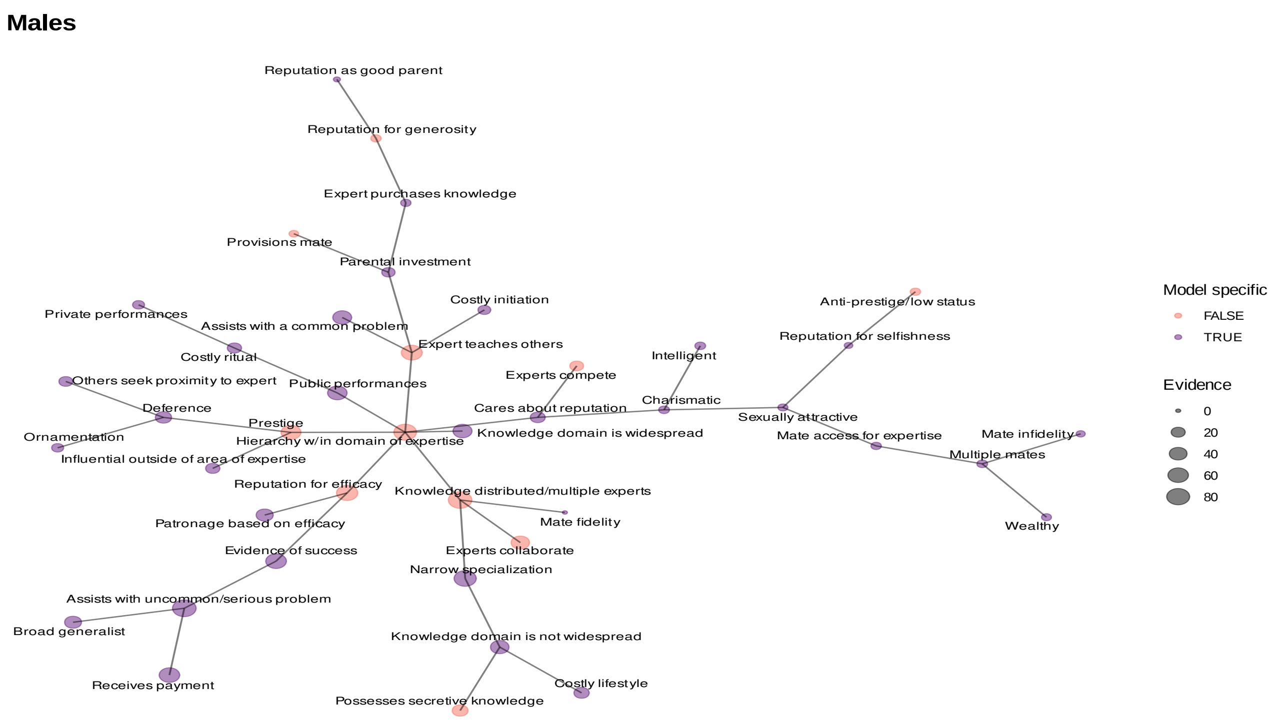

Figure B.37: Minimum spanning tree of the variable binary distance matrix for text records with males present. See text for details.

Lastly, it is worth addressing the possibility that sex-specific roles co-occurred in some text records where males and females were *both* present. (For example, in a few cases, males had specialized knowledge for healing and divination whereas females had specialized knowledge about midwifery and childbirthing.) This co-occurrence of sex-specific roles and males and females in a single text record occurred in 12 text records (about 2% of our dataset). These text records were not sufficiently descriptive to infer sex-specific trends that were relevant to our theoretical models. Further, recreating the heatmap from our main results, and annotating these 12 text records, did not suggest that they were generally associated with one of our data clusters. See figure B.38.

C Supplementary Information for Chapter 4: *Ethnomedical specialists and their supernatural theories of disease*

C.1 Supplementary descriptions of methods in Study 1

Here we provide details about the methods used for the results of the cross-cultural study in the main text, which was based on text records from the electronic Human Relations Area Files (eHRAF).

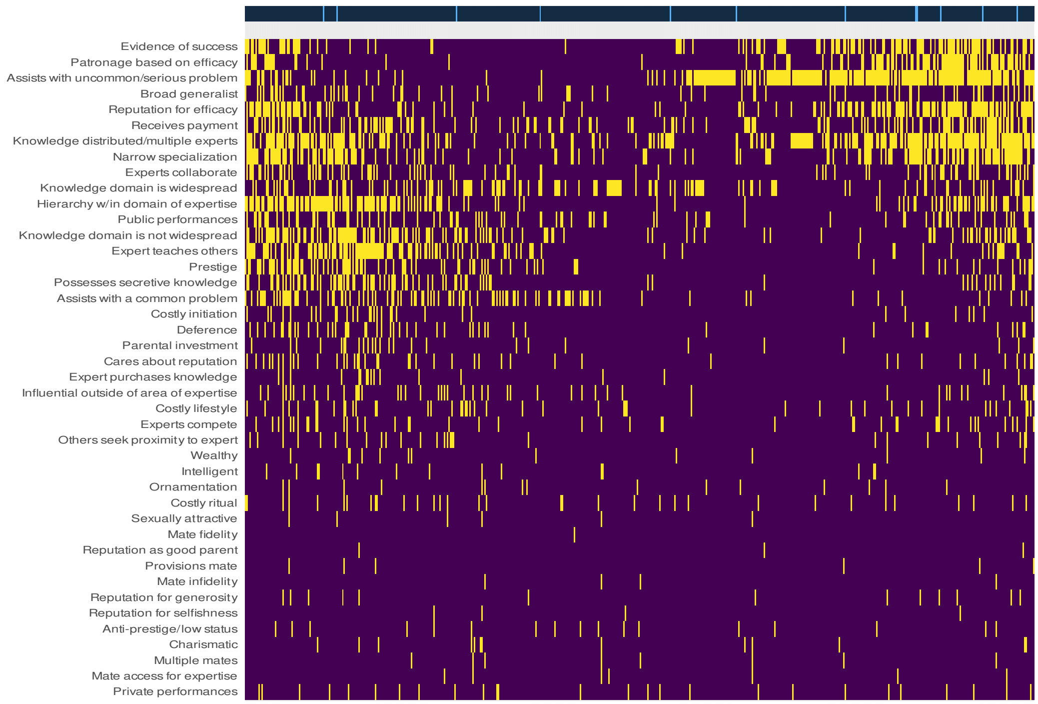

Figure B.38: Heatmap visualizing the coded dataset based on presence (light cells) vs. absence (dark cells) of evidence for each variable in each text record. For readability, the dataset shown here is transposed, i.e., each row represents a variable and each column represents a single text record. Rows and columns are ordered using the PCA angle seriation method, as shown in the main text. The annotated uppermost row indicates which text records have both male and female experts present, with some kind of sex-specific specialization involved (light blue cells).

Statistical analyses

Our dataset, which comprised a 341 row by 58 column binary matrix of 0's (no evidence) and 1's (evidence for), consisted of text records (rows) nested within authors, who were nested within cultures. To assess levels of evidence for each variable, we determined the proportion of text records with evidence for (text record level evidence) and the proportion of cultures with at least one text record supporting the variable (culture level evidence). To account for the hierarchical structure of the data – some text records came from the same document, and multiple documents reported on the same culture – we fit an intercept-only generalized logistic mixed effects regression model (GLMM) for each binary variable, with random intercepts for authors nested within cultures. The value of the fixed-effect intercept (and its 95% CI) represents the proportion of text records with evidence for a given variable, adjusted for the hierarchical structure of the data. The proportion of cultures with evidence for a given variable was similarly computed, except that its confidence interval was computed with cluster bootstrapping. We then converted each estimated proportion and its CI into percentages, which we reported as the variable's level of support.

To more formally assess and compare the levels of evidence for each hypothesized role of ethnomedical specialists (as efficacious healers, specialists in a market for useful skills, religious figures, and/or prestigious mentors), we grouped the variables relevant to each hypothesis and computed a "total score" for each. (We also include "anti-efficacy" and "anti-mentorship" hypotheses because some evidence against their counterparts was available.) The "total score" was the proportion of cells in the data matrix with evidence for each hypothesis. For example, our coding scheme included 6 religious variables, so there was a 341×6 dimension binary matrix for this hypothesis. Of the 2046 cells, 459 (22.4%) had evidence for religious variables. This percentage was the total score, and hypotheses with higher total scores were judged to have more support.

Exploratory analyses of religiosity and the supernatural

To explore religiosity (measured by the total score for religious variables) and the presence/absence of supernatural theories of disease, we used three key techniques.

First, to determine the dimensions of ethnomedical expertise that are associated with religiosity and the supernatural, we fit a poisson regression model with the text record religion scores as the outcome and a logistic regression model with text record supernatural theories (present/absent) as the outcome. In each model, the remaining coded variables on ethnomedical expertise were predictors. Prior to fitting, we removed variables with almost no evidence (>95% zeros) to avoid spuriously large estimates and CI's. Because inclusion of many predictors risks overfitting, we used *elasticnet* regression (Friedman 2021), a popular type of penalized regression that was developed for use in situations where the number of predictors, p is large relative to the number of observations, n. We used the "lasso" penalty, which sets some coefficients to 0, with the non-zero coefficients representing the "best" predictors, given the limitations of the data. (See below for a brief description of the elasticnet regression.)

Second, to determine if continental region and/or mode of subsistence were associated with religiosity and the supernatural among ethnomedical specialists, we fit two separate logistic GLMMs with presence/absence of supernatural theories in each text record as the outcome variable. In one model, continental region of each of the 47 cultures was the predictor variable, and in the other model, subsistence strategy for each of these cultures was the predictor variable. In both models, we included random intercepts for cultures. We then repeated this process using two separate poisson GLMMs, with religion scores in each text record as the outcome variable.

Third, to determine if dimensions of cultures other than their continental region or mode of subsistence were associated with religiosity and supernatural theories of disease, we first compiled all complete quantitative data on 186 cultures from the Standard Cross Cultural Sample (SCCS) from D-PLACE (Kirby et al. 2016) into a dataset. Specifically, we collected all ordinal and continuous variables from the SCCS, and filtered all variables with missing observations. The resulting dataset contained 44 variables with observations for all 186 societies in the SCCS.

We then scaled the entire SCCS data matrix and conducted a principal components analysis (PCA) to reduce the dimensionality of the cross-cultural data. We retained the largest principal components based on variance explained (a scree plot "elbow") and interpretability, along with the principal component values for each culture that was also in our eHRAF dataset of ethnomedical specialists (the *PCs*). Out of the 47 cultures in our eHRAF dataset, 44 cultures were also in the SCCS. We excluded the remaining 3 cultures from this analysis. In a logistic GLMM, we then modeled presence/absence of supernatural theories for each text record as the outcome, culture-level PCs as the predictors, and random intercepts for cultures.

Exploratory analyses of markets and mentorship

To explore the roles of market specialization, efficacy, and mentorship, we used two additional techniques.

First, at the text record level, we weighed the levels of evidence for common incentives for laypersons to patronize ethnomedical specialists (see figure 2 in the main text). In some cases, we also had evidence for corresponding disincentives (e.g., reputation for efficacy vs. reputation for inefficacy); in other cases, we had evidence for contrasting incentives (e.g., assistance with uncommon and serious problems vs. assistance common and everyday problems). To compare the weight of evidence for incentives vs. disincentives, or for contrasting incentives, we used logistic regression to compute the odds ratios of evidence for one vs. the other. Our comparisons were: *specialists conferring benefits* vs. imposing costs; *reputations for efficacy* vs. reputations for inefficacy; *assistance with uncommon and serious problems* vs. assistance common and everyday problems; *patronage based on efficacy* vs. patronage based on tradition, convenience, or cost (referred to as "socioeconomic" considerations); *evidence of success* vs. evidence of failure; *trustworthy specialists* vs. untrustworthy specialists; and *freely shared services* vs. services for payment.

Second, we assessed which variables were associated with an expansion of the market for ethnomedical specialists. As a proxy for presence/absence of expanding markets, we used the acculturation variable, which usually included presence/absence of foreign hospitals and clinics nearby and, in some cases, ethnomedical specialists from other cultures. Here, we modeled each of our coded variables as the outcome in separate logistic GLMMs, with the acculturation variable as the predictor (i.e., presence/absence of foreign hospitals and clinics nearby and, in some cases, ethnomedical specialists from other cultures) for each model, and authors nested within cultures as random intercepts.

Exploratory analysis of the variables in our data

Finally, to examine structure in our entire data matrix, i.e., to determine which groups of variables tended to have evidence in the same text records and therefore might indicate important abstractions about ethnomedical expertise, we used a network clustering technique known as a minimum spanning tree (MST). We computed the square matrix of all pairwise binary distances between column vectors in our dataset, where a binary distance = 0 means that two variables both had evidence in exactly the same text records, and a binary distance = 1 means that two variables never had evidence in the same text records. The resulting matrix can be conceptualized as an adjacency matrix that defines a weighted graph (G), where each vertex is a variable and each weighted edge is the distance between these variables.

From this we computed the MST, which is a subgraph of G in which every node is connected in a single path, minimizing the total weighted path distance without creating any closed paths (Prim 1957; Dijkstra 1959). In the resulting MST, only similar variables (the vertices) are connected to each other. We then identified "clusters" of variables by visual inspection of the MST, seeking groups of adjacent variables that were conceptually related.

Explanation of the elasticnet regression model

Here, we briefly describe the elasticnet regression model. Standard regression models are fit by minimizing an objective function. In ordinary least squares regression the objective function is the residual sum of squares (RSS), and in logistic regression it is the negative log-likelihood, $-loglik(\beta)$. Penalized regression models instead minimizes the objective function plus a penalty term based on the magnitude of the coefficient vector. For linear regression this is:

$$\frac{1}{2}RSS/n + \lambda * penalty$$

and for logistic regression:

$$-loglik(\beta)/n + \lambda * penalty$$

There are two popular forms of penalized regression: ridge regression and lasso regression. For ridge regression the penalty is $||\beta||_2^2 = \sum_{j=1}^{p} \beta_j^2$, where the β_j are the regression coefficients, and for lasso regression the penalty is $||\beta||_1 = \sum_{j=1}^{p} |\beta_j|$. When $\lambda = 0$, this reduces to the standard estimation. As $\lambda \to \infty$, the coefficients β_j are "shrunk" to 0. Thus, when λ is small, the βs are relatively unrestricted, which can result in a good fit to the current sample (low bias), but a poor fit on future samples (high variance); roughly, the model will tend to be over-fitted. When λ is large, the βs tend to shrink toward 0, which reduces fit on the current sample (high bias), but results in a more stable fit across samples (low variance); roughly, the model will tend to be under-fitted. The optimal value of λ is typically found by minimizing cross-validation error.

With the lasso penalty, some coefficients might be set to 0, i.e., dropped from the model, which aids interpretation, but when variables are correlated, the lasso might drop some that are genuinely related to the outcome. In ridge regression, in contrast, the coefficients of correlated variables are shrunk to similar values; although the coefficients of some predictors might be very small, all predictors are retained in the model, which can make interpretation difficult.

Elastic net regression combines the advantages of ridge and lasso penalties using an additional tuning parameter α, $0 \leq \alpha \leq 1$:

$$penalty = (1-\alpha)/2||\beta||_2^2 + \alpha||\beta||_1.$$

Thus, $\alpha = 0$ is the ridge penalty and $\alpha = 1$ is the lasso penalty. With intermediate values of α, there is a 'grouping' effect in which strongly correlated variables tend to enter or leave the model together (i.e., have their coefficients set to 0).

In the main text, we used elastic net regression to fit a logistic regression model of each domain type (conceptual, motor, medicine) as functions of our other coded (binary) variables. Following standard procedure, we used 10-fold cross-validation to find the optimum value of λ, i.e., the one that minimized cross-validation error.

Description of our search query in the eHRAF

In the original Lightner et al. (2021) study, we collected text records from the electronic Human Relations Area Files World Cultures database while intentionally targeting those that reflect some kind of "[ethno]scientific expertise" in the ethnographic literature. Inclusion was therefore based on descriptions of specialized expertise in a potentially relevant conceptual knowledge domains, such as botany, zoology, meteorology, genealogy, traditional history, conflict resolution, wartime strategies, illness, disease, life and death, and physiology. Our exact search query, i.e., the set of

OCM codes and search terms that generated our initial results, was:

((Cultures = (Any Culture)) AND (((Subjects = ('173' OR '278' OR '571' OR '577' OR '578' OR '581' OR '582' OR '583' OR '584' OR '751' OR '752' OR '753' OR '757' OR '758' OR '759' OR '761' OR '802' OR '803' OR '804' OR '805' OR '810' OR '811' OR '812' OR '813' OR '814' OR '815' OR '816' OR '820' OR '821' OR '822' OR '823' OR '824' OR '825' OR '826' OR '827' OR '828' OR '829' OR '830' OR '831' OR '832' OR '833' OR '834' OR '835' OR '836' OR '837' OR '838' OR '839' OR '840' OR '841' OR '842' OR '843' OR '844' OR '845' OR '846' OR '847' OR '848' OR '860' OR '861' OR '862' OR '863' OR '864' OR '865' OR '866' OR '867' OR '868' OR '869' OR '875' OR '877')) AND (Text = (knowledgeable OR expert* OR proficient* OR skilled OR specialist* OR practitioner*)))))))

The initial results from the entire eHRAF database found 5734 paragraphs in 1901 documents in 311 cultures, and filtering Probability Sample Files (PSF) found 1595 paragraphs in 483 documents in 60 cultures. ADL read, contextualized, and filtered these remaining 1595 paragraphs to determine whether or not they were appropriate examples of ethnoscientific expertise, i.e., requiring high levels of culturally specific conceptual knowledge about the social and/or natural world. Text records that were included consisted of the focal paragraph from the results, and a contiguous set of paragraphs that provided context necessary for understanding the paragraph that turned up in the results. These are referred to as "text records" in our study.

Inclusion criteria

The *a priori* justification for including text records was based on whether or not some kind of "[ethno]scientific" expertise was described. We defined scientific domains in this context as conceptual domains where knowledge is ultimately acquired though observation, testing, and/or learning about natural and/or social principles, which in turn result in developing theories, either over the life course or via cumulative culture, that could potentially be usefully applied to a number of possible types of tasks or applications (e.g., crafts, healing, hunting, trapping, conflict resolution, or ethical quandaries). Crucially, we were searching for knowledge that is not specific to any particular use, but uses might recur because they are relevant to certain types of knowledge. For example, it is unsurprising that plant knowledge (ethnobotany) is frequently relevant to medicine, despite its potential uses in basket weaving. Similarly, animal knowledge (ethnozoology) is useful to hunting and trapping, but might not be limited to these activities alone. In other words, knowledge might be "for something", but what that "something" is was not the topic being queried. Rather, it is high levels of investment in the underlying knowledge (expertise) that were our outcomes of interest.

Filtering ethnomedical specialists

The protocol described above yielded 547 text records in 55 cultures from a wide variety of domains of ethnoscientific expertise. In our previous study, text records were coded on a large number of knowledge and skill domains (e.g., presence/absence of botanical expertise), with knowledge about medicine as the largest domain of expertise (present in 341 text records). Medicine was also frequently linked to other domains, such as botany, zoology, and healing injuries. To focus specifically on ethnomedical specialists in this study, we filtered the text records in our original dataset to only include those with specialized knowledge about medicine present.

Complete description of our coding scheme

Each text record was coded by two independent coders (ADL and CH) for each variable in our coding scheme, as described in the main text. Note that some variables in our dataset are evidence against variables in our coding scheme.

Categorical variables are indicated in the descriptions, and were coded as presence/absence for each category as a separate column/variable in our data matrix. This meant that multiple categories could be present in a single text record. For example, if male and female experts were both present in a text record, then we coded presence for both males and females.

Here are our coded variables and a brief description of each:

Text ID: Provides a unique key id number corresponding to a text record, citation, and OCM codes.

Case/model: Does the text record describe a specific case about an expert, a cultural model of expertise, or both? (*Categorical:* Case, model, both)

Age: How old are the experts described? (*Categorical:* Child/adolescent, Adult, Older adult/elderly)

Sex: What is the sex of the experts described? (*Categorical:* Male, female, either/both present)

Costly lifestyle: Does being an expert entail some kind of costly lifestyle, where the expert must fulfill certain obligations on a regular basis, making his/her life substantially more difficult than it would be otherwise?

Costly ritual: When applying his/her expertise (e.g., to perform a service, teaching), does the expert perform some kind of ritual (can be either public or private) in which s/he takes on some kind of cost, e.g., in the form of fitness, money, resources, pain, or risk?

Costly initiation: Does the expert perform some kind of initiation rite, in which s/he takes on some kind of cost (e.g., in the form of fitness, money, resources, pain, or risk) as a condition of being considered an expert by other people?

Expert teaches others: Do experts teach other people what they know? Does becoming an expert entail some kind of apprenticeship, mentorship, assistantship, or knowledge sharing, for example? The expert is described sharing his "know-how" (knowledge or skills) with others, which might or might not be exchanged for something else.

Expert purchases knowledge: Experts conferred a benefit to another expert in exchange for acquiring their knowledge/skill from another person.

Public performance: The expert demonstrates his/her abilities in a public setting, perhaps involving some kind of performance that is visible to others.

Private performance: The expert demonstrates his/her abilities or provides services to others in a private setting.

Experts compete: If multiple experts exist, then they are described as having a competitive relationship with each other.

Experts collaborate: If multiple experts exist, then they are described collaborating or as having a collaborative relationship with each other.

Distributed knowledge among multiple experts: If multiple experts exist, then their expertise is distributed across different roles or types of expertise, which do not strongly overlap with each other.

Hierachy within the domain of expertise: If multiple experts exist, then their expertise involves a hierarchical structure *among the experts* within a given domain, either in seniority among experts or level of skill. (This is not a reference to prestige in the broader community; it is strictly within-domain structure among experts, e.g., senior vs. novice specialists.)

Sexually attractive: The expert is described as being sexually attractive.

Charismatic: The expert is described as being charismatic.

Intelligent: The expert is described as, or has a reputation for being, intelligent.

Multiple mates: The expert has multiple mates.

Deference: People (non-experts or novices) are described as deferring to the expert by displaying signs of respect. (For example, this might include deferring to someone by paying them a respectful greeting, but would *not* include people simply deferring to a medical expert for medical advice.)

Prestige: The expert is considered prestigious, high status, and/or is well-respected in the community. This might include people who are generally paid more attention than others, but is distinct from reputation for efficacy (see below).

Others seek proximity to expert: Is the expert a preferred social partner (e.g., friend, coworker), or frequently/preferentially sought out for advice? Do people (non-experts) seek proximity to the expert, including for reasons that are not directly to the benefits or traditions relating directly to their domain of expertise?

Generosity: Is the expert generous, or does s/he have a reputation for being generous?

Mate fidelity: Does the expert have a mate who gives him/her exclusive sexual access? (Note: this one mostly comes up when violations/evidence against arise. It can include involuntary examples, such as cheating on partners, and voluntary ones, such as wife sharing among experts.)

Reputation as good parent: The expert has a reputation for being a good parent.

Parental investment: The expert is described conferring some kind of benefit to his/her offspring.

Provisions mate: The expert is described conferring some kind of benefit to his/her mate.

Narrow specialization: An expert or experts is/are described as having a narrowly specialized knowledge in their domain of expertise.

Broad generalist: An expert or experts is/are described as having a broad range of general knowledge, such as multiple domains of expertise (e.g., medicine, geography, and meteorology) or multiple unrelated specialties in a domain of expertise (herbal medicine, bone-setting, and childbirth).

Influential outside of area of expertise: The expert has influence over other people in domains outside of his/her domain of expertise. (Examples might include political influence, if the expert's domain is not related to politics, or trusted with medical advice if the expert's domain is not related to medicine.)

Evidence success: Evidence is documented by the ethnographer or his informant describing the expert as applying his/her knowledge or skill for a patron, and successfully bringing about an intended and/or desired outcome.

Evidence of failure: Evidence is documented by the ethnographer or his informant describing the expert as applying his/her knowledge or skill for a patron, but failing to about an intended and/or desired outcome.

Rationalizes failure: If, when applying his/her knowledge or skill for a patron, an expert fails to bring about an intended or desired outcome, s/he rationalizes the event in a self-serving way.

Secretive knowledge: An expert or experts is/are secretive about their knowledge or skills ("know-how"), and attempt to keep it hidden from (e.g., uninitiated) non-experts.

Assists with an uncommon and serious problem: Does the expert have patronage or clientele for their applied knowledge and/or services based on an uncommon and serious problem that arises for the patron (which the expert might be able to help with)?

Receives payment: Does the expert receive money or other material resources (e.g., gift or payment) for his/her applied knowledge and/or services?

Access to mates: Does the expert receive mates or sexual favors for his/her applied knowledge and/or services?

Patronage based on efficacy: Does the expert have patronage or a clientele for their applied knowledge and/or services based on an apparent expectation that the expert will bring about desired and/or beneficial outcomes for the patron? OR Does the expert have patronage or a clientele that is a consequence of the failure of another specialist? (Instead of costs, familiarity, or tradition, for example.)

Patronage based on social/economic considerations: Does the expert have patronage or a clientele for their applied knowledge and/or services based on costs, familiarity, interpersonal trust, and/or tradition?

Cares about reputation: The expert cares about his/her reputation and takes measures to present himself/herself in a positive and self-serving way.

Reputation for efficacy: The expert has a reputation for applying his/her knowledge in a way that can bring about desirable results for other people.

Possesses widely distributed knowledge: While the expert is highly knowledgeable in his/her domain (by definition), other "non-experts" in the community also tend to be fairly knowledgeable in the same domain.

Ornamentation: The expert wears some kind of ornamentation or body alteration that symbolizes to others his/her special status as an expert.

Supernatural: The expert invokes supernatural concepts in his/her theories of disease, appears to use supernatural methods to achieve some outcome, and/or relies on supernaturalistic models of the world to navigate his/her domain of expertise. Supernatural concepts include invisible agents, such as witches or ghosts, or processes that do not conform to the laws of nature.

Religious leader: The expert is described as a religious leader, such as a priest, or holds some kind of significant position/role in a religious group.

Acculturation: Does an expert/ do experts operate in a setting that involves substantial outside cultural contact and blending of new ideas, e.g., from Western cultures?

Examples of our coded variables

In this section, we include examples of text that would be coded as supportive for each variable in this study. Note that some of these might be multiply coded, i.e., some text records would also constitute evidence for additional variables, in addition to the variables for which they are illustrative examples.

Supernatural

> The co-operation of spirits can be obtained (1) mechanically, through spells, prayers, rites, and sanctified healing waters; or (2) personally and directly, when a debtera forces a demon into his presence and compels his assistance, or when a shaman allows a zar spirit to possess her. The nature of the connection between spirits and numerological instructions, special objects, and astrological-numerological reckonings (a combination especially used in preparing medicaments) is not understood by lay folk. . . . Magical directions are specific for each cure and are inherited with it. Any ecclesiastic can annoint sick people with sanctified healing waters. A shaman persuades zar familiars to provide information and influence other

sickness-causing zars. Debtera who have special powers can be either "demon-pullers" (ganel sabiy), whose powers come from demon familiars and magic, or minor debtera (tinish debtera), whose powers come from magic only.

Possesses secretive knowledge

The secret language follows the grammatical patterns of standard Trukese, but it is laced with cryptic distortions. Secret words, altered regular words, regular words with special meanings, and esoteric metaphors make this language incomprehensible to those who speak only standard Trukese. Masters of strategy use this language among themselves and in speeches at formal meetings. It is also the medium in which they preserve "significant history" (wuruwo), that is, history that justifies claims to valuables.

Parental investment

Knowledge of this kind is freely applied to the curing of a lineage mate or other close relative as a personal favor. Any one else, however, must pay in advance. The patient brings goods to the specialist and requests his aid. When cured, he is further obligated to the practioner and makes him a present. Such knowledge, then, not only has practical social value, but through its application can provide other forms of wealth for the specialist.

To this knowledge, too, the specialist's children and lineage mates have a claim. Without their permission, he may not teach it to another unless he receives compensation for it. For if the specialist teaches someone else, he dissipates the monopoly his heirs will someday enjoy and lowers their future earning power.

Costly initiation

Offers of help soon give way to competition as the established students come to regard him as a rival for the master's personal instruction and encouragement. To be the master's favorite means rapid advancement through the curriculum and a seat at his table. Without his patronship, a student is committed to years of physical misery, scraping to meet his subsistence needs, and paying his "tuition" in arduous and humbling ways, by gathering wood for the master's fire, tilling his garden, and washing the feet of the master and his visitors.

Assists with uncommon/serious problem

The ng'aka, therefore, is employed where a malady or misfortune is caused by something mysterious and inexplicable to ordinary people. He is consulted only on the advice of a diviner though... he may himself be the diviner.

Hierarchy w/in domain of expertise

Most adult men know something about the curing of minor ailments, but very few know how to cure serious illness. There is a graded series of curing techniques and only the most widely known shamans know all of them. Shamans are thus ranked according to their knowledge and abilities. Their powers are founded upon their knowledge of myths. Most adult men know a considerable number of myths but shamans differ from the rest in two respects: first, they know more myths, and secondly, they know and understand the esoteric meaning behind them.

Assists with a common problem

Wood for building purposes is felled when one comes across a suitable tree in the forest. . . . Carpenters keep wood stored at home. Some men are so interested in woodwork that they cannot make any conversation except about wood. An old man in Utsjoki called Tor'te-t seähtsi ("Uncle Spinning Wheel") had gathered so much wood in his home that he could hardly find room enough to sleep in. Boats and sleds require the longest time to prepare, but making a spinning wheel requires the greatest skill. Specialists in making spinning wheels have been known in Utsjoki since at least the middle of the previous century.

Broad generalist

A few people are experts in several different forms of special knowledge; some know one kind, and some know only fragments of one kind. Although everyone knows that many kinds of special knowledge exists, any particular type is important because few others share it.

Charismatic

Another reason why the Toradja are set on the treatment with kajoe sina by a Mohammedan is because he combines with his work all sorts of mysterious things, which are impressive. With great ostentation the medical expert pronounces a magic formula over the pot, and if the sick person recovers, then he ascribes this more to the power of this formula than to the effect of the medicine.

Reputation for efficacy

When a somewhat more complicated disease develops, one has recourse to the known herbal specialists. These specialists. . . have become known for their general skill or perhaps for success in treating special diseases.

Receives payment

> The patient pays the doctor a fee, usually tobacco and some common article, but one person charges a fee of $5.00 per treatment.

Knowledge domain is not widespread

> There are types of special knowledge relating to medicine and curing, house and canoe construction, navigation, sorcery, divination, and fighting. In general, only older people have special knowledge. ... Not everyone in the older generations possesses special knowledge. It is carefully guarded from outsiders and can only be learned from a close kinsman, or purchased at considerable expense from a non-kinsmen.

Deference

> There are types of special knowledge relating to medicine and curing, house and canoe construction, navigation, sorcery, divination, and fighting. In general, only older people have special knowledge. ... Not everyone in the older generations possesses special knowledge. It is carefully guarded from outsiders and can only be learned from a close kinsman, or purchased at considerable expense from a non-kinsmen.

Knowledge domain is widespread

Laymen have little difficulty in selecting an appropriate kind of wogeysa , since the ailments treated by each category of wogeysa are characterized by unambiguous syndromes which are easily identified by laymen.

Costly lifestyle

The agamiy exposes himself to certain dangers in the performance of this therapy. Because he must remove a pathogenic substance through the medium of the sickman's blood, there is the danger that, should any of the blood enter his own mouth, the agamiy may himself fall ill with the ailment he is treating. In addition, contact with this blood threatens those chronic ailments from which the sickman suffers (such as the rheumatoid pains associated with kitin, syphilis).

Public performances

The wabeno was a highly honoured public official, in a sense, for he was the servant of his community, even though he was entitled to charge a fee for his services. Since his prestige depended partly on his popularity he generally gave a public feast and dance whenever a patient paid for the remedy that dispelled his sickness, or a hunter offered fitting compensation for the medicine that had delivered the game into his hands.

Costly ritual

At intervals in the dances one of the medicine-men might drum and dance alone around the fire, then, stooping, pick up from the embers a hot stone; or he might dip his fingers into a boiling cauldron, extract a piece of meat, and swallow it without evidence of pain. Some Indians say that he derived these powers from the medicines he rubbed on his hands, and that although he neither ate nor drank for four days and four nights previously, his strength remained totally unimpaired.

Knowledge distributed/multiple experts

Knowledge of magic and privileged access to spirits is distributed among four categories of people: herbalists, ecclesiastics, shamans, and debtera. Most herbalists incorporate some magic into their recipes. The rural herbalist is usually a farmer, indistinguishable from his fellows except for his curing. He is known to his public by his ability to treat a specific, named ailment, and his professional title indicates only his disease name specialty and his degree of proficiency, e.g., "expert curer for body ulcers." Few herbalists offer therapies for more than three or four ailments.

Influential outside of area of expertise

Throughout these years, the intellectuals, as literati associated with the court (and often the court itself: some of Thailand's greatest poets and dramatists were kings) helped maintain, develop, and glorify this civilization, but not change it radically.

Evidence of success

Besides the priestess, in each village there are several men and women about whom it is known that for certain indispositions they are familiar with a remedy that has already been applied with success many times. Such a person is then asked to come to try his skill on the sick person.

Evidence of failure

Having two types of medical practice at one's disposal is not always an unmixed blessing, however, since the decision that an illness is natural or supernatural may be, or may be held to be, influenced by external circumstances. A case in point is the following which happened to a very poor family in Hsin Hsing. The parents were no longer young and already had three daughters and a small son when another daughter was born. Before the infant was named (naming takes place on the ninth day and is, in effect, when an infant becomes human) she became quite ill. Instead of calling in a practitioner of Western medicine, which many villagers insisted they would have done first, the family chose to consider the illness supernatural because the baby was not yet nine-days-old. They called in one shaman, and then another. Despite their efforts, the infant died. Under the traditional ideas the death was attributable to the will of the gods, and the family had done all it could do.

Experts collaborate

Every tagañ owns a recipe for an unguent, and the medicaments used in it are kept a professional secret. However, not all tagañs have recipes for kusil prophylaxis. Without the latter, a tagañ who wishes to treat compound fractures must obtain the services of an herbalist whose specialty is the treatment of kusil.

Experts compete

In their social role, midwives felt personal but not group solidarity. A solid bond existed between an older midwife and the particular younger one to whom he or she had given training and magic. . . . The expert who brought mother and baby through before the deposed midwives glowed inwardly with pride and skill and satisfaction that the magic of his particular teacher had proved effective. The sharpness of the competition reverberated through the words, "I pushed the other midwives down." Community standing or "face" was not lost by an unsuccessful case because of the midwives' fundamental role as helpers only, their faith in their own experiences, and again, the conviction that the course of childbirth was merit-determined.

Reputation for generosity

These first abinet [esoteric skill] are generally gifts from student friends . . . Among these companions favors are expected to be freely given and no formal accounting is made. Beyond this circle all students are implicitly rivals (towdaderiy). Another source of abinet at this time is some older, more knowledgeable student. Here, the relationship between donor and recipient is framed as an exchange between a patron (radat) and his client (taraj), a customary dyad contrasting power with dependency, and generosity with deference. The new boy appeals that he is abject and threatened by mortal dangers; the donor, by his gift, publicly asserts a status difference which sets him off from novices in general.

Patronage based on efficacy

There is no particular problem with illnesses which can be clearly diagnosed as natural or supernatural. But there are many cases in which the diagnosis is not so easy or clear-cut. Mainly, the villagers rely on past experience to tell them which set of symptoms indicates which category of illness, and thus which kind of practitioner to call in. Naturally, there are considerable variations among the villagers themselves which may predispose a decision in one direction or the other – level of education, amount of experience, financial ability, and even types of social pressure. As one would expect, the actual availability of drugs and doctors affects choice. In recent years the dependence upon Western medicines and Western-oriented doctors has increased as a result of the increased supply of both at relatively low cost. The ease of access to antibiotics and patent medicines, their effectiveness, and the doctors' record of successes have given confidence in Western science, with the result that it is common today for the villagers to turn to Western methods first for most illnesses.

Patronage based on social/economic reasons

Though the poor felt the 20 to 30 baht cost of a midwife was too expensive, and so utilized the free help of a compassionate kinsman (usually the mother) or neighbor, the latter sometimes were as expert manually as a midwife or even on their way to becoming one.

Intelligent

Certain natives, served by a good memory and a livelier intelligence, took an interest in these traditions and legends to the extent of learning those of neighboring families and even of neighboring kingdoms and little by little acquired a reputation as specialists in these matters.

Multiple mates

First, by being a powerful ritual specialist, Roberto had political influence and social prestige in society. Therefore, he could claim a woman in exchange for his ritual services. Secondly, he knew well that Eulalia was the only child of an old, widowed and remarried man in the headwaters area of the Goya stream ... Alberto, who indeed cared for Eulalia as for a proper sister, was indebted to Roberto and dependent upon his ritual services. So they could do nothing but accept the marriage. In this way, Roberto took Eulalia as his second wife and became one of the few polygynous men in the territory.

Narrow specialization

Aymara medicine is highly specialízed, and consequently has a great many different categories of practitioners. ... It is probably safe to say that no other primitive group known to modern ethnology has such a rich specialization among practitioners of native medicine.

Ornamentation

> As soon as possible, the patient's family presents the principal specialist with a string of multi-colored glass beads, which he places around his neck for the ceremony to follow … The multi-colored bead necklaces are frequently worn by snake medicine men even when they are not working on a case, and serve as identity badges.

Prestige

> In fishing, especially deep-sea fishing, and in some other crafts, knowledge of the technical processes and of the associated ritual is unequally distributed. … One effect of the possession of such knowledge lacking in others is the opportunity of enlarging one's resources. This is done by resort to fishing banks not commonly known, or use of a special technique at times when the fish refuse all others; or, in the case of a craftsman, by more prompt replacement of his implements, or by gaining goods in payment for his work for others; or to a small extent by the securing of a material return for the imparting of his knowledge to others. Important as an inducement to the acquisition of such personal knowledge, however, is the prestige that it obtains.

Private performances

> There is no particular moment that is better than any other for infor-

mal conversation about genealogies, except that people are most likely to want to discuss genealogy when they are contemplating a marriage, considering litigation that involves genealogical claims, or asking for financial assistance or political support on grounds of kinship. The conversation usually occurs inside the hut or room of the person whose genealogy is being discussed. The occasion is quite private, and other griots are not likely to attend.

Provisions mate

When, as a result of a different political structure, Ogobara was no longer “canton chief”, the village secretary was obliged to look for other occupations. He went to Bandiagara and in the hospital there began a course in male nursing. He lives there in the family house and provides for his two wives and his children who have stayed with Ogobara’s family in Sanga.

Mate access for expertise

Most of the bridewealth and other marriage expenses are waived and the girl is given to the husband by those having authority over her marriage dispensation rights … A man may wish to express his gratitude to a mallam for supernatural aid having to do with medicine, prayers, or divination used by the practitioner for the benefit of the group bestowing the girl. In the same way, most individuals having power to bestow a girl would hesitate before refusing the request of a mallam because of the general awe in which he and his supernatural powers are held in the public eye.

Wealthy

The ideal type [of specialist] is a person of respectfulness, bravery, and strong thought who also controls abundant valuables.

Sexually attractive

Some experts may use the DixBo'ne [ritual object] on their own account, in which case they become irresistible to all women in the village. Informant mentioned the name of an individual who was an exceedingly successful love expert on his own account.

Others seek proximity to expert

If the professor wants to discourse on the domain of a particular spirit residing in the jungle, he will do so, and on his own time. If he wants to collect medicines one day, the student may follow along. And if he decides to pass on some esoteric information about the plants being gathered – or if he decides not to – that is the way things will happen.

Expert teaches others

When a young Kuna becomes a disciple of an experienced curing specialist he places himself in a thoroughly submissive position with regard to his teacher. Once the branch of knowledge he wishes to learn has been decided upon and fixed, the specialist controls the manner in which instruction proceeds, the sequence in which all knowledge is passed out, and the topics to be discussed during each session ... When learning proper begins, the student characteristically listens attentively to a short portion of a chant several times, then is told to repeat it. When he has mastered this task adequately, another piece of the chant is given to him in the same fashion, and he repeats it. On and on it goes until the entire chant has been learned. As the student progresses and demonstrates his capacity for learning he is given information or symbols and their underlying meanings, commentaries on the nature of curing and disease in general, and instruction in accompanying ritual. Such information is conveyed to the student either by demonstration or verbally.

Acculturation

The public health worker is in a position to inherit some of the awe felt for the learned dabtara, especially since the health teams operate out of centers which provide therapy as well as instruction, which gives them the benefit of association with the quasi-magical powers attributed to one who performs successful treatment. In addition, he can be aided by the Amhara peasant's personal devotion to someone who has helped him and won his confidence. Whether this devotion can be stimulated depends, in the last analysis, on the character and resourcefulness of the public health workers themselves. Those who are able to communicate in a dignified manner with the peasants, who avoid dealing with them as an inferior and backward people, who refrain from flaunting the most important local norms, and who are on good terms with local authorities and respected men, have a substantial chance of being accepted after an initial period of suspicion and alienation. Thus it was that a Gojjami peasant, asked why some of the local people were hearkening to the advice of the public health team at Dabra Marqos, explained: "We have come to realize that what you tell us to do is for our own advantage, not yours." Elsewhere in Gojjam, a similar response was the eventual issue of a more pronounced initial rejection of public health workers. In the village of Dajan doors were closed against a venereal disease team which was taking blood samples of the entire population for Kahn test analysis. Popular suspicion was voiced in a number of ways; the health workers were accused of selling blood, of being missionaries, and of otherwise trying to cheat the locals. The health officer in charge of the team then brought some of the objectors to the mobile laboratory, patiently explained what was going on, and how it would benefit the people. Before long word got around that these outsiders were not so evil after all, and the doors of Dajan opened.

In Ceylon, modern medicine whether it is indigenous or Western, has been institutionalized so that there are schools, certificates and centers for the practice of medicine. The village ayurvedic physician who is not associated with the institutions of modern medicine emerges in the hierarchy as a second rung specialist. It is not simply the fact that he is associated with a traditional 'science' and not Western medicine that calls his authority into question. There is general confidence in ayurvedic medicine, and the Ceylon government gives official encouragement to its practice. It is rather that the village specialist either is a successful apprentice to another local practitioner, perhaps to an older, more experienced close relative, or is in some cases even self-taught. His 'science', on the other hand, has become institutionalized along the lines of Western medicine and has adopted some of its practices.

Imposes costs on others

Trobrianders believe in spirits who reside in the bush who cause illness and death but the greatest source of fear is sorcery. Only some people are believed to have the knowledge of spells that will "poison" a person and such experts can be petitioned to exercise their power for others. Counterspells are also known; chemical poisons obtained from elsewhere are thought to be prevalent.

Religious leadership

Treatment of disease and injury [colds, flu] may involve many distinct techniques. There are a great variety of professional medical practitioners such as Western-style doctors, traditional Chinese doctors, various folk specialties such as acupuncture, different shamans, and temple priests who furnish charms to drink.

Learns by revelation

The kusabindugeyu were primarily seers, gifted by their adolescent visions to discern what was normally hidden from human eyes. Most of them claimed to derive their power from thunder, but during the winter months, when thunder had retreated far to the southward (thunderstorms are exceedingly rare in Parry Sound during the winter) they summoned other manidos to aid them in their rites, principally perhaps a small owl (kokoko) and the whip-poor-will (waholi).

Interrater reliability

Our dataset was coded independently, using the coding scheme described above, by the first author (ADL) and second author (CH) on this study. After the independent coding phase, we checked the interrater reliability and reported these as percentage agreement in our data matrix (85.5%) and Cohen's kappa (0.49) in the main text. An agreement plot visualizes our level of agreement, prior to reconciling the differences in our codes (figure C.39). After the independent coding and interrater reliability analysis, ADL and CH went through each disagreement of each text record and agreed on how they should be reconciled.

C.2 Supplementary results in Study 1

This section outlines additional exploratory results from the cross-cultural study, based on data from the eHRAF and, in a few specified cases, from the SCCS.

Generalized linear mixed models based on cross-cultural data

We use a generalized logistic mixed model (GLMM) to model our PCA results (PC1: culture complexity and scale; PC2: pathogen stress, proximity to equator, and lower reliance on market economies) as predictors of presence/absence of super-

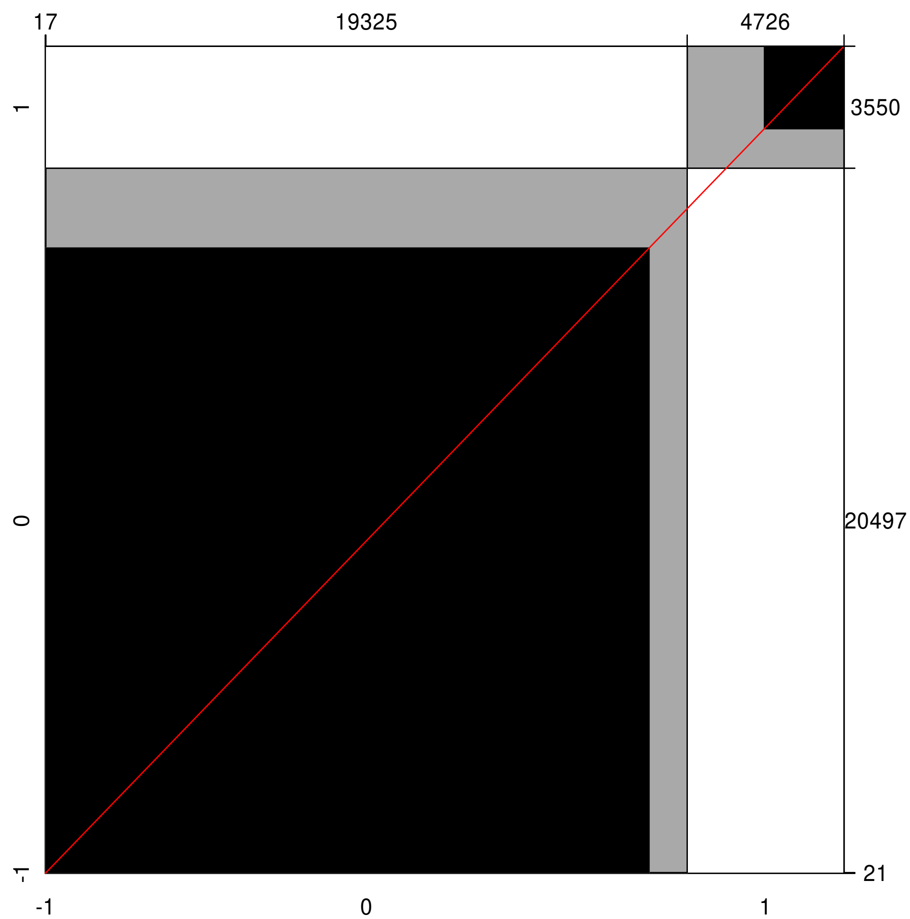

Figure C.39: Agreement plot showing the proportions of agreement between the two independent coders (ADL and CH). The dark spaces represent the proportion of agreement for the presence and absence of all aggregated variables in the entire dataset, and the gray spaces represent the proportions of disagreement for presence and absence.

natural theories of disease in the text records, with cultures as random intercepts. We found a "statistically significant" result, in which PC2 was positively associated with supernatural theories of disease, and PC1 was not clearly associated with the supernatural. See table S1.

Table C.20: Generalized logistic mixed model results for supernatural theories of disease predicted by the first two principal components from a cross-cultural PCA of the SCCS data. Estimates are log odds, with standard error in parentheses.

	Dependent variable:
	supernatural
pc1	−0.03
	(0.04)
	p = 0.53
pc2	0.27
	(0.08)
	p = 0.0003***
Constant	1.11
	(0.14)
	p = 0.00***
Note:	*p<0.05; **p<0.01; ***p<0.001

This result, though interesting, should be viewed with skepticism. PC1 consists of cultural complexity variables, such as urbanization, population size and density, and cash- and market-based economies. PC2 consists of three underlying types of variables: Pathogen stress, proximity to the equator (absolute value of the latitude), and a low reliance on cash and market economies. An explanation that might *seem* compelling, and is consistent with our hypotheses in the paper, is that pathogen stress is a key driver of supernatural theories of disease.

As we state in the main text, however, we can not draw this conclusion based on the association between PC2 and the supernatural, because pathogen stress is confounded by other contributing factors to PC2, such as latitude and cultural complexity. In fact, PC1 and PC2 are sufficiently related that we cannot even draw a firm conclusion about the apparent lack of effect of PC1 on the supernatural.

To see this, notice in table S2 that if pathogen stress is the sole predictor of supernatural, then as we might have expected, we find the weak positive association between pathogen stress and supernatural theories of disease. Adding latitude as a predictor, however, makes the effect of pathogen stress disappear. This is perhaps unsurprising; pathogen stress might be higher in tropical climates than in temperate ones. And yet, further complicating matters, adding PC1 (cultural complexity and scale) thereafter makes PC1 appear to have a significant negative effect on supernatural theories. See table S2.

This is not to suggest that our analyses of PC1, PC2, and supernatural theories of disease is completely uninformative (quite the contrary). However, it does suggest that, as we conclude in the main text, confirmatory research is needed to directly

Table C.21: Generalized logistic mixed model results for supernatural theories of disease predicted by the first two principal components from a cross-cultural PCA of the SCCS data. Estimates are log odds, with standard error in parentheses.

	Dependent variable:		
	supernatural		
scale(pathogen_stress)	0.24	−0.01	0.20
	(0.14)	(0.23)	(0.24)
	p = 0.10	p = 0.99	p = 0.42
scale(latitude)		−0.29	−0.37
		(0.22)	(0.22)
		p = 0.19	p = 0.10
scale(pc1)			−0.37
			(0.18)
			p = 0.05*
Constant	1.06	1.07	1.08
	(0.15)	(0.15)	(0.13)
	p = 0.00***	p = 0.00***	p = 0.00***

Note: *p<0.05; **p<0.01; ***p<0.001

test the hypothesis that pathogen stress is associated with supernatural theories of disease.

C.3 Supplementary results in Study 2: Maasai field data

This section outlines additional data and results from the Maasai fieldwork study.

Participant examples of conflict between science and religion

Some Maasai participants ($N = 12$) agreed that scientific ideas sometimes conflict with their beliefs about god or religion. All of these participants were Christians. When asked as a follow-up question to give an example of how this might be the case, some (but not all) participants offered an example. The following quotations are examples of responses that were transcribed during interviews:

> There may sometimes be "satanic emotions" in wise or educated people.

> For example, if doctors say that someone is HIV-positive then they will say that you have to take this medicine and that you might die. The person might start to worry that they will die and have fear because of what the doctor said to them. But the person who believes in god can pray, and it is the prayer, not the medicine, that will make them better.

> Sometimes scientists say there is no god, which I disagree with.

> Science says that there is no god, but we believe differently. The scientists and doctors will not be disturbed by this if they have faith in god also.

> Sometimes I disagree with scientists and teachers if they might say, for example, that there is no god.

> I will sometimes disagree with doctors or scientists if they do not think that god exists or if they are not Christians. But this does not happen if they separate those beliefs with their work.

> My beliefs in god sometimes make me disagree with scientists; unbelievable things in the world are not man-made, but are made by god. Doctors do good things by treating other people though.

Mosaic plot of preferred specialists for serious illnesses

As we show in the main text, participants overwhelmingly preferred to use the clinic in cases of serious illness, though many also preferred to use either friends, family, or religious specialists. We reported these preferences in the main text by religious identity. Here, we include them in the aggregate to show how strongly the clinic was preferred overall, and how religious options (the church and the laibon) both slightly increased after the first option would hypothetically fail. The clinic was the most popular first option, but as seen in the main text, some participants defaulted initially to family and friends as their first option, but fell back on the clinic as their second option. See figure C.40.

PCA results for explanations of how herbal medicines work

After coding for presence/absence of content features of each participant's explanation of how a common herbal medicine works, we concluded based on visual inspection of the heatmap (figure 14 in the main text) that people were broadly divided into "don't know", "knowing when/how to make the medicine", and and "mechanistic" explanations that use substance and essence terms. We also conducted a PCA on the binary data matrix of these responses. PC1 showed that participants who did not know how the medicine worked, and/or did not have a working model of the mechanisms by which the medicine worked, tended to be associated with explanations invoking the conditions under which a person should prepare the medicine, whereas explanations tended to invoke substances, essences, and physiological terms. See figure C.41.

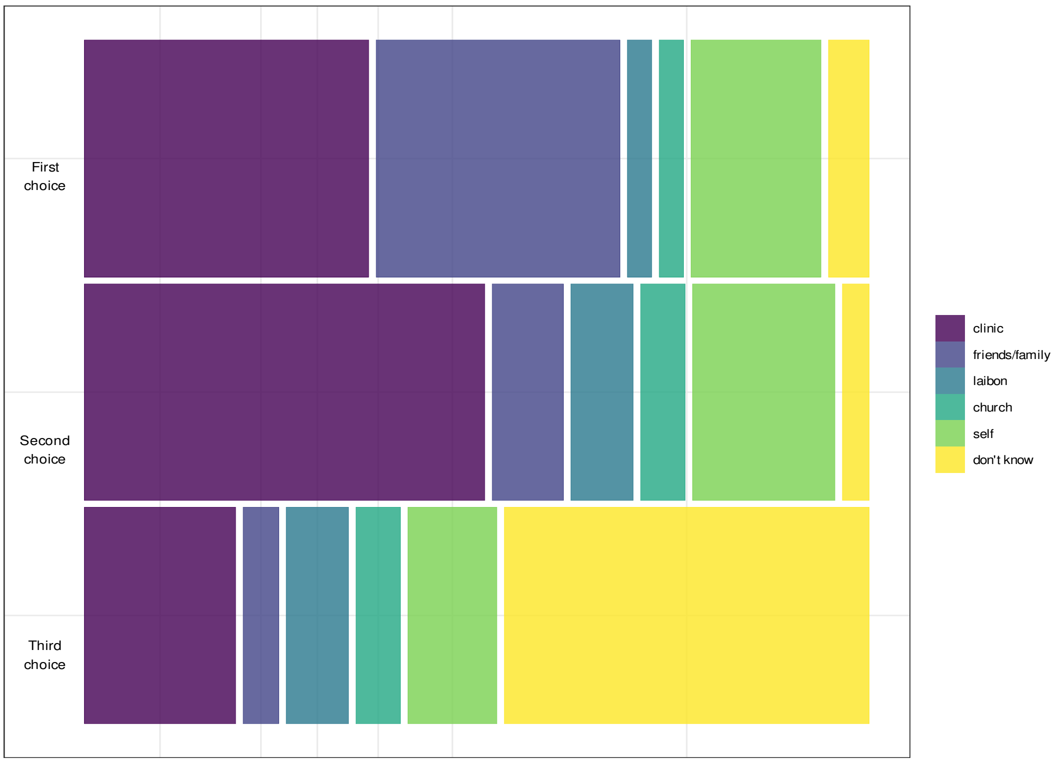

Figure C.40: Mosaic plot of the proportions of participants who identified different types of specialists as their first, second, and third choices to help them in the case of having a serious illness. Colors represent categories of responses given by participants in each option.

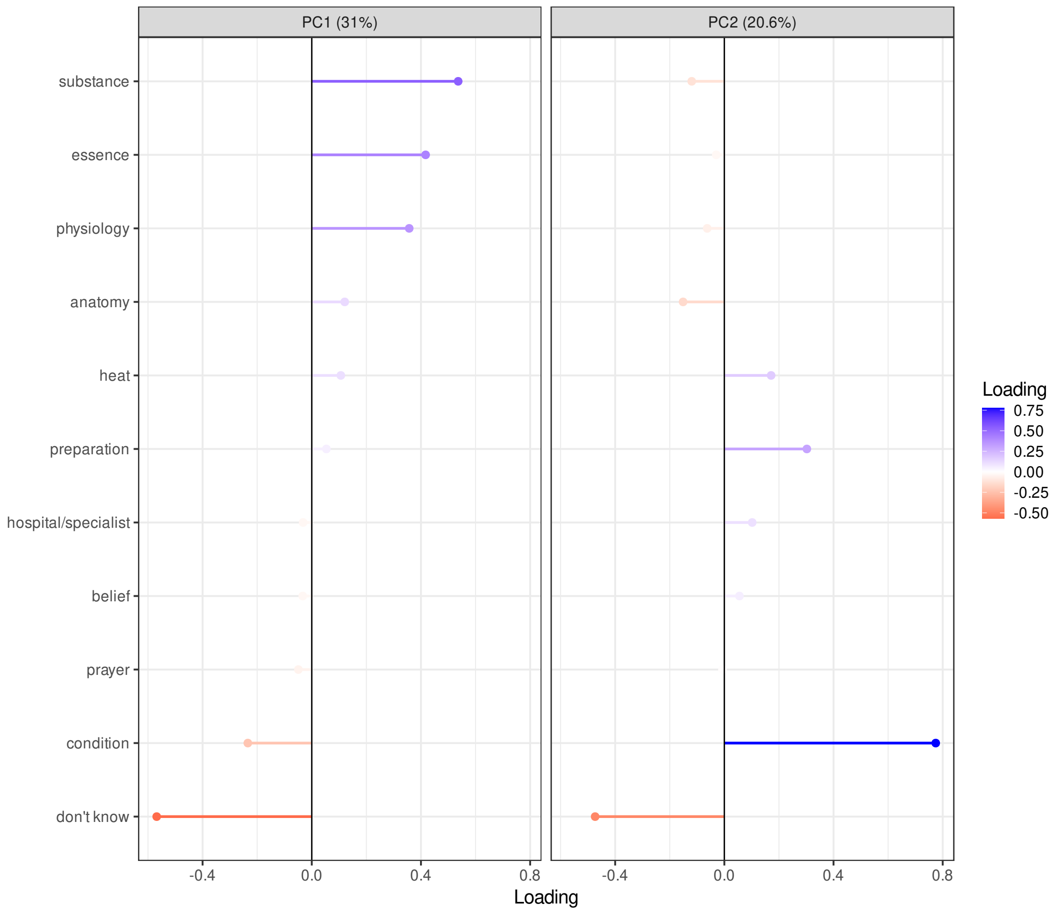

Figure C.41: PCA loadings on the first two principal components in the explanations of how herbal medicine works among Maasai participants. PC1 corresponds to knowledgeability and detail of explanation, and PC2 corresponds to the necessary conditions and preparation steps for making the medicine.