

The Origins of Superstition: Environmental Volatility and Magical Beliefs

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Abstract

This paper provides a global quantitative test of the ‘Malinowski Hypothesis,’ arguing that uncertainty drives the cultural evolution of magic as a cognitive adaptation to manage environmental risk and restore perceived control. We construct a Magical Intensity Index from the Folklore database, covering 1,219 traditional societies worldwide. We find that fishing societies exposed to storms, or agricultural societies exposed to higher precipitation variance, drought risk, and flood risk exhibit more magical folklore. Consistent with a risk-coping mechanism, the effect is absent for love magic, amplified by soil texture, and mitigated by irrigation. In a subsample of historically relocated societies, agricultural magic is more closely associated with current local volatility than with ancestral conditions, suggesting that superstition serves as a functional institutional response to risk. These results help explain why non-evidential beliefs remain resilient features of human culture during periods of heightened insecurity.

Keywords: Uncertainty, Superstition, Environmental Volatility, Belief Formation, Folklore

JEL Classification: Z12, D81, Q54, O17

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1 Introduction

“La magie a bien l’air d’être une gigantesque variation sur le thème du principe de causalité.” [Magic gives every outward appearance of being a gigantic variation on the theme of the principle of causality.]

— Henri Hubert & Marcel Mauss

Understanding how uncertainty shapes belief formation is a central challenge in social science. Periods of heightened uncertainty, such as economic crises, pandemics, or natural disasters, are often accompanied by the proliferation of beliefs that emphasize hidden causation, intentional agency, or forces beyond individual control. Contemporary discussions frequently focus on phenomena such as conspiracy theories or resistance to scientific expertise during crises, yet empirical evidence on the deeper origins of these responses remains limited. In particular, it remains unclear whether such beliefs are idiosyncratic features of modern information environments or manifestations of a fundamental cognitive default that links uncertainty to causality.

A long tradition in structural anthropology argues that ritual and magical beliefs arise as functional responses to uncertainty, particularly when outcomes are consequential yet only weakly controllable by individual effort. In his seminal work, [Malinowski \(1922\)](#) observed that ritual practices among the Trobriand Islanders were closely associated with high-variance activities such as deep-sea fishing, while being largely absent in predictable settings such as lagoon fishing. This functionalist interpretation extends beyond anxiety reduction to encompass explanatory completeness as well. As [Evans-Pritchard \(1937\)](#) famously articulated with the concept of the ‘Second Spear,’ magic provides the causal link that explains the timing and incidence of misfortune (e.g., why a granary collapses exactly when a specific person sits under it). Magical beliefs are not symptoms of confused thinking, but rather a ‘technology of the mind’: a means of rendering irreducible uncertainty cognitively and socially manageable ([Malinowski, 1948](#)). This perspective implies that beliefs invoking su-

pernatural intervention should be systematically related to environmental volatility, rather than to poverty, ignorance, or general cultural traditionalism.

While anecdotal evidence is plentiful (e.g. [Mendoza, 2024](#)), testing this hypothesis quantitatively has historically remained elusive due to the absence of systematic data on cultural beliefs. This paper addresses that challenge by constructing a novel measure of magical belief intensity across 1,219 traditional societies. Leveraging the Folklore database ([Michalopoulos and Xue, 2021](#)), which systematically catalogs the oral traditions of pre-industrial groups, we employ natural language processing techniques to identify motifs explicitly related to productive magic, including divination, protective rituals, and supernatural interventions aimed at managing environmental risk. We then normalize the frequency of these motifs to generate a society-level index that is distinct from general storytelling intensity or the volume of ethnographic recording for a given society.

To validate this measure, we complement the NLP approach with an independent classification using a large language model (GPT-4o-mini), which reads each motif’s entire description and classifies it along structured dimensions of risk context, functional magic, and mechanism type. A blind validation exercise in which two independent human coders classified stratified random samples using the identical schema yields a pooled human–LLM agreement rate of 79%. Results are similar across the NLP and LLM classification approaches, mitigating concerns that the findings are driven by any particular coding scheme. By focusing on folklore, an expressive cultural domain relatively insulated from strategic political or institutional incentives, we obtain a tractable way to study belief formation under uncertainty.

To operationalize environmental risk, we combine the folklore data with detailed historical weather records spanning four decades, which allow us to construct detailed measures of climatic volatility at the ethnic group level. Using daily data on rainfall, temperature, and wind, we capture multiple dimensions of environmental risk, including inter-annual variability, the frequency of extreme events, and the persistence of adverse conditions such

as deluges, heatwaves, or prolonged dry spells. Focusing on volatility rather than mean climatic conditions, we examine whether societies exposed to greater environmental risk place systematically greater emphasis on magical and supernatural motifs in their expressive culture.

According to functionalist anthropology, this cultural response should be tailored to a society’s specific material vulnerabilities and subsistence strategies: agricultural dependence should amplify the link between precipitation variance and weather magic, just as reliance on fishing should condition the link between storm frequency and protective rituals.

Consistent with the Malinowski hypothesis, we document a robust positive relationship between climatic volatility and the reliance on functional magic. The effect is economically meaningful: in the preferred specifications, a one standard deviation increase in precipitation volatility raises agricultural magic by roughly 8–9 percentage points more in societies that are more dependent on agriculture, an effect equal to nearly the entire sample mean of the NLP agricultural magic index. A comparable increase in scorch risk raises agricultural magic by about 12–15 percentage points. This pattern is driven specifically by motifs related to productive interventions, protective rituals, and divination, practices explicitly aimed at managing stochastic outcomes. The results hold across multiple metrics of environmental risk, including the coefficient of variation in rainfall, scorch events, flood risk, and the incidence of extreme dry spells, and are robust to controlling for mean climatic baselines. This specificity suggests that the volatility-magic gradient captures a targeted response to environmental variance, rather than a proxy for general climatic harshness.

To further ensure these findings capture a targeted adaptation to environmental risk instead of a generalized increase in superstition or cognitive load, we implement a placebo test examining expressive motifs unrelated to productive uncertainty. If climatic volatility induced a uniform societal shift toward magical thinking, we would expect an observable rise in ritualistic narratives across all domains of life. To evaluate this alternative hypothesis, we examine the prevalence of love magic, capturing spells and interventions associated with

courtship, jealousy, and marriage. Because precipitation variance and weather shocks do not mechanically alter the uncertainty of romantic outcomes, environmental risk should have no direct functional relevance in this domain. Consistent with a specific risk-coping mechanism, we document a precise null result: environmental volatility is statistically unrelated to the intensity of love magic across all specifications. This suggests that pre-industrial populations do not simply adopt generalized superstitious frameworks during periods of environmental stress, supporting the functionalist interpretation.

We extend these findings using medieval paleoclimate reconstructions of the Palmer Drought Severity Index (PDSI) drawn from historical drought atlases spanning the period 1100–1400 AD. This pre-colonial window offers two advantages: it captures climatic conditions temporally closer to the formation of oral traditions recorded in the Folklore database, and it provides variation that is plausibly independent of modern economic or institutional development. Societies whose current territories experienced greater PDSI volatility and more frequent extreme droughts during this period exhibit substantially higher levels of agricultural magic. In terms of magnitude, these paleoclimatic results are comparable to the contemporary baseline findings: in the fully controlled LLM specification, the key interaction remains on the order of 12 percentage points, reinforcing the interpretation that environmental risk, not merely contemporary weather measurement, drives the observed relationship.

We next probe the interpretation of these findings through a series of heterogeneity and falsification tests motivated by the underlying theory. First, we isolate locally mediated material risk from pure weather events by interacting environmental volatility with additional geographic characteristics. Specifically, we exploit soil texture, defined as the local composition of sand and clay, to examine how physical endowments naturally amplify or dampen the impact of extreme rainfall. Clay-heavy soils, characterized by poor drainage and high water retention, increase the vulnerability of crops to waterlogging and root asphyxiation during intense deluge events. Consequently, high soil clay content exacerbates

the relationship between flood risk and agricultural magic. Conversely, highly permeable sandy soils allow excess rainfall to dissipate, acting as a physical buffer that mitigates this relationship. These interaction effects are economically meaningful: for farmers cultivating clay-heavy soils, a one standard deviation increase in flood risk nearly doubles the predicted intensity of magical beliefs, whereas for farmers on sandy soils the corresponding effect is roughly halved.

Second, we examine whether the relationship between climatic volatility and magical beliefs is conditional on physical exposure, testing the substitution hypothesis that tangible technologies can crowd out the psychological demand for ritual control. If agricultural magic functions as a cognitive adaptation for managing unmitigated environmental variance, physical infrastructure that directly neutralizes these threats should reduce the marginal utility of functional superstition. To test this mechanism, we focus on societies that practice irrigation, an agricultural technology that provides direct physical control over water supply by storing rainfall during wet periods to buffer against dry spells. Consistent with technological substitution, we document that the presence of irrigation infrastructure mechanically decouples crop production from immediate precipitation variance and attenuates the link between rainfall volatility and magical beliefs. In the preferred LLM specifications, irrigation reduces the precipitation-volatility interaction by roughly 4–5 percentage points, about one-third of the baseline effect.

Lastly, to try and disentangle whether magical beliefs are adaptations to current environmental risks or persistent cultural traits inherited from ancestors, we implement an epidemiological strategy focusing on migrant societies. By restricting our sample to groups currently located more than 500 km from their linguistic homeland (or *Urheimat*, the reconstructed ancestral territory of a language group), we weaken the correlation between ancestral and contemporary climates. In this migrant sample, agricultural magic is more closely related to current agricultural risk than to Heimat risk (i.e., the climatic risk at the ancestral location). In a horse race regression, current precipitation volatility, scorch risk, or

medieval paleoclimatic risk enter positively, while the corresponding Heimat risk is generally statistically indistinguishable from zero. These results seem to suggest that farmers discard (invent) functionalist rituals when moving to stable (volatile) environments.

These historical patterns offer a new lens through which to view the contemporary puzzles regarding belief formation introduced at the outset. If magical thinking is partly a functional adaptation to environmental volatility (i.e., a cognitive strategy for imposing causal order on stochastic outcomes), it suggests that the cognitive demand for agency and causality remains potent in modern high-variance settings. The proliferation of conspiracy theories or the rejection of probabilistic explanations during crises may be modern manifestations of the Second Spear: attempts to impose narrative order on stochastic threats. By quantifying this relationship in pre-industrial societies, our findings are consistent with the view that the impulse to assign hidden agency to chance events is a deep-seated feature of human psychology, activated by exposure to individually uncontrollable risk.

Related Literature. This paper contributes to the growing literature in economics that studies the deep determinants and persistence of cultural traits. A large body of work documents how historical, geographic, and institutional factors shape contemporary cultural values, beliefs, and behaviors, with lasting economic consequences (e.g., [Nunn, 2009](#); [Alesina and Giuliano, 2015](#)). While early contributions focused on the agrarian origins of gender roles or patience ([Alesina et al., 2013](#); [Galor and Özak, 2016](#)), later work has isolated the role of environmental risk and disease in shaping social trust, cooperation, and moral universalism ([Enke, 2019](#); [Bugge and Durante, 2021](#); [Giuliano and Nunn, 2021](#)), including how specific subsistence activities generate lasting cooperative norms ([Gneezy et al., 2016](#); [Zhou et al., 2023](#)). This evolutionary perspective is further grounded in evidence that historical environmental volatility and Malthusian constraints forged deep-rooted cultural traits, such as loss aversion and long-term orientation ([Galor et al., 2018](#); [Galor and Savitskiy, 2018](#); [Galor, 2022](#)). More recently, a strand of literature has developed that empirically tests an-

thropological theories of social structure and belief (Moscona et al., 2020; Cao et al., 2021; McGuirk and Nunn, 2024).

Within this domain, we speak directly to the economics of superstition (Miguel and Gugerty, 2005). Gershman (2015, 2016) establish the economic origins of the evil eye and witchcraft, linking them to envy, inequality, and the erosion of social capital, while Gershman (2022) extends this analysis globally. We complement this focus on social friction by isolating environmental uncertainty as a distinct driver. This mechanism is similar to that explored by Espín-Sánchez et al. (2023), who construct a rainfall hazard database to empirically test their model on rain-making as an instrumental religious belief. Psychological evidence further links high-variance outcomes to ritual behavior in both modern laboratory settings (Rudski and Edwards, 2007) and historical medical folklore (de Barra et al., 2025). Closest to this paper methodologically, Michalopoulos and Xue (2021) introduce folklore as a systematic source of data on cultural transmission, showing how historical environments and events are encoded in narrative form. We build on this approach by focusing not on specific narrative types, but on the functional content of expressive culture. In doing so, we provide new evidence on how environmental volatility shapes belief systems, highlighting risk rather than education, income, or envy as a fundamental driver of cultural content.

The paper also contributes to a growing literature in economics and psychology on belief formation under uncertainty. Theoretical and experimental work has shown that individuals disproportionately rely on heuristics, distorted expectations, or motivated beliefs to manage anxiety or maintain hope when outcomes are consequential but only partially controllable (Barberis, 2013; Gennaioli et al., 2012; Bénabou and Tirole, 2016; Golman et al., 2017). As emphasized by Shiller (2017), these psychological biases are frequently encoded and propagated through stories, yet empirical evidence on the origins of such narratives remains rare. Field studies document that exposure to natural disasters and economic insecurity drives the adoption of religious coping mechanisms, traditionalism, and even resistance to scientific information (Bentzen, 2019; Allcott et al., 2020; Atkin et al., 2025). Within development

economics, this response is often linked to the scarcity mindset, where high-variance environments deplete cognitive bandwidth, increasing reliance on heuristics and ritualized behaviors to restore a sense of agency (Mani et al., 2013; Haushofer and Fehr, 2014; Schilbach et al., 2016). Our analysis extends this evidence to a global, historical context, demonstrating that environmental volatility systematically shapes the prevalence of magical beliefs across pre-industrial societies. Unlike lab or contemporary studies, folklore provides a lens into expressive culture largely insulated from strategic incentives or political manipulation, allowing us to observe the emergence of risk-driven belief systems at the societal level.

This focus on risk-driven beliefs directly connects our findings to the economics of religion (see Becker et al., 2021, for a survey). A well-established hypothesis in this field posits that religiosity functions as a coping mechanism that provides existential security in the face of distress. Empirical evidence strongly supports this view, documenting that exposure to acute shocks, such as earthquakes (Belloc et al., 2016; Bentzen, 2019), pandemics (Bentzen, 2021), financial crises (Chen, 2010), and war (Henrich et al., 2019), significantly increases religious participation and the intensity of belief. While we share the premise that insecurity drives belief, our work diverges in two key dimensions. First, whereas this literature focuses on religiosity (typically measured by church attendance or belief in high gods), we focus on the content of folklore, separating the functional role of magical thinking from formal religious institutions. Second, while previous studies largely identify the short- to medium-term response to realized disasters (shocks), we isolate the long-run adaptation to environmental uncertainty (volatility). In this regard, our results complement models where beliefs facilitate cooperation under ambiguity (Levy and Razin, 2012) and Ager and Ciccone (2018), who show that rainfall risk drove the spread of religious communities in 19th-century America as a form of social insurance. We extend this logic to show that environmental variance shapes the narrative structure of expressive culture, even outside the domain of organized religion.

Finally, the paper bridges the gap between the anthropological literature on risk-coping and economic research on environmental adaptation. Classical anthropologists hypothesized

that ritual and magical practices function as adaptive responses to activities characterized by high stakes and low individual control (Frazer, 1890; Hubert and Mauss, 1902; Malinowski, 1922; Homans, 1941; Malinowski, 1948; Lévi-Strauss, 1966). This functionalist view has been refined by modern evolutionary anthropology, which models ritual and supernatural beliefs as evolved mechanisms for social cohesion and anxiety reduction in stochastic environments (Sosis, 2003, 2007; Jackson et al., 2023). We connect this perspective to the economic literature on climatic shocks, which has largely focused on material adaptations such as crop choice, migration, mortality, or conflict (Bloom, 2009; Hsiang, 2010; Hsiang et al., 2013; Dell et al., 2014; Burgess et al., 2017). By integrating these views, we provide evidence for a cognitive channel of adaptation: we show that environmental volatility shapes the content of belief systems, acting as mental insurance where formal markets for risk-sharing are absent (Townsend, 1994; Udry, 1994).

The remainder of the paper proceeds as follows: Section 2 reviews the anthropological background; Section 3 details the data construction; Section 4 presents the empirical evidence; Section 5 examines mechanisms and alternative explanations; Section 6 tests cultural adaptation versus persistence; and Section 7 concludes.

2 Anthropological Background

2.1 The Functional View of Magic

Anthropological theories of magic and ritual have long emphasized their relationship to uncertainty and risk. In contrast to early evolutionary accounts that treated magical beliefs as vestiges of pre-scientific reasoning, Malinowski (1948) advanced a functional interpretation, arguing that magic emerges most strongly in contexts where outcomes are uncertain, stakes are high, and individual effort provides limited control.

A central implication of Malinowski’s account is that magical beliefs are not uniformly distributed across societies or domains of activity, but instead respond systematically to the

structure of risk. Magic, in this view, does not substitute for technical competence; rather, it complements it in situations where effort alone is insufficient to ensure outcomes. This distinction is important for our empirical analysis, as it implies that beliefs invoking supernatural causation should be particularly prevalent in environments characterized by volatility rather than harshness or low productivity. More precisely, the functionalist framework predicts that magical beliefs should respond to higher-order moments of the environment (such as volatility, seasonality, and the unpredictability of shocks) rather than to average climatic conditions or long-run productivity alone. The rest of this section reviews the ethnographic evidence suggesting that superstition is not a substitute for technical knowledge, but a specialized response to high-variance environments.

Lagoon vs. Open Sea. The foundational framework for this relationship comes from [Malinowski \(1922\)](#)’s own ethnography of the Trobriand Islanders, *Argonauts of the Western Pacific*. Malinowski observed a sharp discontinuity in the use of magic based on the specific risk profile of economic activities. When fishing in the calm, reliable waters of the inner lagoon, where the catch was certain and danger low, the Islanders relied entirely on their skill and technology, employing no magical rituals. However, when the same men ventured into the open sea, an environment characterized by unpredictable yields and physical danger, their preparations were accompanied by elaborate magical rituals. Malinowski concluded that magic serves as a coping mechanism for the gap between effort and outcome: “We find magic wherever the elements of chance and accident and the emotional play between hope and fear have a wide and extensive range. We do not find magic wherever the pursuit is certain, reliable, and well under the control of rational methods” ([Malinowski, 1948](#)).

Agrarian Risk and the Second Spear. This functionalist view is further supported by [Evans-Pritchard \(1937\)](#)’s classic account of the Azande in North Central Africa. The Azande possess sophisticated empirical knowledge of agriculture and construction, yet they invoke witchcraft to explain unfortunate events and outcomes that are statistically improbable and

damaging. Evans-Pritchard illustrates this with the collapse of a granary. The Azande understand that termites eat the wood (the natural cause), but when a granary collapses specifically at the moment a person is sitting under it, they attribute the timing (i.e., the uncertainty) to witchcraft. They refer to this as the ‘Second Spear’: “It is known that the termite has eaten the supports ... but why should the granary collapse at the very moment that X is sitting underneath it? ... Witchcraft is the second spear. The elephant is the first spear [natural cause], and witchcraft is the second spear [the element of uncertainty] and together they kill the man” (Evans-Pritchard, 1937).

Similarly, regarding agricultural pests, Evans-Pritchard notes that the Azande apply this same dual causality to crop failure. They recognize that blight or parasites are the biological agents that destroy ground-nuts, but they do not view the mere presence of pests as a sufficient explanation for the loss of a harvest. When a specific farmer’s crop is decimated while neighbors’ fields remain untouched, or when labor yields no return, the intensity and allocation of the infestation are attributed to witchcraft. In summary, the pest is the weapon, but witchcraft is the agency that directs it.

Comparative evidence suggests this pattern is universal rather than specific to a single culture. Anthropological accounts from Southern Africa confirm that ritual intensity spikes specifically during periods of climatic volatility. Junod (1927)’s study of the Thonga people notes that regular dry seasons cause no alarm, but deviations from the mean (i.e., volatility) trigger intense ritual activity: “Rain may not fall during seven months ... and nobody worries about it. But if it fails in November and December ... it is a dreadful misfortune ... [resulting in] rites, and charms, and all the powers of magic.”

This link between variance and superstition extends even to modern contexts. Gmelch (1971) documents ‘Baseball Magic’ among professional athletes, observing that superstition is heavily concentrated in high-variance activities (pitching and hitting), where the correlation between effort and outcome is low (a .300 batting average is excellent). In contrast, fielding, which is a low-variance activity where success is highly correlated with skill, is almost

entirely devoid of magical rituals. This mirrors the Trobriand distinction, suggesting that rational superstition is a general cognitive response to high-variance environments. While ethnographic evidence often emphasizes within-society variation across activities, the persistence of such domain-specific responses implies that long-run exposure to environmental risk may become encoded in collective cultural narratives.

2.2 Risk, Control, and Belief Formation

Subsequent anthropological and psychological research has reinforced the link between uncertainty and beliefs emphasizing hidden or supernatural agency ([Miguel, 2005](#); [Whitson and Galinsky, 2008](#)). Across a wide range of societies, ritual practices are disproportionately associated with weather-dependent production, illness, navigation, and other domains where causal mechanisms are opaque and outcomes are only imperfectly predictable ([Sosis and Handwerker, 2011](#); [Legare and Souza, 2012](#)). From this perspective, magic can be understood as a cognitive and cultural response to risk, providing explanatory narratives and perceived control in environments where randomness would otherwise dominate experience ([Gershman, 2016](#); [Hobson et al., 2018](#)). In these accounts, environmental uncertainty precedes and conditions belief formation instead of reflecting endogenous choices over effort, location, or production.

The functionalist framework does not require that ritual practices materially improve agricultural yields or navigation safety. Economic models of motivated cognition suggest that beliefs may persist because they provide intrinsic utility: reducing anxiety or maintaining motivation in the face of repeated failure ([Bénabou and Tirole, 2016](#)). Furthermore, cultural evolutionary accounts argue that shared rituals, even if costly, serve as commitment devices that facilitate social coordination and trust within the group, particularly in high-risk environments ([Sosis and Ruffle, 2003](#); [Henrich, 2016](#)). Additionally, evolutionary accounts of error management suggest that in high-stakes environments, the cost of a false positive (performing a useless ritual) is far lower than the cost of a false negative (ignoring a potential

survival strategy), biasing human cognition toward superstitious pattern-seeking (Foster and Kokko, 2009; Johnson et al., 2013). The functionalist view thus generates a sharp empirical prediction: societies exposed to greater environmental volatility should disproportionately encode magical interventions in domains where outcomes are economically consequential yet only imperfectly controllable.

To measure these beliefs, we focus on oral traditions rather than formal religious institutions (Espín-Sánchez et al., 2023). As established by Michalopoulos and Xue (2021), folklore represents a unique repository of “deep culture”: narratives transmitted vertically across generations that reflect the specific environmental constraints and values of a society. Because folklore is transmitted intergenerationally, it reflects cumulative exposure to environmental risk as opposed to short-run shocks or transient beliefs. Unlike formal laws or organized religion, which are often imposed by elites or external colonizers, folklore tends to evolve organically from the bottom up (Bisin and Verdier, 2001). This makes it a cleaner proxy for indigenous cognitive responses to environmental risk, relatively free from strategic political manipulation.

2.3 Risk vs. Alternative Mechanisms

The functional interpretation of magic stands in contrast to alternative accounts that emphasize social cohesion, political authority, or elite control as primary drivers of ritual intensity. The dominant view in the economics of religion posits that rituals serve primarily as costly signals of group commitment (Iannaccone, 1992; Berman, 2000) or as ‘social glue’ that fosters cooperation within the group (Durkheim, 1912; Radcliffe-Brown, 1945). Similarly, political theories of ritual argue that ceremonial complexity is driven by the need to legitimize hierarchical authority rather than to manage environmental risk (Bell, 1992; Chaney, 2013).

While such mechanisms undoubtedly explain certain forms of ceremonial behavior, they do not naturally predict why ritual practices should vary systematically with environmental volatility, nor why they should be concentrated in domains directly exposed to stochastic

outcomes. If rituals were solely for social bonding or political control, they should be distributed according to group size or political complexity, not precipitation variance. A key empirical challenge, therefore, is to distinguish beliefs that plausibly respond to productive risk from those serving primarily social or distributive functions.

The analysis in this paper follows Malinowski in focusing on beliefs related to protection, divination, and control over uncertain outcomes, and contrasts these with expressive motifs that serve as a placebo (e.g., love-related magic), as they are less directly tied to environmental risk. By combining detailed measures of climatic volatility with fine-grained classification of folklore content, the paper seeks to provide systematic evidence for a long-standing anthropological hypothesis that has, to date, received limited quantitative evaluation.

3 Data and Measurement

3.1 Folklore and Magic Motifs

To measure the intensity and focus of magical thinking, we utilize the folklore dataset constructed by [Michalopoulos and Xue \(2021\)](#), which digitizes and structures the Folklore and Mythology Electronic Catalogue (FMEC) originally curated by Yuri Berezkin and Evgeny Duvakin ([Berezkin and Duvakin, 2026](#)). This dataset represents the most comprehensive quantitative archive of comparative mythology available, linking specific narrative elements to 1,219 traditional societies that match the ethno-linguistic groups in the Ethnographic Atlas ([Murdoch, 1967](#)).

The dataset contains 2,560 unique motifs, yielding a total of $N \approx 114,000$ society-motif observations. In the context of comparative folklore, a motif is defined as the fundamental unit of narrative transmission: a ‘narrative atom’ capable of persisting in tradition and crossing linguistic boundaries. Unlike full-text corpora, which may be sensitive to translation idiosyncrasies or the literary flourishes of specific storytellers, motifs capture the underlying semantic content of a culture’s oral tradition. These motifs range from cosmological expla-

Table 1: Examples of Risk-Related Folklore Motifs

<i>Risk Context</i>	Motif Description & Magical Implication
Agricultural	<p><i>The Thunderbirds (i1)</i>. Creatures that produce rain and thunderstorms are birds or anthropomorphic beings.</p> <p>↔ Implication: Weather is an animated entity that can be engaged with; implies the efficacy of rituals directed at these beings to secure rain.</p>
Protective	<p><i>Magic Objects (k131)</i>. Narratives focused on the acquisition, exchange, or theft of specific items (amulets, weapons) that grant power or invulnerability.</p> <p>↔ Implication: Survival and defense depend on the possession of material objects imbued with supernatural power (apotropaic magic).</p>

nations (e.g., “The sun is a human figure made of fire”) to specific ritual prescriptions (e.g., “Sacrificing a black animal to stop a storm”).

The data are structured as a binary vector indicating the presence or absence of each motif for each ethnic group in the sample. This structure allows us to move beyond anecdotal evidence and systematically quantify the cultural imaginary of each group. We interpret the composition of a society’s folklore corpus as a proxy for its cognitive and cultural preoccupations. Following the Malinowski hypothesis, we expect that if a society is subject to high environmental volatility, its oral traditions will be disproportionately saturated with motifs concerning weather control, divination, and protective rituals, in place of purely social fables or entertainment. Table 1 provides concrete examples of how these narrative atoms encode magical beliefs relevant to the economic and survival risks found within the dataset.

For each society s , we calculate the intensity of belief in category c as the share of their total folklore corpus devoted to that topic:

$$\text{Intensity}_{s,c} = \frac{\sum_{m \in M_s} \mathbb{I}(m \in \mathcal{C}_c)}{|M_s|} \quad (1)$$

where M_s is the set of all motifs present in society s , $|M_s|$ is the total count of motifs in that society, and $\mathcal{C}_c$ represents the set of motifs identified as belonging to risk category c by our

classification algorithms. This normalization ensures that we measure the relative salience of a topic, controlling for the fact that some well-studied societies (e.g., the Zuni) have much larger recorded corpora than others.

While the underlying database aggregates tens of thousands of individual narratives, these are distilled into 2,560 unique semantic motifs. To systematically categorize these motifs without manual bias, we employ two distinct computational strategies: an NLP lexical dictionary approach coupled with semantic expansion for coverage, and a Large Language Model (LLM) approach for contextual depth. These methods aim to quantify the extent to which a society’s folklore is saturated with themes of magical intervention.

The NLP Approach. To capture the prevalence of magical beliefs without relying on arbitrary keyword selection, we implement a semantic expansion algorithm using WordNet,¹ a lexical database of English. This approach prioritizes semantic coverage over strict lexical precision, allowing us to capture synonymous concepts (e.g., detecting “monsoon” or “deluge” from the seed “rain”).

We begin by defining seed words for two distinct environmental contexts (agriculture and protection) and one placebo category (love). First, agricultural context anchors the vocabulary in production risks (e.g., “drought,” “rain,” “harvest,” “famine”). Second, protective context captures somatic risks and survival (e.g., “sickness,” “wound,” “heal,” “cure”). Finally, we define a love and romance placebo context tracking social themes (e.g., “marriage,” “suitor,” “jealousy”) to serve as a counterfactual.

To distinguish specific ritual beliefs from general storytelling, we also generate a vocabulary of magical operators. These seeds capture both active supernatural manipulation (e.g., “transform,” “summon,” “spell,” “curse”) and passive supernatural perception (e.g., “omen,” “prophecy,” “taboo”).

The algorithm executes a three-step expansion procedure for all categories. First, it

¹WordNet is a large, publicly available lexical database of the English language created and maintained by Princeton University. Instead of organizing words alphabetically like a traditional dictionary, WordNet groups words together based on their meanings and semantic relationships.

retrieves synsets from the WordNet graph to identify cognitive synonyms for each seed word. Second, it extracts the lemmas associated with those synsets. Third, it stems morphological variations (e.g., reducing “planting” to “plant”) using the Snowball Stemmer. We then classify a motif as agricultural magic if and only if it contains terms from the expanded agricultural vocabulary and the expanded magical vocabulary. This intersectional constraint ensures our measure captures supernatural responses to environmental stress, rather than straightforward descriptions of weather or farming.

The LLM Approach. While dictionary and semantic approaches provide a transparent baseline, they suffer from context blindness. A keyword search for “rain” cannot distinguish between a fable where a fox waits for the rain (narrative setting) and a description of a ritual performed to cause rain (functional magic). Furthermore, keyword methods struggle to separate etiological myths (i.e., narratives explaining why the world is the way it is) from genuine prescriptions for control.

To overcome this limitation, we employ a Large Language Model (GPT-4o-mini) to classify each of the 2,560 motifs. Unlike bag-of-words models, the LLM parses syntactic structure and narrative intent. We prompt the model to code each motif along four dimensions: (1) Risk Context, which identifies the substantive domain (e.g., Agriculture vs. Social Conflict); (2) Functional Magic, which distinguishes instrumental supernatural principles from passive folklore; (3) Mechanism, which differentiates between active rituals versus passive omens; and (4) Goal, which analyzes productive versus protective outcomes. Table 2 details the classification schema, definitions, and examples used in the prompting strategy.

The classification is performed using a few-shot prompting strategy, providing the model with expert-coded examples to guide its classification logic. For instance, a motif describing a ‘Truth Ordeal’ (where a suspect’s guilt is revealed by a supernatural test) is coded as Social Conflict (Context) + Active Ritual (Mechanism). By aggregating these codes, we construct a context-aware index of magical intensity, specifically measuring the prevalence of

Table 2: LLM Classification Schema

Dimension	Definition	Examples
1. Risk Context	The substantive domain of the motif, regardless of magic presence.	Agriculture, Protection, Love.
2. Functional Magic	Determines if the motif describes an instrumental belief to influence outcomes (vs. etiology).	<i>Excluded:</i> “How the leopard got its spots” (Just-So story).
3. Mechanism	Classifies the nature of the ritual action.	<i>Active Ritual</i> vs. <i>Passive Omen</i> .
4. Goal	Analyses the goal of the intervention.	<i>Productive</i> (Rainmaking) vs. <i>Protective</i> (Warding).

instrumental beliefs attempting to control the uncertain environment through ritual means. To validate the LLM’s classifications, we conducted a blind human coding exercise in which two independent coders classified a random sample of motifs using the same instructions. Agreement on the primary magic binary ranges from 65–95%, with disagreements driven by threshold differences rather than random error. Appendix A.2 reports the full results.

Temporal Provenance of Motifs. A natural concern is that we cannot observe when individual motifs entered a society’s oral tradition. The FMEC records only when stories were collected by ethnographers, not when they originated. The median society in our sample has a first publication date of 1905, with the bulk of ethnographic material appearing during the late nineteenth and early twentieth centuries (see also Michalopoulos and Xue, 2021, p. 1997). Phylogenetic studies suggest that some narrative structures may be considerably older: da Silva and Tehrani (2016) estimate that tales such as *Beauty and the Beast* originated between 2,500 and 6,000 years ago. This raises the question of whether the folklore we measure reflects the contemporary environmental conditions of these societies or those of a distant climatic past.

Several features of our design mitigate this concern. First, and most directly, our epidemiological analysis in Section 6 provides a suggestive test: among migrant societies, current climatic volatility predicts agricultural magic while ancestral conditions have no detectable

effect. If the functional motifs in the corpus were ancient relics, frozen at the time of creation and carried passively through migration, ancestral risk should retain predictive power. The horse race regressions indicate it does not.

Second, the temporal concern is most acute for cosmological and etiological motifs (i.e., narratives explaining the origins of natural phenomena) which folklorists consider among the oldest layers of oral tradition (Jason, 1970). Our classification strategy explicitly filters these out. The LLM pipeline’s “Functional Magic” dimension retains only motifs encoding instrumental supernatural beliefs: active rituals, divination, and protective practices aimed at influencing uncertain outcomes. These functional prescriptions have a clear use-it-or-lose-it character: a rain ritual is maintained only as long as rain is a salient concern for the community. This selectivity makes our measure inherently more responsive to prevailing environmental conditions than an undifferentiated motif count.

Third, the second-moment characteristics of climate that we exploit (volatility, seasonality, and the frequency of extreme events) are structurally determined by geography and thus persistent over the historical time-frames relevant to folklore evolution (see Section 3.3). A location that is volatile today was likely volatile centuries ago, because precipitation variance is driven by stable geographic features: distance to moisture sources, orographic effects, continentality, and latitude. Consequently, even if certain motifs are old, they emerged in response to the same risk environment that we measure. Finally, following Michalopoulos and Xue (2021), we control for the log number of publications and the log year of first publication for each society in robustness checks, accounting for the possibility that the timing and intensity of ethnographic collection could systematically bias the recorded corpus.

3.2 Ethnic Group Mapping and Ancestor Coordinates

Aggregating the motif classifications via Equation 1 yields a vector of society-level risk and magic variables for each of the 1,219 societies. To test the Malinowski hypothesis, we must link these cultural proxies to exogenous environmental volatility metrics. We therefore

execute a dual spatial matching procedure to capture both the immediate environmental constraints and the historical climatic legacy of each group.

First, we assign each society a set of contemporary geographic coordinates (centroid latitude and longitude) based on the Ethnographic Atlas (Murdock, 1967). These coordinates represent the location of the group at the time of ethnographic description (typically pre-1950). This spatial pinning allows us to query the NASA POWER API for local climatic volatility, providing a measure of the environmental risks faced by the society in its observed habitat. Figure 1 displays the global distribution of all the ethnic groups.

A central challenge in testing the Malinowski hypothesis is distinguishing between adaptation (belief systems adjusting to current risks) and persistence (belief systems inherited from ancestors and carried to new environments). To address this, we reconstruct ancestral coordinates for these societies, tracing their locations prior to major historical migrations.

By calculating the environmental volatility at these ancestral locations, we can test whether magical beliefs are sticky (i.e., persisting as cultural traits even after a group moves to a different climatic niche) or whether they are plastic, rapidly updating to match the new environment. Figure 1 illustrates these ancestral locations, highlighting the variation in spatial disconnect between recent habitation and historical origins for migratory groups. We classify a traditional society as migratory if their current homeland coordinates are more than 500 km away from their language family’s *Urheimat* coordinates. Table A4 describes the source and proposed *Urheimat* location with coordinates for 35 language families. These locations cover 986 traditional societies or 81% of the full ethnographic sample.

Language phylogeny for PGLS. To complement the language-family fixed effects used in the baseline regressions, we also construct a phylogenetic robustness sample that links EA societies to individual tips on a global language tree. We use the EA–D-PLACE concordance supplied by Gershman and Mumladze (2025), which matches 1,184 EA societies to tree tips, and the modified maximum-clade-credibility global language tree derived from Bouckaert

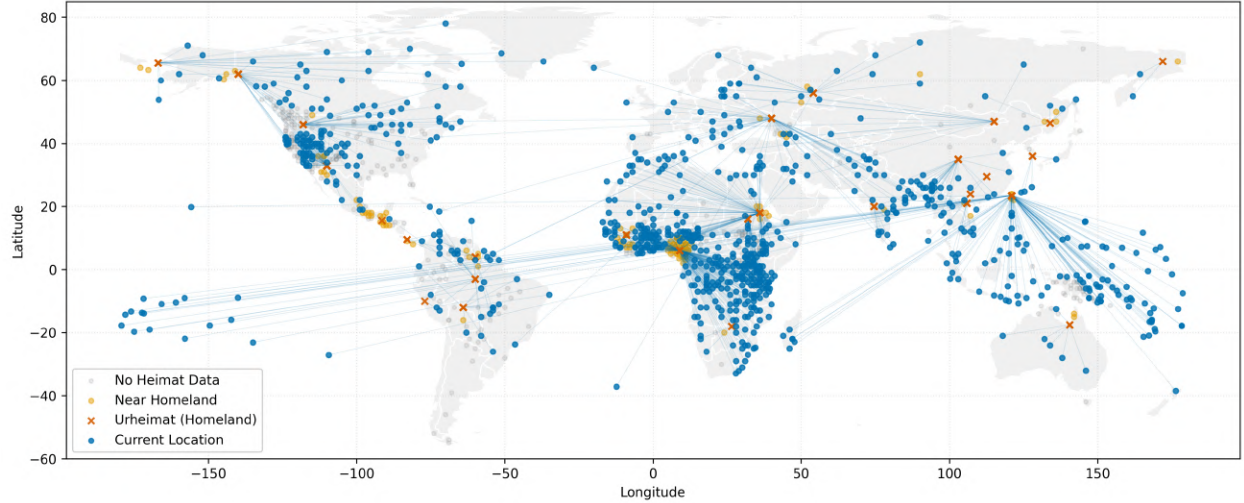


Figure 1: Spatial Distribution of Traditional Societies and Urheimats

Notes. The blue dots display the contemporary homeland locations of the 1,219 societies in the sample as recorded in the Ethnographic Atlas. The orange crosses display reconstructed ancestral coordinates (Urheimat) based on language family expansion, see Appendix A.4.

et al. (2022). The tree is used only in the PGLS robustness exercises: it supplies the expected covariance of regression residuals among societies as a function of linguistic relatedness, while the main OLS specifications continue to use language-family fixed effects and language-family clustered standard errors.

3.3 Environmental Data and Risk Measures

Climatic variables were constructed using daily meteorological data obtained from the NASA Prediction of Worldwide Energy Resources (POWER) Project API (NASA POWER Project, 2026).² We queried the `daily/point` temporal endpoint to retrieve high-resolution daily records for precipitation, temperature, wind speed, relative humidity, and solar irradiance. All metrics are calculated at the EA ethnic group coordinate over the period 1984–2024.

To capture the specific environmental constraints relevant to pre-industrial societies, we construct indices focusing on volatility, extremes, and compound risks rather than simple

²Acknowledgement: These data were obtained from the NASA Langley Research Center POWER Project funded through the NASA Earth Science Directorate Applied Science Program.

averages. This approach is theoretically grounded in the Malinowski hypothesis, which posits that magical thinking responds to uncertainty and uncontrollability (e.g., unpredictable rainfall) rather than baseline harshness (e.g., permanent aridity). Consequently, we distinguish between first-moment climatic endowments and second-moment environmental risks. While our climatic data are contemporary (1984–2024), we rely on the assumption that the second-moment characteristics of a climate (volatility, seasonality, and the frequency of extreme events) are structurally determined by geography and thus persistent over the historical time-frames relevant to folklore evolution.

Baseline Endowments. We explicitly control for mean annual precipitation and mean annual temperature. These variables capture the fundamental ecological endowment of a location, determining carrying capacity, biome type, and base agricultural potential. Including these controls ensures that our risk metrics isolate the effect of environmental variance, independent of the general effects of living in a hot or dry climate.

Environmental Risk Measures. We construct a set of environmental risk measures to capture the unpredictability of agricultural and subsistence inputs. Our baseline measure is Precipitation Volatility, defined as the inter-annual coefficient of variation (CV) of total precipitation. This serves as our primary independent variable, as it captures the fundamental, long-term insecurity in water supply that defines agricultural viability in pre-industrial societies. It is the most standard metric in the literature for approximating the overall unpredictability of the environment ([Michalopoulos, 2012](#)).

For societies dependent on fishing rather than farming, the relevant risk profile differs. We calculate Storm Risk to capture conditions that make open-water fishing dangerous (to proxy for Malinowski’s observations). This is defined as the frequency of compound events where both wind speed and precipitation exceed their local historical 90th percentiles. This variable provides an alternative test of the hypothesis for fishing-dependent groups.

We also construct Scorch Risk, defined as the frequency of compound hot ($> 90^{\text{th}}$ per-

centile) and dry (< 1 mm precipitation) days. This measure captures heat-stress events that threaten agricultural production through simultaneous moisture and temperature shocks.

Finally, we construct Drought Risk (the average length of the longest continuous dry spell with < 1 mm precipitation) and Flood Risk (the proportion of annual rainfall occurring within the single wettest 7-day window). We utilize these primarily as robustness tests to ensure our results are not driven by a single definition of risk. Furthermore, Flood Risk is particularly valuable for testing mechanisms, as it allows us to exploit the interaction with soil texture (clay vs. sand) to isolate material risk from pure weather events.

Appendix Table A2 reports the cross-correlations between these measures. Two patterns are notable. First, Storm Risk is effectively orthogonal to the agricultural risks, displaying weak or negative correlations with precipitation volatility (-0.17) and flood risk (-0.04). This confirms that it captures a distinct environmental dimension suitable for testing fishing-specific hypotheses. Second, while Scorch Risk is positively correlated with the other agricultural measures, the correlation with our baseline Precipitation Volatility is relatively low (0.35). This indicates that Scorch Risk contains substantial unique variation, capturing heat-stress events that are not simply a function of rainfall volatility, and therefore warrants inclusion as a distinct measure of agricultural insecurity.

Paleoclimate Reconstructions. To directly test whether pre-modern climate conditions predict magical beliefs, we supplement the satellite-era data with annually resolved paleoclimate reconstructions from the Old World Drought Atlas (OWDA; Cook et al., 2015) and the North American Drought Atlas (NADA; Cook et al., 2004). These atlases reconstruct the Palmer Drought Severity Index (PDSI), a standardized measure of soil moisture balance, from networks of tree-ring chronologies. PDSI values below -2 indicate moderate drought; values below -3 indicate severe drought. We extract reconstructions for the period 1100–1400 AD, well before the era of ethnographic observation and colonial contact.

For each society with atlas coverage ($N = 458$; $N = 429$ in the baseline regressions and

$N = 378$ with full social controls), we compute two measures at the society’s current coordinates: PDSI Volatility (standard deviation of annual PDSI) and Drought Frequency (share of years with PDSI below -3). Because the drought atlases cover Europe, the Mediterranean, Central Asia, and North America, the paleoclimate subsample is geographically more restricted than the full satellite-era sample but encompasses a diverse range of subsistence systems and climatic zones. Section 4.4 reports the results.

3.4 Ethnographic Controls and Moderators

To isolate the effect of environmental risk from broader cultural or institutional characteristics, we merge our geospatial data with society-level traits from the Ethnographic Atlas (Murdock, 1967).

Subsistence Channels. A central prediction of the Malinowski hypothesis is that magical beliefs should track specific material anxieties (e.g., drought risk should predict Rain Magic among farmers but not fishers). To allow for the testing of these heterogeneous effects, we utilize the Atlas’s subsistence dependence codes (v1–v5), which quantify the percentage of caloric intake derived from gathering, hunting, fishing, animal husbandry, and agriculture. We construct interaction variables that pair environmental stressors with their corresponding economic sector: Precipitation Volatility, Flood, Drought, and Scorch Risk are mapped to Agricultural Dependence; and Storm Risk is mapped to Fishing Dependence.

Buffers and Ecological Moderators. We construct measures to test the ‘substitution hypothesis’: the idea that formal institutions or technology can mitigate the psychological demand for ritual control. To proxy for state capacity, we utilize Jurisdictional Hierarchy (v33), which measures the number of political levels beyond the local community (ranging from 1 for stateless societies to 5 for large states). To proxy for technological buffering, we control for the Intensity of Agriculture (v28), specifically creating an indicator for societies that practice irrigation.

Furthermore, we introduce Soil Composition as an ecological moderator that can physically amplify climatic variance. Using high-resolution soil grids, we calculate the percentage of sand and clay at each society’s coordinate. We hypothesize a triple interaction where soil texture determines the severity of the shock: sandy soils (low water retention) are expected to exacerbate the scarcity risks associated with Precipitation CV, while clay-heavy soils (poor drainage) are expected to amplify the damaging run-off effects of Rainfall Concentration.

Finally, we include a vector of baseline ethnographic controls to account for confounding cultural and economic traits. To capture social complexity and hierarchy, we control for Class Stratification, the presence of Slavery, and the degree of Sedentism, as the accumulation of folklore may correlate with settlement density and complex stratified societies may generate different volumes of folklore than egalitarian bands. We account for family and mating structures by controlling for Polygyny and Kinship Structure, particularly patrilineal descent, which often exhibits distinct patterns of ancestor worship that could be conflated with other forms of magic.

To distinguish the effects of environmental risk from those of environmental quality, we explicitly control for Agricultural Suitability, ensuring our results capture the response to volatility rather than to land productivity or potential wealth. We also control for the Year of Observation to account for the potential erosion of traditional beliefs in later contact periods. Finally, unless otherwise noted, the main OLS specifications include Language Family Fixed Effects to absorb unobservable cultural traits and common ancestry shared within linguistic phyla.

3.5 Descriptive Statistics

Table 3 presents summary statistics for the merged analysis dataset. Our folklore-based estimation sample consists of 1,219 traditional societies for which we successfully matched ethnographic data, folklore motifs, and high-resolution climatic records; the broader merged file contains 1,291 societies with variable coverage depending on the outcome or control.

Table 3: Summary Statistics by Traditional Society

Variable	(1) Mean	(2) S.D.	(3) Min	(4) Max	(5) N
<i>Panel A: Magical Intensity Indices (Normalized)</i>					
Agricultural Magic (NLP)	0.10	0.05	0.00	0.30	1,219
Agricultural Magic (LLM)	0.02	0.02	0.00	0.23	1,219
Protective Magic (NLP)	0.13	0.05	0.00	0.27	1,219
Protective Magic (LLM Context)	0.19	0.07	0.00	0.67	1,219
Love Magic (NLP)	0.07	0.04	0.00	0.22	1,219
Love Magic (LLM)	0.05	0.04	0.00	0.33	1,219
<i>Panel B: Environmental Risk Measures</i>					
Precipitation Volatility (CV)	0.27	0.14	0.10	1.10	1,288
Scorch Risk (Frequency)	0.08	0.02	0.01	0.10	1,291
Storm Risk (Frequency)	0.01	0.01	0.00	0.06	1,291
Drought Risk (Duration)	53.36	43.29	6.41	334.41	1,291
Flood Risk (Concentration)	0.13	0.07	0.05	0.74	1,291
<i>Panel C: Subsistence Strategies</i>					
Agricultural Dependence (Scale 0–9)	4.45	2.73	0.00	9.00	1,290
Fishing Dependence (Scale 0–9)	1.54	1.72	0.00	9.00	1,290
<i>Panel D: Ethnographic Characteristics</i>					
Jurisdictional Hierarchy (Levels 1–5)	1.94	1.11	1.00	5.00	1,155
Settlement Complexity (Scale 1–8)	5.12	2.22	1.00	8.00	1,187
Polygyny	3.26	1.80	1.00	7.00	1,257
Patrilineage	3.13	2.29	1.00	7.00	1,274
Total Folklore Motifs	90.48	74.06	8.00	604.00	1,219
Urheimat Migration Distance (km)	2,261	2,044	0.00	14,970	986

Notes. The table reports summary statistics for the merged analysis dataset. Magical Intensity indices measure the share of a society’s total folklore corpus devoted to a specific topic, normalized by the total number of motifs ($|M_s|$). NLP refers to the lexical dictionary index expanded via WordNet; LLM refers to the context-aware classification using GPT-4o-mini. Environmental Risk Measures are calculated using daily NASA POWER data (1984–2024): Precipitation Volatility is the inter-annual coefficient of variation (CV). Scorch Risk is the frequency of compound hot ($> 90^{th}$ percentile) and dry ($< 1\text{mm}$) days. Storm Risk is the frequency of compound high wind and rain events. Drought Risk is the average duration of the longest continuous dry spell. Flood Risk is the proportion of annual rainfall occurring within the wettest 7-day window. Subsistence Dependence follows the Ethnographic Atlas ordinal scale (0–9), where 9 represents $> 85\%$ dependence. Jurisdictional Hierarchy measures levels of political authority beyond the local community. Urheimat Migration Distance is the geodesic distance between the society’s current centroid and its reconstructed linguistic homeland. Variable-specific N reflects differing coverage across the 1,291-society merged file; folklore outcomes are observed for 1,219 societies.

The coverage of the folklore database is extensive but heterogeneous. The average society in our sample possesses 90 recorded motifs, ranging from a minimum of 8 to a maximum of over 600 (e.g., the Zuni or Navajo). The normalization procedure ensures that our Magical Intensity indices capture the relative salience of these beliefs rather than the intensity of ethnographic sampling. As shown in the table, the normalized indices exhibit substantial variation, with agricultural magic being particularly prevalent in the arid subtropics and rarer in the circumpolar regions.

The sample covers a diverse array of economic systems. Approximately 45% of the societies rely on agriculture as their primary source of calories ($> 50\%$ dependence), while 20% are primarily hunter-gatherers. This variation is crucial for our identification strategy, as it allows us to test whether the impact of climatic risk is conditional on the specific mode of production. Institutional complexity also varies widely: 45% of the societies with non-missing hierarchy data are stateless (Jurisdictional Hierarchy = 1), while 11% fall in the top two hierarchy categories (Hierarchy ≥ 4), providing the necessary variation to test the substitution hypothesis.

Figure 2 visualizes the spatial correlation between risk, economy, and magic. Panel A maps the global distribution of Precipitation Volatility. We observe high inter-annual variability in the Sahel, Southern Africa, and parts of Australia: regions historically characterized by erratic rainfall patterns. Panel B displays the distribution of agricultural dependence, while Panel C maps the intensity of agricultural magic. The visual correlation is notable: societies located in high-volatility zones (Panel A) who rely on farming (Panel B) exhibit a visibly higher density of rituals dedicated to rain-making and weather control (Panel C) compared to their neighbors in more stable climatic bands. Similarly, Figure 3 maps the corresponding spatial distribution for maritime societies, illustrating a clear visual alignment between storm frequency, fishing dependence, and the prevalence of protective magic.

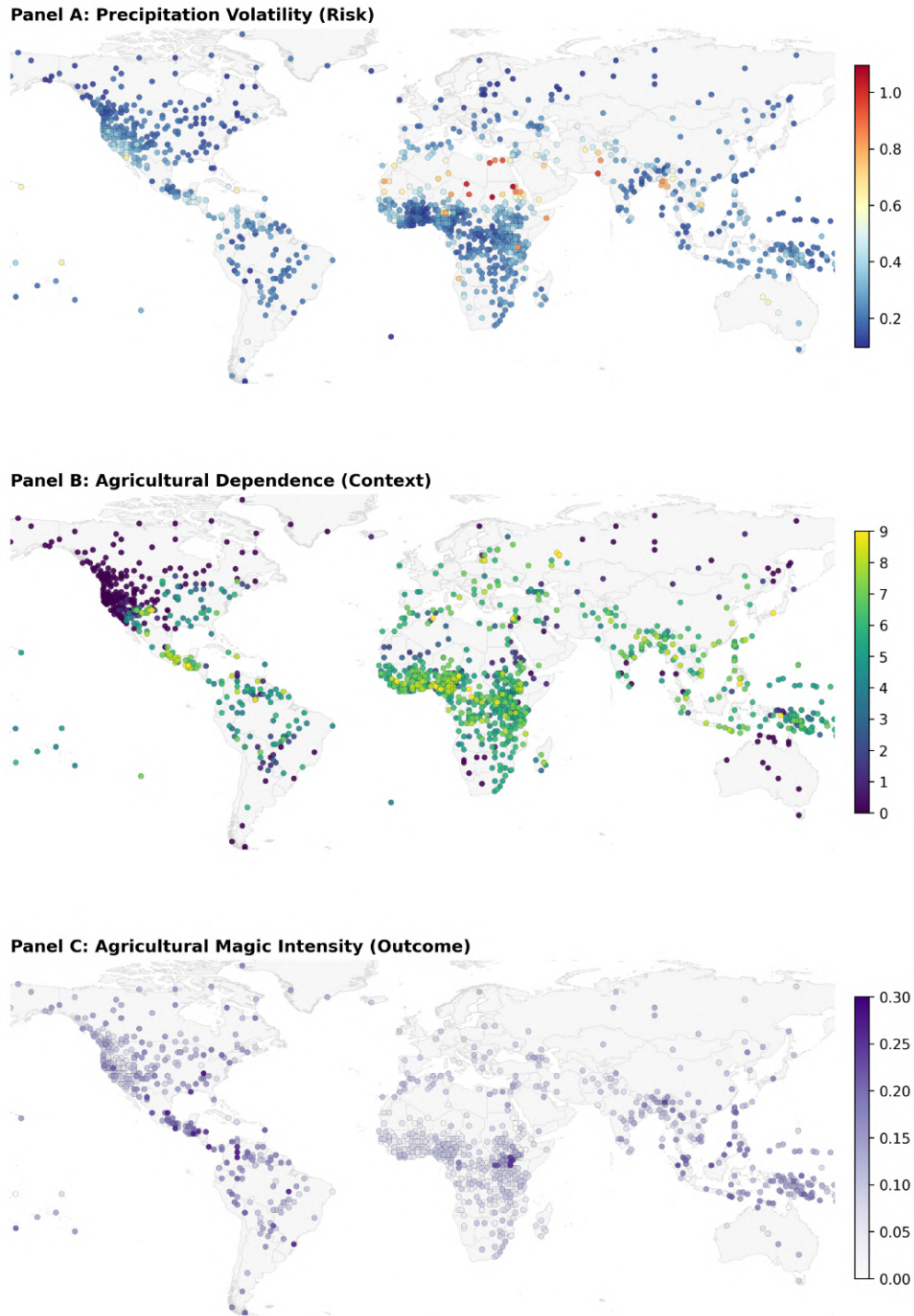


Figure 2: The Geography of Risk, Subsistence, and Magic for Agriculture

Notes. Panel A displays the Coefficient of Variation (CV) of annual precipitation. Panel B displays the percentage of caloric dependence on agriculture. Panel C displays the normalized intensity of Agricultural Magic (NLP).

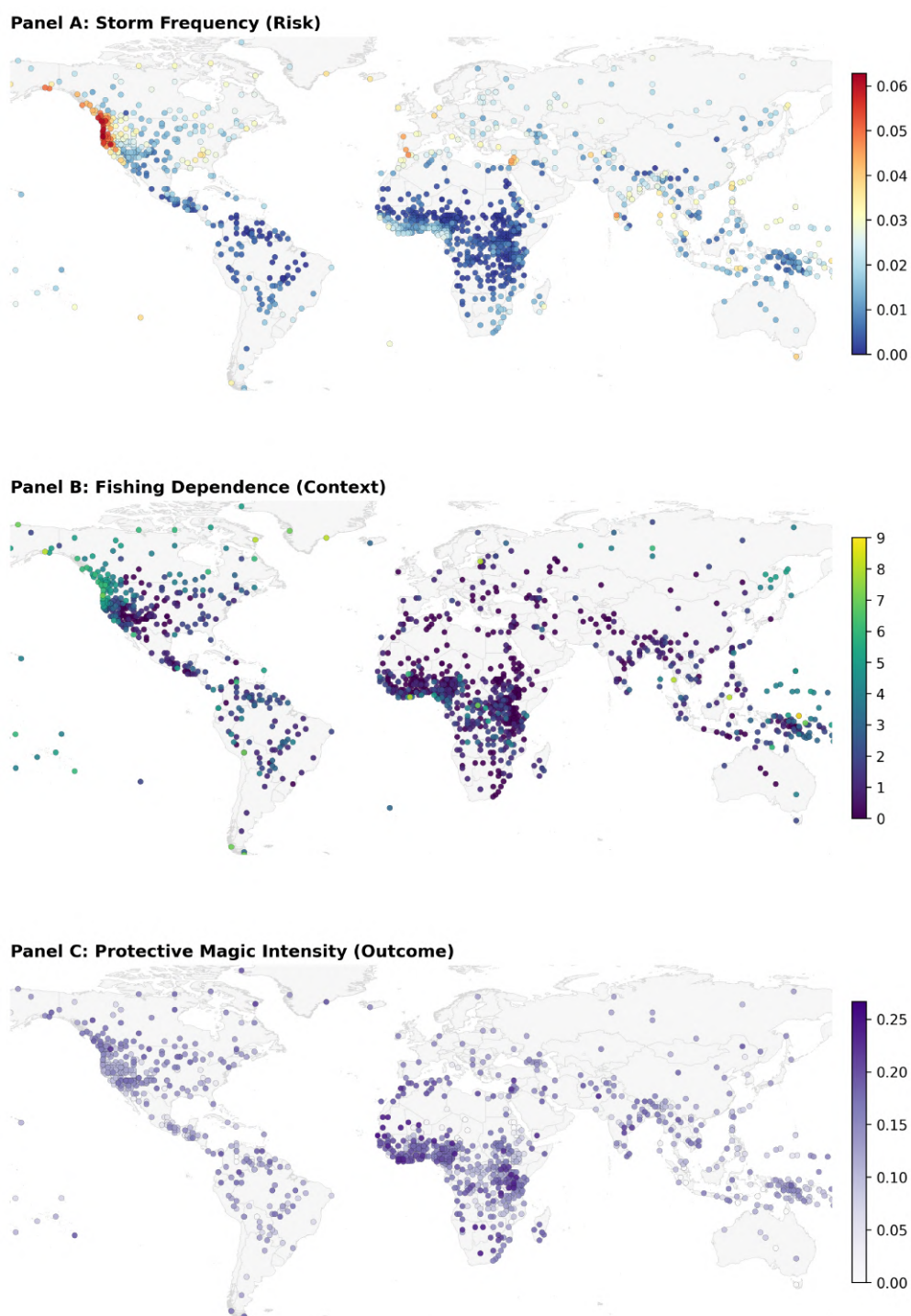


Figure 3: The Geography of Risk, Subsistence, and Magic for Fishing

Notes. Panel A displays the frequency of storms. Panel B displays the percentage of caloric dependence on fishing. Panel C displays the normalized intensity of Protective Magic (NLP).

4 Empirical Strategy and Results

4.1 Estimation Framework

To test the hypothesis that environmental volatility drives the evolution of magical beliefs, we employ a cross-sectional identification strategy that exploits variation in both climatic risk and subsistence technology across 1,219 traditional societies.

Our identification relies on a ‘functional necessity’ argument derived from functionalist anthropological theory: environmental volatility should only necessitate magical intervention if the society’s livelihood explicitly depends on the threatened resource. A simple correlation between drought and rain magic could be confounded by omitted geographic variables (e.g., latitude). However, if the Malinowski hypothesis holds, drought risk should predict rain magic only for farmers, not for hunter-gatherers living in the same environment.

To formalize this, we estimate the following interaction specification using OLS:

$$\text{Magic}_{i,c} = \alpha + \beta_1 \text{Risk}_i + \beta_2 \text{Dep}_{i,c} + \beta_3 (\text{Risk}_i \times \text{Dep}_{i,c}) + \mathbf{X}_i' \boldsymbol{\eta} + \delta_{f(i)} + \epsilon_i \quad (2)$$

where $\text{Magic}_{i,c}$ is the normalized intensity of magical motifs related to context c (e.g., Agriculture) in society i . Risk_i is the climatic volatility measure (e.g., Precipitation CV), $\text{Dep}_{i,c}$ is the society’s dependence on the relevant subsistence strategy (e.g., % reliance on Agriculture), and $f(i)$ indexes society i ’s language family.

The coefficient of interest is β_3 . A positive and significant estimate implies that the effect of environmental risk on magical thinking is amplified by material dependence. Conversely, β_1 captures the baseline effect of climate on magic for a society with zero dependence on that resource (e.g., the effect of rain variance on a pure hunter-gatherer). We interpret β_1 as a falsification test; a large positive coefficient here would suggest that our risk measure is picking up general environmental harshness rather than a specific functional adaptation. In practice, β_1 is negative in several LLM specifications, consistent with a composition effect:

societies in volatile environments that did not adopt agriculture developed folklore reflecting non-agricultural concerns, mechanically lowering their agricultural magic share. This pattern reinforces rather than undermines the functional interpretation.

We estimate this equation for distinct Risk-Dependence pairs. We interact Precipitation CV, Flood, Drought, and Scorch Risk with Agricultural Dependence. Finally, we map Storm Risk to Fishing Dependence to proxy for open-sea survival risk as in [Malinowski \(1922\)](#).

Heterogeneity and Mechanisms. We further estimate expanded versions of Equation (2) to test whether technology or soil composition act as buffers. We introduce a triple interaction term ($\text{Risk} \times \text{Dep} \times Z_i$) to test two specific mechanisms.

First, we examine ecological amplifiers. We use Soil Texture as a moderator for Flood Risk, hypothesizing that the physical properties of the soil determine whether heavy rainfall translates into agricultural disaster. We predict a divergence in effects: Clay-heavy soils, characterized by poor drainage and high water retention, should exacerbate the risks of root asphyxiation during deluge events, thereby amplifying the demand for magical intervention. Sandy soils, however, which possess high permeability, should allow excess water to dissipate quickly, acting as a natural buffer that attenuates the relationship between extreme rainfall and magical belief.

Second, we test the ‘substitution hypothesis’: technology can decouple a society from immediate environmental variance. We hypothesize that irrigation acts as a technological buffer, reducing the marginal utility of rain magic even in volatile climates. We test this by using an indicator for societies practicing irrigation as the moderator Z_i .

To account for the non-independence of cultures sharing a common ancestry (Galton’s Problem³), we include language family fixed effects ($\delta_{f(i)}$) and cluster standard errors at the language family level. The vector of controls $\mathbf{X}'_i$ accounts for confounding geographic and cultural traits. We control for mean annual temperature and precipitation (endowments),

³First identified in early anthropology, Galton’s Problem (phylogenetic autocorrelation) highlights the risk of spurious correlations in cross-cultural research when sample units are not statistically independent due to shared ancestry or cultural diffusion ([Tylor, 1889](#); [Mace et al., 1994](#)).

agricultural suitability, absolute latitude, and elevation. To account for social complexity, we control for settlement density, class stratification, slavery, and jurisdictional hierarchy. Finally, we include indicators for polygyny and patrilineal kinship to absorb variation in ritual focus unrelated to environmental risk.

Threats to Identification. Our cross-sectional design faces three potential concerns. First, selection: societies with a latent propensity for magical thinking could sort into volatile environments. This is unlikely given that settlement locations in the Ethnographic Atlas largely predate colonial-era mobility and reflect deep historical processes of migration and expansion governed by ecological opportunity rather than cultural preferences over risk. Nonetheless, the language family fixed effects absorb shared unobservable traits among linguistically related groups, ensuring that identification comes from within-family variation in climatic exposure.

Second, reverse causality: magical beliefs could cause societies to remain in volatile areas, for instance, if rituals provide psychological resilience that reduces out-migration. We address this concern directly in Section 6, where our epidemiological analysis of migrant societies shows that agricultural magic tracks current local volatility rather than ancestral conditions, implying that beliefs update to the environment rather than anchoring societies to it.

Third, omitted variables: geographic features correlated with both volatility and cultural complexity could confound our estimates. We mitigate this by controlling for baseline climatic endowments (mean temperature and precipitation), elevation, absolute latitude, and agricultural suitability, ensuring that our risk measures capture variance rather than level differences in the environment. The interaction-based identification strategy provides an additional layer of protection: even if an omitted geographic variable correlates with both volatility and magic, it would need to do so differentially across subsistence types to bias β_3 , a considerably more demanding confounding structure.

4.2 Main Results

Table 4 presents the baseline estimates of the relationship between environmental volatility and magical belief. To ensure that our results are not artifacts of a specific coding scheme, we present results using two distinct measurement strategies: the WordNet-expanded semantic NLP index (Columns 1–3) and the context-aware LLM classification (Columns 4–6).

Agricultural Anxiety. In Panel A, we examine the interaction between Precipitation CV (inter-annual rainfall volatility) and Agricultural Dependence. The outcome variable is the intensity of Agricultural Magic. Across all six specifications, the coefficient on the interaction term is positive and statistically significant. The results provide strong support for the functionalist hypothesis. The positive interaction indicates that rainfall volatility does not generate ‘rain magic’ in a vacuum; it only does so when a society’s livelihood is explicitly dependent on farming. For a hunter-gatherer society (where Agricultural Dependence ≈ 0), the effect of rainfall variance is statistically indistinguishable from zero. However, as reliance on farming increases, the cultural responsiveness to volatility rises sharply.

The estimated effect size increases as we move to the more sophisticated LLM measure (Columns 4–6). In the preferred specification with full social controls, a one standard deviation increase in volatility in a fully agrarian society is associated with a substantial increase in the intensity of agricultural magic. The increase in coefficient magnitude as we move from NLP to LLM specifications reflects the reduction of attenuation bias: whereas keyword searches generate false positives (noise) that bias estimates downward, the LLM’s contextual filtering provides a cleaner signal of functional belief.

In Panel B, we replace general rainfall volatility with a specific ‘disaster’ metric: Scorch Risk (the frequency of compound heat-drought events). The results confirm that specific threats drive specific adaptations. The interaction coefficients in Panel B are consistently larger than those in Panel A (e.g., $\beta = 0.149$ in Column 6 compared to $\beta = 0.093$). This suggests that the existential threat of crop withering, a visible and devastating event, is a

Table 4: Baseline Estimates of Environmental Risk $\times$ Subsistence Strategy

Specification:	<i>Dependent Variable: Magical Belief Intensity (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: Precipitation Volatility</i>						
Precipitation Volatility	−0.017 (0.054)	−0.039 (0.047)	−0.022 (0.045)	−0.067* (0.035)	−0.058 (0.039)	−0.067** (0.031)
Risk $\times$ Ag. Dependence	0.069*** (0.020)	0.077*** (0.022)	0.084*** (0.024)	0.077** (0.037)	0.082** (0.039)	0.093** (0.042)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
<i>Panel B: Scorch Risk</i>						
Scorch Frequency	−0.083 (0.072)	−0.115* (0.064)	−0.128** (0.058)	−0.085 (0.060)	−0.100* (0.057)	−0.057 (0.057)
Risk $\times$ Ag. Dependence	0.122** (0.055)	0.133** (0.059)	0.119* (0.065)	0.139*** (0.041)	0.150*** (0.040)	0.149*** (0.046)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
<i>Panel C: Storm Risk</i>						
Storm Risk	0.047 (0.063)	0.019 (0.062)	0.017 (0.069)	−0.049 (0.041)	0.053 (0.041)	0.018 (0.045)
Risk $\times$ Fish. Dependence	0.058* (0.031)	0.060** (0.026)	0.059** (0.027)	0.135*** (0.020)	0.118*** (0.026)	0.131*** (0.024)
Mean Motifs	0.13	0.13	0.13	0.19	0.19	0.19
Observations	1,218	1,206	1,052	1,218	1,206	1,052
Clusters	139	139	129	139	139	129
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Controls	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates of environmental risk effects on agricultural and protective magic. The risk measure refers to the panel-specific climatic variable; its interaction with subsistence dependence tests the functional hypothesis. Panel A: precipitation coefficient of variation ($CV = \frac{\sigma}{\mu} \times 100\%$). Panel B: frequency of dry ($< 1mm$) and hot ($> 90^{th}pctl.$) days (scorch risk). Panel C: frequency of wind- and rainy ($> 90^{th}pctl.$) days (storm risk). NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Mean motifs indicate the average percentage of the corpus classified as agricultural or protective magic. Panel A has three fewer observations in each specification because negative precipitation-CV values are set to missing. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Climate controls include mean temperature and precipitation; geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

more potent driver of magical thinking than simple statistical variance in rainfall.

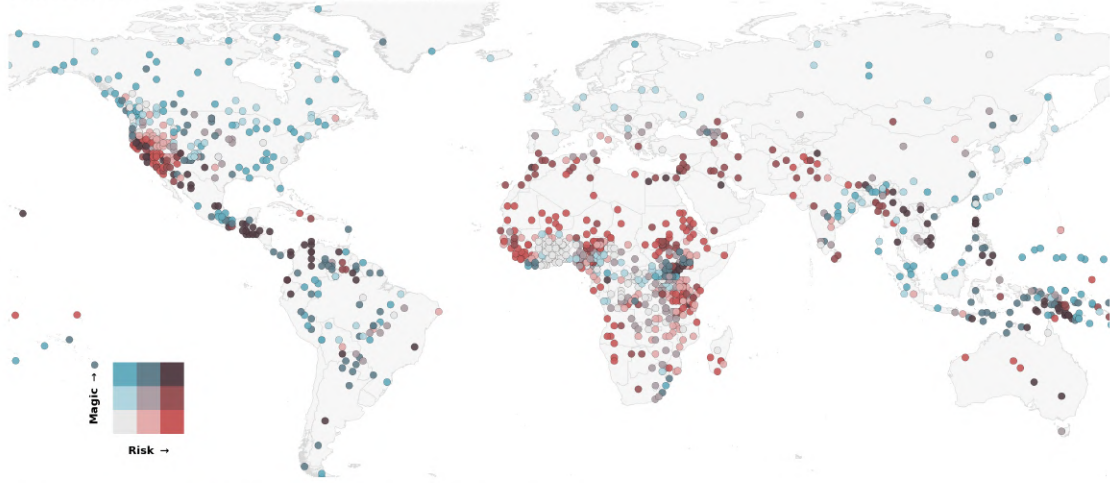
Maritime Risks. In Panel C, we shift the focus from the farmer to the fisher. Here, we test the interaction between Storm Risk and Fishing Dependence. The outcome variable is Protective Magic: motifs concerning healing, survival, and warding off physical harm (i.e., a consistent outcome for storm risk, which threatens life at sea). The results are supportive, particularly in the LLM specification (Column 6, $\beta = 0.131$). This confirms that the logic of the Malinowski hypothesis generalizes across domains: just as farmers develop magic to manage drought, fishing communities develop magic to manage storms. The NLP method (Cols 1–3) shows weaker results here; the vocabulary of “safety” is vaguer and plausibly more context-dependent than the vocabulary of “rain,” potentially pointing to the value of the LLM’s contextual parsing.

Figure 4 provides a spatial validation of these regression results using bivariate mapping. While a simple map of risk against magic (Panel A) shows only a noisy baseline correlation, mapping the interaction term against magic (Panel B) reveals a precise spatial pattern. The dark purple clusters highlight societies that are simultaneously high-risk, high-dependence, and high-magic. This visual evidence confirms that our statistical results are not driven by outliers but represent a systematic global pattern, visible from the arid zones of the Sahel to the agricultural fringes of the Americas. Notice how the hunter-gatherer societies of the Pacific Northwest (PNW) are correctly identified as low-risk in Panel B only. Figure 5 extends this visual validation to maritime environments. Mirroring the agricultural pattern, the bivariate map reveals that societies combining high storm risk with high fishing dependence are precisely those that exhibit the highest intensity of protective magic.

4.3 Falsification: Specificity of Belief

The Malinowski hypothesis posits that magic is not a generalized superstitious response to anxiety, but a targeted technology deployed against specific functional risks. This implies two

Panel A: Co-Occurrence of Risk and Magic



Panel B: The Mechanism (Risk x Dependence vs Magic)

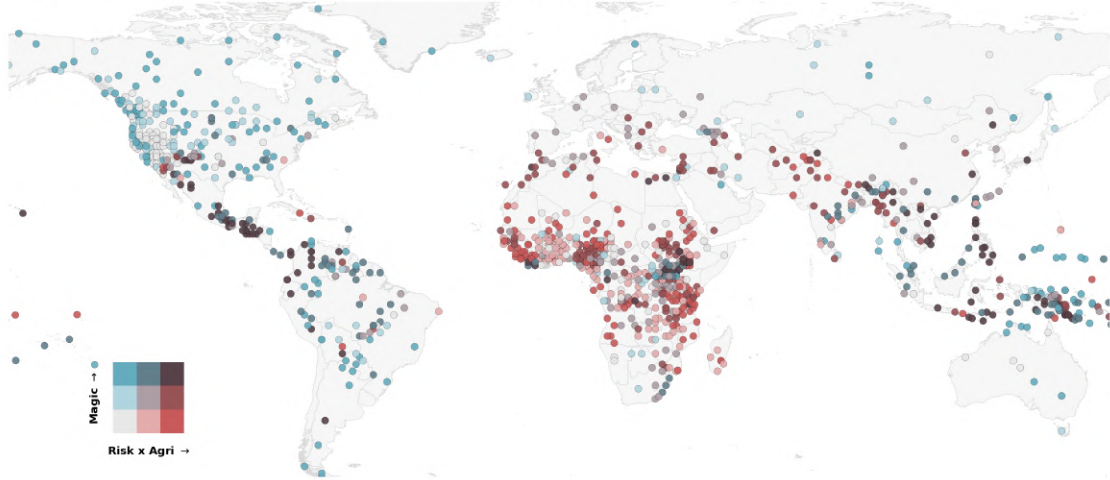
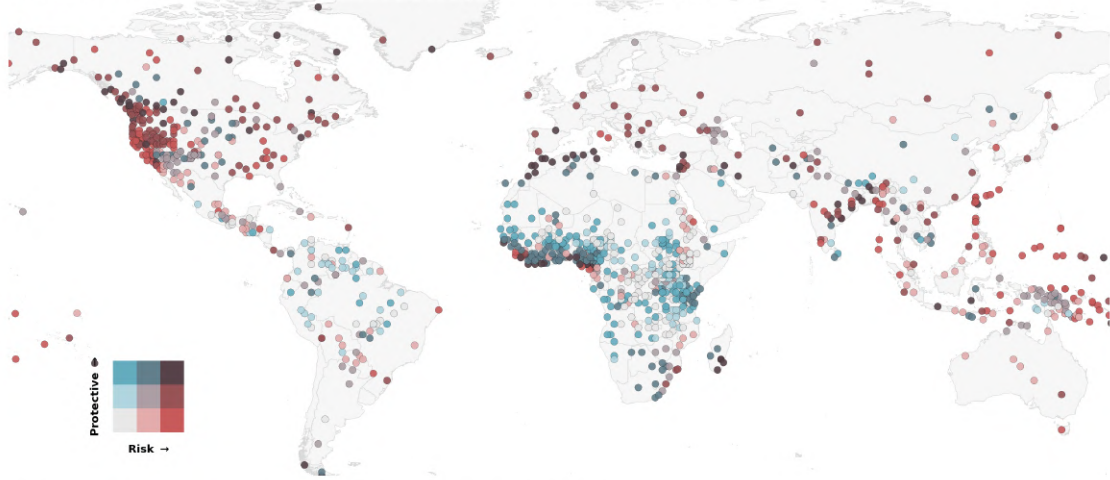


Figure 4: Visualizing the Functionalist Hypothesis for Agriculture

Notes. Bivariate maps using a 3×3 quantile scale. Panel A maps Precipitation Volatility against Magic, showing a baseline correlation. Panel B maps the Interaction Term (Risk $\times$ Subsistence) against Magic. Dark brown points represent societies that are both high-risk farmers and possess high magic intensity.

Panel A: Co-Occurrence of Storm Frequency and Protective Magic



Panel B: Mechanism (Risk $\times$ Fishing vs Protective Magic)

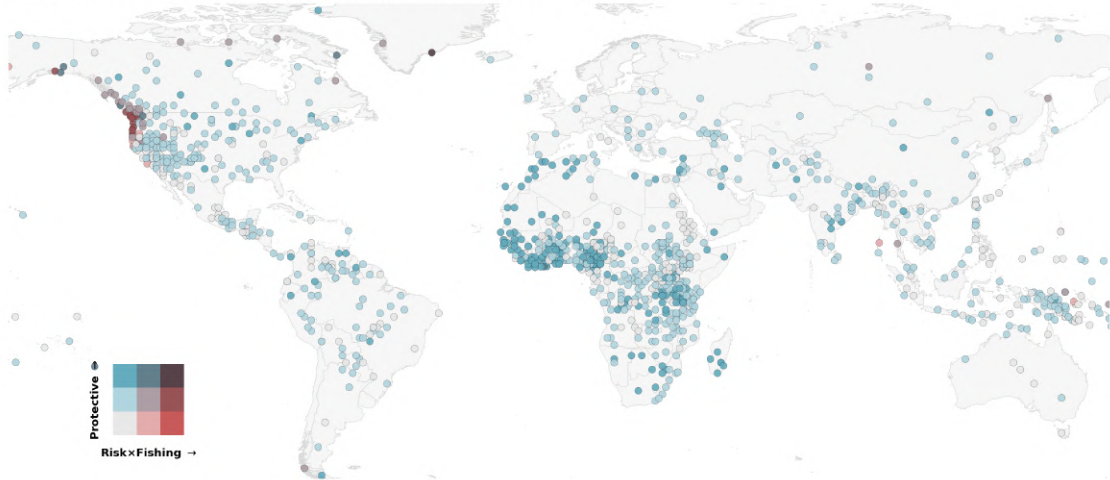


Figure 5: Visualizing the Functionalist Hypothesis for Fishing

Notes. Bivariate maps using a 3×3 quantile scale. Panel A maps Storm Risk against Magic, showing a baseline correlation. Panel B maps the Interaction Term (Risk $\times$ Subsistence) against Magic. Dark brown points represent societies that are both high-risk fishers and possess high magic intensity. Notice that the *Trobriand islanders* (right of Papua New Guinea) are identified as a ritualistic society, consistent with what Malinowski observed over a century ago in *Argonauts of the Western Pacific* (Malinowski, 1922).

testable predictions: (1) environmental risks should not predict “placebo” magic unrelated to the environment (e.g., love spells), and (2) specific risks should only trigger relevant types of magic (e.g., rain risk should not drive hunting rituals).

Placebo Test: Love Magic. To test the “General Anxiety” hypothesis, Table 5 regresses the intensity of Love Magic (spells for courtship, jealousy, and marriage) on the interaction between our primary environmental risks and subsistence dependence. If rainfall volatility merely increased general societal stress or cognitive load, we might expect an increase in all types of ritual activity. The results strongly support a functional interpretation. In the preferred LLM specifications (Columns 4–6), the interaction coefficients are statistically insignificant and close to zero across all risk categories. For instance, while Storm Risk strongly predicts protective magic among fishers (Table 4), it has no predictive power for love magic ($\beta = -0.029, p > 0.10$). Farmers and fishers appear to worry about their livelihoods, and they seem to not simply become more “superstitious” in general.

4.4 Medieval Climate Data

A concern with our climate measures is that NASA POWER satellite-era data (1984–2024) may not reflect the climatic conditions under which folklore traditions were actively developing and being transmitted. If the spatial distribution of precipitation risk has shifted substantially over the past centuries, our modern risk measures could introduce measurement error or, worse, systematic bias.

To address this directly, we replicate the baseline interaction specification from Table 4 using the medieval PDSI reconstructions described in Section 3.3. This specification contains no contemporary climate controls; all climate variation comes from the 1100–1400 AD drought atlases. If medieval drought patterns predict modern folklore content, this would provide strong evidence that the climate risk channel operates over the centuries-long timescales relevant to oral tradition.

Table 5: Placebo Test of Environmental Risk $\times$ Subsistence Strategy

Specification:	<i>Dependent Variable: Love Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: Precipitation Volatility</i>						
Precipitation Volatility	0.021 (0.024)	0.001 (0.029)	0.005 (0.027)	0.093* (0.056)	0.088 (0.064)	0.092 (0.064)
$\times$ Ag. Dependence	0.047 (0.028)	0.042 (0.027)	0.037 (0.023)	0.030 (0.036)	0.025 (0.037)	0.022 (0.034)
Mean Motifs	0.07	0.07	0.07	0.05	0.05	0.05
<i>Panel B: Scorch Risk</i>						
Scorch Frequency	-0.019 (0.047)	-0.008 (0.052)	0.004 (0.055)	0.048 (0.047)	-0.015 (0.088)	-0.014 (0.088)
$\times$ Ag. Dependence	-0.003 (0.042)	-0.003 (0.041)	0.006 (0.045)	-0.010 (0.030)	-0.019 (0.030)	-0.006 (0.031)
Mean Motifs	0.07	0.07	0.07	0.05	0.05	0.05
<i>Panel C: Storm Risk</i>						
Storm Risk	0.087 (0.083)	0.052 (0.081)	0.053 (0.091)	0.014 (0.096)	-0.027 (0.078)	-0.016 (0.093)
$\times$ Fish. Dependence	-0.007 (0.031)	0.003 (0.027)	0.005 (0.028)	-0.047 (0.033)	-0.030 (0.034)	-0.029 (0.030)
Mean Motifs	0.07	0.07	0.07	0.05	0.05	0.05
Observations	1,218	1,206	1,052	1,218	1,206	1,052
Clusters	139	139	129	139	139	129
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Controls	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates of environmental risk effects on love magic, serving as a placebo test. Panel A and B interact Precipitation/Scorch risks with agricultural dependence. Panel C interacts Storm risk with fishing dependence. NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Mean motifs indicate the average percentage of the corpus classified as love magic. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Climate controls include mean temperature and precipitation; geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 reports the results. Panel A interacts medieval PDSI volatility with agricultural dependence. The LLM interaction coefficient is 0.179 in the baseline specification, rising to 0.202 with geographic controls and remaining significant at 0.118 with social controls. These effects are approximately twice as large as the corresponding modern Precipitation CV interaction in Table 4 (0.077–0.093), consistent with the expectation that pre-modern drought patterns may have been more directly relevant for the formation of agricultural folklore. The NLP estimates are positive but not statistically significant, mirroring the pattern in the main results where the LLM measure tends to detect subtler signals.

The baseline PDSI coefficient (Risk Main) is itself positive and significant for the LLM measure, indicating that medieval drought volatility predicts agricultural magic content even unconditional on subsistence mode. This contrasts with the negative baseline risk coefficient for modern Precipitation CV in Table 4, and suggests that medieval climate risk is more directly aligned with the geographic distribution of agricultural folklore than its modern counterpart.

The sample is smaller ($N = 429$ in the baseline and geography specifications, $N = 378$ with social controls, vs. $N \approx 1,200$ for modern data) because the drought atlases cover the Old World and North America. Despite this reduced statistical power, the effects are robust. These results provide evidence that the spatial patterns of climate risk relevant for folklore formation have been persistent over centuries, and that modern satellite data provides a plausible estimate of the true relationship.

Table 6: Medieval Climate Risk (1100–1400 AD) $\times$ Agricultural Dependence

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: PDSI Volatility</i>						
Risk (Main)	0.022 (0.061)	0.021 (0.052)	−0.001 (0.075)	0.215* (0.116)	0.252** (0.104)	0.062 (0.076)
PDSI Volatility $\times$ Ag. Dep.	0.049 (0.039)	0.040 (0.039)	0.047 (0.046)	0.179** (0.078)	0.202*** (0.076)	0.118** (0.050)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
Observations	429	429	378	429	429	378
Clusters	50	50	45	50	50	45
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates of medieval PDSI volatility effects on agricultural magic. Risk (Main) shows the direct effect of the PDSI measure. Interaction captures the differential effect of medieval PDSI volatility for societies more dependent on agriculture. PDSI reconstructions are sampled at societies' current coordinates from the Old World Drought Atlas (Cook et al., 2015) and North American Drought Atlas (Cook et al., 2004) for the period 1100–1400 AD. Panel A uses PDSI volatility (standard deviation of annual PDSI). NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Mean motifs indicate the average percentage of the corpus classified as agricultural magic. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5 Mechanisms and Alternative Explanations

5.1 Soil Texture Interactions

To probe whether agricultural magic is a response to actual material risk rather than simply a cultural reaction to salient weather events, we must isolate variation in risk that is independent of the weather itself. If farmers are rationally responding to uncontrollable risk in their production function, then the same weather event should elicit different levels of magical beliefs depending on the local environmental vulnerability. If, conversely, magic is merely a superstitious reaction to frightening weather, local material conditions should matter little. Soil texture provides an ideal exogenous source of variation to adjudicate between these accounts. The physical properties of soil alter how crops experience precipitation, effectively decoupling the meteorological event from the agricultural consequence.

We focus specifically on the interaction between soil composition and flood risk (intense precipitation concentration). Our hypothesis is derived from the hydrological properties of soil particles, as illustrated in the standard soil texture triangle (Figure 6). Clay soils possess high water retention capacities and low permeability; while beneficial in droughts, this poor drainage makes them highly susceptible to waterlogging during intense rainfall (Brady and Weil, 2016). In clay-heavy regions, a deluge event is more likely to lead to soil anoxia (oxygen deprivation), root asphyxiation, and subsequent crop failure (Setter and Waters, 2003). Conversely, sandy soils are highly permeable and drain more rapidly. While this makes them risky during droughts, it provides a natural buffer against flooding, allowing heavy rainfall to dissipate quickly without damaging crops. Therefore, if the risk-coping hypothesis holds, we expect soil clay content to exacerbate the relationship between flood risk and magical beliefs (a positive triple interaction), while soil sand content should attenuate it (a negative triple interaction).

Table 7 presents the results of this triple-difference estimation. Panel A reports the

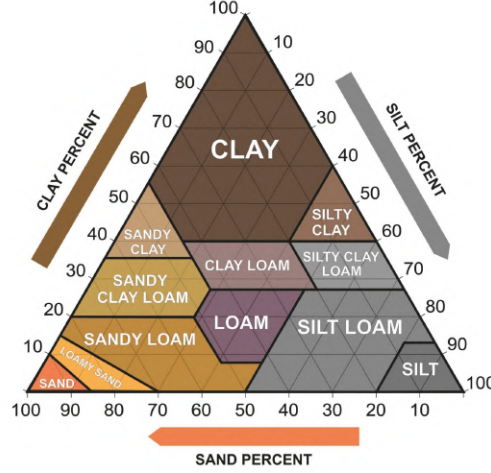


Figure 6: Soil Texture Triangle

Notes. The triangle illustrates the classification of soil based on the relative proportions of sand, silt, and clay. In the context of heavy rainfall, clay soils (top vertex) are characterized by fine particles and poor drainage, which increases susceptibility to waterlogging and crop asphyxiation. Conversely, sandy soils (bottom-left) have high permeability and drain rapidly, acting as a natural buffer against flood damage. Silt (bottom-right) possesses intermediate drainage properties.

interaction with soil clay percentage. Consistent with our hypothesis, the coefficient on the triple interaction term ($FloodRisk \times Ag.Dependence \times Clay\%$) is positive across all specifications and statistically significant in the context-sensitive LLM-based measures of agricultural magic (Columns 4–6). In the baseline LLM specification (Column 4), a one standard deviation increase in clay content increases the marginal effect of flood risk on magical beliefs by 0.099 standard deviations. Given that the baseline interaction effect is 0.096, high clay content effectively doubles the sensitivity. This suggests that farmers working clay-heavy soils view intense rainfall as a distinct, existential threat requiring greater magical intervention than their counterparts on more permeable land.

Panel B tests the moderating effect of sand. As predicted, the coefficients are mostly negative, indicating that sandy soils dampen the impact of flood risk on magical beliefs. This buffering effect is only visible in the LLM specifications (Models 4–6), where the interaction is significant at the 5% level. The coefficient of -0.039 in the baseline model (Column 4) implies that for societies located on sandy soils, the link between heavy rainfall and magical

Table 7: Flood Risk and Soil Texture Triple Interaction Estimates

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: Clay Soil</i>						
Risk $\times$ Ag. Dependence	0.114*** (0.030)	0.118*** (0.032)	0.113*** (0.031)	0.096** (0.041)	0.104*** (0.039)	0.110** (0.048)
... $\times$ Clay %	0.036 (0.032)	0.043** (0.022)	0.033 (0.028)	0.099*** (0.038)	0.088*** (0.028)	0.079** (0.031)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
<i>Panel B: Sand Soil</i>						
Risk $\times$ Ag. Dependence	0.094** (0.041)	0.092** (0.039)	0.091** (0.039)	0.057* (0.034)	0.067* (0.036)	0.086** (0.039)
... $\times$ Sand %	-0.002 (0.018)	-0.001 (0.018)	0.004 (0.020)	-0.039** (0.017)	-0.032** (0.015)	-0.037** (0.016)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
Observations	1,184	1,173	1,022	1,184	1,173	1,022
Clusters	138	138	128	138	138	128
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Controls	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates of the triple interaction: Flood Risk $\times$ Agricultural Dependence $\times$ Soil Percentage. Flood risk is defined as the proportion of annual rainfall occurring within the single wettest 7-day window. Panel A reports the interaction with Soil Clay percentage; Panel B reports the interaction with Soil Sand percentage. The Baseline interaction ($\times$ Ag. Dependence) represents the effect of Flood Risk $\times$ Ag. Dependence when the soil moderator is at zero. NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Climate controls include mean temperature and precipitation; geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

practice is significantly weaker. On average, sandy soils diminish the relationship between flood risk and agricultural magic by half. The baseline interaction term ($\times$ Ag. Dependence) remains positive and significant in almost all columns, confirming that while soil texture modulates the intensity of the response, the fundamental relationship between agricultural dependence and environmental risk persists. Together, these results support the materialist interpretation: farmers are not only reacting to the rain itself but to the specific, locally mediated risk that the rain poses to their livelihoods.

5.2 Technological Substitution

If agricultural magic functions as a technology of the imagination for managing unmitigated risk, it follows that tangible technologies for risk mitigation may crowd it out.⁴ We test this substitution hypothesis using irrigation, a technology that provides physical control over water supply. Table 8 reports triple-interaction estimates interacting environmental risk, agricultural dependence, and the presence of irrigation. Across both panels, the baseline double interaction between environmental risk and agricultural dependence remains positive and statistically significant. This confirms that the primary relationship between climatic volatility and magical beliefs holds for societies lacking technological buffers.

Panel A examines the interaction with precipitation volatility. Because irrigation infrastructure is designed to smooth inter-annual volatility by storing water in wet years to buffer against dry ones, it should mechanically decouple production from rainfall variance. Consistent with this, the context-aware LLM specifications (Columns 4–6) yield a negative and significant triple interaction coefficient, indicating that the presence of irrigation attenuates the link between rainfall volatility and magical beliefs. However, this effect is not detected by the keyword-based NLP measure (Columns 1–3). This divergence suggests that the dampening effect of irrigation on general rainfall anxiety is captured more clearly in the structural narratives of the folklore (parsed by the LLM) than in raw keyword frequencies.

⁴ “We do not find magic wherever the pursuit is certain, reliable, and well under control of rational methods.” (Malinowski, 1948).

Table 8: Technological Substitution and Irrigation Triple Interaction Estimates

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: Precipitation Volatility</i>						
Risk $\times$ Ag. Dependence	0.052** (0.024)	0.063** (0.025)	0.070** (0.027)	0.105** (0.041)	0.111** (0.045)	0.112** (0.045)
... $\times$ Irrigation	0.009 (0.041)	-0.000 (0.040)	0.004 (0.039)	-0.046** (0.021)	-0.048** (0.021)	-0.040* (0.021)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
<i>Panel B: Scorch Risk</i>						
Risk $\times$ Ag. Dependence	0.057 (0.063)	0.084 (0.063)	0.087 (0.067)	0.129*** (0.045)	0.141*** (0.047)	0.143*** (0.046)
... $\times$ Irrigation	-0.151** (0.060)	-0.119** (0.061)	-0.097 (0.060)	-0.014 (0.059)	-0.024 (0.058)	-0.011 (0.043)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
Observations	1,117	1,106	1,049	1,117	1,106	1,049
Clusters	134	134	129	134	134	129
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Controls	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates of the triple interaction testing for technological substitution via irrigation. Risk $\times$ Ag. Dependence reports the baseline interaction coefficient. The ... $\times$ Irrigation row reports the coefficient on the triple interaction term: Risk $\times$ Ag. Dependence $\times$ Irrigation. Panel A uses Precipitation Volatility (Precipitation CV) as the risk measure; Panel B uses Scorch Risk. NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Climate controls include mean temperature and precipitation; geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Panel B extends the analysis to scorch risk. Here, the measurement sensitivity reverses: the NLP specifications (Columns 1–3) capture a negative and significant substitution effect, while the LLM estimates are directionally consistent but statistically insignificant. Where significant, the magnitude of this technological buffer is substantial, with the triple interaction coefficient completely offsetting the baseline marginal effect of scorch risk.

Taken together, because the statistical significance of the substitution effect is sensitive to the text classification strategy, these results should be interpreted as suggestive rather than definitive. Nonetheless, the economically large coefficients and consistent directional signs provide preliminary evidence that physical technology may act as a substitute for belief-based coping mechanisms, potentially crowding out the demand for functional magic when environmental threats are mechanically neutralized.

6 Cultural Adaptation vs. Persistence

A central question in cultural evolution is whether belief systems are adaptations to the immediate environment or traits inherited from ancestral experience (See [Voightländer and Voth, 2012](#); [Giuliano and Nunn, 2021](#)). This question has particular force in our setting, since we cannot observe when individual folklore motifs were composed. If functional magic motifs are ancient narratives transmitted passively across generations, the correlation we document between contemporary climatic volatility and magical intensity could reflect the geographic persistence of climate patterns rather than an active cultural response to risk. The Malinowski hypothesis, however, views magic as a functional technology, which implies a high degree of plasticity: if the risk disappears, the psychological need for the ritual should vanish, and the motif should be discarded or de-emphasized in the oral tradition. In contrast, if magic is transmitted vertically as part of a rigid identity package, we should observe persistence even after the environmental stimulus is removed.

6.1 Satellite Data Baseline

To distinguish between these two mechanisms, we implement an epidemiological strategy. By utilizing the reconstructed ancestral coordinates described in Section 3.2, we restrict our sample to migrant societies: defined as groups whose current location is more than 500 km distant from their ancestral origin. This spatial disconnect weakens the collinearity between current and ancestral climates, allowing us to observe whether magical beliefs track the conditions a group currently faces or those it left behind. If the folklore corpus is a static archive of ancient beliefs, ancestral conditions should dominate. If it is a living repertoire that updates in response to environmental pressures, current conditions should dominate.

We test this by estimating the following horse race specification:

$$\text{Magic}_i = \alpha + \gamma_1(\text{Risk}_{Curr} \times \text{Dep}) + \gamma_2(\text{Risk}_{Anc} \times \text{Dep}) + \mathbf{X}_i' \eta + \epsilon_i \quad (3)$$

Table 9 presents the results of this contest across the three primary risk categories. All estimates restrict the sample to the > 500 km migrant sample; Appendix Table A5 reports how this restriction affects the estimation samples. The findings point toward adaptation dominating persistence. In the migrant sample, current agricultural risk remains positively associated with agricultural magic for precipitation volatility and scorch risk, while the coefficient on ancestral risk (Heimat risk) is generally small, statistically indistinguishable from zero, and occasionally negative.

For precipitation volatility (Panel A), current risk is positive across all NLP and LLM specifications and statistically significant for the NLP measure, while Heimat risk is generally null or negative. The results are more pronounced for Scorch Risk (Panel B), which represents the most immediate existential threat to agrarian societies. In the preferred LLM specification with full social controls (Column 6), the effect of current risk remains large and marginally significant ($\gamma_1 = 0.151$), while the effect of ancestral risk is always negative and effectively zero ($\gamma_2 = -0.034$).

Table 9: Horse Race of Current vs Heimat Risk $\times$ Agricultural Dependence

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: Precipitation Volatility</i>						
Current Risk $\times$ Ag. Dep	0.065* (0.036)	0.065* (0.036)	0.073** (0.036)	0.078 (0.050)	0.067 (0.048)	0.070 (0.056)
Heimat Risk $\times$ Ag. Dep	-0.036 (0.036)	-0.012 (0.033)	-0.007 (0.039)	-0.081* (0.047)	-0.070 (0.044)	-0.012 (0.028)
<i>Panel B: Scorch Risk</i>						
Current Risk $\times$ Ag. Dep	0.097 (0.080)	0.083 (0.083)	0.061 (0.090)	0.189** (0.090)	0.172** (0.085)	0.151* (0.090)
Heimat Risk $\times$ Ag. Dep	-0.076 (0.076)	-0.037 (0.070)	-0.040 (0.080)	-0.066 (0.087)	-0.065 (0.082)	-0.034 (0.082)
<i>Panel C: Storm Risk</i>						
Current Risk $\times$ Fish. Dep	-0.040 (0.034)	-0.025 (0.029)	-0.006 (0.028)	-0.015 (0.019)	-0.006 (0.016)	0.004 (0.019)
Heimat Risk $\times$ Fish. Dep	-0.007 (0.029)	0.010 (0.035)	-0.002 (0.033)	0.026 (0.028)	0.031 (0.031)	0.003 (0.028)
Observations	792	780	684	792	780	684
Clusters	28	28	25	28	28	25
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Means	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates from a horse race specification that includes both contemporary and heimat risk interactions simultaneously. Sample restricted to societies whose current coordinates are more than 500 km from their Heimat coordinates. Risk is interacted with the relevant subsistence dependence measure (agricultural dependence for crop risks; fishing dependence for storm risk). Including both current and historical risk allows direct comparison of explanatory power. All models include main effects for both risk measures. NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Climate means include both contemporary and heimat averages; geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Panel C extends this analysis to Storm Risk, our test for fishing societies. Here, the adaptive pattern vanishes. Neither current nor Heimat storm risk predicts protective magical beliefs in the migrant sample. This divergence highlights a fundamental difference in production technologies: while agricultural magic appears more responsive to present agrarian risks, the fishing-related test provides little evidence that protective magic is recalibrated to either current or ancestral risk exposure.

These findings offer a refinement to our theory. Unlike deep moral values or gender norms, which often persist for centuries after migration, agricultural magic appears relatively plastic. When a group moves from one climatic environment to another, its agricultural ritual content tracks current agrarian exposure more closely than assigned Heimat exposure. This supports the interpretation of agricultural magic as a responsive technology for managing present-day uncertainty, rather than being part of a rigid cultural inheritance.

These results also speak directly to the temporal provenance concern raised in Section 3.3. If the functional motifs we measure were frozen relics of a distant climatic regime, ancestral risk should retain predictive power among migrants. It does not, indicating that the corpus contains an active component whose retention tracks present-day environmental relevance. This complements the observation of [Michalopoulos and Xue \(2021\)](#) that folklore reflects a society’s “contemporary ecology” and potentially extends it from a cross-sectional correlation to a within-family test among populations that have changed environments.

6.2 Medieval Paleoclimate Robustness

The preceding analysis demonstrates that agricultural magic is more closely related to current than to ancestral climatic conditions using modern satellite data. However, a recurring plausible concern is that contemporary climate patterns might diverge from the historical conditions these societies actually experienced during their migrations, introducing measurement error. To address this, we replicate the horse race specification (Equation 3) using paleoclimate data, again replacing contemporary NASA POWER precipitation measures with

historical PDSI reconstructions from the OWDA and NADA drought atlases (1100–1400 AD).

Table 10 reports the results. For medieval PDSI volatility, the current-location interaction is positive: the LLM coefficient reaches 0.325 in the geographic specification and remains positive when adding social controls. In contrast, the Heimat-location interaction is statistically indistinguishable from zero in the migrant sample. This pattern mirrors the modern-data horse race in Table 9 and indicates that the adaptation finding is unlikely to be solely an artifact of using satellite-era climate data.

This estimation sample is restricted to societies located more than 500 km from their Heimat that also have PDSI coverage at both their current and Heimat coordinates ($N = 240$ in the base and geography specifications; $N = 217$ with social controls). This strict dual-coverage requirement yields only 14 language-family clusters in the base specifications, meaning that the estimates are inherently less precise than the full modern-data analysis. Nevertheless, the qualitative pattern remains similar: medieval drought volatility at a society’s current location appears to predict agricultural magic content more strongly than medieval drought volatility at its ancestral homeland.

Taken together, the baseline satellite estimates and the medieval paleoclimate replications provide consistent evidence against the characterization of magical folklore as an inert, purely persistent cultural artifact. While deep structural norms and historical identities often exhibit strong long-run inertia, functional magic operates with a degree of cultural plasticity. As migrant societies transition across ecological regimes, their oral traditions appear to systematically update: motifs addressing inactive ancestral threats are de-emphasized or discarded, while narratives mitigating active, localized risks are retained or incorporated. Ultimately, this dynamic recalibration strongly supports Malinowski’s functionalist framework, indicating that magical beliefs act as living technologies continuously revised to manage salient environmental uncertainty.

Table 10: Horse Race of Current vs Heimat Paleo PDSI $\times$ Ag. Dependence

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: PDSI Volatility (1100-1400 AD)</i>						
Current PDSI $\times$ Ag. Dep	0.055* (0.031)	0.061 (0.060)	0.136*** (0.040)	0.180** (0.070)	0.325*** (0.055)	0.169*** (0.063)
Heimat PDSI $\times$ Ag. Dep	1.820 (1.459)	1.380 (1.309)	1.189 (1.272)	2.632 (1.930)	1.277 (2.209)	0.763 (1.484)
<i>Panel B: Extreme Drought Frequency (1100-1400 AD)</i>						
Current PDSI $\times$ Ag. Dep	0.047 (0.066)	0.014 (0.072)	0.118* (0.064)	0.381*** (0.108)	0.380*** (0.103)	0.062 (0.087)
Heimat PDSI $\times$ Ag. Dep	0.399 (0.346)	0.361 (0.307)	0.284 (0.329)	-0.173 (0.403)	-0.231 (0.421)	0.076 (0.360)
Observations	240	240	217	240	240	217
Clusters	14	14	13	14	14	13
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Means	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates from a horse race specification that includes both current-location and heimat-location paleo PDSI interactions simultaneously. The sample is restricted to societies whose current coordinates are more than 500 km from their Heimat coordinates and that have PDSI coverage at both locations. PDSI measures are derived from historical drought atlas reconstructions (OWDA/NADA) for the period 1100–1400 AD. Panel A uses PDSI volatility (standard deviation); Panel B uses extreme drought frequency ($\text{PDSI} < -3$). Including both locations allows direct comparison of which geographic reference point better predicts modern magical beliefs. All models include main effects for both PDSI measures. Heimat PDSI is assigned at the language family level; the interaction is identified from within-family variation in subsistence dependence. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

7 Conclusion

This paper provides evidence that the prevalence of magical beliefs often observed in traditional societies is not simply an immutable cultural feature or a symptom of irrationality, but is partly shaped by environmental risk. The combination of irreducible uncertainty and the absence of formal insurance markets appears to encourage ritual frameworks for rendering the unpredictable cognitively manageable. This finding qualifies the view that superstition is inherently antithetical to economic development; rather, it may function as a rational second-best institution that provides psychological stability where first-best technologies such as irrigation or formal insurance are missing.

While educational interventions often treat superstition as an informational error to be corrected, our findings regarding the substitution effects of irrigation suggest that the demand for magic falls when environmental variance is dampened or insured. Successful development policy, therefore, should address the underlying demand for certainty as opposed to directly attacking the supply of superstition.

The cognitive mechanism we identify need not be confined to the ethnographic record. Modern secular societies exhibit similar patterns when technological control fails. The COVID-19 pandemic triggered an unprecedented surge in conspiracy beliefs precisely when the gap between the severity of the threat and the availability of effective countermeasures was widest (see Appendix B.3). Conspiracy theories, like the rain rituals of drought-stricken farmers, appear to offer structured causality where standard explanations leave a residual of unexplained misfortune. The responsiveness of belief documented in the ethnographic record may reflect a broader feature of human cognition under uncertainty, with direct implications for how we understand resistance to scientific authority in modern crises.

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A Data Construction and Validation

A.1 Classification of Folklore Motifs

To construct the Magical Intensity indices, we distinguish between general supernatural narratives (e.g., origin myths, trickster tales) and specific supernatural practices aimed at controlling uncertain outcomes. We employ two independent classification strategies: NLP-based and LLM-based classification.

A.1.1 Semantic Expansion (WordNet)

To capture synonymous concepts without manual enumeration, we implement a semantic expansion algorithm using WordNet. For each domain, we define a set of seed words and a separate set of Magical Operator seeds.

Context Seeds.

- **Agriculture:** sun, rain, wind, cloud, storm, flood, drought, sky, earth, food, eat, hunger, starve, famine, water, drink, plant, sow, dig, gather, garden, field.
- **Protection:** sick, ill, pain, weak, wound, hurt, bleed, die, death, dead, kill, corpse, grave, bury, heal, cure, medicine, recover, alive, life.
- **Love:** wife, husband, bride, groom, lover, mother, father, marry, wedding, love, desire, sleep, birth, pregnant.

Magic Operator Seeds.

- **Active:** turn, transform, become, change, shape, disguise, summon, call, fly, vanish, appear, create, make, spirit, demon, monster, god, ghost, witch, shaman, ogre, dragon.
- **Passive:** dream, omen, sign, prophecy, vision, charm, amulet, taboo, sacred, holy, secret.

The algorithm executes a three-step expansion for each category: (1) *Synset Retrieval* queries

the WordNet graph for cognitive synonyms of each seed; (2) *Lexical Expansion* extracts all lemmas from matching synsets (filtered by part-of-speech for context categories to reduce noise); (3) *Stemming* standardizes morphological variants using the Snowball Stemmer. A motif is classified as, e.g., “Agricultural Magic” if and only if its stemmed text matches both the expanded agricultural context vocabulary and the expanded magical operator vocabulary. This intersectional constraint ensures the measure captures supernatural responses to environmental stress rather than mere descriptions of weather or farming.

A.1.2 LLM Classification

While the text-based approaches provide transparent baselines, they are context-blind: a keyword match for “rain” cannot distinguish between a fable where a fox waits for rain (narrative setting) and a ritual performed to cause rain (functional magic). To overcome this, we employ a Large Language Model (GPT-4o-mini) to classify each of the 2,560 unique motifs according to a fixed response template.

Classification Dimensions. Each motif is coded along four dimensions using a fixed classification template:

1. **Risk Context:** The subject matter of the motif, tagged regardless of whether magic is present. Categories: agriculture/weather, health/survival, love/courtship, social conflict, or none.
2. **Functional Magic:** An indicator equal to one if the motif describes any magical act, ritual, spell, omen, taboo, or supernatural belief used to influence or predict outcomes.
3. **Mechanism:** Active ritual, passive omen, taboo, or none.
4. **Goal Orientation:** Productive (to gain), protective (to prevent), destructive (to harm), or neutral.

Of these four dimensions, two enter the regression analysis directly. The LLM-based dependent variables used throughout the paper are constructed by intersecting Risk Context

with Functional Magic. For example, Agricultural Magic (LLM) is defined as the share of a society’s motifs classified as both agriculture/weather and functional magic. Analogous intersections produce the Love Magic (placebo) and Protective Magic indices. Mechanism and Goal Orientation are retained for completeness but do not enter the main specifications.

Classification Instruction. The model receives the following instruction:

You are an expert anthropologist cataloguing magic in folklore.

DECISION LOGIC:

1. *CONTEXT: What is the topic? Assign a risk context even if there is no magic.*
2. *MAGIC: Does the text contain supernatural techniques (ritual, spell, omen, taboo)?*

If yes, classify it as functional magic.

- *Do NOT exclude “myths” if they describe a magical principle (e.g. “The Thunderbirds make rain” → True).*

CONFIDENCE CALIBRATION:

- *10/10: EXPLICIT HUMAN RITUAL. “The shaman sacrifices a bull.”*
- *8/10: EXPLICIT RULE/BELIEF. “If you see a crow, you will die.”*
- *5/10: MYTHOLOGICAL MAGIC. “The God of Wind blew the storm away.”*
- *1/10: PURE FICTION. “The fox tricked the bear.”*

CONSISTENCY: If a motif is classified as non-magical, mechanism must be “none” and goal must be “neutral.”

Few-Shot Examples. The model receives four expert-coded examples before classifying each motif:

1. **The Thunderbirds** (“Creatures that produce rain and thunderstorms are birds or anthropomorphic beings”: agriculture/weather, magical, active ritual, productive, confidence 6).
2. **Person Sacrifices His Child** (“To cure his friend, person agrees to sacrifice his small son”: health/survival, magical, active ritual, protective, confidence 10).

3. **The Shortened Stick** (“A judge gives sticks to suspects... tells them the guilty one’s stick will grow”: social conflict, magical, active ritual, protective, confidence 9).
4. **The Entrapped Suitors** (“A pretty wife invites suitors... they are caught by the husband”: social conflict, non-magical, none, neutral, confidence 10).

Classification is performed deterministically using this fixed response format, ensuring that each motif receives a complete and internally consistent set of codes. The procedure is then applied uniformly to all 2,560 motifs in the corpus.

A.2 Human Validation of LLM Classifications

To assess whether the LLM classifier produces judgements comparable to those of informed human coders, we conducted a blind validation exercise. We drew a stratified random sample of 100 motifs from the full corpus of 2,560 and divided them into five documents of 20 motifs each. Two independent coders (neither of whom had prior knowledge of the LLM’s classifications) each completed one document using the identical category definitions and classification instructions provided to the LLM. To ensure maximal comparability, each document included an appendix reproducing the exact system prompt, schema, and few-shot examples used by the LLM classifier. Table A1 reports the results across five dimensions.

Agreement on the magic binary. The primary classification variable (i.e., whether a motif contains functional magic) shows strong agreement between Coder 1 and the LLM (95%, 18 of 19 non-ambiguous motifs). Coder 2 agrees with the LLM on 65% of motifs (13 of 20). All seven of Coder 2’s disagreements are in the same direction: Coder 2 classifies a motif as non-magical where the LLM classifies it as magical. This asymmetry reflects a systematic difference in threshold rather than random noise. Coder 2 consistently applied a stricter standard, requiring explicit ritual activity, while the LLM (and Coder 1) followed the prompt instruction to include myths that *describe* a magical principle even without an explicit human ritual. For example, Coder 2 classified “The bribed guards” (i25), in which a

person placates supernatural creatures guarding a pathway, as a fable without magic, while the LLM flagged the supernatural creatures as evidence of a magical belief system.

One disagreement is particularly instructive. Motif m199a (“Extracting brain from the earth”) describes a man who buries animal bowels and then *pretends* to extract brains from the ground. Coder 2 correctly identified this as deception rather than magic (confidence: 1/10), while the LLM classified it as an active ritual. This case illustrates a limitation of the LLM: it can struggle to distinguish descriptions of magic from descriptions of *pretending* to do magic, a distinction that requires pragmatic reasoning about narrative intent.

Agreement on risk context. Agreement on the substantive domain (agriculture, health, social conflict, etc.) is lower for both coders (60% and 55%). This is expected: many motifs span multiple domains (e.g., a sacrifice to the Sun could plausibly be coded as agriculture/weather or health/survival), and the classification schema forces a single choice. The moderate agreement suggests that the risk context dimension introduces more measurement noise than the magic binary, consistent with our decision to use the intersection of risk context and functional magic as the primary dependent variable.

Confidence calibration. The LLM’s confidence scores are systematically higher and less dispersed than the human coders’ scores. While both humans range down to 1–3 on ambiguous motifs, the LLM never assigns a confidence below 5 and clusters around 7–8. This suggests the LLM is overconfident on genuinely ambiguous cases. In practice, this matters less than it might appear, because the confidence score does not enter the construction of the dependent variable, only the binary magic classification does.

Consistency rule compliance. The instructions specify that if a motif is classified as not containing magic, then mechanism must be set to “none” and goal to “neutral.” The LLM follows this rule perfectly across all 40 motifs. The human coders violate it four times in total (e.g., marking “no magic” but setting mechanism to “taboo”), suggesting that the LLM’s

mechanical consistency is an advantage in large-scale coding tasks where schema discipline is important.

Pooling across both coders, human–LLM agreement on the magic binary is 79% (31 of 39 non-ambiguous motifs), with all disagreements driven by a conservative coder applying a stricter threshold. The LLM’s classifications are broadly consistent with informed human judgement, though they exhibit a mild liberal bias toward classifying ambiguous motifs as magical, consistent with the explicit prompt instruction to include mythological magic. This directional bias should be noted when interpreting magnitudes: the LLM-based magic index may slightly overcount magic relative to what the most conservative human coder would produce. However, this bias is constant across societies and therefore does not threaten the identification of cross-sectional variation in magical intensity.

Panel B of Table A1 reports standard classification metrics (precision, recall, F1, and Cohen’s κ) for the LLM’s functional-magic classification against each human coder.

For Coder 1, the LLM achieves a precision of 0.909, recall of 1.000, and F1 of 0.952, with Cohen’s $\kappa = 0.894$ (“Almost Perfect” agreement per Landis and Koch (1977)). The single false positive (LLM classified as functional magic, Coder 1 disagreed) accounts for the slight reduction from perfect precision. Importantly, the LLM identified all motifs that the human coder labeled as functional magic (zero false negatives), suggesting the classification errs on the side of inclusion rather than omission.

For Coder 2, precision drops to 0.462 and F1 to 0.632, with $\kappa = 0.375$ (“Fair”). The divergence between coders highlights that the primary source of disagreement lies not in the LLM’s classification algorithm but in the inherent ambiguity of distinguishing “functional” from “non-functional” magic, a judgment call on which reasonable human coders themselves disagree. The LLM’s recall remains perfect (1.000) against both coders: it never misses a motif that either human coder identified as functional magic.

The asymmetry between the two human coders’ agreement with the LLM underscores a key point: Coder 2 applied a more restrictive definition of functional magic, classifying several

Table A1: Human–LLM Agreement on Folklore Motif Classification

	Coder 1	Coder 2
	(Document 1, $N = 20$)	(Document 2, $N = 20$)
<i>Panel A: Agreement on Functional Magic (Yes/No)</i>		
Agreement rate	95% (18/19) ^a	65% (13/20)
Human Yes, LLM Yes (TP)	10	6
Human No, LLM No (TN)	8	7
Human Yes, LLM No (FN)	0	0
Human No, LLM Yes (FP)	1	7
<i>Panel B: Classification Metrics</i>		
Precision	0.909	0.462
Recall	1.000	1.000
F1 Score	0.952	0.632
Cohen’s κ	0.894	0.375
<i>Panel C: Agreement on Risk Context</i>		
Agreement rate	60% (12/20)	55% (11/20)
<i>Panel D: Confidence Scores</i>		
Human mean confidence	6.7	4.2
LLM mean confidence	7.9	7.7
Human confidence range	3–10	1–9
LLM confidence range	5–10	5–10
<i>Panel E: Consistency Rule Compliance^b</i>		
Human violations	3	1
LLM violations	0	0

Notes. Each coder independently classified 20 randomly sampled folklore motifs using the same instructions and category definitions provided to the LLM. Coders were shown the LLM’s exact system prompt and few-shot examples in an appendix to ensure identical framing. Neither coder had prior knowledge of the LLM’s classifications. Panel B treats human labels as ground truth and LLM labels as predictions. Cohen’s κ adjusts for chance agreement (Landis and Koch, 1977): <0.20 = Slight, 0.21 – 0.40 = Fair, 0.41 – 0.60 = Moderate, 0.61 – 0.80 = Substantial, 0.81 – 1.00 = Almost Perfect.

^a One motif was marked “depends on the version” by Coder 1 and is excluded from the denominator.

^b The consistency rule states: if a motif is classified as not containing magic, then mechanism must be “none” and goal must be “neutral.”

motifs as non-functional that both Coder 1 and the LLM considered functional. This pattern is consistent with the LLM implementing a definition closer to Coder 1’s interpretation. For our purposes, the liberal classification bias of the LLM (high recall, potentially lower precision against stricter coders) means that any measurement error in the dependent variable works against finding significant results, biasing our estimates toward zero.

A.3 Weather Data Construction

Daily meteorological data were obtained from the NASA Prediction of Worldwide Energy Resources (POWER) Project API ([NASA POWER Project, 2026](#)), querying the `daily/point` temporal endpoint for each ethnic group centroid. We retrieved daily records for precipitation (`PRECTOTCORR`), maximum and minimum temperature (`T2M_MAX`, `T2M_MIN`), and wind speed (`WS10M`) over the period 1984–2024. Table A3 provides formal definitions and calculation methods for all climatic variables.

Additionally, Table A2 below reports the pairwise cross-correlations among these constructed environmental risk measures to confirm they capture distinct dimensions of environmental volatility.

Table A2: Cross-Correlations of Environmental Risk Measures

Variable	(1)	(2)	(3)	(4)	(5)
(1) Precipitation Volatility	1.00				
(2) Flood Risk	0.72	1.00			
(3) Drought Risk	0.56	0.78	1.00		
(4) Scorch Risk	0.35	0.43	0.58	1.00	
(5) Storm Risk	-0.17	-0.04	-0.25	-0.17	1.00

Notes. The table reports pairwise Pearson correlation coefficients. All measures are calculated at the ethnic group centroid using daily meteorological data (1984–2024). Variables are ordered to group highly correlated agricultural risks (1–4), demonstrating that while scorch risk is positively correlated with other agricultural constraints, it contains substantial unique variation. Storm risk (5) captures maritime hazards and remains effectively orthogonal to the agricultural cluster.

Table A3: Climatic Controls and Environmental Risk Metrics

Variable	Definition & Calculation Method
<i>Panel A: Baseline Climatic Controls</i>	
Mean Precipitation	Average total annual rainfall (mm/year). Controls for overall water availability.
Mean Temperature	Average daily temperature (°C). Controls for base thermal energy and growing season length.
<i>Panel B: Predictability & Volatility</i>	
Precipitation CV	The inter-annual coefficient of variation in total rainfall (σ_{rain}/μ_{rain}), measuring long-term water insecurity.
Flood Risk	Intra-annual rainfall irregularity. The proportion of total annual rain falling within the single wettest 7-day window.
Drought Risk	The mean annual maximum dry spell, defined as the average length of the longest run of consecutive days per year with precipitation < 1 mm.
<i>Panel C: Extreme Events & Compound Risks</i>	
Scorch Risk	Frequency of compound heat-dry events. Proportion of days where T_{max} exceeds the local 90 th percentile and precipitation is negligible (< 1 mm).
Storm Risk	Compound extreme events. Proportion of days where <i>both</i> precipitation and wind speed exceed their local 90 th percentiles.

Notes: Data Source: [NASA POWER Project \(2026\)](#). All metrics are calculated using daily point-data from the NASA POWER API [1984–2024]. CV denotes Coefficient of Variation. Percentiles for compound risks are calculated relative to the local historical baseline.

A.4 Linguistic Urheimat Designations and Sources

Table A4 details the specific reconstructed ancestral homelands (*Urheimaten*) for the 35 major language families utilized in our spatial matching procedure. The main text outlines the theoretical framework for identifying migratory groups (defined by a > 500 km displacement from these origins); this appendix catalogs the precise geocoordinates and disciplinary sources used to establish those historical baselines.

The 35 language families are distributed across six global macro-regions, collectively encompassing the origins of the 986 traditional societies analyzed in the persistence estimations. The coordinates rely on a synthesis of contemporary consensus in historical linguistics, Bayesian phylogeography, and archaeolinguistics. The sources range from computationally intensive Bayesian models of lexical evolution (Bouckaert et al., 2018; Walker and Ribeiro, 2011) to archaeological evidence of early agricultural expansions (e.g., Anthony, 2007, for the Pontic-Caspian Steppe; Whitman, 2011 for Korean Peninsula rice farmers). These standardized origin points form the ancestral environmental baseline against which the contemporary spatial coordinates from the Ethnographic Atlas are compared.

A.5 Sample Accounting for Migrant and Phylogenetic Analyses

The cultural persistence and phylogenetic specifications require smaller estimation samples than the baseline cross-sectional tables. This attrition is due to strict data requirements: societies must have assigned Heimat coordinates, migrate at least 500 km from those origins, possess historical PDSI coverage at both current and ancestral locations, or precisely match the tips of the global language tree. Table A5 summarizes these sequential restrictions and reports the resulting regression-complete observation counts for each specific robustness check.

Table A4: Ancestral Locations (Urheimat) for 35 Major Language Families

Language Family	Proposed Urheimat	Coordinates	Source
<i>Africa & Middle East</i>			
Afro-Asiatic	Red Sea Hills / Eastern Sudan	18.0°N, 36.0°E	Ehret (2002)
Atlantic-Congo	Benue-Cross River	6.0°N, 9.0°E	Grollemund et al. (2015)
Khoe-Kwadi	Middle Zambezi Valley	18.0°S, 26.5°E	Güldemann (2008)
Mande	Inland Niger Delta	11.0°N, 9.0°W	Vydrin (2009)
Nilo-Saharan	Middle Nile Valley	16.0°N, 32.0°E	Ehret (2001)
<i>Eurasia (West & South)</i>			
Austroasiatic	Red River Delta (N. Vietnam)	21.0°N, 105.8°E	Sidwell (2022)
Dravidian	Upper Godavari (Maharashtra)	20.0°N, 74.5°E	Krishnamurti (2003)
Indo-European	Pontic-Caspian Steppe	48.0°N, 40.0°E	Anthony (2007)
Kartvelian	Colchis (Rioni River)	42.5°N, 42.5°E	Tuite (1998)
<i>Eurasia (East & North)</i>			
Chukotko-Kamchatkan	Anadyr River Basin	66.0°N, 172.0°E	Fortescue (2005)
Hmong-Mien	Middle Yangtze (Daxi Culture)	29.5°N, 112.5°E	Ratliff (2010)
Japonic	Korean Peninsula (Rice Farmers)	36.0°N, 128.0°E	Whitman (2011)
Kra-Dai (Tai-Kadai)	Pearl River / Guangxi	24.0°N, 107.0°E	Pittayaporn (2009)
Mongolic	Argun River (Manchuria)	49.5°N, 119.0°E	Janhunen (2003)
Sino-Tibetan	Upper Yellow River Basin	35.0°N, 103.0°E	Zhang et al. (2019)
Tungusic	Middle Amur Basin	46.5°N, 134.0°E	Robbeets (2017)
Turkic	East Mongolia / Transbaikal	47.0°N, 115.0°E	Robbeets (2017)
Uralic	Kama River / Southern Urals	56.0°N, 54.0°E	Häkkinen (2009)
Yeniseian	Central Siberia (Yenisei)	58.0°N, 92.0°E	Vajda (2010)
<i>North & Middle America</i>			
Algic	Columbia Plateau	46.0°N, 118.0°W	Goddard (1994)
Chibchan	Talamanca Range (Costa Rica)	9.5°N, 83.0°W	Constenla Umaña (1991)
Eskimo-Aleut	Norton Sound (Coastal)	64.5°N, 162.5°W	Fortescue et al. (2010)
Mayan	Cuchumatanes Highlands	15.5°N, 91.5°W	Campbell (1988)
Mixe-Zoque	Isthmus of Tehuantepec (Olmec)	17.5°N, 94.5°W	Campbell et al., 1976
Na-Dene	Central Alaska / Yukon	62.0°N, 140.0°W	Kari (2010)
Oto-Manguean	Tehuacán Valley	18.5°N, 97.4°W	Kaufman (2006)
Uto-Aztecan	US Southwest Borderlands	33.0°N, 110.0°W	Merrill et al. (2009)
<i>South America</i>			
Arawakan	Central Amazon (Manaus Inland)	3.0°S, 60.0°W	Walker et al., 2011
Cariban	Guiana Highlands	4.0°N, 60.0°W	Gildea (2012)
Macro-Jê	Brazilian Planalto (Cerrado)	15.0°S, 50.0°W	Jolkesky (2016)
Quechuan	Central Peru (Ancash)	10.0°S, 77.0°W	Heggarty et al., 2012
Tupian	Madeira-Guaporé Confluence	12.0°S, 64.0°W	Rodrigues (2007)
<i>Oceania</i>			
Austronesian	Taiwan	23.5°N, 121.0°E	Bellwood (1991)
Pama-Nyungan	Gulf Plains (Queensland)	17.5°S, 140.5°E	Bouckaert et al. (2018)
Trans-New Guinea	PNG Central Highlands	6.0°S, 145.0°E	Pawley (2005)

Table A5: Sample Accounting for Persistence and PGLS Analyses

Sample or specification	Observations	Additional restriction
Analysis dataset	1,291	EA societies in final regression file
Heimat coverage	986	Non-missing Heimat distance
Migrant sample	843	Current-Heimat distance > 500 km
Migrant sample with tree tip	792	Also matched to MCC language tree
Precipitation-CV cleaning adjustment	-3	Negative precipitation-CV values set to missing
OLS Heimat horse race	684–792	Complete controls; 25–28 language-family clusters
PDSI Heimat horse race	217–240	Migrants with PDSI at current and Heimat coordinates
PGLS Heimat horse race	647–746	Migrants matched to MCC language tree
PGLS precipitation baseline	975–1,118	Full tree-matched baseline sample
PGLS PDSI baseline	322–365	Tree-matched PDSI coverage

Notes. The table reports the sample restrictions used in the persistence and phylogenetic robustness analyses. Ranges indicate the minimum and maximum regression-complete sample sizes across outcomes, panels, and control specifications. The migrant sample is defined as societies whose contemporary coordinates are more than 500 km from their assigned Heimat coordinates. Precipitation-CV specifications can have slightly fewer observations than scorch or storm specifications because invalid precipitation-CV values are set to missing during the data-cleaning stage and are then excluded by complete-case regression.

B Additional Results and Robustness

B.1 Robustness Across Risk Measures

To ensure our findings capture a generalized response to environmental insecurity rather than artifacts of specific variable construction, Table A6 presents robustness checks using alternative definitions of climatic stress. We move beyond statistical moments (like the coefficient of variation) to measures that capture the physical texture of risk: the duration of scarcity and the intensity of excess.

Drought Risk. Panel A focuses on drought risk, operationalized as the average duration of the longest continuous dry spell in a year. Unlike the coefficient of variation, which captures inter-annual volatility (year-to-year instability), this metric captures intra-seasonal stress: the tangible “lived experience” of waiting for rain. The interaction with Agricultural Dependence remains positive and statistically significant across almost all specifications. In the NLP models, the coefficient is particularly stable ($\beta \approx 0.10, p < 0.01$), suggesting that the length of the dry season is a salient driver of magical beliefs, independent of the total volume of rainfall. This confirms that farmers are responding to specific physiological threats to crop maturation, not just abstract variance.

Flood Risk. Panel B shifts focus from scarcity to excess, examining flood risk (peak rainfall intensity). While water scarcity is often the primary constraint in pre-industrial agriculture, erratic heavy rains pose a distinct threat. Intense precipitation events can destroy harvests through soil erosion, root asphyxiation, and crop lodging (the bending over of stems near ground level). We find a robust positive relationship between Flood Risk and agricultural magic, particularly in the NLP specifications where coefficients range from 0.094 to 0.099 ($p < 0.01$). The LLM estimates are also positive, though identifying the effect requires conditioning on geographic and social controls (Columns 5–6).

Table A6: Robustness Estimates of Alternative Environmental Risk Measures

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: Drought Risk</i>						
Dry Spell Duration	−0.030 (0.092)	−0.075 (0.059)	−0.072 (0.059)	−0.088** (0.042)	−0.086* (0.048)	−0.099** (0.046)
× Ag. Dependence	0.083*** (0.029)	0.102*** (0.027)	0.102*** (0.030)	0.058 (0.038)	0.066* (0.035)	0.068** (0.033)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
<i>Panel B: Flood Risk</i>						
Peak Rainfall Intensity	0.055 (0.105)	0.020 (0.082)	0.034 (0.078)	−0.047 (0.029)	−0.024 (0.050)	−0.024 (0.046)
× Ag. Dependence	0.094*** (0.035)	0.095*** (0.032)	0.099*** (0.033)	0.041 (0.027)	0.052* (0.029)	0.065** (0.032)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
Observations	1,218	1,206	1,052	1,218	1,206	1,052
Clusters	139	139	129	139	139	129
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Controls	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates of robustness checks using alternative environmental risk definitions' effects on agricultural magic. Panel A: average duration of the longest continuous dry spell (consecutive days < 1mm) in a year. Panel B: proportion of annual rainfall occurring within the single wettest 7-day window. Both variables are interacted with agricultural dependence to predict agricultural magic. NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Mean motifs indicate the average percentage of the corpus classified as agricultural magic. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Climate controls include mean temperature and precipitation; geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Medieval Drought Risk. As a final robustness check on the measurement of historical risk, we employ paleoclimate reconstructions to measure the frequency of extreme droughts ($PDSI < -3$) between 1100 and 1400 AD. While our primary medieval specification uses continuous PDSI volatility, examining extreme tail events captures the distinct threat of existential agricultural disaster. As shown in Table A7, the LLM interaction is large and significant in the baseline and geographic specifications, attenuating slightly with social controls. The baseline drought frequency coefficient is also exceptionally large (0.615–0.617), indicating that societies in regions prone to severe medieval droughts developed substantially more agricultural magic (see Mendoza, 2024). Despite the reduced sample size inherent to the drought atlases covering primarily the Old World and North America, the effects appear directionally consistent.

B.2 Phylogenetic Robustness

A pervasive concern in cross-cultural empirical work is Galton’s problem: even conditional on broad language-family fixed effects, societies are not statistically independent if closely related groups share unobserved cultural histories. To ensure our findings are not overturned by phylogenetic non-independence, we re-estimate our primary specifications using phylogenetic generalized least squares (PGLS). This approach replaces the categorical language-family fixed effects with a continuous covariance matrix derived from the modified MCC global language tree (described in Section 3.2).

Methodology. The estimating equation is unchanged in its mean structure,

$$\text{Magic}_i = \alpha + \gamma_1(\text{Risk}_i \times \text{Dep}_i) + \mathbf{X}_i' \boldsymbol{\eta} + \epsilon_i, \quad (4)$$

but the residuals are allowed to covary according to phylogenetic distance:

$$\epsilon \sim N(0, \sigma^2 \mathbf{V}_\lambda), \quad \mathbf{V}_\lambda = \lambda(\mathbf{V} - \text{diag}(\mathbf{V})) + \text{diag}(\mathbf{V}). \quad (5)$$

Table A7: Medieval Drought Risk (1100–1400 AD) $\times$ Agricultural Dependence

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: PDSI Drought Frequency</i>						
Risk (Main)	0.125* (0.066)	0.114* (0.067)	0.152 (0.109)	0.615*** (0.133)	0.617*** (0.137)	0.293** (0.124)
Drought Frequency $\times$ Ag. Dep.	0.066 (0.047)	0.032 (0.047)	0.069 (0.069)	0.286*** (0.102)	0.285*** (0.104)	0.109* (0.062)
Mean Motifs	0.10	0.10	0.10	0.02	0.02	0.02
Observations	429	429	378	429	429	378
Clusters	50	50	45	50	50	45
Language Family FE	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports OLS estimates of medieval drought risk effects on agricultural magic. Risk (Main) shows the direct effect of the PDSI measure. Interaction captures the differential effect of drought risk for societies more dependent on agriculture. PDSI reconstructions are sampled at societies' current coordinates from the Old World Drought Atlas (Cook et al., 2015) and North American Drought Atlas (Cook et al., 2004) for the period 1100–1400 AD. Panel A uses extreme drought frequency (share of years with PDSI < -3). NLP uses WordNet similarity scores to create a keyword dictionary; LLM uses GPT-4o-mini classified counts. Mean motifs indicate the average percentage of the corpus classified as agricultural magic. Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent. Standard errors clustered at the language family level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Here, $\mathbf{V}$ is the tree-implied Brownian-motion covariance matrix and Pagel’s λ scales the off-diagonal covariance. If $\lambda = 0$, the model collapses to independent residuals; if $\lambda = 1$, residual covariance follows the tree fully. We estimate λ separately for each regression and report a likelihood-ratio test against $\lambda = 0$.

Baseline PGLS Results. Given the historical nature of phylogenetic non-independence, we apply the PGLS framework to our main paleoclimate estimates. Matching societies with both paleo PDSI and MCC global language tree coverage reduces our sample size by 15% in this exercise. Table A8 reports the results for medieval PDSI. As expected given the high estimated phylogenetic signal in the residuals (λ ranges from 0.35 to 0.84), the PGLS standard errors are substantially wider than the OLS estimates, rendering the NLP measure statistically insignificant. However, the point estimates for the core interaction remain positive and stable across all LLM specifications, retaining significance in all but the fully controlled PDSI volatility model. This suggests that the positive baseline correlation is not entirely an artifact of shared ancestral lineage, though accounting for tree topology inherently reduces estimation precision when compared to language family FEs.

Horse Race PGLS Results. Table A9 reports the PGLS analogue of the migrant horse race (Equation 3). While the conservative standard errors weaken the precision of the current-environment interactions, the core test of cultural persistence is unchanged: Heimat risk interactions remain small and statistically indistinguishable from zero across all three risk domains. The only marginally significant remaining current-environment signal is for LLM-coded scorch risk, though point estimates remain uniformly positive in all specifications. These PGLS estimates are best interpreted as a rigorous bounds check: they impose a high burden of proof that reduces the precision of the adaptive signal, but they do not resurrect ancestral-risk effects.

Table A8: PGLS Estimates of Medieval PDSI Risk $\times$ Agricultural Dependence

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: PDSI Volatility $\times$ Ag. Dependence</i>						
Risk (Main)	-0.028 (0.051)	-0.034 (0.051)	-0.097 (0.067)	0.141** (0.062)	0.129** (0.063)	-0.061 (0.076)
PDSI $\times$ Ag. Dep.	0.044 (0.035)	0.025 (0.036)	0.009 (0.046)	0.159*** (0.044)	0.146*** (0.046)	0.058 (0.054)
Mean Motifs	0.12	0.12	0.11	0.02	0.02	0.02
Observations	365	365	322	365	365	322
Pagel λ	0.84	0.82	0.81	0.52	0.52	0.57
Tree-Match Coverage	0.31	0.31	0.27	0.31	0.31	0.27
<i>Panel B: Drought Frequency $\times$ Ag. Dependence</i>						
Risk (Main)	0.059 (0.054)	0.013 (0.055)	-0.008 (0.072)	0.371*** (0.063)	0.363*** (0.066)	0.222*** (0.075)
PDSI $\times$ Ag. Dep.	0.035 (0.036)	-0.014 (0.038)	-0.031 (0.049)	0.200*** (0.043)	0.198*** (0.047)	0.107** (0.052)
Mean Motifs	0.12	0.12	0.11	0.02	0.02	0.02
Observations	365	365	322	365	365	322
Pagel λ	0.79	0.80	0.75	0.53	0.52	0.35
Tree-Match Coverage	0.31	0.31	0.27	0.31	0.31	0.27
Phylogenetic covariance	✓	✓	✓	✓	✓	✓
Subsistence controls	✓	✓	✓	✓	✓	✓
Geography controls		✓	✓		✓	✓
Social controls			✓			✓

Notes. The table reports phylogenetic generalized least squares estimates of medieval drought risk effects on agricultural magic. The sample is restricted to societies with available paleo PDSI coverage that can be matched to the modified MCC global language tree. PGLS uses the tree-derived covariance matrix with Pagel’s lambda estimated by `phylo1m`; the reported λ captures residual phylogenetic dependence in the errors. The PGLS specifications omit language-family fixed effects because non-independence and model-based uncertainty are handled through the phylogenetic covariance structure. Panel A uses PDSI volatility (standard deviation); Panel B uses extreme drought frequency (share of years with PDSI < -3). Subsistence controls include dependence on all non-target subsistence strategies, gathering acts as a baseline. Geography controls include absolute latitude, agricultural suitability, and continent fixed effects; and social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A9: PGLS Estimates of Current vs. Heimat Risk $\times$ Subsistence Dependence

Specification:	<i>Dependent Variable: Agricultural Magic (Normalized)</i>					
	NLP			LLM		
	(1) Base	(2) Geo	(3) Social	(4) Base	(5) Geo	(6) Social
<i>Panel A: Precipitation Volatility</i>						
Current Risk $\times$ Ag. Dep.	0.043 (0.037)	0.048 (0.036)	0.062 (0.040)	0.032 (0.041)	0.023 (0.041)	0.018 (0.042)
Heimat Risk $\times$ Ag. Dep.	0.004 (0.039)	0.004 (0.038)	−0.002 (0.043)	−0.050 (0.043)	−0.052 (0.043)	−0.004 (0.045)
Observations	744	732	647	744	732	647
Pagel λ	0.97	0.97	0.96	0.97	0.96	0.90
Tree-Match Coverage	0.94	0.92	0.82	0.94	0.92	0.82
<i>Panel B: Scorch Risk</i>						
Current Risk $\times$ Ag. Dep.	0.053 (0.046)	0.057 (0.046)	0.042 (0.050)	0.097* (0.050)	0.085* (0.051)	0.090* (0.051)
Heimat Risk $\times$ Ag. Dep.	−0.051 (0.050)	−0.050 (0.050)	−0.050 (0.054)	−0.043 (0.055)	−0.041 (0.055)	−0.007 (0.055)
Observations	746	734	649	746	734	649
Pagel λ	0.97	0.97	0.96	0.97	0.96	0.90
Tree-Match Coverage	0.94	0.93	0.82	0.94	0.93	0.82
<i>Panel C: Storm Risk</i>						
Current Risk $\times$ Fish. Dep.	0.052 (0.041)	0.061 (0.042)	0.070 (0.047)	0.043 (0.035)	0.049 (0.035)	0.031 (0.039)
Heimat Risk $\times$ Fish. Dep.	0.028 (0.042)	0.024 (0.043)	0.033 (0.047)	0.018 (0.036)	0.008 (0.036)	0.019 (0.040)
Observations	746	734	649	746	734	649
Pagel λ	0.98	0.98	0.98	1.00	1.00	0.99
Tree-Match Coverage	0.94	0.93	0.82	0.94	0.93	0.82
Phylogenetic Covariance	✓	✓	✓	✓	✓	✓
Subsistence Controls	✓	✓	✓	✓	✓	✓
Climate Means	✓	✓	✓	✓	✓	✓
Geography Controls		✓	✓		✓	✓
Social Controls			✓			✓

Notes. The table reports phylogenetic generalized least squares estimates from a horse race specification that includes both contemporary and Heimat risk interactions simultaneously. The sample is restricted to societies whose current coordinates are more than 500 km from their Heimat coordinates and that can be matched to the modified MCC global language tree. PGLS uses the tree-derived covariance matrix with Pagel’s lambda estimated by `phy101m`; $p(\lambda = 0)$ is the likelihood-ratio test for residual phylogenetic signal. The PGLS specifications omit language-family fixed effects; non-independence and model-based uncertainty are handled through the phylogenetic covariance structure. Climate means include both contemporary and Heimat averages; geography controls include absolute latitude, agricultural suitability, and continent fixed effects; social controls include jurisdictional hierarchy, settlement complexity, polygyny, and patrilineal descent.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

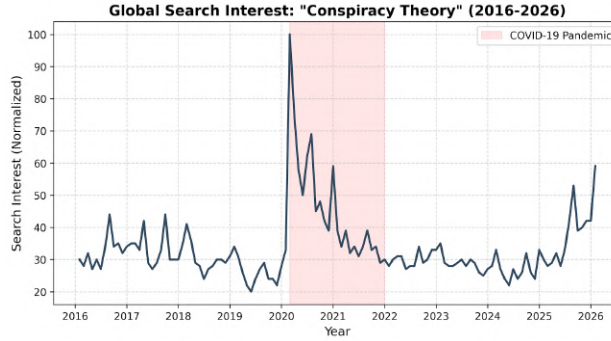


Figure A1: Google Trends Data on Global “Conspiracy Theory” Searches

Notes. The figure plots the relative search interest (0–100) for the topic “Conspiracy Theory” worldwide over the last decade. The shaded vertical background marks March 2020, coinciding with the WHO’s declaration of the COVID-19 pandemic.

B.3 Contemporary Parallels: Uncertainty and Conspiracy Beliefs

Figure A1 plots global Google Trends search interest for the term “Conspiracy Theory” over the decade 2015–2025. Interest remained stable at baseline levels throughout 2015–2019, fluctuating narrowly between 20 and 40 on the normalized index. In March 2020, coinciding with the WHO’s declaration of the COVID-19 pandemic, search interest spiked to 100, an increase of approximately 150% relative to the preceding five-year average. The spike was abrupt, rising from baseline to peak within two weeks, and was followed by a sustained elevation throughout 2020–2021 before gradually returning toward pre-pandemic levels.

The timing of the surge coincides with the period of maximal epidemiological uncertainty: prior to the availability of vaccines, effective therapeutics, or reliable transmission models. During this window, standard biomedical explanations could not satisfactorily account for the origin, spread, or lethality of the virus, leaving a causal residual that alternative narratives (e.g., attributing the pandemic to bioweapons, telecommunications infrastructure, or coordinated elite action) moved to fill (Whitson and Galinsky, 2008; Douglas et al., 2017). As pharmaceutical countermeasures became available in 2021, the demand for these alternative explanations declined, tracking the reduction in uncontrollable risk.