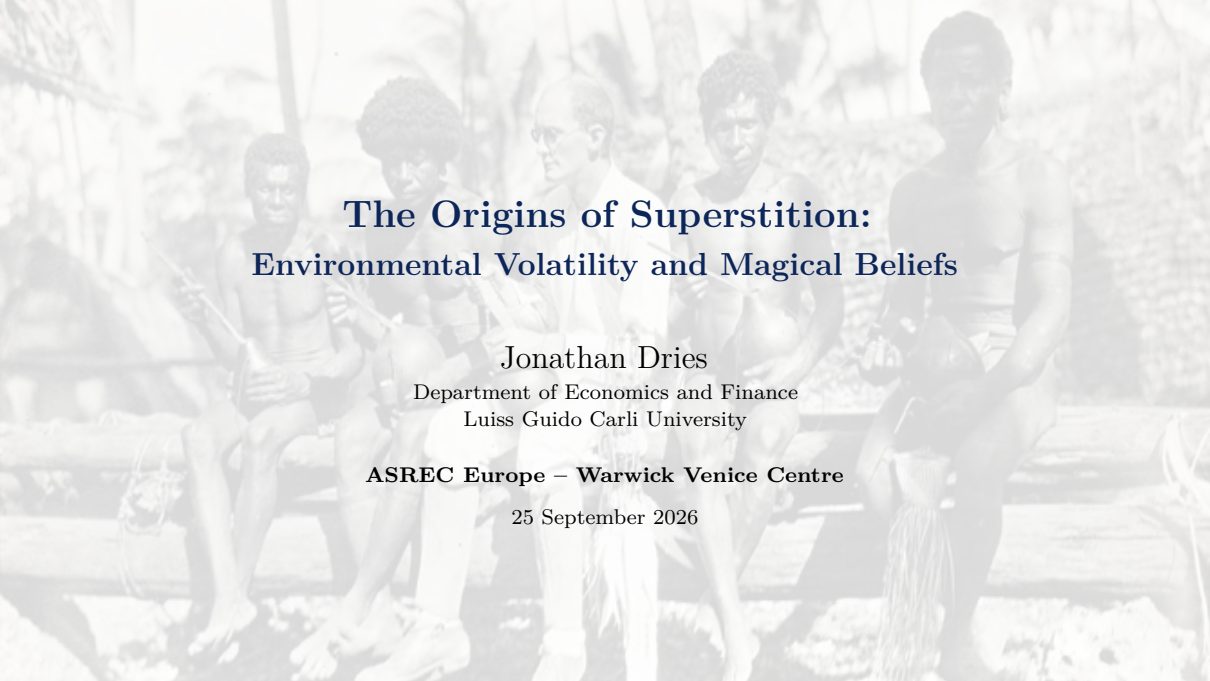




# The Origins of Superstition: Environmental Volatility and Magical Beliefs

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# Superstition: The Puzzle

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- Across history, humans have invested resources in magical beliefs (rituals, taboos, sacrifices)
- These practices are costly and scientifically ineffective
- *Why do "irrational" beliefs persist in a competitive environment?*
- **The Malinowski Hypothesis:** Magic is not "confused thinking," but a functional response to risk

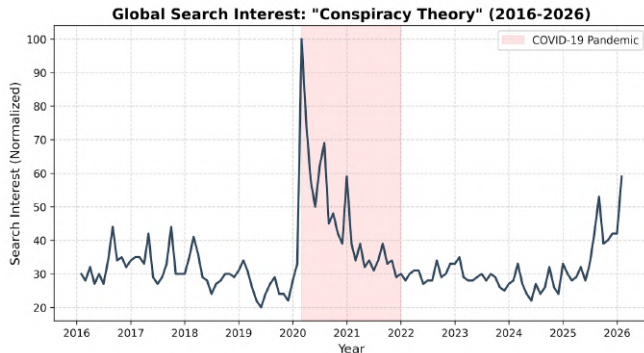
## This Paper:

Does **environmental volatility** systematically affect the adoption of magical beliefs?

# Why Should We Care?

**Broader implications:** belief formation under uncertainty

- High uncertainty often triggers beliefs in **hidden causation** (e.g., conspiracy theories, magic)
- Is this a modern information problem or a more fundamental cognitive default?



# Contribution: Roots of Belief Formation

---

## 1. Literature: The Economics of Culture

- **Persistence:** Culture is a sticky constraint inherited from the past  
(e.g., Nunn & Wantchekon, 2011; Voigtländer & Voth, 2012; Buggle & Durante, 2021)
- **Adaptation:** Culture is a flexible response to current incentives  
(e.g., Qian, 2008; Alesina et al., 2013; Giuliano & Nunn, 2021)
- **Religiosity:** Religion as a reaction to shocks  
(e.g., Chen, 2010; Belloc et al., 2016; Henrich et al., 2019; Bentzen, 2019, 2021)

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(e.g., Chen, 2010; Belloc et al., 2016; Henrich et al., 2019; Bentzen, 2019, 2021)

## 2. This Paper's Contribution:

- Global "Magical Intensity Index" using NLP and LLMs on folklore (1,219 societies)
- **Results:** empirical validation of magical beliefs as a functional response to risk  
(*Rational Superstition*)
  - **Risk Coping Mechanism:** supported by soil and irrigation evidence
  - **Adaptation vs. Persistence:** agricultural magic appears more closely related to current than ancestral conditions

# The Intuition: The Malinowski Hypothesis

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Bronislaw Malinowski (1922): *Argonauts of the Western Pacific*

## The Lagoon

---

### Environment:

Calm water, predictable catch  
(Low risk)

### Behavior:

"No magic is used"  
Reliance on skill and technology

→ Outcome: "Rationality"

## The Open Sea

---

### Environment:

Storms, unpredictable yield  
(High risk)

### Behavior:

"Extensive rituals"  
*Canoe magic*, safety incantations

→ Outcome: "Superstition"

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### Behavior:

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*Canoe magic*, safety incantations

→ Outcome: "Superstition"

### The Functionalist Argument:

Magic is Insurance  
(A functional response to uninsurable risk)

# Data: Measuring Magic in Folklore

- **Folklore Database:** 2,560 distinct motifs linked to Murdock's Ethnographic Atlas (Michalopoulos & Xue, 2021)
- *Challenge:* distinguishing the share of risk-related magical beliefs for each society from mythology (*etiology*)

## Method 1: NLP Semantic Index

**Logic:** Keyword Intersection

We only count a motif if it contains **both**:

1. A **Risk Context** term  
(e.g., *rain, drought, hunt*)
2. An **Agency** term  
(e.g., *summon, ritual, spell*)

*Source:* Princeton WordNet synonyms

## Method 2: LLM Classification

**Logic:** Contextual Parsing

Uses an LLM to read the full motif text and filter:

1. **Input:** Full motif description  
(e.g., *i1: the thunderbirds*)
2. **Task:** Classify functional intent  
(e.g., *agricultural magic*)

*Source:* Openai GPT-4o-mini API

► Appendix: Calibrating the LLM

# Data: Classifying Functional Magic (Examples)

## Example 1: Functional Magic

**Motif:** *"Person sacrificed to the Sun"*

"To make the Sun rise... or move across the sky... a person has to be sacrificed."

**LLM Classification:**

- **Context:** agriculture\_weather
- **Functional Magic:** **True**
- **Mechanism:** active\_ritual

*Interpretation:* A prescribed sacrifice is believed to ensure the Sun's movement, linking human ritual to a natural outcome

## Example 2: Non-Functional Fable

**Motif:** *"The Entrapped Suitors"*

"A pretty wife invites suitors... they are caught by the husband."

**LLM Classification:**

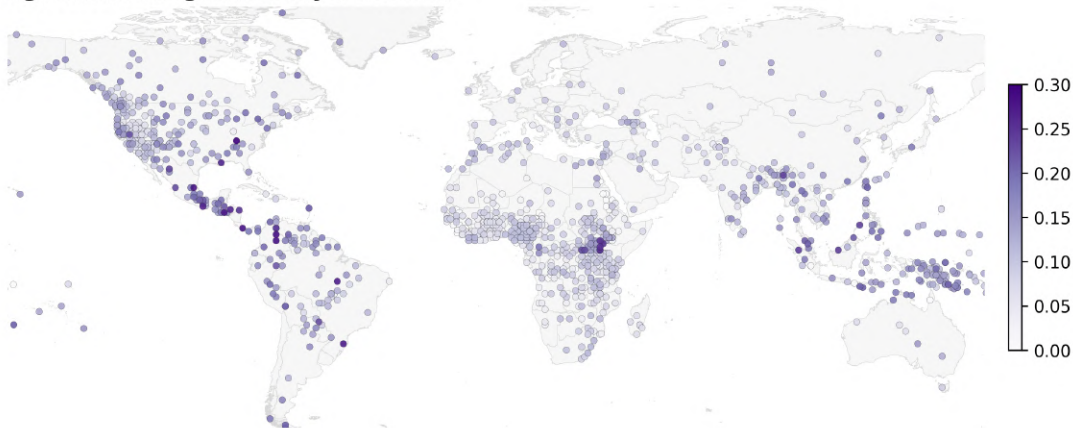
- **Context:** social\_conflict
- **Functional Magic:** **False**
- **Mechanism:** none

*Interpretation:* A moral or entertaining fable regarding human behavior, containing no supernatural risk-coping technology

# Data: Measuring Magic in Folklore

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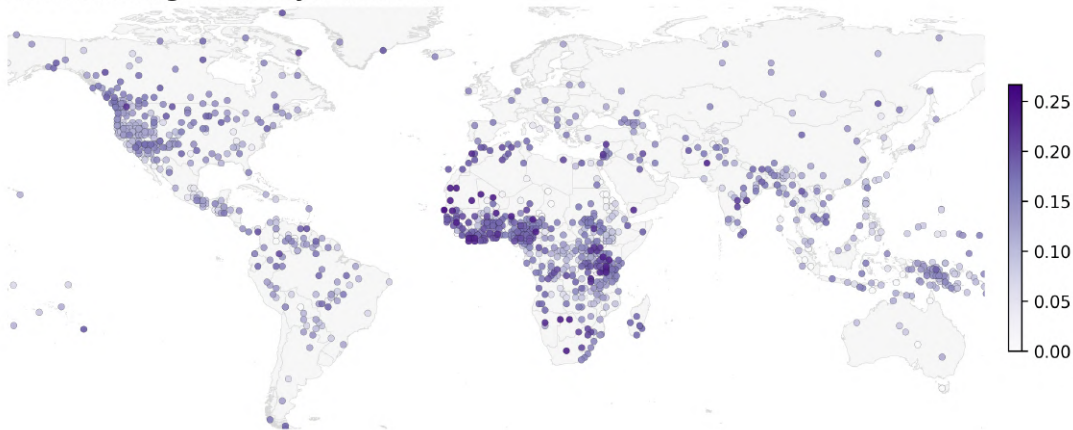
## Agricultural Magic Intensity (Outcome)



# Data: Measuring Magic in Folklore

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## Protective Magic Intensity (Outcome)



# Anthropological Framework: Functionalism

**Hypothesis:** Risk drives magic *only* for societies dependent on the threatened resource

$$\text{Magic}_i = \alpha + \beta_1 \text{Risk}_i + \beta_2 \text{Dependence}_i + \beta_3 (\text{Risk}_i \times \text{Dependence}_i) + \varepsilon$$

**Agricultural Dependence (Context)**



# Anthropological Framework: Functionalism

**Hypothesis:** Risk drives magic *only* for societies dependent on the threatened resource

$$\text{Magic}_i = \alpha + \beta_1 \text{Risk}_i + \beta_2 \text{Dependence}_i + \beta_3 (\text{Risk}_i \times \text{Dependence}_i) + \varepsilon$$

**Fishing Dependence (Context)**



# Data: Measuring Environmental Volatility

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## The Source:

- **NASA POWER:** High-resolution daily meteorology ( $0.5^\circ \times 0.5^\circ$ )
- **Coverage:** Daily records 1984–2024 for all 1,291 societies in the EA

Transforming meteorological data into volatility indices

- **Raw Inputs:** TEMPERATURE, PRECIPITATION, WIND
- Calculated indices:
  - **Precipitation Volatility:** Interannual CV of annual precipitation ( $CV = \frac{\sigma}{\mu} \times 100\%$ )
  - **Scorch Risk:** Compound Heat + Drought (Max Temp > 90<sup>th</sup> %ile & Rain < 1mm)
  - **Storm Risk:** Compound Wind + Rain (Wind speed > 90<sup>th</sup> %ile & Rain > 90<sup>th</sup> %ile)
  - **Drought Risk:** Max consecutive dry days per year
  - **Flood Risk:** Percentage of rain in wettest week per year (Precipitation Concentration)

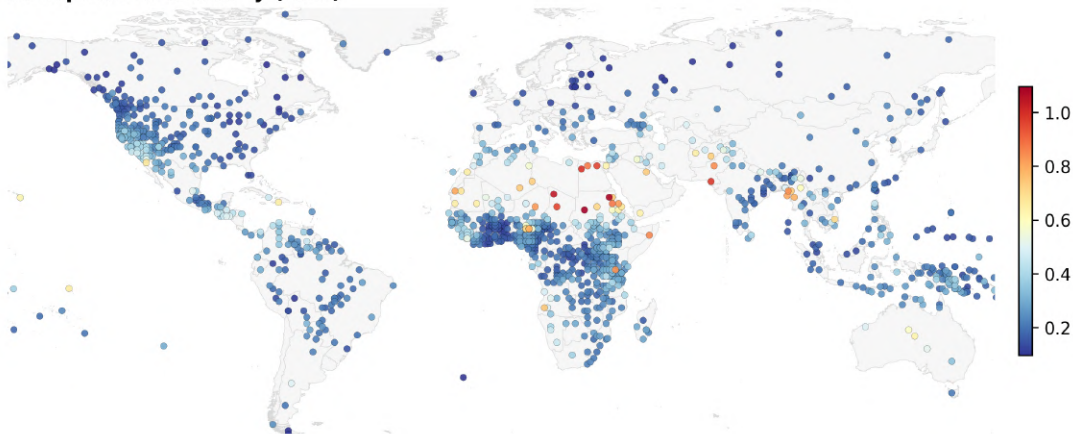
## Spatial Matching:

- Indices calculated for both **Current Locations** (Ethnographic Atlas) and **Ancestral Homelands** (Urheimat) to later disentangle adaptation from persistence

# Data: Measuring Environmental Volatility

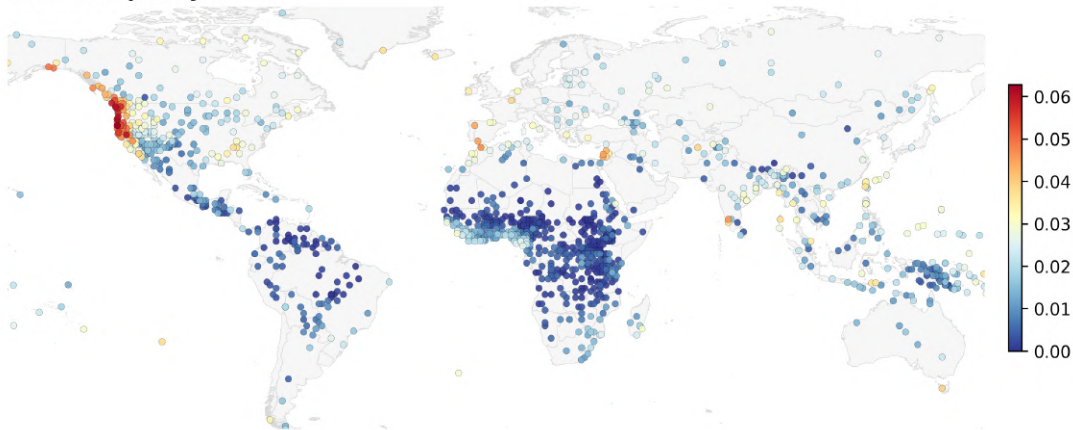
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## Precipitation Volatility (Risk)



# Data: Measuring Environmental Volatility

## Storm Frequency (Risk)



# Main Results: The Functional Response

**The Test:** Do societies ritually respond to the *specific* volatility of their livelihood?

| Risk Factor:                                            | Dependent Variable: Magic Intensity (LLM) |                                       |                                  |
|---------------------------------------------------------|-------------------------------------------|---------------------------------------|----------------------------------|
|                                                         | (1) Agriculture<br><i>Rain Volatility</i> | (2) Agriculture<br><i>Scorch Risk</i> | (3) Fishing<br><i>Storm Risk</i> |
| Interaction Term<br>( <i>Risk</i> × <i>Dependence</i> ) | <b>0.093**</b><br>(0.042)                 | <b>0.149***</b><br>(0.046)            | <b>0.131***</b><br>(0.024)       |
| Risk Main Effect                                        | -0.067**                                  | -0.057                                | 0.018                            |
| Language Family FE                                      | Yes                                       | Yes                                   | Yes                              |
| Climate & Subsistence Controls                          | Yes                                       | Yes                                   | Yes                              |
| Geo & Social Controls                                   | Yes                                       | Yes                                   | Yes                              |

Notes. Columns (1-2): Ag. Magic; Column (3): Protective Magic.

**Interpretation:** Environmental risk is more strongly associated with magical folklore where livelihoods depend *more heavily* on the threatened resource

► Appendix: Full Table

# The Domain-Specificity of Magic (Placebo)

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**The Critique:** *"Maybe volatile weather just makes people generally anxious or superstitious?"*

# The Domain-Specificity of Magic (Placebo)

**The Critique:** *"Maybe volatile weather just makes people generally anxious or superstitious?"*

**The Prediction:** If magic is just stress-relief, rainfall volatility should increase **love magic** (spells for courtship/jealousy)

**The Test:** Regress **love magic** on environmental risk and its interaction with dependence

|                                    | Ag./Prot. Magic  | Love Magic (Placebo) |
|------------------------------------|------------------|----------------------|
| <i>Dependent Variable:</i>         | <b>Adaptive</b>  | <b>Unrelated</b>     |
| Precipitation CV $\times$ Ag. Dep. | <b>+0.093**</b>  | 0.022 (n.s.)         |
| Scorch Risk $\times$ Ag. Dep.      | <b>+0.149***</b> | -0.006 (n.s.)        |
| Storm Risk $\times$ Fishing Dep.   | <b>+0.131***</b> | -0.029 (n.s.)        |

**Conclusion:** Magic is a precise technology targeted at specific risks

► Appendix: Full Table

# Robustness: Paleoclimate Reconstructions

**The Critique:** Modern satellite data (1984–2024) may not reflect the climate when oral traditions were actively forming

**The Test:** Predict modern folklore using medieval climate data

- **Data:** Old World/North American Drought Atlases
- **Metric:** PDSI (Drought) Volatility from 1100–1400 AD

| Specification:  | <i>Dependent Variable: Agricultural Magic (LLM)</i> |                    |                    |                    |
|-----------------|-----------------------------------------------------|--------------------|--------------------|--------------------|
|                 | Paleo                                               |                    | Satellite          |                    |
|                 | Baseline                                            | Full Controls      | Baseline           | Full Controls      |
| Risk × Ag. Dep. | 0.179**<br>(0.078)                                  | 0.118**<br>(0.050) | 0.077**<br>(0.037) | 0.093**<br>(0.042) |

Notes. Paleo: medieval PDSI volatility. Satellite: modern precipitation CV.

# Mechanism: Soil and Material Risk

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**Question:** *"Is magic merely a reaction to the weather, or related to material risk?"*

# Mechanism: Soil and Material Risk

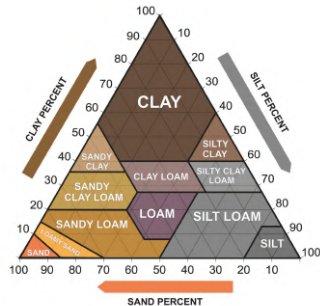
**Question:** *"Is magic merely a reaction to the weather, or related to material risk?"*

## The Experiment:

- Two farmers face identical rainfall concentration (flood risk)
- **Farmer A:** Clay soil (retains water)
- **Farmer B:** Sandy soil (drains water)

**Prediction:** Flood risk should be more (less) terrifying for Farmer A (B)

Soil Texture Triangle



## Estimation (Triple Interaction):

Flood Risk  $\times$  Ag. Dep.  $\times$  Soil Clay (Sand) % = Positive (Negative)

# Mechanism: Soil and Material Risk

## The Data:

- The *harmonized world soil database v2.0 (HWSD2)*
- Comprehensive global soil inventory that offers detailed insights into soil properties

| Predictor:                   | Dependent Variable: Agricultural Magic (LLM) |                            |
|------------------------------|----------------------------------------------|----------------------------|
|                              | × Clay                                       | × Sand                     |
| Risk × Ag. Dependence × Soil | <b>0.079**</b><br>(0.031)                    | <b>-0.037**</b><br>(0.016) |
| Full Controls                | Yes                                          | Yes                        |
| Interpretation               | Exacerbates                                  | Mitigates                  |

**Finding:** Farmers react to actual risk, not just to the weather

# Mechanism: Technology Substitutes for Magic

**Hypothesis:** If magic is a "second-best" technology for managing risk, the existence of a "first-best" technology (irrigation) should crowd it out

| Triple Interaction               | Agricultural Magic                         |
|----------------------------------|--------------------------------------------|
| Rain Volatility $\times$ Ag Dep  | <b>0.095**</b><br>(Baseline Vulnerability) |
| ... $\times$ Irrigation Presence | <b>-0.040*</b><br>(Technological Buffer)   |

Notes. Irrigation Presence as observed at first contact.

*"We do not find magic where  
the pursuit is certain."  
– Malinowski*

**Finding:** Irrigation reduces the rainfall-risk  $\times$  agricultural-dependence interaction by  $\approx 42\%$

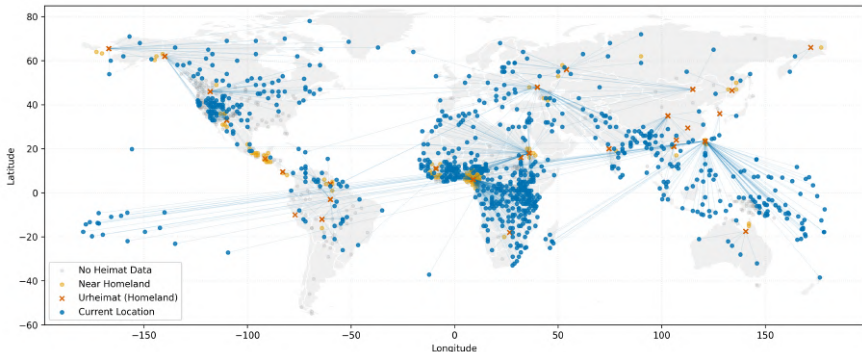
► Appendix: Full Table

# Cultural Hysteresis: Adaptation vs. Persistence

**The Puzzle:** Is magic a flexible tool (adaptive) or a deep identity (persistence)?

The strategy:

- **Sample:** migrant societies ( $> 500$  km from linguistic homeland / *Urheimat*)



# Results: Adaptation vs. Persistence

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The **Horse Race** Regression:

$$\text{Magic} = \beta_1(\text{Current Risk} \times \text{Dep}) + \beta_2(\text{Ancestral Risk} \times \text{Dep}) + X$$

Current risk: evidence on adaptation

Ancestral risk: evidence on persistence

## 1. Farmers (Agricultural Magic)

- **Current Risk: Positive** ( $\beta = 0.091^*$ )
- **Ancestral Risk: Null** ( $\beta = -0.007$ )

### Conclusion: Suggestive Adaptation

The current rainfall-risk estimate is positive, evidence is stronger for scorch risk

## 2. Fishermen (Protective Magic)

- **Current Risk: Null** ( $\beta = 0.005$ )
- **Ancestral Risk: Null** ( $\beta = 0.035$ )

### Conclusion: Inconclusive

Neither current nor ancestral storm risk is precisely associated with protective magic

# Conclusion

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## 1. Findings

- **The general case:** environmental volatility is a robust predictor of magical beliefs globally
- **Specificity:** the effect is limited to the threatened domain (Ag./Fishing), not generalized (Love)

## 2. Implications

- **Reframing superstition:** it is not random "error," but a specific institutional response
- **Policy:**  
To reduce reliance on non-scientific beliefs, we must reduce **insecurity**  
(e.g., crop insurance may reduce the demand for rain doctors)

*When the world is uncertain, magic seems to be a common, "rational" response*

# Thank you!

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# Appendix: Calibrating the LLM

**The strategy:** treat GPT-4o-mini as a *classifier* with strict structural constraints  
Structured Output Schema (**JSON** enforcement):

- **Risk Context:** the domain of the anxiety (e.g., agriculture\_weather, health\_survival)
- **Mechanism:** distinguishes active\_ritual (doing something to control outcomes) from passive\_omen (knowing the outcome)
- **Goal:** productive (to gain rain) vs. protective (to stop drowning)

```
SYSTEM_PROMPT = """
You are an expert anthropologist cataloguing magic in folklore.

DECISION LOGIC:
1. CONTEXT: What is the topic? Tag 'risk_context' even if there is no magic.
2. MAGIC: Does the text contain supernatural techniques (Ritual, Spell, Omen, Taboo)? If yes, set True.
   - 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 is_functional_magic is False -> mechanism="none", goal="neutral".
"""
```

Input: "You are an expert anthropologist..."

```
class FolkloreCoding(BaseModel):
    risk_context: Literal["agriculture_weather", "hunting", "health_survival", "social_conflict", "love_courtship", "none"] = Field(
        description="The SUBJECT MATTER. Tag the activity/risk even if no magic occurs."
    )

    is_functional_magic: bool = Field(
        description="True if the text describes ANY magical act, ritual, spell, omen, taboo, or supernatural belief used to influence or predict outcomes."
    )

    mechanism_type: Literal["active_ritual", "passive_omen", "taboo", "none"] = Field(
        description="ACTIVE: Doing something to change outcome. PASSIVE: Knowing outcome. TABOO: Avoiding action."
    )

    goal_orientation: Literal["productive", "protective", "destructive", "neutral"] = Field(
        description="Productive: To GAIN. Protective: To PREVENT. Destructive: To HARM."
    )

    confidence: int = Field(..., description="Score 1-10.")
    reasoning: str = Field(..., description="Concise justification.")
```

Output: Structured Classification (JSON)

[Return](#)

# Appendix: Human Validation of Motif Classification

## Coder 1: Functional Magic

**Motif:** *"Person sacrificed to the Sun"*

"To make the Sun rise... or move across the sky... a person has to be sacrificed."

### Human Classification:

- **Context:** agriculture\_weather
- **Functional Magic:** **True**
- **Mechanism:** active\_ritual

*Annotator's Note:* "First actual ritual?"

(Confidence: 10/10)

⇒ **79%** pooled agreement on magic binary

## Coder 2: Non-Functional Fable

**Motif:** *"The bribed guards"*

"Way to a certain person is guided by dangerous creatures. Person placates them by gifts..."

### Human Classification:

- **Context:** social\_conflict
- **Functional Magic:** **False**
- **Mechanism:** none

*Annotator's Note:* "More like a fable than a ritual."

(Confidence: 3/10)

# Appendix: Full Baseline Table

| Specification:                    | Dependent Variable: Magical Belief Intensity (Normalized) |                     |                     |                     |                     |                     |
|-----------------------------------|-----------------------------------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                                   | NLP                                                       |                     |                     | LLM                 |                     |                     |
|                                   | (1)<br>Base                                               | (2)<br>Geo          | (3)<br>Social       | (4)<br>Base         | (5)<br>Geo          | (6)<br>Social       |
| Panel A: Precipitation Volatility |                                                           |                     |                     |                     |                     |                     |
| Precipitation Volatility          | -0.017<br>(0.054)                                         | -0.039<br>(0.047)   | -0.022<br>(0.045)   | -0.067*<br>(0.035)  | -0.058<br>(0.039)   | -0.067**<br>(0.031) |
| Risk × Ag. Dependence             | 0.069***<br>(0.020)                                       | 0.077***<br>(0.022) | 0.084***<br>(0.024) | 0.077**<br>(0.037)  | 0.082**<br>(0.039)  | 0.093**<br>(0.042)  |
| Mean Motifs                       | 0.10                                                      | 0.10                | 0.10                | 0.02                | 0.02                | 0.02                |
| Panel B: Scorch Risk              |                                                           |                     |                     |                     |                     |                     |
| Scorch Frequency                  | -0.083<br>(0.072)                                         | -0.115*<br>(0.064)  | -0.128**<br>(0.058) | -0.085<br>(0.060)   | -0.100*<br>(0.057)  | -0.057<br>(0.057)   |
| Risk × Ag. Dependence             | 0.122**<br>(0.055)                                        | 0.133**<br>(0.059)  | 0.119*<br>(0.065)   | 0.139***<br>(0.041) | 0.150***<br>(0.040) | 0.149***<br>(0.046) |
| Mean Motifs                       | 0.10                                                      | 0.10                | 0.10                | 0.02                | 0.02                | 0.02                |
| Panel C: Storm Risk               |                                                           |                     |                     |                     |                     |                     |
| Storm Frequency                   | 0.047<br>(0.063)                                          | 0.019<br>(0.062)    | 0.017<br>(0.069)    | -0.049<br>(0.041)   | 0.053<br>(0.041)    | 0.018<br>(0.045)    |
| Risk × Fish. Dependence           | 0.058*<br>(0.031)                                         | 0.060**<br>(0.026)  | 0.059**<br>(0.027)  | 0.135***<br>(0.020) | 0.118***<br>(0.026) | 0.131***<br>(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                   |                                                           |                     | ✓                   |                     |                     | ✓                   |

# Appendix: Full Placebo Table

| Specification:                           | Dependent Variable: Love Magic (Normalized) |                   |                  |                   |                   |                   |
|------------------------------------------|---------------------------------------------|-------------------|------------------|-------------------|-------------------|-------------------|
|                                          | NLP                                         |                   |                  | LLM               |                   |                   |
|                                          | (1)<br>Base                                 | (2)<br>Geo        | (3)<br>Social    | (4)<br>Base       | (5)<br>Geo        | (6)<br>Social     |
| <i>Panel A: Precipitation Volatility</i> |                                             |                   |                  |                   |                   |                   |
| Precipitation Volatility                 | 0.021<br>(0.024)                            | 0.001<br>(0.029)  | 0.005<br>(0.027) | 0.093*<br>(0.056) | 0.088<br>(0.064)  | 0.092<br>(0.064)  |
| × Ag. Dependence                         | 0.047<br>(0.028)                            | 0.042<br>(0.027)  | 0.037<br>(0.023) | 0.030<br>(0.036)  | 0.025<br>(0.037)  | 0.022<br>(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<br>(0.047)                           | -0.008<br>(0.052) | 0.004<br>(0.055) | 0.048<br>(0.047)  | -0.015<br>(0.088) | -0.014<br>(0.088) |
| × Ag. Dependence                         | -0.003<br>(0.042)                           | -0.003<br>(0.041) | 0.006<br>(0.045) | -0.010<br>(0.030) | -0.019<br>(0.030) | -0.006<br>(0.031) |
| Mean Motifs                              | 0.07                                        | 0.07              | 0.07             | 0.05              | 0.05              | 0.05              |
| <i>Panel C: Storm Risk</i>               |                                             |                   |                  |                   |                   |                   |
| Storm Frequency                          | 0.087<br>(0.083)                            | 0.052<br>(0.081)  | 0.053<br>(0.091) | 0.014<br>(0.096)  | -0.027<br>(0.078) | -0.016<br>(0.093) |
| × Fish. Dependence                       | -0.007<br>(0.031)                           | 0.003<br>(0.027)  | 0.005<br>(0.028) | -0.047<br>(0.033) | -0.030<br>(0.034) | -0.029<br>(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                          |                                             |                   | ✓                |                   |                   | ✓                 |

# Appendix: Full Paleo-Climatic Table

| Specification:                         | <i>Dependent Variable: Agricultural Magic (Normalized)</i> |                   |                   |                     |                     |                    |
|----------------------------------------|------------------------------------------------------------|-------------------|-------------------|---------------------|---------------------|--------------------|
|                                        | NLP                                                        |                   |                   | LLM                 |                     |                    |
|                                        | (1)                                                        | (2)               | (3)               | (4)                 | (5)                 | (6)                |
|                                        | <i>Base</i>                                                | <i>Geo</i>        | <i>Social</i>     | <i>Base</i>         | <i>Geo</i>          | <i>Social</i>      |
| <i>Panel A: PDSI Volatility</i>        |                                                            |                   |                   |                     |                     |                    |
| Risk (Main)                            | 0.022<br>(0.061)                                           | 0.021<br>(0.052)  | −0.001<br>(0.075) | 0.215*<br>(0.116)   | 0.252**<br>(0.104)  | 0.062<br>(0.076)   |
| PDSI Volatility × Ag. Dep.             | 0.049<br>(0.039)                                           | 0.040<br>(0.039)  | 0.047<br>(0.046)  | 0.179**<br>(0.078)  | 0.202***<br>(0.076) | 0.118**<br>(0.050) |
| Mean Motifs                            | 0.10                                                       | 0.10              | 0.10              | 0.02                | 0.02                | 0.02               |
| <i>Panel B: PDSI Drought Frequency</i> |                                                            |                   |                   |                     |                     |                    |
| Risk (Main)                            | 0.125*<br>(0.066)                                          | 0.114*<br>(0.067) | 0.152<br>(0.109)  | 0.615***<br>(0.133) | 0.617***<br>(0.137) | 0.293**<br>(0.124) |
| Drought Frequency × Ag. Dep.           | 0.066<br>(0.047)                                           | 0.032<br>(0.047)  | 0.069<br>(0.069)  | 0.286***<br>(0.102) | 0.285***<br>(0.104) | 0.109*<br>(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                        |                                                            |                   | ✓                 |                     |                     | ✓                  |

# Appendix: Full Soil Table

| Specification:            | <i>Dependent Variable: Agricultural Magic (Normalized)</i> |                     |                     |                     |                     |                     |
|---------------------------|------------------------------------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                           | NLP                                                        |                     |                     | LLM                 |                     |                     |
|                           | (1)<br>Base                                                | (2)<br>Geo          | (3)<br>Social       | (4)<br>Base         | (5)<br>Geo          | (6)<br>Social       |
| <i>Panel A: Clay Soil</i> |                                                            |                     |                     |                     |                     |                     |
| Triple Interaction        | 0.036<br>(0.032)                                           | 0.043**<br>(0.022)  | 0.033<br>(0.028)    | 0.099***<br>(0.038) | 0.088***<br>(0.028) | 0.079**<br>(0.031)  |
| × Ag. Dependence          | 0.114***<br>(0.030)                                        | 0.118***<br>(0.032) | 0.113***<br>(0.031) | 0.096**<br>(0.041)  | 0.104***<br>(0.039) | 0.110**<br>(0.048)  |
| <i>Panel B: Sand Soil</i> |                                                            |                     |                     |                     |                     |                     |
| Triple Interaction        | -0.002<br>(0.018)                                          | -0.001<br>(0.018)   | 0.004<br>(0.020)    | -0.039**<br>(0.017) | -0.032**<br>(0.015) | -0.037**<br>(0.016) |
| × Ag. Dependence          | 0.094**<br>(0.041)                                         | 0.092**<br>(0.039)  | 0.091**<br>(0.039)  | 0.057*<br>(0.034)   | 0.067*<br>(0.036)   | 0.086**<br>(0.039)  |
| 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           |                                                            |                     | ✓                   |                     |                     | ✓                   |

# Appendix: Full Substitution Table

| Specification:                           | Dependent Variable: Agricultural Magic (Normalized) |                      |                      |                     |                     |                    |
|------------------------------------------|-----------------------------------------------------|----------------------|----------------------|---------------------|---------------------|--------------------|
|                                          | NLP                                                 |                      |                      | LLM                 |                     |                    |
|                                          | (1)<br>Base                                         | (2)<br>Geo           | (3)<br>Social        | (4)<br>Base         | (5)<br>Geo          | (6)<br>Social      |
| <i>Panel A: Precipitation Volatility</i> |                                                     |                      |                      |                     |                     |                    |
| Irrigation × Risk                        | 0.009<br>(0.041)                                    | -0.000<br>(0.040)    | 0.004<br>(0.039)     | -0.046**<br>(0.021) | -0.048**<br>(0.021) | -0.040*<br>(0.021) |
| State × Risk                             | -0.035<br>(0.033)                                   | -0.045<br>(0.030)    | -0.044<br>(0.031)    | 0.009<br>(0.044)    | 0.001<br>(0.041)    | 0.007<br>(0.041)   |
| <i>Panel B: Scorch Risk</i>              |                                                     |                      |                      |                     |                     |                    |
| Irrigation × Risk                        | -0.151**<br>(0.060)                                 | -0.119**<br>(0.061)  | -0.097<br>(0.060)    | -0.014<br>(0.059)   | -0.024<br>(0.058)   | -0.011<br>(0.043)  |
| State × Risk                             | -0.178***<br>(0.060)                                | -0.170***<br>(0.052) | -0.172***<br>(0.052) | -0.042<br>(0.052)   | -0.049<br>(0.054)   | -0.032<br>(0.052)  |
| Observations                             | 1,120                                               | 1,109                | 1,052                | 1,120               | 1,109               | 1,052              |
| Clusters                                 | 134                                                 | 134                  | 129                  | 134                 | 134                 | 129                |
| Language Family FE                       | ✓                                                   | ✓                    | ✓                    | ✓                   | ✓                   | ✓                  |
| Subsistence Controls                     | ✓                                                   | ✓                    | ✓                    | ✓                   | ✓                   | ✓                  |
| Climate Controls                         | ✓                                                   | ✓                    | ✓                    | ✓                   | ✓                   | ✓                  |
| Geography Controls                       |                                                     | ✓                    | ✓                    |                     | ✓                   | ✓                  |
| Social Controls                          |                                                     |                      | ✓                    |                     |                     | ✓                  |

# Appendix: Full Heimat Table

| Specification:                           | <i>Dependent Variable: Agricultural Magic (Normalized)</i> |                     |                     |                    |                    |                    |
|------------------------------------------|------------------------------------------------------------|---------------------|---------------------|--------------------|--------------------|--------------------|
|                                          | NLP                                                        |                     |                     | LLM                |                    |                    |
|                                          | (1)<br>Base                                                | (2)<br>Geo          | (3)<br>Social       | (4)<br>Base        | (5)<br>Geo         | (6)<br>Social      |
| <i>Panel A: Precipitation Volatility</i> |                                                            |                     |                     |                    |                    |                    |
| Current Risk $\times$ Ag. Dep            | 0.074***<br>(0.026)                                        | 0.071***<br>(0.025) | 0.079***<br>(0.027) | 0.095**<br>(0.045) | 0.085**<br>(0.042) | 0.091*<br>(0.049)  |
| Heimat Risk $\times$ Ag. Dep             | -0.033<br>(0.037)                                          | -0.010<br>(0.036)   | -0.015<br>(0.043)   | -0.065*<br>(0.039) | -0.056<br>(0.035)  | -0.007<br>(0.029)  |
| <i>Panel B: Scorch Risk</i>              |                                                            |                     |                     |                    |                    |                    |
| Current Risk $\times$ Ag. Dep            | 0.120*<br>(0.073)                                          | 0.109<br>(0.076)    | 0.095<br>(0.088)    | 0.142**<br>(0.067) | 0.131**<br>(0.064) | 0.139**<br>(0.069) |
| Heimat Risk $\times$ Ag. Dep             | -0.078<br>(0.070)                                          | -0.040<br>(0.067)   | -0.045<br>(0.076)   | -0.010<br>(0.080)  | -0.013<br>(0.074)  | -0.017<br>(0.073)  |
| <i>Panel C: Storm Risk</i>               |                                                            |                     |                     |                    |                    |                    |
| Current Risk $\times$ Fish. Dep          | -0.036<br>(0.032)                                          | -0.022<br>(0.027)   | -0.007<br>(0.027)   | -0.017<br>(0.021)  | -0.008<br>(0.016)  | 0.005<br>(0.023)   |
| Heimat Risk $\times$ Fish. Dep           | 0.002<br>(0.030)                                           | 0.020<br>(0.036)    | 0.011<br>(0.037)    | 0.041<br>(0.028)   | 0.053*<br>(0.032)  | 0.035<br>(0.032)   |
| Observations                             | 925                                                        | 913                 | 786                 | 925                | 913                | 786                |
| Clusters                                 | 32                                                         | 32                  | 32                  | 32                 | 32                 | 32                 |
| Language Family FE                       | ✓                                                          | ✓                   | ✓                   | ✓                  | ✓                  | ✓                  |
| Subsistence Controls                     | ✓                                                          | ✓                   | ✓                   | ✓                  | ✓                  | ✓                  |
| Climate Means                            | ✓                                                          | ✓                   | ✓                   | ✓                  | ✓                  | ✓                  |
| Geography Controls                       |                                                            | ✓                   | ✓                   |                    | ✓                  | ✓                  |
| Social Controls                          |                                                            |                     | ✓                   |                    |                    | ✓                  |