The Terror of History: Solar Eclipses and the Origins of Critical Thinking and Complexity

Anastasia Litina
Èric Roca Fernández

University of Ionannina
Aix-Marseille Université

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This Paper

- We propose a novel determinant of pre-modern critical thinking —a precursor of human capital— and social complexity.
  - The incidence of rare events, in particular, solar eclipses.

Motivation

- Human capital is crucial for economic growth.
  - Mokyr (2005), Voitgländer and Squicciarini (2015), Valencia Caicedo (2018), Galor and Weil (2000).
- Economic prosperity and social complexity have always been inter-related.
  - Diamond (1997), Harari (2011), Mann (2012), Moav et al. (2018).

Main Hypothesis and Mechanism

Main Hypothesis

- We study the impact of total solar eclipses on critical thinking and social complexity.
- Idea similar to Boerner et al. (2019) and Battista and Boerner (2019).

Identification strategy:
We exploit the advantages inherent in rare phenomena.

- They are exogenous.
- They are rare $\rightarrow$ People do not get used to them.
- Are recurrent $\rightarrow$ Demand for explanation remains over time.

Mechanism:

- As such, rare events challenge social groups, that ultimately become better at thinking and solving problems.

Mechanism

"Since the cause of being afraid is not to know, isn't it very worthwhile to know, so we can be unafraid? How much better it is to inquire into the causes and, in fact, to be intent on this with the whole of our mind," for, "there is nothing greater than this: to know nature." (**Seneca, Natural Questions, 6.3.4**)

Solar Eclipses

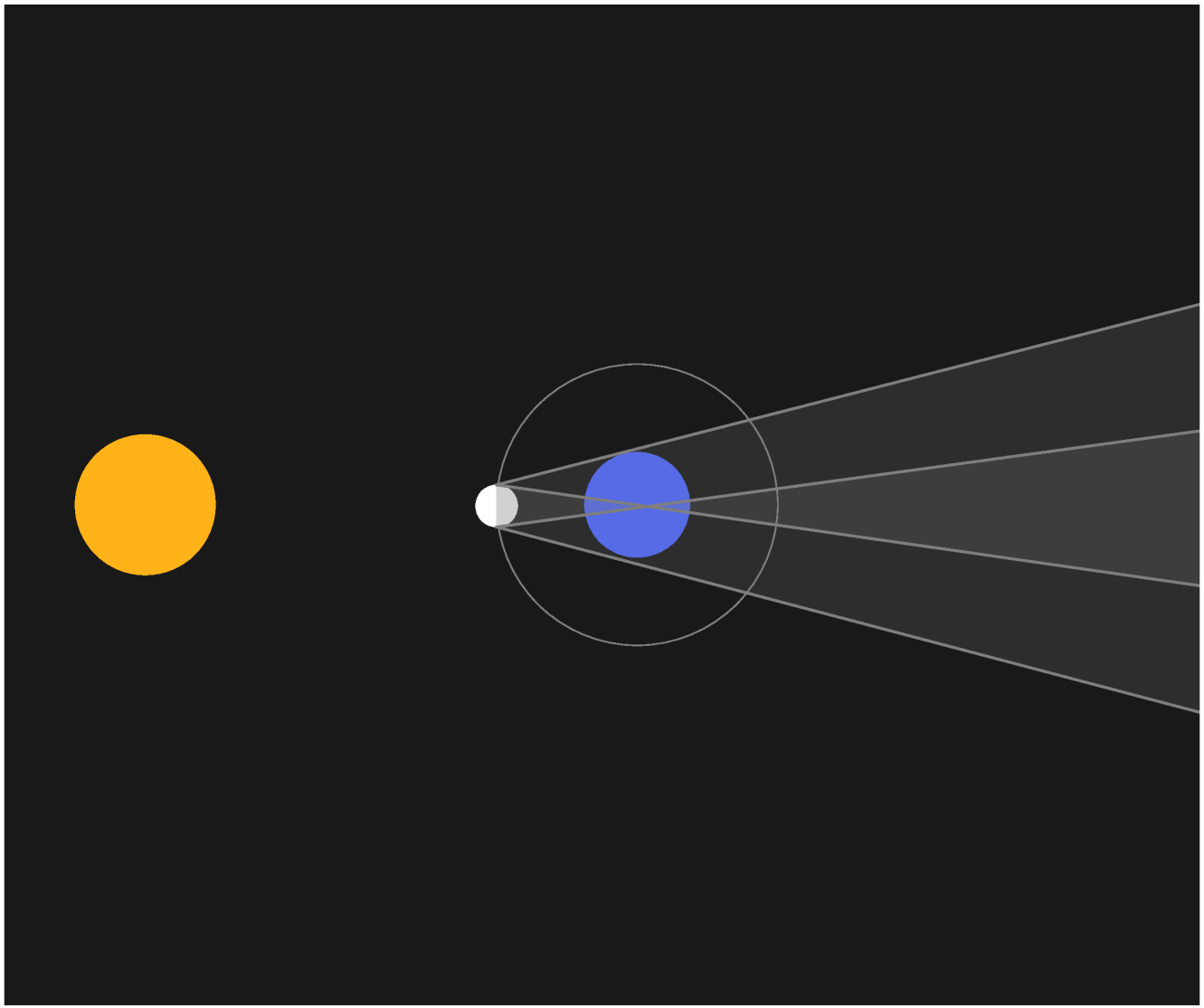
Definition:

- Alignment between the Sun, the Moon and the Earth.
- The Moon obscures the Sun.

Characteristics:

- A solar eclipse can be seen from a narrow path on Earth.
- Random occurrence.
- 100 km wide, stretching long distances east-west.
- Affects several locations simultaneously.

Solar Eclipses



Why Solar Eclipses

- Other intimidating phenomena:
  - Volcano eruptions,
  - Earthquakes,
  - Lunar eclipses

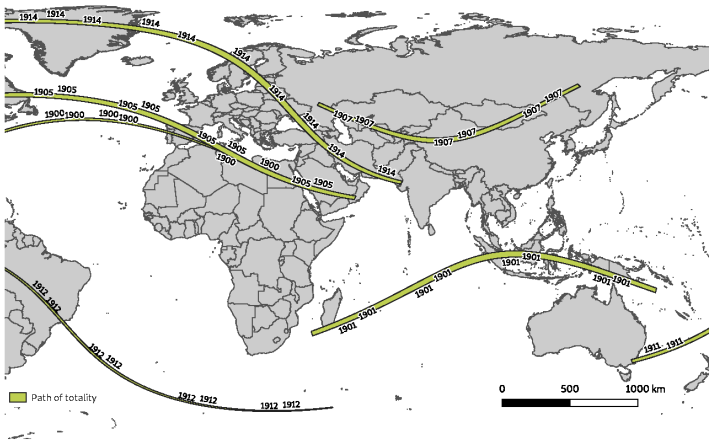
- Why eclipses?
  - Not common (as lightning) but not too rare.
  - Do not destroy physical nor human capital.
  - Narrow area of effect: provides variation.
  - Lunar eclipses can be seen from half of the world,

Data: Total Solar Eclipses

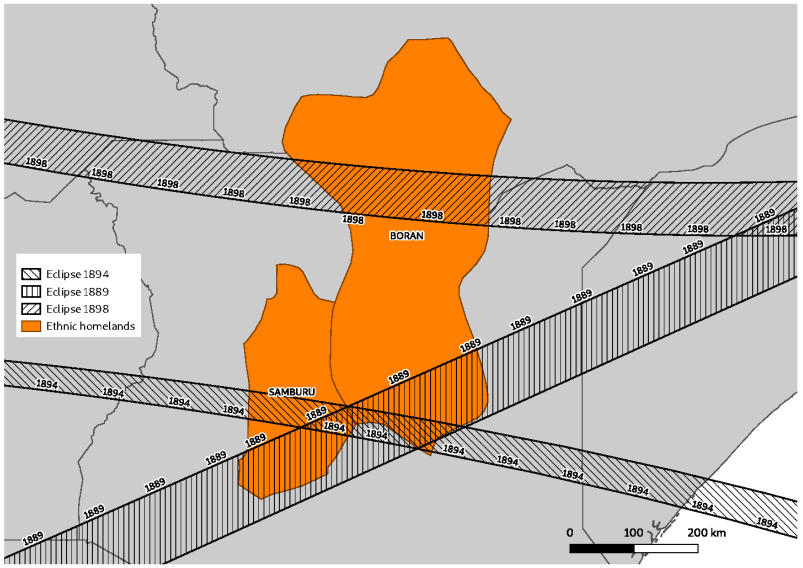
- We intersect eclipse paths with ethnic homelands.
- We consider all total solar eclipses between -2000 and 2000.
  - Partial eclipses covering less than 90% of the Sun are unnoticeable in terms of darkening.
- We count the number of total solar eclipses visible from within an ethnic homeland.

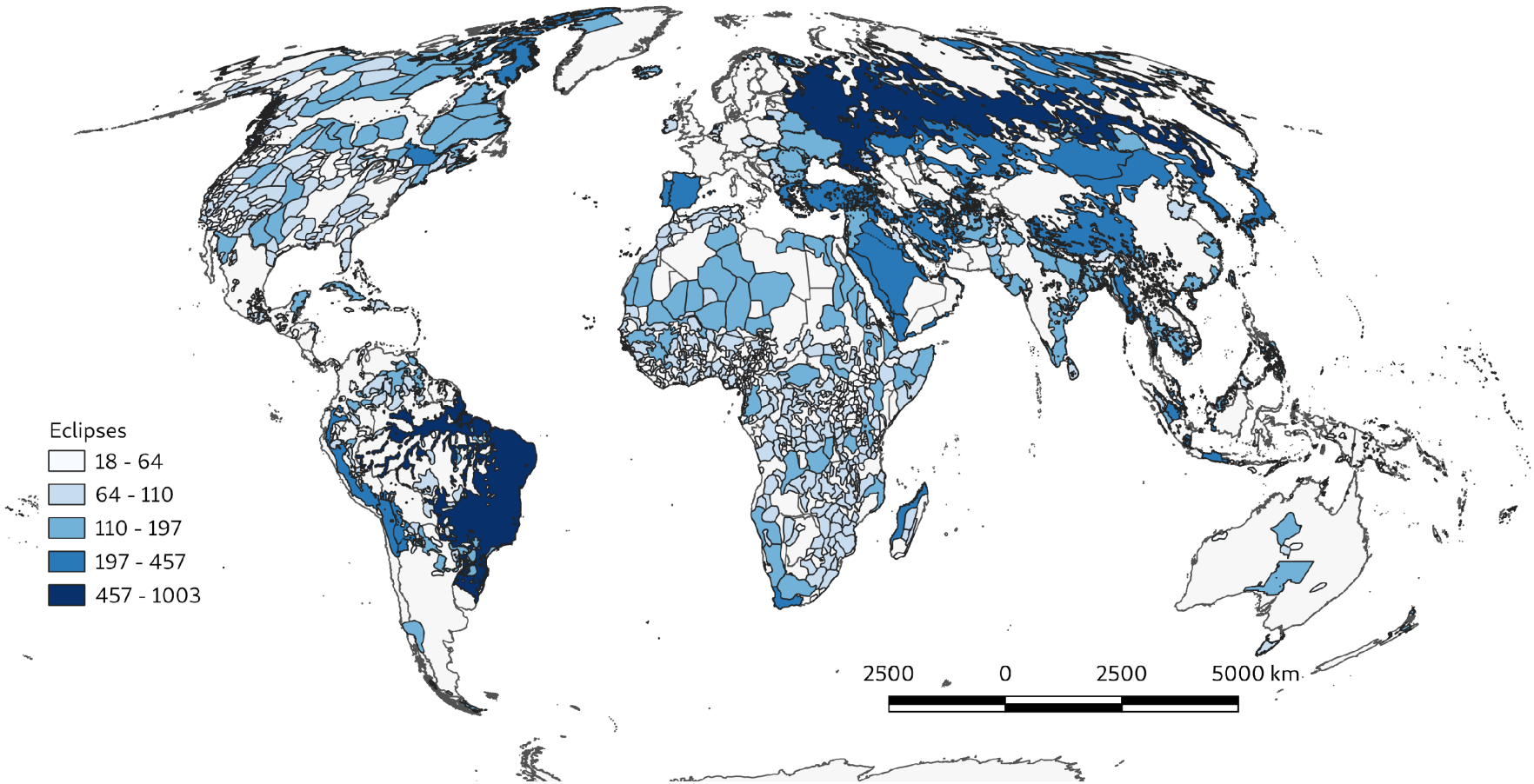
Data: Total Solar Eclipses

(a) Paths of totality.



(b) Computation of the total number of eclipses.




Eclipses
18 - 64
64 - 110
110 - 197
197 - 457
457 - 1003
2500
0
2500
5000 km

Data: Outcome Variables

Ethnographic Atlas data:

- Social complexity.
  - Jurisdictional Hierarchy Beyond Local Community.
    {No levels; . . .; four levels}
  - Political Integration
    {Absence; Local com.; Peace groups; Min. states; Little states; States}
  - Class Stratification
    {Absence; Wealth; Elite; Dual; Complex.}
- Critical thinking
  - High Gods. {No high gods; Not active in human affairs; Active, not supportive of morality; Supportive of morality}
  - Playing strategy games.
    {No games present, Games present}

Summary Statistics

	Mean	*Std.Dev.*	*Min.*	*Max.*
Eclipses				
Number of eclipses	77.264	61.576	17.000	1002.000
Max. Time between eclipses	2.921	1.239	0.242	8.575
Min. Time between eclipses	0.021	0.025	0.000	0.214
Avg. time between eclipses	0.658	0.289	0.040	2.151
Number of lunar eclipses	1584.582	106.359	1521.000	2780.000
Jurisdictional Hierarchy				
No levels	0.447	0.497	0.000	1.000
One level	0.312	0.463	0.000	1.000
Two levels	0.149	0.356	0.000	1.000
Three levels	0.071	0.257	0.000	1.000
Four levels	0.021	0.143	0.000	1.000
Class Stratification				
Absence among freemen	0.493	0.500	0.000	1.000
Wealth distinctions	0.186	0.389	0.000	1.000
Elite	0.039	0.193	0.000	1.000
Dual	0.216	0.412	0.000	1.000
Complex	0.067	0.249	0.000	1.000
Political Integration				
Absence	0.017	0.129	0.000	1.000
Automous local comm.	0.100	0.300	0.000	1.000
Peace groups	0.008	0.087	0.000	1.000
Minimal states	0.064	0.246	0.000	1.000
Little states	0.023	0.150	0.000	1.000
States	0.031	0.174	0.000	1.000
High Gods				
Absent	0.353	0.478	0.000	1.000
Not active in hum. affairs	0.344	0.476	0.000	1.000
Active in hum. affairs, not supp. of hum. morality	0.058	0.234	0.000	1.000
Supportive of hum. morality	0.243	0.429	0.000	1.000
Strategy Games				
Strategy games	0.177	0.382	0.000	1.000

	Mean	*Std.Dev.*	*Min.*	*Max.*
Annual mean temp.	196.738	85.867	−158.621	301.410
Annual precipitation	1324.715	945.300	0.264	6415.639
Temp. seasonality	3504.329	3475.523	108.250	20324361
Precipitation seasonality	66.201	33.373	5.048	215.847
Ecological diversity	0.419	0.246	0.000	0.839
Dist. coast (degrees)	4.223	3.921	0.000	16.535
Dist. river (degrees)	2.360	7.834	0.002	77.675
Dist. Addis Ababa (degrees)	233.323	268.472	1.119	723.192
Ruggedness	88.099	32.506	0.000	199.000
Elevation	163.290	25.378	0.000	210.116
Malaria	0.170	0.206	0.000	0.688
Caloric yield	1252.093	892.230	0.000	4975.770
Abs. latitude	21.111	17.447	0.017	78.070
South (0/1)	0.212	0.409	0.000	1.000
Major Crop Type				
None	0.200	0.400	0.000	1.000
Non food crop	0.002	0.043	0.000	1.000
Vegetables	0.002	0.043	0.000	1.000
Tree fruits	0.070	0.255	0.000	1.000
Roots or tubers	0.201	0.401	0.000	1.000
Cereal grains	0.525	0.500	0.000	1.000

Results: Social Complexity

	Jurisdictional Hierarchy			Political Integration			Class Stratification		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Total number of eclipses	0.014*** (0.003)	0.015*** (0.002)	0.015*** (0.002)	0.011*** (0.003)	0.013*** (0.003)	0.016*** (0.003)	0.008*** (0.003)	0.011*** (0.003)	0.011*** (0.003)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.148	0.219	0.229	0.093	0.192	0.228	0.082	0.157	0.162
Observations	906	906	906	251	251	251	821	821	821

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Critical Thinking

	Higher Gods			Strategy Games		
	(1)	(2)	(3)	(4)	(5)	(6)
Total number of eclipses	0.009*** (0.003)	0.006*** (0.002)	0.006*** (0.002)	0.002*** (0.000)	0.001*** (0.000)	0.001*** (0.000)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes
R^2	0.140	0.238	0.247	0.540	0.617	0.655
Observations	584	584	584	334	334	334

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Size of the Effects

Table: Marginal eff. of the avg. number of total solar eclipses per century.

Jurisdictional Hierarchy		Political Integration		Class Stratification		Higher Gods		Strategy Games	
(2)		(2)		(3)		(4)		(5)	
No levels	-0.096***	Absent	-0.033***	Absent	-0.083***	No Gods	-0.033***		
	(0.013)		(0.012)		(0.020)		(0.011)		
1 level	0.012***	Local com.	-0.058***	Wealth	0.008**	Not active	0.004		
	(0.005)		(0.008)		(0.003)		(0.003)		
2 levels	0.043***	Peace groups	-0.001	Elite	0.005**	Active, no morality	0.005**		
	(0.007)		(0.001)		(0.002)		(0.002)		
3 levels	0.030***	Min. states	0.018**	Dual	0.045***	Morality	0.024***		
	(0.005)		(0.008)		(0.011)		(0.008)		
4 levels	0.010***	Little states	0.024***	Complex	0.025***				
	(0.004)		(0.004)		(0.008)				
		States	0.050***						
			(0.012)						
								0.057***	
								(0.012)	
N	906		251		821		584		334

Competing Mechanisms

- Other rare events
  - Lunar eclipses,
  - Distance to volcanoes,
  - Distance to tectonic plates.

Rare events

Other Competing Mechanisms

- Population density: scalar stress (Johnson, 1982)
- Ecological diversity (Fenske, 2014).

Additional controls

Other Competing Mechanisms

- Bigger ethnic homelands experiences more eclipses.
- We tackle this by:
  - Control for area.
  - Redefine the main variable:
    Total number of eclipses in a 100-km radius circle around ethnic homelands' centroids.

Area

Robustness

- Validity of eclipses measure:
  - Average time between eclipses,
  - Maximum time between eclipses,
  - Minimum time between eclipses.
  - Other time frames: -2000 to -1500, -1500 to -1000, etc.

Alt. eclipses

Robustness: Other Ethnic Controls

- Other ethnic controls:
  - Reliance on agriculture,
  - Reliance on hunting and gathering,
  - Subsistence types.

Alt. ethnic

Spatial Correlation

- Control for neighbour's number of eclipses,
- Different clustering,
- Control for language family.

Spatial cor.

Concluding Remarks

- We find that higher exposure to total solar eclipses is related with:
  - More complex thinking,
  - More complex societies.
- We hypothesize that the underlying mechanism is the need to understand and, ultimately, tame nature.

Results: Other Rare Events

Back

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Volcanoes				
Total number of eclipses	0.015***	0.013***	0.012***	0.006***	0.001***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.000)
Dist. Volcano	0.014	0.004	−0.055**	−0.009	0.001
	(0.021)	(0.020)	(0.026)	(0.035)	(0.004)
R^2	0.229	0.211	0.167	0.248	0.655
Observations	906	267	821	584	334
	Panel B: Tectonic plates				
Total number of eclipses	0.015***	0.013***	0.011***	0.006***	0.001***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.000)
Dist. Tec. Plate	−0.018	−0.011	−0.024	0.011	−0.002
	(0.016)	(0.020)	(0.025)	(0.027)	(0.002)
R^2	0.229	0.212	0.163	0.248	0.656
Observations	906	267	821	584	334
	Panel C: Lunar Eclipses				
Total number of eclipses	0.016***	0.013***	0.012***	0.007**	0.002***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.000)
Total number of lunar eclipses	−0.001	−0.000	−0.001	−0.001	−0.000
	(0.002)	(0.002)	(0.001)	(0.002)	(0.000)
R^2	0.229	0.211	0.162	0.248	0.656
Observations	906	267	821	584	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Additional Controls

Back

	Panel A: Population density				
Total number of eclipses	0.017***	0.020***	0.018***	−0.002	0.001
	(0.003)	(0.008)	(0.005)	(0.005)	(0.001)
Population density					
< 1 p. / 1-5 sq. mile	Ref.	Ref.	Ref.	Ref.	Ref.
1 p. / 1-5 sq. mile	−0.203	−1.763	2.969***	0.677	−0.021
	(0.821)	(1.730)	(0.968)	(0.539)	(0.182)
1-5 p. / sq. mile	2.227	1.151	−0.085	−0.502	0.312**
	(1.673)	(1.772)	(1.109)	(1.194)	(0.135)
1-25 p. / sq. mile	3.517**	1.087	0.757	0.169	0.275
	(1.752)	(1.168)	(0.952)	(1.182)	(0.233)
26-100 p. / sq. mile	2.503	2.842**	1.131	0.007	0.007
	(1.786)	(1.325)	(0.793)	(0.657)	(0.156)
101-500 p. / sq. mile	3.187*	2.353	1.313	0.827	0.164
	(1.837)	(2.387)	(1.019)	(0.959)	(0.388)
> 500 p. / sq. mile	3.962**	3.939***	1.333	−0.552	0.403
	(1.965)	(1.358)	(1.464)	(1.170)	(0.343)
R^2	0.411	0.439	0.408	0.337	0.799
Observations	113	86	114	103	76
	Panel B: Ecological Diversity				
Total number of eclipses	0.015***	0.012***	0.011***	0.006***	0.001***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.000)
Eco. divesity	1.379***	1.443**	1.458***	−0.205	−0.040
	(0.335)	(0.625)	(0.322)	(0.431)	(0.086)
R^2	0.236	0.218	0.171	0.248	0.656
Observations	906	267	821	584	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Resuts: Area

Back

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Area				
Total number of eclipses	0.016***	0.011***	0.012***	0.006***	0.001***
	(0.003)	(0.003)	(0.003)	(0.002)	(0.000)
Area	−0.002	0.007	−0.003	0.001	0.000
	(0.005)	(0.006)	(0.004)	(0.008)	(0.001)
R^2	0.229	0.213	0.162	0.247	0.655
Observations	906	267	821	584	334
	Panel B: Buffer				
Total number of eclipses (buffer)	0.017*	0.035**	0.004	0.039**	0.000
	(0.010)	(0.015)	(0.008)	(0.016)	(0.002)
R^2	0.187	0.168	0.137	0.245	0.626
Observations	906	267	821	584	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Alt. Eclipses

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	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Maximum time between eclipses				
Total number of eclipses	0.012***	0.017***	0.008***	0.005	0.001***
	(0.002)	(0.004)	(0.003)	(0.003)	(0.000)
Max. time between eclipses	−0.258*	0.089	−0.211	−0.115	−0.015
	(0.140)	(0.224)	(0.154)	(0.144)	(0.024)
R^2	0.233	0.229	0.165	0.248	0.656
Observations	906	251	821	584	334
	Panel B: Minimum time between eclipses				
Total number of eclipses	0.014***	0.017***	0.011***	0.006**	0.002***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.000)
Min. time between eclipses	−7.932	8.792*	0.506	−2.041	1.608***
	(6.208)	(4.835)	(4.366)	(5.253)	(0.333)
R^2	0.230	0.231	0.162	0.248	0.661
Observations	906	251	821	584	334
	Panel C: Avg. time between eclipses				
Total number of eclipses	0.008***	0.012***	0.007***	0.003	0.002***
	(0.002)	(0.004)	(0.002)	(0.003)	(0.000)
Avg. time between eclipses	−1.986***	−0.931	−1.109*	−0.915	0.108
	(0.706)	(1.014)	(0.663)	(0.578)	(0.095)
R^2	0.236	0.230	0.165	0.250	0.657
Observations	906	251	821	584	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Additional Ethnic Controls

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Gathering				
Total number of eclipses	0.015***	0.012***	0.010***	0.005***	0.001***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.000)
Dependence on gathering	−0.342***	−0.509***	−0.356***	−0.234**	−0.027*
	(0.079)	(0.108)	(0.086)	(0.110)	(0.015)
R^2	0.237	0.232	0.172	0.252	0.660
Observations	906	267	821	584	334
	Panel B: Agriculture				
Total number of eclipses	0.015***	0.013***	0.012***	0.006***	0.001***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.000)
Dependence on agriculture	0.121*	0.247***	0.226***	−0.014	0.036***
	(0.062)	(0.069)	(0.056)	(0.075)	(0.011)
R^2	0.231	0.220	0.171	0.247	0.667
Observations	906	267	821	584	334
	Panel C: Agricultural intensity				
Total number of eclipses	0.014***	0.011***	0.010***	0.006**	0.001***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)
Agricultural intensity					
No agric.	Ref.	Ref.	Ref.	Ref.	Ref.
Casual agric.	1.010	2.645**	1.108*	0.328	0.338***
	(0.838)	(1.220)	(0.652)	(1.903)	(0.102)
Extensive agric.	0.845	2.920*	1.487	0.260	0.420***
	(0.973)	(1.577)	(1.076)	(1.917)	(0.083)
Horticulture	−1.861*	0.984	−0.081	0.060	0.298**
	(1.100)	(2.193)	(1.385)	(2.131)	(0.119)
Intensive agric.	1.796**	3.557*	2.669***	0.420	0.456***
	(0.891)	(1.843)	(0.861)	(1.906)	(0.116)
Intensive irrigated agric.	1.823*	4.198**	2.594***	0.276	0.494***
	(1.042)	(1.753)	(1.003)	(2.111)	(0.124)
R^2	0.253	0.231	0.185	0.248	0.662
Observations	906	267	821	584	334

Results: Additional Ethnic Controls

Back

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
			Panel D: Subsistence economoy		
Total number	0.014***	0.013***	0.011***	0.005***	0.001***
of eclipses	(0.002)	(0.003)	(0.003)	(0.002)	(0.000)
Subsistence					
Gathering	Ref.	Ref.	Ref.	Ref.	Ref.
Fishing	0.398	−0.622	0.701	0.198	0.005
	(0.500)	(0.538)	(0.542)	(0.491)	(0.051)
Hunting	0.555	1.330***	−0.149	0.255	0.019
	(0.569)	(0.505)	(0.630)	(0.573)	(0.055)
Pastoralism	1.227**	1.081	0.466	1.186	0.008
	(0.549)	(0.919)	(0.604)	(0.745)	(0.166)
Int. agric.	0.552	0.627	0.458	0.388	0.137
	(0.357)	(0.717)	(0.550)	(0.626)	(0.085)
Two or more sources	1.643***	1.922**	1.678***	0.455	0.186**
	(0.518)	(0.806)	(0.606)	(0.518)	(0.080)
Agric.	0.417	0.182	0.236	0.829	−0.038
	(0.465)	(0.580)	(0.525)	(0.645)	(0.041)
Ext. agric.					
R^2	0.244	0.236	0.183	0.251	0.668
Observations	906	267	821	584	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies.

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Spatial Correlation

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	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Clustering at linguistic families				
Total number of eclipses	0.016*** (0.002)	0.013*** (0.003)	0.013*** (0.002)	0.007*** (0.002)	0.001*** (0.000)
R^2	0.226	0.209	0.158	0.269	0.653
Observations	861	247	779	552	311
	Panel B: Clustering at ecoregions				
Total number of eclipses	0.016*** (0.002)	0.013*** (0.003)	0.013*** (0.003)	0.007*** (0.002)	0.001** (0.000)
R^2	0.226	0.209	0.158	0.269	0.653
Observations	861	247	779	552	311
	Panel C: Language Family Fixed Effects				
Total number of eclipses		0.016*** (0.004)	0.011*** (0.003)	0.005* (0.003)	0.001** (0.001)
Language FE		Yes	Yes	Yes	Yes
R^2		0.308	0.215	0.354	0.729
Observations		267	821	584	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

[1] Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

[2] * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.