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

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Motivation

- Two strands of the literature explain economic growth:
  - Importance of human capital: evidence starts for relatively modern times.
    - Mokyr (2005), Voitgländer and Squicciarini (2015).
  - Deep-rooted factors: geography, climate, etc.
    - Ashraf and Galor(2011), Dalgaard et al. (2015), Galor and Özak (2016), Nunn and Puga (2017), etc.

- However, there is no evidence about the long-run role of human capital on economic development.

This Paper

Research question

Is human capital related to economic growth in pre-modern times?

- Main idea:
  - Curiosity: precursor of human capital.
  - Explaining rare phenomena: intellectual endeavour.
  - More rare phenomena $\rightarrow$ Comparative advantage in thinking.
  - Human capital and economic growth.
- Focus of the paper:
  - Pre-modern ethnic groups: Australian aborigines, African tribes, North-American natives, etc.

Solar Eclipses and Curiosity

- Solar eclipses are an impressive: today and during the past.
- Day turns into night, temperature drops, animals change behaviour.
- Demand for an explanation.
- Idea similar to Boerner et al. (2019) and Battista and Boerner (2019).
  Characteristics:
  - A solar eclipse can be seen from a narrow path on Earth.
  - Random, exogenous occurrence.
  - Affects several locations simultaneously.

Competing Natural Events

- Other strange and unexplained phenomena:
  - Volcano eruptions,
  - Earthquakes,
  - Lunar eclipses.
  - All these cause massive destruction.

- However, solar eclipses:
  - Do not destroy physical nor human capital.
  - Impressive effects: obscurity, wind, temperature.
  - Narrow area of effect: provides variation.

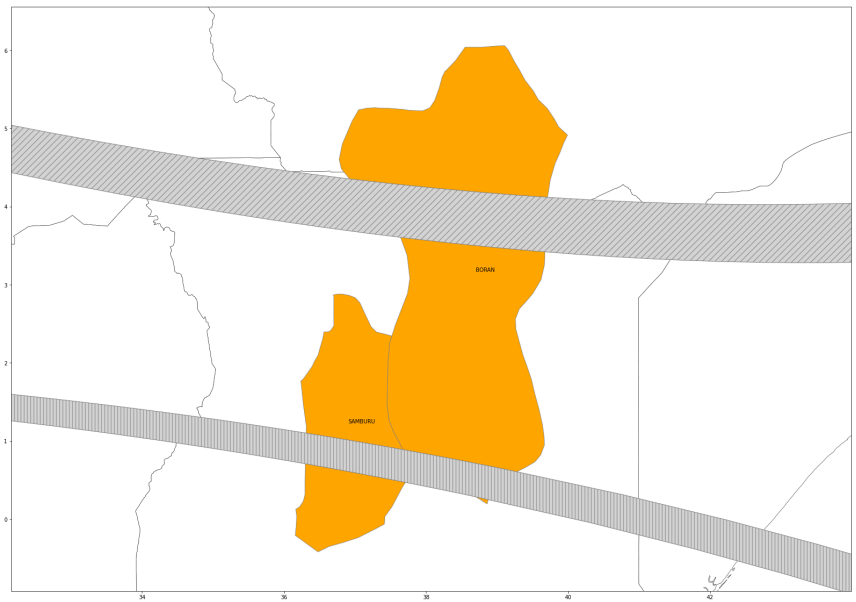
Empirical Strategy

- Unit of observation: ethnic groups.
- Regress indicators of economic development on the number of total solar eclipses.

$$y_{i,j} = f(\alpha eclipses_{i,j} + X_{i,j}\beta + \gamma_j + \epsilon_{i,j})$$

Data: Total Solar Eclipses

- Intersect eclipse paths with ethnic homelands.
- Time frame: 2000BCE to 1500CE
- Count the number of total solar eclipses visible from within an ethnic homeland.



Data: Outcome Variables

- Proxies for economic development
  - Social complexity (Ethnographic Atlas)
    - 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.}
- Other proxies of economic development (SCCS):
  - Technological level
  - Population density
    $\{< 1$ people / sq. mile; . . . > 500 people / sq. mile$\}$
- Proxies for human capital
  - Presence of writing
  - Play of strategy games
  - Folkloric understanding of eclipses
  - Similar to Michalopoulos and Xue (2019).

Preview of the Results

We find that a higher frequency of exposure to solar eclipses is associated with

- more economic development,
- and higher human capital.

Summary Statistics

	Mean	*Std.Dev.*	*Min.*	*Max.*
Eclipses				
Number of eclipses	69.117	54.483	13.000	883.000
Avg. time between eclipses(centuries)	0.658	0.300	0.040	2.560
Min. Time between eclipses(centuries)	0.023	0.028	0.000	0.290
Max. Time between eclipses(centuries)	2.857	1.252	0.194	8.575
Number of lunar eclipses	1391.215	90.897	1336.000	2443.000
Jurisdictional Hierarchy				
No levels	0.461	0.499	0.000	1.000
One level	0.298	0.458	0.000	1.000
Two levels	0.142	0.349	0.000	1.000
Three levels	0.073	0.260	0.000	1.000
Four levels	0.026	0.159	0.000	1.000
Class Stratification				
Absence among freemen	0.487	0.500	0.000	1.000
Wealth distinctions	0.191	0.393	0.000	1.000
Elite	0.035	0.184	0.000	1.000
Dual	0.213	0.410	0.000	1.000
Complex	0.074	0.262	0.000	1.000
Political Integration				
Absence	0.018	0.132	0.000	1.000
Autonomous local comm.	0.107	0.309	0.000	1.000
Peace groups	0.007	0.083	0.000	1.000
Minimal states	0.062	0.241	0.000	1.000
Little states	0.023	0.151	0.000	1.000
States	0.034	0.181	0.000	1.000
Technological Level				
Technological Level	9.536	1.492	7.194	13.378
Population Density				
Less than 1 / sq. mile	0.280	0.450	0.000	1.000
1–5 / sq. mile	0.161	0.368	0.000	1.000
5–25 / sq. mile	0.181	0.386	0.000	1.000
25–100 / sq. mile	0.197	0.399	0.000	1.000
100–500 / sq. mile	0.124	0.331	0.000	1.000
500 or more / sq. mile	0.057	0.232	0.000	1.000
Writing				
Writing	0.212	0.410	0.000	1.000
Strategy Games				
Strategy games	0.169	0.375	0.000	1.000
Eclipse Explanation				
No explanation	0.640	0.480	0.000	1.000
Naive	0.258	0.438	0.000	1.000
Involve Moon and Sun	0.102	0.303	0.000	1.000

Mean	*Std.Dev.*	*Min.*	*Max.*
Annual mean temp.	192.946	89.340	−166.522	301.410
Annual precipitation	1327.907	954.285	0.264	6415.639
Ecological diversity	0.420	0.246	0.000	0.839
Dist. coast (km)	430.916	412.958	0.054	1648.241
Dist. river (km)	248.096	836.981	0.198	8401.051
Dist. Addis Ababa (km)	14.675	13.162	0.125	43.844
Ruggedness	86.664	32.505	0.000	199.000
Elevation	162.953	26.374	0.000	210.116
Malaria	0.173	0.206	0.000	0.688
Caloric yield	1170.170	860.545	0.000	4975.770
Abs. latitude	21.443	17.700	0.017	78.070
South (0/1)	0.203	0.403	0.000	1.000
Dependence on gathering (%)	24.149	128.998	2.500	1830.500
Dependence on agriculture (%)	45.249	26.581	2.500	90.500
Intensity of Agriculture				
No agriculture	0.206	0.404	0.000	1.000
Casual agriculture	0.036	0.187	0.000	1.000
Extensive agriculture	0.401	0.490	0.000	1.000
Horticulture	0.083	0.275	0.000	1.000
Intensive agriculture	0.166	0.372	0.000	1.000
Intensive irrigated agriculture	0.109	0.311	0.000	1.000
Major Crop Type				
None	0.213	0.410	0.000	1.000
Non food crop	0.002	0.041	0.000	1.000
Vegetables	0.003	0.050	0.000	1.000
Tree fruits	0.068	0.252	0.000	1.000
Roots or tubers	0.197	0.398	0.000	1.000
Cereal grains	0.517	0.500	0.000	1.000
Subsistence Economy				
Gathering	0.080	0.271	0.000	1.000
Fishing	0.093	0.290	0.000	1.000
Hunting	0.060	0.237	0.000	1.000
Pastoralism	0.061	0.240	0.000	1.000
Extensive agriculture	0.372	0.484	0.000	1.000
Intensive agriculture	0.214	0.410	0.000	1.000
Two or more above	0.051	0.220	0.000	1.000
Agriculture, unknown type	0.070	0.255	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*** (0.003)	0.008*** (0.002)	0.011*** (0.003)	0.012*** (0.004)	0.011** (0.004)	0.008*** (0.003)	0.013*** (0.003)	0.008*** (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
Pseudo-R^2	0.138	0.212	0.262	0.073	0.180	0.259	0.075	0.144	0.179
Observations	1111	911	911	307	255	255	1067	825	825

[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: Technology and Pop. Density

	Technology Level			Population Density		
	(1)	(2)	(3)	(4)	(5)	(6)
Total number of eclipses	0.003*	0.004***	0.004**	0.002	0.004	0.016***
	(0.002)	(0.001)	(0.002)	(0.002)	(0.003)	(0.006)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes
Pseudo-R^2	0.345	0.577	0.706	0.090	0.276	0.454
Observations	129	108	108	166	139	139

[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

Jurisdictional Hierarchy (1)		Political Integration (2)		Class Stratification (3)		Technological Level (4)		Population Density (5)	
No levels	-0.046^{***}	Absent	-0.019^{**}	Absent	-0.057^{***}		0.175^{**}	Less than 1 / sq. mile	-0.040^{***}
	(0.013)		(0.009)		(0.019)		(0.070)		(0.014)
1 level	0.004^{**}	Local com.	-0.038^{**}	Wealth	0.005^{**}			1-5 / sq. mile	-0.008
	(0.002)		(0.015)		(0.003)				(0.006)
2 levels	0.020^{***}	Peace groups	-0.001	Elite	0.003^{**}			5-25 / sq. mile	-0.005
	(0.006)		(0.001)		(0.001)				(0.005)
3 levels	0.016^{***}	Min. states	0.008	Dual	0.031^{***}			25-100 / sq. mile	0.016^{***}
	(0.004)		(0.006)		(0.011)				(0.004)
4 levels	0.006^{***}	Little states	0.016^{**}	Complex	0.018^{***}			100-500 /sq. mile	0.024^{**}
	(0.002)		(0.007)		(0.006)				(0.011)
		States	0.033^{**}					500 or more / sq. mile	0.014^{***}
			(0.014)						(0.005)

[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] $^{*}\,p < 0.1$, $^{**}\,p < 0.05$, $^{***}\,p < 0.01$.

Competing Mechanisms

- Other rare events Rare events
  - Lunar eclipses,
  - Distance to volcanoes,
  - Distance to tectonic plates.
- Alternative drivers of social complexity Additional controls
  - Population density: scalar stress (Johnson, 1982)
  - Ecological diversity (Fenske, 2014).

Other Competing Mechanisms

- Bigger ethnic homelands experiences more eclipses.
- We tackle this by:
  - Control for area.
  - Redefine the main variable:
    Predicted number of eclipses based on area, while controlling for the actual number.

Area

Robustness

- Validity of eclipses measure: Other times
  - Other time frames: -2000 to -1500, -1500 to -1000, etc.

Robustness: Other Ethnic Controls

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

Spatial Correlation

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

Spatial cor.

The Mechanism

- We argue that eclipses raise human capital by prompting thinking.
- Test this hypothesis on variables indicative of human capital:
  - Writing,
  - Play of strategy games,
  - Folkloric understanding of eclipses.

The Mechanism

	Writing			Strategy Games			Eclipse Explanation		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Total number of eclipses	0.003*** (0.000)	0.003*** (0.001)	0.004** (0.001)	0.001*** (0.000)	0.001*** (0.000)	0.002*** (0.000)	0.001 (0.001)	0.002* (0.001)	0.004** (0.002)
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
Pseudo-R^2	0.212	0.520	0.573	0.486	0.599	0.653	0.061	0.142	0.158
Observations	139	117	117	448	336	336	567	437	436

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

Concluding Remarks

- We study human capital and growth for pre-modern ethnic groups.
- Our results suggest that:
  - Exposure to inexplicable phenomena is related to
  - economic growth.
- We provide evidence compatible with the hypothesis of human capital accumulation.
  - Solar eclipses call for an explanation.
  - Contributes to develop thinking and human capital.

APPENDIX

Results: Other Rare Events

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	Jurisdict. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
	Panel A: Volcanoes				
Total number of eclipses	0.008***	0.011**	0.009***	0.004**	0.016***
	(0.002)	(0.004)	(0.003)	(0.002)	(0.006)
Dist. Volcano	0.000	−0.000	−0.001**	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
R^2 Pseudo-R^2	0.262	0.259	0.185	0.706	0.455
Observations	911	255	825	108	139
	Panel B: Tectonic Faults				
Total number of eclipses	0.008***	0.011**	0.009***	0.004**	0.016***
	(0.002)	(0.004)	(0.003)	(0.002)	(0.006)
Dist. Tec. Fault	−0.000	−0.000	−0.000	0.000	−0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
R^2 Pseudo-R^2	0.262	0.260	0.181	0.708	0.460
Observations	911	255	825	108	139
	Panel C: Lunar Eclipses				
Total number of eclipses	0.007**	0.009	0.007**	0.007	0.017*
	(0.003)	(0.006)	(0.004)	(0.006)	(0.010)
Total number of lunar eclipses	0.001	0.002	0.001	−0.002	−0.001
	(0.001)	(0.003)	(0.001)	(0.005)	(0.008)
R^2 Pseudo-R^2	0.262	0.259	0.179	0.706	0.454
Observations	911	255	825	108	139
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: Alternative Drivers

Back

	Jurisdict. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
	Panel A: Population Density				
Total number of eclipses	0.017*	0.040***	0.019**	0.002	
	(0.009)	(0.012)	(0.009)	(0.002)	
Pop. Density					
< 1 p. / sq. mile	Ref.	Ref.	Ref.	Ref.	
1-5 p. / sq. mile	−1.091**	−0.807	0.104	0.502	
	(0.521)	(1.282)	(1.090)	(0.773)	
5-25 p. / sq. mile	2.980**	4.316***	1.510	0.309	
	(1.456)	(1.635)	(1.274)	(0.932)	
25-100 p. / sq. mile	2.739	3.650***	1.696	1.104	
	(1.706)	(1.395)	(1.241)	(0.943)	
100-500 p. / sq. mile	3.656*	4.629**	2.712**	0.803	
	(1.962)	(2.350)	(1.302)	(1.196)	
> 500 p. / sq. mile	5.414***	5.208*	3.377	−0.142	
	(1.898)	(2.940)	(2.242)	(1.174)	
R^2 Pseudo-R^2	0.433	0.533	0.310	0.740	
Observations	139	100	139	98	163
	Panel B: Ecological Diversity				
Total number of eclipses	0.008***	0.010**	0.008***	0.004*	0.016***
	(0.002)	(0.004)	(0.003)	(0.002)	(0.006)
Eco. diversity	0.580	0.731	0.932***	0.297	3.557**
	(0.374)	(0.717)	(0.304)	(0.740)	(1.690)
R^2 Pseudo-R^2	0.263	0.261	0.182	0.707	0.475
Observations	911	255	825	108	139
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: Area

Back

	Jurisdict. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
	Panel A: Area				
Total number of eclipses	0.007**	0.005	0.007***	0.005	0.016**
	(0.003)	(0.004)	(0.002)	(0.004)	(0.008)
Area	0.000	0.000***	0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2 Pseudo-R^2	0.257	0.257	0.176	0.694	0.419
Observations	943	269	856	113	145
	Panel B: Expected eclipses, 50 km radius				
Total number of eclipses	0.007***	0.006	0.007***	0.005	0.016**
	(0.003)	(0.004)	(0.003)	(0.004)	(0.007)
Expected eclipses 50 km radius area	0.001	0.005**	0.000	−0.000	−0.000
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
R^2 Pseudo-R^2	0.257	0.256	0.176	0.694	0.419
Observations	943	269	856	113	145
	Panel C: Expected eclipses, 100 km radius				
Total number of eclipses	0.007***	0.005	0.007***	0.005	0.016**
	(0.003)	(0.004)	(0.003)	(0.004)	(0.007)
Expected eclipses 100 km radius area	0.001	0.004***	0.000	−0.000	−0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
R^2 Pseudo-R^2	0.257	0.257	0.176	0.694	0.419
Observations	943	269	856	113	145
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: Other Times

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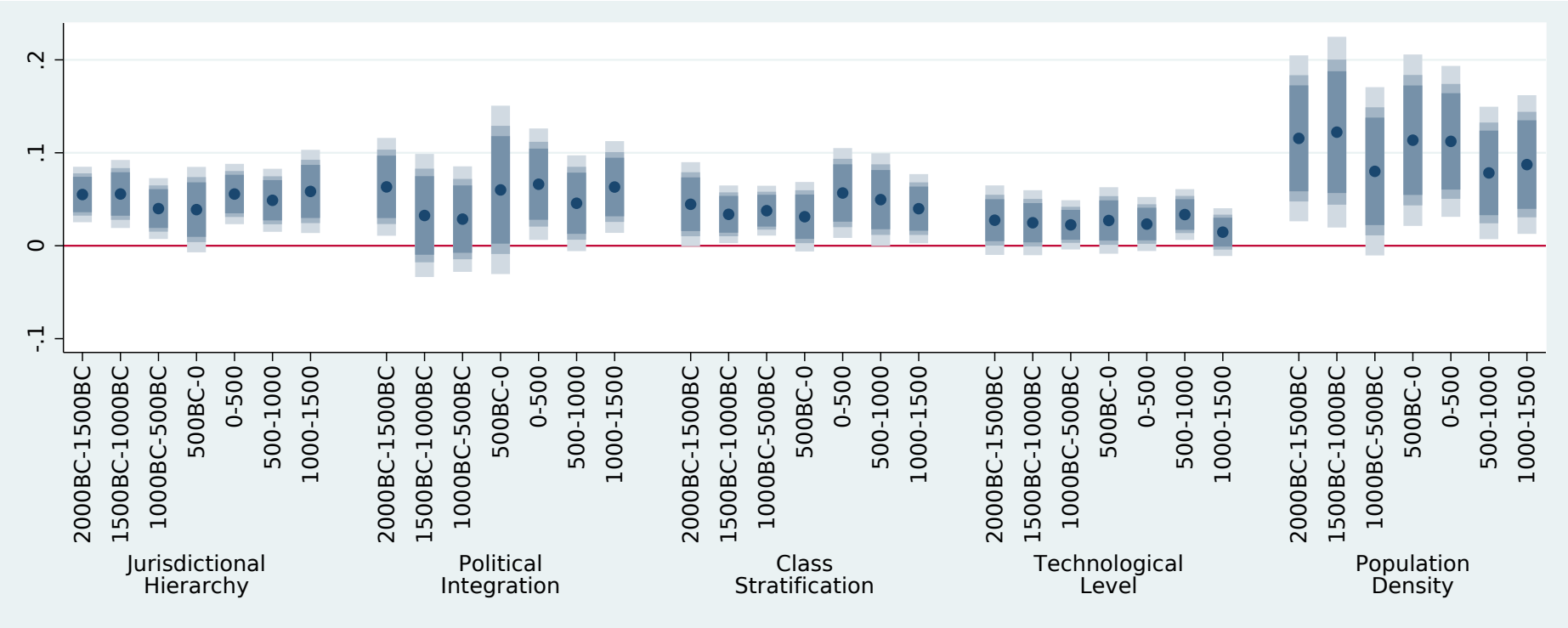

Results: Other Ethnic Characteristics

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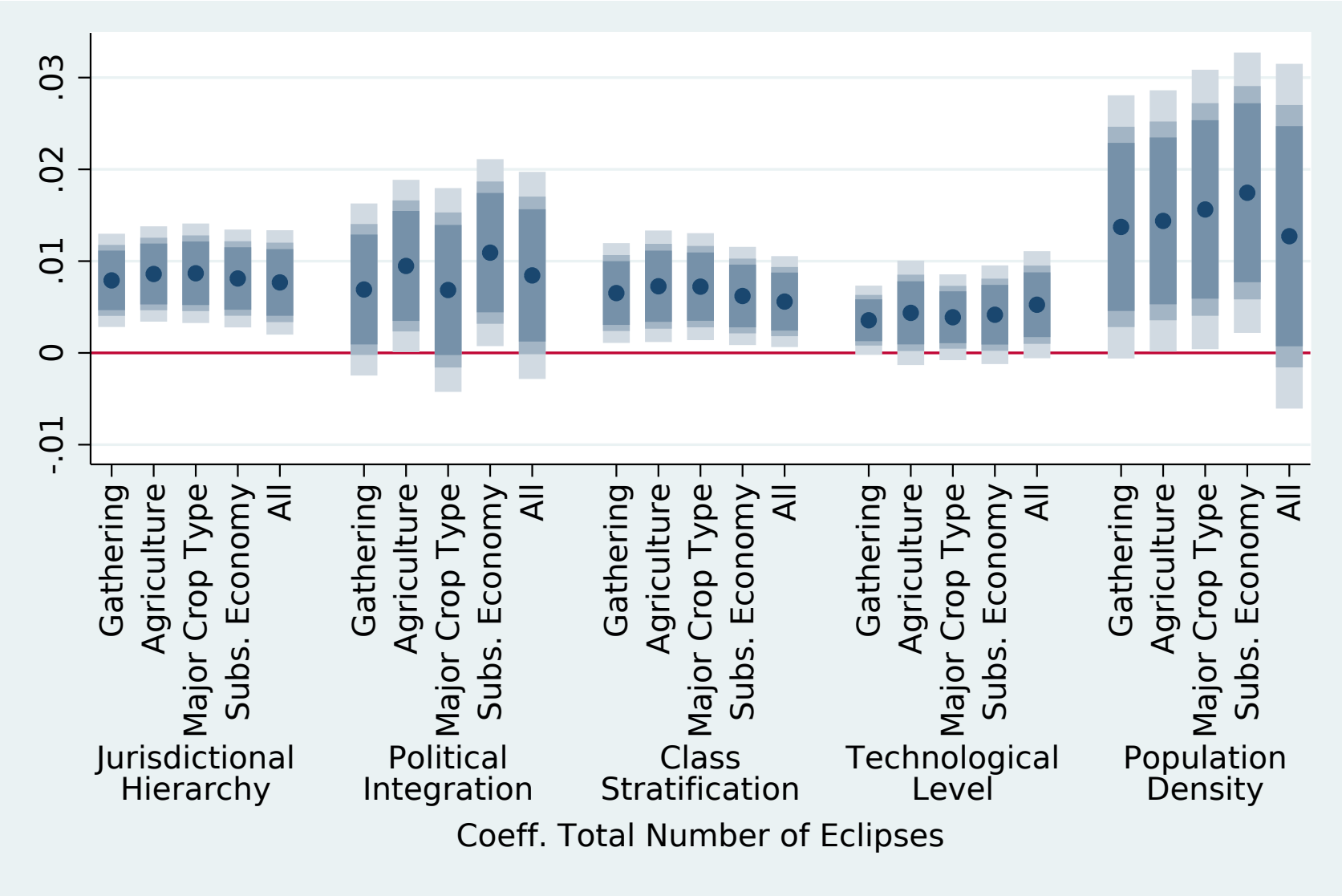

Results: Spatial Correlation

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	Jurisdict. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
	A: Nearest Neighbour				
Total number of eclipses	0.009***	0.010*	0.010***	0.006**	0.015**
	(0.002)	(0.006)	(0.004)	(0.002)	(0.006)
Eclipses neighbour	−0.002	0.001	−0.004	−0.011	0.003
	(0.002)	(0.003)	(0.003)	(0.006)	(0.004)
Pseudo-R^2	0.259	0.258	0.179	0.730	0.463
Observations	892	246	807	103	134
	B: Clustering at ecoregions				
Total number of eclipses	0.008***	0.011***	0.008***	0.004**	0.016***
	(0.002)	(0.004)	(0.003)	(0.002)	(0.006)
Pseudo-R^2	0.262	0.259	0.179	0.706	0.454
Observations	911	255	825	108	139
	C: Language Fixed Effects				
Total number of eclipses		0.021***	0.006***	0.016	−0.037
		(0.007)	(0.002)	(0.027)	(0.023)
Language FE		Yes	Yes	Yes	Yes
Controls (common to all regressions)					
Fixed effects		Yes	Yes	Yes	Yes
Geography		Yes	Yes	Yes	Yes
Ethnic		Yes	Yes	Yes	Yes
R^2 Pseudo-R^2		0.381	0.235	0.926	0.718
Observations	703	255	825	108	139

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