SOLAR ECLIPSES AND THE ORIGINS OF CRITICAL THINKING AND COMPLEXITY*

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This paper relates curiosity to economic development through its impact on human capital formation and technological advancement in pre-modern times. More specifically, we propose that exposure to inexplicable phenomena prompts curiosity and thinking in an attempt to comprehend these mysteries, thus raising human capital and technology, and, ultimately, fostering growth. We focus on solar eclipses as one particular trigger of curiosity and empirically establish a robust relationship between their number and several proxies of economic prosperity. We also offer evidence compatible with the human capital and technological increases we postulate, finding a more intricate thinking process and more developed technology among societies more exposed to solar eclipses. Among other factors, we study the development of written language, the playing of strategy games and the accuracy of folkloric explanations for eclipses, as well as the number of tasks undertaken in a society, their relative complexity and broad technological indicators. Lastly, we document rising curiosity both at the social and individual levels: societies incorporate more terms related to curiosity and eclipses in their folklore, and people who observed a total solar eclipse during their childhood were more likely to have entered a scientific occupation.

Scientific progress and (high-end) human capital are widely considered important contributors to economic growth, both theoretically and empirically (Mokyr, 2005; Squicciarini and Voigtländer, 2015).[1] However, the deep-rooted determinants of critical thinking, science and, ultimately, human-capital creation are not well understood. This paper proposes curiosity as a natural precursor to human capital. Motivated by Adam Smith's (1795) idea that '[w]onder [...] is the first principle which prompts mankind to the study [...]', we examine whether curiosity motivates critical thinking, improving human capital and technology. Moreover, because curiosity is 'an essential human trait without which no historical theory of useful knowledge makes sense' (Mokyr, 2004, pp.15–6), curiosity can be seen as one root cause of economic prosperity, complementing other channels proposed in the literature.

Curiosity is acknowledged as a driver of knowledge in a diverse range of scientific fields. Described by (the philosopher and psychologist) William James as 'the impulse towards better cognition' (James, 1983), it is widely argued to be an integral stage of human development (Hall

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[1] Seminal papers include Romer (1986), Lucas (1988) and Rebelo (1991), and the empirical relevance of the topic goes back to Mankiw *et al.* (1992), Barro (2001) and Gennaioli *et al.* (2012).

and Smith, 1903; Dember and Earl, 1957; Oswald, 1965; Kinney and Kagan, 1976; Berlyne, 1978).[2] Jean Piaget argued that the purpose of curiosity was to 'construct knowledge' through interactions with the world (Piaget, 2013).[3] Curiosity associated with the acquisition of knowledge (epistemic curiosity; Berlyne, 1954) is predominantly encountered in humans, where it can be driven either by extrinsic stimuli or intrinsic motives (Butler, 1953; Loewenstein, 1994; Oudeyer and Kaplan, 2007). Focusing on externally driven curiosity, history has given us numerous examples.[4]

This paper relates curiosity to economic development through its impact on human capital formation and technological advancement in pre-modern times. Curiosity measures are elusive—especially for pre-modern societies. To circumvent this limitation, we focus on *triggers* of human curiosity, and in particular, on natural phenomena. Natural events are good candidates with which to approximate curiosity—humans have always sought to comprehend the world around them. Thus, we argue that pre-modern societies more exposed to inexplicable natural phenomena gained a comparative advantage in critical thinking as people attempted to rationalise mysteries. However, different types of events may have opposite effects on growth depending on their typology.[5] For instance, earthquakes, volcanic eruptions and flooding combine an intellectual challenge with high economic costs.[6]

In this paper, we focus on total solar eclipses. Owing to their particular characteristics, these are one of the most impressive natural phenomena and can hardly go unnoticed: during a total solar eclipse, the Moon blocks sunlight, throwing parts of the Earth into the shadows and turning day into night.[7] Because humans have always sought to understand the revolving skies (Iwaniszewski, 2014, p.288), and with sunlight being essential for life, for pre-modern societies, the disappearance of the Sun from the sky was a mystery worth unravelling. In this sense, solar eclipses represented a particularly curiosity-spurring riddle (Barale, 2014, pp.1763–6)[8] that 'render[ed] them [people] [...] more desirous to know [...]' (Smith, 1795, p.21). Indeed, although eclipse forecasting was an elusive task—especially for solar eclipses—several people achieved surprising success, attesting to their intellectual efforts to comprehend them.[9,10]

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[2] Similar observations regarding the role of curiosity in the learning process have been made for animals as well. For example, the 'What is this?' reflex is defined as a form of curiosity by Pavlov (2010).

[3] Several other studies have confirmed that children systematically prefer to engage with toys whose mechanism is not familiar to them (Schulz and Bonawitz, 2007) or with toys that involve information gains (Cook *et al.*, 2011).

[4] For example, Liller (2000, p.112) documented that the Rapa Nui people started carving the moai statues shortly after a series of five solar eclipses in ten years that was followed by a sixth one and the passage of a comet 65 years later. Ancient mythology contains ample evidence of attempts to explain natural phenomena through myths and folklore.

[5] To discuss the capacity of events to spur curiosity, we classify them along two independent criteria: the frequency of the event and its destructiveness. See Online Appendix A.

[6] There is evidence of disaster-driven technological change. For instance, Indonesian ethnic groups improved their construction techniques to be earthquake resistant (Kurnio *et al.*, 2021). This gradual improvement of construction techniques echoes Shumpeterian creative destruction. However, it is not driven by curiosity and the desire to understand incomprehensible events but, rather, is the result of a directed effort to solve a very specific problem.

[7] Depending on the level of obscuration, solar eclipses are categorised as one of three types: *total solar eclipses* completely occlude the Sun; *annular solar eclipses* leave only a rim of light around the Moon and *partial solar eclipses* only partially cover the Sun. Besides the obvious decrease in luminosity, during a solar eclipse the temperature can drop up to 10° and winds slow down (Gray and Harrison, 2012; Eugster *et al.*, 2017).

[8] See also Murray (2014, p.240).

[9] See Littmann *et al.* (1999, ch.4). Recorded eclipses also reflect interest in the phenomenon, with Chinese record keeping stretching as far as 2043 BCE; see Kelley and Milone (2011, p.118) and Pankenier (2014, pp.2044, 2073–4). Other people also kept records: the Zapotec (Justeson, 2014, p.765) and Swedes (Ruggles, 2014, p.357).

[10] Online Appendix B explains classical methods used in eclipse prediction, distinguishing between forecasting the date of an eclipse—a relatively easy task—and its local visibility.

In summary, we suggest that, throughout history, people whose curiosity was excited by natural events more often exerted a higher mental effort to understand nature.[11] Albeit slowly, continued cognitive efforts quickened thinking, paving the way to increased human capital and facilitating future discoveries and technological change. Thus, in light of the unified growth theory, this accumulation of knowledge and, especially, the development of mental skills, can be seen as a latent variable that ultimately contributed to the (relative) take-off of pre-modern societies. A crucial aspect of this process is the harmless nature of solar eclipses.

To document and elucidate this relationship, we combine different datasets. Proceeding in stages, we first show the direct impact of total solar eclipses on economic development.[12] We then investigate the core mechanism associating solar eclipses and human capital. We further document a more advanced technology in places where total solar eclipses are more prevalent. Lastly, we close the loop, confirming that solar eclipses stimulate curiosity. To lend additional credence to our results, we assess the scope of religion as an alternative channel, finding no supporting evidence relating curiosity to religion. A set of placebo tests also confines the impact of solar eclipses to curiosity.

Solar eclipses have already entered economics. Severgnini and Boerner (2019) and Boerner *et al.* (2021) leveraged them as an instrument to study the adoption of mechanical clocks in medieval Europe, while Miao *et al.* (2021) related solar eclipses to social unrest in Imperial China. However, our interest lies in the cognitive challenge of rationalising the unknown and how devoting mental resources to this task may increase human capital, a topic not explored in the literature. In doing so, our paper relates to research explaining human capital accumulation in pre-modern times. There is ample evidence regarding religion (Becker and Woessmann, 2009; Waldinger, 2017; Valencia Caicedo, 2018), the early introduction of the printing press (Baten and van Zanden, 2008) and institutional factors (Galor *et al.*, 2009; Bobonis and Morrow, 2014). Nevertheless, we focus on a crucial prior stage: cognisance and human capital shaped early in history by natural events.

This paper is also related to the literature that analyses the effects of natural events on social organisation. Calne (2000) showed that natural disasters promote political revolutions, thereby affecting growth. Belloc *et al.* (2016) and Bentzen (2019) focused on earthquakes, finding a slowdown in the transition from autocracy to self-governance in medieval Italy and an increase in religiosity, respectively. In analysing the effects of solar eclipses, which are harmless phenomena, we depart from this literature. The distinction is important as we are interested in human curiosity: destructive events may divert the interest of thinkers away from explaining a phenomenon towards the more urgent task of reconstruction, or they may kill them. Similarly, physical capital losses could retard economic growth, eroding the need for more complex social organisation.

Lastly, this study also contributes to research on the long-run determinants of growth, with a novel focus on human capital and technology. From a theoretical perspective, Galor and Moav (2002) proposed that heritable human traits that afford a higher income provided an evolutionary advantage. This is the case, for instance, with innovativeness (Galor and Michalopoulos, 2012). Empirically, there is sound evidence relating human capital to growth in pre-modern times (Squicciarini and Voigtländer, 2015; Mokyr, 2018; Chen *et al.*, 2020). However, the deep-rooted

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[11] The outcomes of such efforts slowly accumulated as folklore captured people's understanding of the world. To help rationalise our findings, Online Appendix A.4 presents an extension to the model of Giuliano and Nunn (2021) featuring destructive and non-destructive events.

[12] Throughout the paper, we consider both total solar eclipses and annular solar eclipses. However, to facilitate reading, we refer to both as total solar eclipses.

determinants of human capital are still undocumented. With regard to technology adoption, Galor and Özak (2016) established time preference to be a root cause, and Özak (2018) further investigated incentives to innovate. The relative lack of evidence connecting technology and human capital to economic growth stands in stark contrast to the wealth of evidence documenting alternative deep-rooted factors of development, notably agriculture, geography and climate (Ashraf and Galor, 2011; 2013; Alsan, 2015; Dalgaard *et al.*, 2015; Cervellati *et al.*, 2019).[13] Our paper bridges the gap in the previous literature, connecting human capital and economic growth in the very long run.

The remainder of the paper is organised as follows. Section 1 presents the data we use to substantiate our working hypothesis and the empirical strategy. Benchmark results are reported in Section 2, and a series of robustness tests follow in Section 3. Section 4 offers some concluding remarks. The online appendices present the conceptual framework and the associated theoretical model, as well as additional results.

1. Data and Empirical Strategy

This paper combines multiple datasets to study the role of curiosity in economic development, and its driving factors. Although none of the data are perfect, we source information on the same topic from different origins to increase our confidence in the findings. The next subsections introduce the datasets we use, and Online Appendix Table C.13 presents summary statistics for the most relevant variables.

1.1. *Ethnic-Level Data*

The most prominent compilation regarding the living modes of ethnic groups is the Ethnographic Atlas of Murdock (1967). This work samples more than 1,000 ethnicities scattered around the globe and contains details about subsistence, marital practices and labour division. The observation date varies depending on data availability, though most groups are observed during the twentieth century. An important aspect that differentiates the Ethnographic Atlas (and related data) from other databases we employ is its cross-sectional nature. We rely on Fenske (2014a,b) to establish ethnic homeland boundaries.

From this corpus of information, we retrieve several indicators attesting to economic development, human capital and technology. Since we focus on pre-modern societies still in the Malthusian regime, the most appropriate measure of economic prosperity is *Population Density* (Ashraf and Galor, 2011). The Atlas captures this information using an increasing scale with eight levels denoting the mean size of local communities, which ranges from fewer than 50 people to cities with more than 50,000 inhabitants.[14] A second indicator that is used in the literature is *Settlement Patterns* (Michalopoulos and Papaioannou, 2013). Although it is not as widely used as population density, it aptly captures development by indicating the most prevalent type of settlement pattern for an ethnic group. This is also a categorical variable with eight levels, from nomadic groups to complex settlements of towns and associated hamlets.

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[13] Furthermore, cultural traits important for growth—time preference, individualism, cooperation and cultural transmission—are ultimately shaped by these same factors. See Vollrath (2011), Galor and Özak (2016), Litina (2016) and Giuliano and Nunn (2021).

[14] In general, population more or less doubles between consecutive levels, although the progression is faster in the top echelons.

Next, we introduce a set of more distant proxies of economic growth based on the observation of Diamond (1997) that, as societies become economically successful, organisational complexity tends to increase. Three variables conveying this information can be found in the Atlas. The first captures *jurisdictional hierarchy*, with higher values denoting a more complex social organisation: acephalous societies, petty chiefdoms, larger chiefdoms, states and large states. *Class stratification* also attests to social complexity. In this case, one can observe no differences between individuals, wealth distinctions, elite stratification, dual stratification and more complex class systems. The third and final variable documents *political integration* and offers information about relationships and integration with neighbouring communities. It comprises six categories, indicating no higher authority than a family head, autonomous local communities, peace groups encompassing multiple groups, minimal states, little states and states.[15]

Focusing on economic development, this paper proposes human capital and technology as mechanisms through which curiosity could materialise as growth. Verifying this possibility requires information on the former, and the Ethnographic Atlas provides a coarse indicator in this sense. Relying on the suggestion of Spitz (1978) and Zern (1979) that strategic behaviour is indicative of advanced cognitive skills, we create a dummy variable attesting to *strategy games* being played at the ethnic level, in opposition to the playing of games of luck or strength. We argue that among societies where strategic thinking is more relevant, the playing of such games teaches the youth how to operationalise it. To document technological progress, we take advantage of a set of variables investigating gendered specialisation in several activities, counting the number of *tasks* undertaken.[16] However, the set of surveyed activities changes from one group to another, and regressions must account for this fact.

We also leverage additional information linked to the original Ethnographic Atlas. The first is an accompanying dataset, the Standard Cross-Cultural Sample (Murdock and White, 1969), which expands the number of surveyed items, but drastically reduces the number of observations.[17] From this, we retrieve information on the advancement of *writing*, to approximate human capital. Similarly to the playing of games of strategy, we cast the original variable as a dummy indicator asserting the presence of written language. We also incorporate into our analysis a proxy for *technological sophistication* compiled by Eff and Maiti (2013). This is based on the notion that activities form a connected hierarchical network and, thus, activities in upper levels indicate a more advanced technology. For instance, dairy production is only possible once milking has been mastered, which in turn requires the herding of large animals. Thus, a society that only herds large animals scores lower than a society that produces dairy products.[18]

Lastly, Michalopoulos and Xue (2021a,b) expanded the Atlas by supplementing it with two types of information on folklore. The first indicates which of the major storytelling archetypes is featured in the local folklore. Among these, several categories are concerned with eclipses and possible causes, which we classify according to the degree of comprehension they indicate. Thus, folktales may show (a) no understanding, if no myths touch upon an archetype related to eclipses; (b) a naive understanding, if the folkloric explanation of eclipses is fanciful or (c) a good understanding, when myths indicate that eclipses result from an interaction between the Sun and

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[15] A seventh category refers to dependent societies, but we do not include it in our analysis.

[16] Tasks include pottery, metal working, weaving, etc.

[17] We use the data compiled by the D-PLACE project; see Kirby *et al.* (2016a,b).

[18] This variable takes values between 7.19 and 13.37. In our analysis, we apply the log transformation and treat it as continuous, although if we assumed it to be a categorical variable, we would obtain very similar results.

the Moon.[19] We expect more elaborate interpretations the more total solar eclipses are spotted by society. The second type of data Michalopoulos and Xue (2021a,b) compile is the frequency of certain concepts appearing in folktales.[20]

Based on the argument that curiosity begets thinking, we explore the relationship between solar eclipses and the number of *thinking*-related concepts appearing in the folklore. Secondly, we propose that a more careful observation of the skies reveals patterns that form the basis of calendars. Considering the computations involved in the creation of a regular calendar, we consider its existence as demonstrating human capital.[21] Thus, we track the occurrence of a *calendar* to gauge the importance of calendars and attest to their use.[22] A pivotal element in our argument is the hypothesis that eclipses provoke curiosity. Therefore, we focus on the occurrence of concepts related to the terms *eclipse* and *curious*. The first suggests that the event is relevant enough to be worth talking about it. In contrast, the second concept explores a direct consequence, that is, if eclipses spur curiosity, societies observing more eclipses should be more inquisitive, and this should be reflected in folktales.

The main analysis links eclipses and development. Despite the logical connection we propose, other factors may be in operation, including religion. Thus, it is possible that increasing numbers of unfamiliar events may lead to rising religiosity if individuals ascribe them to deities or, alternatively, establish a religious system to rationalise them. In this sense, Bentzen (2019) related more frequent earthquakes to religiosity, and although eclipses are harmless, both events are uncanny. However, the exact impact of religion on development is unclear: Squicciarini (2020) documented lower human capital among the most religious people, while Norenzayan (2013) argued that *high gods* facilitate cooperation. Thus, we focus on the possible relationship between solar eclipses and religion. First, we analyse high-god complexity using data from the Ethnographic Atlas, which categorises groups according to the following criteria: high gods do not exist; they exist, but are inactive in human affairs; they are active in human affairs, but do not support morality; or they are supportive of human morality. Additionally, we select three concepts linked to religion: *religion*, *religiosity* and *pray*.

Finally, we seek to demonstrate that our findings are not incidental. We therefore consider a set of concepts unrelated to economic development, human capital and technology: meteorological phenomena, namely, *Cloud* and *Lightning*,[23] the inanimate concepts of *Sand* and *Rock* and, thirdly, the colours *White* and *Purple*.[24]

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[19] Fanciful explanations typically attribute eclipses to monsters or animals eating the Sun or scaring it away. Interactions between the Sun and the Moon typically imply mating or fighting.

[20] More specifically, Michalopoulos and Xue (2021a,b) counted the number of archetypes that contain a certain word in their description. Descriptions take the form of a condensed story indicating the main protagonists and actions, for instance, 'A young woman turns into a monster and kills her brothers, avenging the death of her husband or lover'. To simplify the exposition, we refer to the number of tales about a given topic or about particular concepts related to this topic.

[21] For instance, the creation of a calendar necessitates the observation that there are 12 full moons in the time it takes the Earth to return to the same position in the sky. Additionally, a functioning calendar needs to compensate for the fact that the length of a day is not an integer multiple of the time it takes the Earth to orbit the Sun.

[22] Other concepts related to time, such as 'day' or 'hour' are commonplace and less cognitively demanding. However, we acknowledge that the frequency with which the word calendar appears in folklore may not be a first-order indicator of human capital.

[23] Regressions dealing with lightning control for its frequency; data from NASA LIS/OTD Science Team (2021). All maps are from the GADM (2019) project.

[24] We choose white and purple because they are unrelated to the skies. For instance, people interested in celestial phenomena should more often speak of blue or black, or refer to red sunsets. White is instead neutral, and purple is a colour that rarely appears in nature.

1.1.1. *Empirical strategy*

The Ethnographic Atlas and related works are cross sectional and demand an extensive set of controls to isolate from confounders the effect on curiosity we are investigating. For each of the different outcomes, we estimate the regression

$$Y_i = f(\alpha_1 E_i + \gamma_1 \mathbf{I}_i + \delta_i + \varepsilon_i), \tag{1}$$

where Y_i is an outcome observed for ethnic group i, E_i denotes the number of eclipses visible from within the homeland boundaries of ethnicity i and $\mathbf{I}_i$ is a vector of covariates. Regressions feature continent fixed effects captured by δ_i. Depending on the dependent variable, we estimate (1) using OLS, a probit model, or an ordered probit model and cluster the SEs at the regional level.[25]

The set of covariates I_i features geographic controls, including average temperature, precipitation and cloud coverage, factors that can affect the visibility of the phenomenon,[26] as well as distance to the coast and to waterways, to account for their effect in promoting state creation (Mann, 2012); distance to the closest volcano and fault line, to approximate exposure to destructive natural events;[27] terrestrial distance to Addis Ababa (Ashraf and Galor, 2013), which approximates genetic diversity and its impact on growth; terrain ruggedness and elevation, which proxy trust levels and isolation (Nunn and Puga, 2012); malaria prevalence, which has long-run implications for social and economic outcomes (Diamond, 1997); the potential caloric yield of the soil, which is associated with important cultural traits (Galor and Özak, 2015; 2016; Galor *et al*., 2016); absolute latitude and an indicator for the southern hemisphere[28] and indicators for the major habitat type and the major crop type at the ethnic-group level.[29] We also account for homeland size using decile indicators to tackle the mechanic relationship between area and the number of eclipses, and also because this may contribute to the development of state capacity.[30]

Lastly, we employ a Poisson model to estimate the number of tales about a certain topic in ethnic folklore. Here, we follow Michalopoulos and Xue (2021a,b) and expand the set of controls with the inclusion of the logarithm of the number of bibliographic elements consulted and the year of first publication, to which we add the (log) number of tales present in the folklore. These controls capture the fact that—for various reasons—some societies developed a more extensive set of stories or were more thoroughly surveyed by folklorists. For each topic, the original

[25] The Ethnographic Atlas considers 24 global regions: Asiatic Russia, Australia/New Zealand, the Caribbean, Central America, Central Asia, eastern Africa, eastern Asia, eastern Europe, European Russia, Melanesia, Micronesia, middle Africa, northern Africa, northern America, northern Europe, Polynesia, south America, southeast Asia, southern Africa, southern Asia, southern Europe, western Africa, western Asia and western Europe. Continents include Asia, Europe, Africa, North America, South America and Oceania.

[26] Theoretically, cloud coverage could impede eclipse visibility. However, from a practical perspective we note that during a total solar eclipse ambient luminosity decreases to about 3.5–4 lux, while a fully overcast sky during sunrise or sunset offers about 40 lux and luminosity during a typical overcast midday is about 1,000–2,000 lux. Human perception of light is logarithmic, and thus it is difficult to mistake a solar eclipse for the passage of clouds.

[27] Data on volcanoes are taken from Venzke (2013) (formatted by Henderson, 2018) and fault lines are from Ahlenius (2014). Information on rivers and shorelines is from Kelso and Patterson (2022). Ideally, we would control for nearby volcanic eruptions and earthquakes, but we do not have information on the settlement dates for different ethnic groups. However, because such events leave a lingering imprint, our variables can still capture the most remote events; see Chester and Duncan (2007) and Matchan *et al.* (2020).

[28] Solar eclipses are slightly more common in the northern hemisphere. We compute distance to Addis Ababa using Özak (2010).

[29] Other variables listed in the Ethnographic Atlas that are informative about modes of living could be impacted by human capital. In this regard, major crop type is relatively exogenous insofar as it depends on soil characteristics.

[30] We prefer to use area-decile fixed effects instead of area because the latter may be endogenous with respect to development. In particular, more developed ethnicities may have been able to capture larger homelands. The use of deciles diminishes this correlation and mitigates this concern. Online Appendix C presents an extensive set of robustness checks to minimise the concern that area is the driving force behind our results.

construction of the dataset considers a series of related words as synonyms.[31] In general, this strategy is sound, but in our particular case these additional words were unrelated to the outcome of interest. Thus, regressions control for synonyms to expunge any potential bias.[32]

1.2. *Panel Data*

Despite our extensive set of controls, the cross-sectional nature of the ethnographic data means that we cannot assuage all concerns related to omitted variables. Thus, we complement it with two data sources that can be arranged in a panel structure: the Seshat database and Ashraf and Galor (2011).

The Seshat database compiles details regarding the cultures of people who inhabited some selected regions, with a focus on military aspects.[33] Unfortunately, little information about the geographical boundaries of the different polities is provided; we have thus manually digitised several maps to attribute to each polity the eclipses visible from its territory in a given time period.

Miranda and Freeman (2020) transformed the original dataset and provided an unbalanced panel structure in which observations are at the polity-century level, interpolating the data as necessary. However, the original polity indicators only allow for a very short time dimension, which, coupled with the steady pace of social transformation, severely limits identification. To rectify this problem, we determined each polity's most-removed predecessor and used it as a fixed effect. For instance, the short-lived Kidarite Kingdom (lasting two centuries) is traced back to the Parthian Empire.[34] The inclusion of polity and time fixed effects subsumes the time-invariant characteristics of polities and corrects for the natural evolution of social change.[35] Some variables included in the Seshat database have an exact counterpart in the Ethnographic Atlas, and we use these in a robustness exercise. These include information on *Population Density*, *Administrative Levels*, *Jurisdictional Hierarchy* and *Writing*. However, due to interpolation, these variables are continuous rather than categorical. In addition, the Seshat database offers a series of additional variables that enable both human capital and technology to be examined from different perspectives. In particular, regarding human capital indicators, it is possible to ascertain the development of a *Calendar* and the different *Text* typologies in use. The first variable is directly connected to the previously outlined argument relating solar eclipses and time measurement. The second qualifies the information about writing, indicating whether texts deal only with worldly subjects or reflect strong imaginative capabilities.[36] Lastly, and owing to the intimate relationship between eclipses and *Geometry*, we include the development of the latter

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[31] We illustrate the issue with an example. Consider the number of tales related to the concept *White*, a variable we use in Section 3. During the original construction of this variable, all tales that touch on this topic are labelled as referring to white. However, because using one word severely limits the number of matches, the original database expands this by using the corpus of words related to white that appears in ConceptNet. For this particular case, one such word is 'rice'. To clean the regressions of this double accounting, we add as an additional control the number of tales about rice.

[32] There are two exceptions to this rule, namely, eclipse-related and pray-related terms, because ConceptNet essentially proposes no alternatives. Thus, when the outcome of interest is *White*, we further control for mentions of *Rice*. Similarly, the analysis of *Rock*, controls for *Roll*; *Purple* controls for *Blue*; *Cloud* controls for *Rain*; *Thinking* controls for *Dream*; *Calendar* controls for *Date*; *Lightning* controls for *Whistle*, *Religious* controls for *Church*; *Religion* controls for *Believe*.

[33] The Seshat project focuses on ten regions of the world. For each, three subregions were selected according to settlement time: early, intermediate or late.

[34] New polities that emerge as the result of an invasion are treated as originating their own dynasty.

[35] We note that, in general, polity fixed effects do not account for the polity area, as this evolves over time.

[36] Before interpolation, the possible text types are lists, calendars, sacred texts, religious literature, practical literature, history, philosophy, scientific literature and fiction.

as an additional measure of human capital. Technological indicators include the type of *Money* in use and a categorisation of major *Infrastructure*.[37]

Overall, the Seshat database complements the Ethnographic Atlas, offering valuable information for studying human social evolution. However, the results when using the Seshat database should be interpreted with caution and used as a robustness exercise to re-validate the findings from the Ethnographic Atlas. Several factors limit the identification of causal effects in the Seshat data, including the interpolation of the original data, the slow pace of social change and the possibility that fixed effects may absorb a large part of the variation therein. Thus, results from the Seshat analysis should be interpreted as a robustness exercise to complement the findings from the Ethnographic Atlas, rather than as definitive evidence.

To better validate our findings, we complement our analysis using other sources that also have a panel dimension. First, Ashraf and Galor (2011) provided several direct measures of technological level for the years zero and 1000 in areas corresponding to today's national borders. These measures focus on various aspects and include two technological aggregates—a global one and a non-agricultural one—as well as indicators of technological sophistication in communications, industry and transportation. We transform the data to take advantage of their underlying panel structure. This minimises problems stemming from omitted variables and unobservable intrinsic characteristics. Second, Section 1.3 introduces individual-level data, with a large host of country and century fixed effects.

1.2.1. *Empirical strategy*

Our empirical strategy for these two data sources accounts for their panel structure by including fixed effects at the relevant levels. Overall, we implement an OLS model in the Seshat analysis, while technology levels follow a censored linear model to account for their relatively narrow ranges and the data's clearly defined limits.

The main specification using the Seshat database includes a set of controls similar to that used with the Ethnographic Atlas, comprising potential calories, elevation, ruggedness, malaria, cloud coverage, lightning intensity and area-decile fixed effects.[38] To these, we add fixed effects capturing political continuity or change between periods, the relationship with supra-national entities and the polity's peak century. Furthermore, because the Seshat database presents data every century, we can also include controls for volcanic *Eruptions*.[39] Additionally, regressions using the Seshat data need to account for the dynamic nature of the panel. Thus, we follow Turchin (2018) and introduce one-period lagged values of each outcome we estimate as a regressor. These controls consider the possibility of (delayed) interrelations between the different proxies of development—for instance, that mastering geometrical measurements facilitates the subsequent creation of a calendar. Moreover, regressions consider potential spillover effects from neighbouring polities by including a distance-weighted average (with an exponential decay) of contemporaneous values for all outcomes. The econometric specification is

$$Y_{i,t} = \beta^E E_{i,t} + \beta^V V_{i,t} + \mathbf{X}_{i,t}\Gamma + \sum_{y \neq Y \in \mathcal{Y}} \beta^y y_{i,t-1} + \sum_{y \in \mathcal{Y}} \gamma^y y_{-i,t} + \delta_i + \kappa_t + \epsilon_{i,t}.$$

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[37] The different types of money the Seshat database considers includes articles (for a basic barter economy), tokens, precious metals, foreign and indigenous coins, paper currency, debt and credit and store of wealth. Infrastructure includes roads, bridges, canals, ports and fuelling stations.

[38] Terrain elevation and ruggedness are from Danielson and Gesch (2011).

[39] We do not consider distance to rivers and to the coast as controls because polities typically extend to the coast and encompass large rivers. Similarly, we do not consider the impact of time-varying controls such as temperature or precipitation, due to a lack of data.

As before, $Y_{i,t}$ denotes the outcome of interest we observe for polity i at time t, while $\mathcal{Y}$ represents the set of outcomes; $E_{i,t}$ and $V_{i,t}$ denote the numbers of total solar eclipses and volcano eruptions that occurred within polity i at time t and $\mathbf{X}_{i,t}$ represents the controls discussed above; δ_i and κ_t are polity and time fixed effects, the term $\sum_{y \in \mathcal{Y}} \gamma^y y_{-i,t}$ indicates the distance-weighted neighbour's externality and $\epsilon_{i,t}$ is the error term. For the Seshat data, we compute two types of SE: clustered at the polity level and considering time and spatial correlation (1,000 years and 5,000 km, respectively).[40]

A similar specification emerges in the case of technological data. However, because only two periods of time are available, the dynamic part of the estimation is not necessary. Hence, we estimate a very simple censored model with country and time fixed effects, namely,

$$Y_{i,t} = f(\beta^E E_{i,t} + \beta^V V_{i,t} + \delta_i + \kappa_t + \epsilon_{i,t}).$$

1.3. *Individual Data*

The use of aggregate data to approximate curiosity may be perceived as problematic insofar as it does not document individuals' reactions to inexplicable events. Thus, we collected individual-level data from the Wikidata project to infer whether a person becomes more interested in knowing about the world following an eclipse.[41] Wikidata is a free and open knowledge base that contains structured data on various topics, including people, places, events and media. It is derived from selected sections of Wikipedia articles and other sources and is regularly updated. To collect the data for our study, we used a query on the Wikidata SPARQL endpoint, which is a standardised query language for accessing and manipulating data stored in Wikidata. Our query focused on individuals born between 1600 BCE and 1800 CE who had information available on their birth date, birthplace and occupation. We limited the time frame to 1600 BCE because all variables were only available for a small number of individuals born before that time.[42] The resulting

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[40] Although the temporal and spatial autocorrelation values may appear large, the entire genealogy of a polity spans more than 800 years, on average. Similarly, multiple polities extended over very large regions, covering well above millions of square kilometres.

[41] Wikidata Contributors (2019).

[42] To collect these data, we queried the Wikidata SPARQL endpoint at https://query.wikidata.org/ using

```
SELECT DISTINCT
  ?person
  ?birthdate
  ?lat ?lon
  ?occupation
  WHERE {
  ?person wdt:P31 wd:Q5;
  wdt:P19 [
    p:P625/psv:P625
    [ wikibase:geoLatitude ?lat;
      wikibase:geoLongitude ?lon ]
    ];
  ?person wdt:P106 ?occupation .
  VALUES ?precision { 9 10 11 }
  ?person p:P569/psv:P569 [
    wikibase:timePrecision ?precision;
    wikibase:timeValue ?birthdate ].
  FILTER ( YEAR(?birthdate) = 1500. )
  }
```

The previous code snippet retrieves the information for individuals born in 1500, and we iterate over birth years. We note that the information available in Wikidata is likely to change between editions, thus preventing the retrieval of the exact same data.

database lists all individuals for whom no data are missing and includes, for each person, their birth date, birthplace coordinates and all occupations in which they were active. To provide an example of how we used individual-level data from Wikidata in our study, we introduce Johannes Browallius, a person born in Sweden in 1707 who is included in our database. As Wikidata is not commonly used in economics research, using a specific example can help illustrate the process and results of our study in more detail.

Using the data from Wikidata, we classify individuals as being active in a *Scientific* or *Religious* occupation and relate occupation choices to the observation of a total solar eclipse during childhood. First, because individuals tend to be active in multiple fields, our classification scheme considers a person active in science or religion if *at least one* of the listed occupations can be classified as such. To do this, we first identified the categories within the Wikidata's ontology that correspond to scientific and religious occupations. For example, the category for scientific occupations include geologists, physicists, zoologists and astronomers, while the category for religious occupations features monks, deacons, rabbis and imams. Next, for each individual, we examined their listed occupations and determined whether any of them fell within the scientific or religious categories. If at least one of their occupations was classified as *Scientific* or *Religious*, we considered the individual to be active in that field. Following with Johannes Browallius, he is listed as having worked as physicist, biologist, priest, theologian, botanist, university teacher and translator. In the final database, we classify him as having occupations in both, i.e., in science and religion.

According to our hypothesis that inexplicable events, such as solar eclipses, can increase curiosity, we expected that individuals who were exposed to solar eclipses during childhood would be more likely to pursue careers in science. This is because scientific occupations involve inquiring about the workings of the world and require a curious mindset. In contrast, religious occupations are not embedded with this inquisitorial dimension, and experiencing an eclipse should not alter the probability with which these occupations are entered. Thus, for each individual, we create a dummy variable stating whether or not a total solar eclipse was visible from her birthplace city between the ages of 5 and 15. To determine local eclipse visibility, we compared the paths of totality of eclipses to the coordinates of each individual's birthplace and only considered the eclipses that occurred during the relevant dates for each individual. This procedure assumes that individuals did not migrate far from their place of birth, as the visibility of solar eclipses extends about 100 km to the north and south of the path of totality. Johannes Browallius was born in Västrås, Sweden, which was within the path of totality of the total solar eclipse that took place on May 3, 1715, when he was eight years old.

In addition to creating a dummy variable for solar eclipses, we also created a similar variable for volcanic eruptions to gather information on another potential source of curiosity. Because cities are often located some distance from volcanoes, we accounted for the fact that volcanic effects such as ash falls and smoke columns can be observed up to 100 km away. Therefore, we considered an individual to have been exposed to a volcanic eruption if their birthplace city was within 100 km of a volcano that experienced an eruption during their childhood.

1.3.1. *Empirical strategy*

We model occupation as a linear probability model:

$$O_{i,j(i),t(i)} = \beta + \beta^E E_{i,j(i),t(i)} + \beta^V V_{i,j(i),t(i)} + \gamma_{j(i)} + \kappa_{t(i)} + \epsilon_{i,j(i),t(i)}. \tag{2}$$

Here $O_{i,j(i),t(i)}$ is a dummy variable indicating that individual i born in country $j(i)$ during century $t(i)$ entered a scientific (or religious) occupation. As before, $E_{I,j(i),t(i)}$ and $V_{i,j(i),t(i)}$ denote eclipses and volcanic eruptions, respectively. To isolate the effect operating through curiosity stemming from global changes regarding the importance of science and local factors influencing the pursuit of discoveries, regressions include time $t(i)$ and location (at the country level) $j(i)$ fixed effects. We cluster SEs at the country-century level. However, the sample size greatly varies over time, with only a handful of observations for the first periods and many more as time advances. If eclipses became less important in determining curiosity in more recent times, unweighted regressions would disproportionately over-represent the more recent cohorts and bias the results towards the current effect of eclipses on curiosity. Thus, we estimate a weighted version of (2) to circumvent this problem. In doing so, we attribute to each individual an equal probability of being in the sample, regardless of their century of birth. We present the results with two alternative sets of weights. The first is data driven and attributes to individual i born in century $t(i)$ a sampling probability equal to the inverse of the percentage that individuals born in century $t(i)$ have in the sample. The second approach considers estimates of centennial total world population to construct the weights.

1.4. *Eclipses*

The most comprehensive eclipse catalogue is the 'Five millennium catalog of solar eclipses: –1999 to +3000' of Espenak and Meeus (2006). This almanac provides the ephemeris corresponding to all eclipses occurring between –1999 and +3000, indicating their key attributes. Jubier (2019b) used this reference to elaborate detailed maps representing the path of totality of each eclipse— that is, the set of locations from which the Sun is completely overshadowed by the Moon.[43] A path of totality covers a narrow strip of land no more than 160 km wide that moves eastward at about 3600 km/h, resulting in solar eclipses being visible from many longitudes, but only from a restricted number of latitudes. We limit the time coverage to the interval of 2000 BCE–1500 CE.[44] Figure B.2 in Online Appendix B depicts some selected paths of totality, illustrating that, for a given eclipse, local visibility varies.

Our data show that a total of 5,635 total and annular solar eclipses occurred in the 3,500 years considered, with an average of 1.61 per year. However, it is necessary to consider that a solar eclipse is only visible from certain points on the globe, and, therefore, the frequency with which they occur at a given location decreases rapidly as precision increases. Thus, if we consider 100×100 km^2 cells,[45] solar eclipse frequency is reduced to only 1.17 solar eclipses per century. At the city level, Steel (2001, p.31) reported an average inter-eclipse span of 410 years. Considering these characteristics, at a given location, total solar eclipses are an almost random variable, albeit they are slightly more likely in the northern hemisphere. To construct our main variable of interest— the number of total solar eclipses observable from an area—we intersect the relevant boundaries with paths of totality. In the cases for which a time dimension is relevant (for instance, people listed in Wikidata), we restrict the eclipses to those occurring during the time frame we consider. Figure 1 indicates the number of eclipses visible from within ethnic homeland boundaries.[46]

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[43] Jubier (2019a) provided equivalent data for lunar eclipses.

[44] Although it is possible to back-predict more distant eclipses, the uncertainty regarding the Earth's rotational speed makes it impossible to accurately determine local visibility.

[45] See Online Appendix Figure C.7.

[46] Plotting the same information using Seshat boundaries is more challenging because they change across time and overlap.
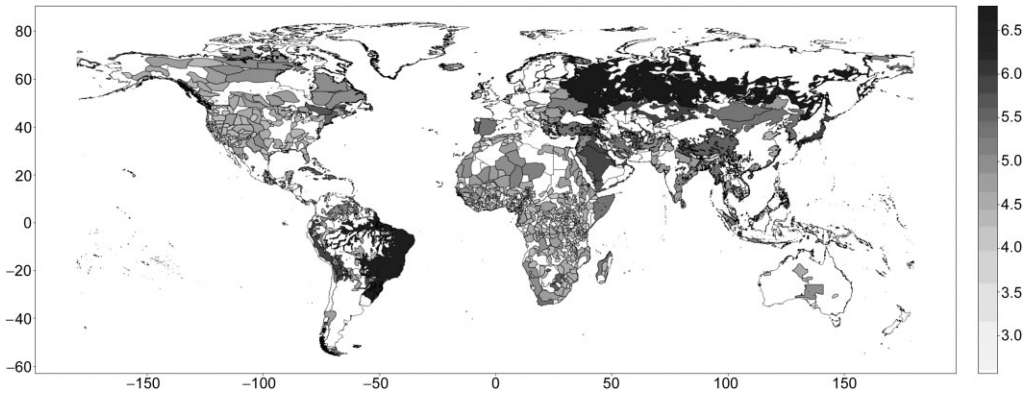
Fig. 1. *(Log) Number of Total Solar Eclipses at the Ethnic-Group Level.*

2. Results

This section analyses the empirical relationship between total solar eclipses and the proxies of development, human capital and technology discussed above. For convenience, we group the results according to the type of outcome. Thus, we first discuss the results pertaining to economic development and then assess the plausibility of human capital and technology as driving mechanisms. We finish by presenting the results concerning curiosity.

2.1. *Economic Development*

Table 1 combines results using the Ethnographic Atlas and Seshat database to portray a coherent assessment of the relationship between the number of total solar eclipses (measured in logarithms) and the various proxies of economic development. Because the Atlas reports these variables as categorical information, we estimate an ordered probit model. Columns (1)–(3) and (4)–(6) focus on *Population Density* and *Settlement Patterns*, using information from the Ethnographic Atlas. The main difference between specifications is the addition of covariates. Thus, columns (1) and (4) present the raw correlation between variables, partialling out only the effect of continents. Columns (2) and (5) introduce a rich set of geographical confounders and, finally, columns (3) and (6) incorporate information about the major crop types cultivated. The econometric specification follows (1).

In contrast, columns (7)–(8) use data from the Seshat database and exploit its underlying panel structure. In these columns, the outcomes are continuous and we estimate the effect of solar eclipses on these using OLS. Column (7) takes polity identifiers directly from the Seshat database, while column (8) uses the most-removed predecessor of a polity.

The coefficient relating solar eclipses to population density in column (1) is positive, but not significant. However, after correcting for geographic determinants of economic growth in column (2), it becomes larger in magnitude and highly significant. Furthermore, including arguably exogenous ethnic-level indicators in column (3) only reinforces the previous findings, increasing the coefficient to 0.68 and reducing its SE.

To gauge the impact of solar eclipses on development, we turn to their average marginal effects, noting that magnitudes are both statistically and economically relevant. More specifically, ethnic

Table 1. *Solar Eclipses and Economic Development.*

| | Ethnographic Atlas | | | | | | Seshat Database | |
| | Population Density | | | Settlement Patterns | | | Population Density | |
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Solar eclipse (log)	0.217	0.582	0.682	−0.292	0.576	0.720	0.037	0.116
	(0.147)	(0.235)**	(0.206)***	(0.166)*	(0.142)***	(0.124)***	(0.077)	(0.105)
							[0.071]	[0.096]
Distance to volcano (log-km)		−0.081	−0.073		−0.041	−0.051		
		(0.058)	(0.056)		(0.057)	(0.058)		
Distance to fault line (log-km)		0.120	0.121		−0.056	−0.081		
		(0.034)***	(0.038)***		(0.024)**	(0.040)**		
Volcanic eruptions (log)							0.022	0.021
							(0.014)	(0.012)*
							[0.011]*	[0.010]**
Fixed effects	Continent	Continent	Continent	Continent	Continent	Continent	Polity	Polity
Time fixed effects	No	No	No	No	No	No	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes	No	No
Controls Seshat	No	No	No	No	No	No	Yes	Yes
R^2/pseudo-R^2	0.074	0.157	0.196	0.067	0.148	0.195	0.994	0.911
Observations	568	466	466	1,133	932	932	233	448

Notes: This table presents the results of ordered probit regressions relating the impact of eclipses on economic development at the ethnic-group level in columns (1)–(6). Columns (1)–(3) report the findings for *Population Density*, while columns (3)–(6) focus on *Settlement Patterns*. These regressions feature robust SEs clustered at the regional level. Columns (7)–(8) estimate the effect of solar eclipses on *Population Density* using the Seshat data and OLS. Column (7) uses Seshat database polity identifiers, and column (8) employs the most-removed predecessor polity identifier. These regressions feature robust SEs clustered at the polity level in brackets and accounting for time and spatial autocorrelation (1,000 years and 5,000 km) in square brackets. Continent fixed effects: indicators for Asia, Europe, Africa, North America, South America and Oceania. Geographic controls: average temperature, precipitation and cloud coverage; distance to the coast, to waterways, to the closest volcano and fault line and terrestrial distance to Addis Ababa; terrain ruggedness and elevation; malaria prevalence; soil potential caloric yield; absolute latitude; south, major habitat type and homeland size decile indicators. Columns using the Seshat data employ the same covariates except for temperature, precipitation and major habitat type (absolute latitude and south are collinear with the fixed effects). Ethnic controls: major-crop-type indicator. Controls Seshat: past and distance-weighted values for population density, administrative levels, hierarchical complexity, writing and text types, geometrical measurements, the use of calendars and money and infrastructure types, polity's continuity dummy, relationship with supra-national entities and peak century.
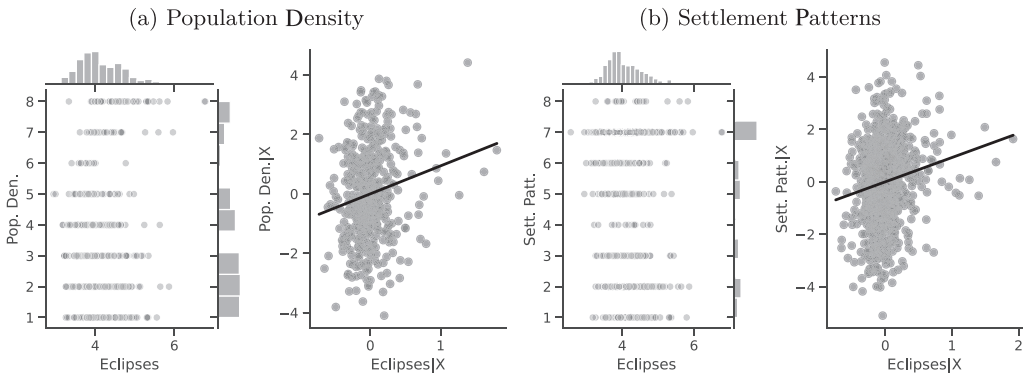* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

(a) Population Density   (b) Settlement Patterns

Fig. 2. *Solar Eclipses and Economic Development.*
Notes: The left panel of (a) displays the raw correlation between the number of solar eclipses (in logarithms) and *Population Density*. The right panel illustrates the remaining correlation once we control for geographical and ethnic factors. The figure is a linear approximation of the underlying ordered probit regression in Table 1. Panel (b) repeats the same procedure for *Settlement Patterns.*

groups are more likely to have a headcount above 200 individuals as the number of eclipses increases. The effect is especially strong for the highest level of population density: indigenous cities of more than 50,000 people show an increase of 7.92% in population density when the number of total solar eclipses increases by one percentage point. In the sample, only 10.52% of societies are in that category.[47] An alternative method to assess the size of the effects consists in comparing the most likely level of population density for ethnic groups while arbitrarily fixing the number of eclipses. For instance, when fixing these at the level of 10th centile, the predicted population density is at its lowest level. However, raising the number of solar eclipses to the level corresponding to the 90th centile drastically changes the prediction: now, population density is likely to correspond to the top category.[48]

Figure 2(a) graphically represents the results for solar eclipses.[49] The left panel displays the raw correlation between variables (with no controls), while the right panel corresponds to column (3). In general, the few outliers do not seem to be driving the regression.

Employing *Settlement Patterns* to approximate economic development confirms the previous results, despite the correlation between variables being only 0.54. As before, the sequential addition of covariates between columns (3) and (6) boosts the coefficient associated with solar eclipses, while decreasing its SE, which displays a value of 0.72 under the most comprehensive specification (also see Figure 2(b)). However, the corresponding marginal effects are less pronounced than before. For instance, observing complex settlements is 3.73% more likely when the number of solar eclipses increases by one percentage point, a significant increase from the sample average of 2.36%. Similarly, the category immediately below becomes 17.17 percentage points more probable,[50] while the other categories show a decrease in probability. Smaller effects

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[47] For the other levels of population density, the marginal increase hovers at around half the sample average.

[48] This exercise involves computing the average probability of observing an ethnic group at some level of the population density distribution. The computation uses the actual value for each covariate, except for the number of eclipses, which we artificially change. Thus, impossible situations are created as we assign low levels of solar eclipses to ethnic groups occupying large areas. The reverse is also true.

[49] This figure corresponds to an OLS version of the regression.

[50] Compared to the sample mean of 46.03, this increase is smaller.

are also observed when we move ethnic groups along the distribution of solar eclipses. In this case, shifting from the 10th to the 90th centile does not affect the most likely category, which remains constant at level 7 out of eight. Instead, we note a dramatic increase in the associated probability, from around 0.36 to about 0.53.

Finally, columns (7) and (8) refer to the relationship between the number of total solar eclipses and population density in the Seshat data. However, in this instance we consider *Population Density* as a continuous variable. Overall, we obtain results broadly compatible with those discussed above, although the coefficient associated with solar eclipses is never significant. In this case, we estimate an elasticity of 0.116 between the variables. Comparing columns (7) and (8), we note that the inclusion of a more complete set of polity fixed effects certainly improves the estimation, in part by allowing for a larger sample, but also because the entire history of polities is better represented. Unfortunately, due to the different scales employed in columns (1)–(6), it is not possible to compare the estimations across specifications. Overall, Table 1 provides empirical evidence of a relationship between solar eclipses and economic development, lending credence to our hypothesis.

In Table 2, we turn our attention to a set of alternative proxies of economic growth, which are all based on Diamond (1997). Columns (1)–(3) employ data from the Ethnographic Atlas, while columns (4)–(7) refer to the Seshat database. In the interest of brevity, the former columns only display the results when the largest set of covariates—including geographic and ethnic controls—is employed. Column (1) approximates growth using *Jurisdictional Hierarchy*, column (2) focuses on different *Class Stratification* schemes and column (3) measures *Political Integration* as the dependent variable. In all cases, regressions follow (1) and use an ordered probit model with SEs clustered at the region level. Equivalent indicators exist in the Seshat database for two variables: *Administrative Levels* (akin to political integration) and *Jurisdictional Hierarchy*. Columns (4)–(5) and (6)–(7) respectively present these with Seshat database polity indicators in even-numbered columns and most-removed polity identifiers in the others.[51]

In general, the specifications in Table 2 confirm our previous results and illustrate an even stronger relationship between curiosity and development. The associated marginal effects reveal an overall significant increase in the probability that an ethnic group belongs to the top category, with values ranging between 1.93 and 7.53. Lastly, and as before, we observe limited changes when comparing the most likely level as we increase the number of solar eclipses from the 10th to the 90th centile: jurisdictional hierarchy is likely to advance from an acephalous society to a petty chiefdom, while class stratification remains at its lowest level and political integration at the second lowest. Yet, for these, the probability of belonging to these rather lower echelons decreases significantly, from 0.58 to 0.34 and from 0.46 to 0.33, respectively.

Results using the Seshat data provide a very similar conclusion, namely, a positive and significant association between curiosity and development. This can be seen in columns (5) and (7), where the coefficient associated with solar eclipses is significant and positive, while the corresponding one in columns (4) and (6) is only positive. As discussed above, this may be the result of poorly designed polity indicators in the Seshat database.[52]

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[51] We present added-variable plots for all regressions featuring the Ethnographic Atlas and the folklore data in Online Appendix Figures C.8 and C.9. Additionally, Online Appendix Figures C.10–C.14 repeat the exercise, dropping the 10, 25, 50, 100 and 150 ethnic groups with the lowest number of solar eclipses, with the results indicating that these are not driving the results. Finally, Online Appendix Figure C.15 presents the results of binned OLS regressions relating the probability of having a low number of solar eclipses against ethnic homeland area (in logarithms).

[52] For the sake of brevity, subsequent tables referring to the Seshat database only include the most-removed predecessor polity fixed effects.

Table 2. *Solar Eclipses and Economic Development—Additional Development Proxies.*

| | Ethnographic Atlas | | | Seshat Database | | | |
| | Jurisdictional Hierarchy | Class Stratification | Political Integration | Administrative Levels | | Jurisdictional Hierarchy | |
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Solar eclipse (log)	0.580	0.629	0.514	0.006	0.026	0.010	0.028
	(0.147)***	(0.210)***	(0.228)**	(0.012)	(0.019)	(0.021)	(0.012)**
				[0.008]	[0.012]**	[0.015]	[0.007]***
Distance to volcano (log-km)	0.021	−0.131	0.165				
	(0.053)	(0.048)***	(0.060)***				
Distance to fault line (log-km)	−0.004	0.001	−0.062				
	(0.048)	(0.048)	(0.082)				
Volcanic eruptions (log)				0.003	−0.001	0.002	0.001
				(0.003)	(0.002)	(0.002)	(0.002)
				[0.002]*	[0.002]	[0.002]	[0.001]
Fixed effects	Continent	Continent	Continent	Polity	Polity	Polity	Polity
Time fixed effects	No	No	No	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	No	No	No	No
Controls Seshat	No	No	No	Yes	Yes	Yes	Yes
R^2/pseudo-R^2	0.234	0.151	0.227	1.000	0.933	0.996	0.939
Observations	933	846	265	79	448	117	448

Notes: This table presents the results of ordered probit regressions relating the impact of eclipses on economic development, approximated by social complexity, at the ethnic-group level in columns (1)–(3) and at the polity level in columns (4)–(7). Column (1) reports the findings for *Jurisdictional Hierarchy*, column (2) focuses on *Class Stratification* and column (3) on *Political Integration*. These regressions feature robust SEs clustered at the regional level. Columns (4)–(7) are estimated using an OLS model whereby the outcome of interest is *Administrative Levels* in columns (4)–(5) and *Jurisdictional Hierarchy* in columns (6)–(7). Columns (4) and (6) use Seshat database polity identifiers and columns (5) and (7) employ the most-removed predecessor polity identifier. These regressions feature robust SEs clustered at the polity level in brackets and accounting for time and spatial autocorrelation (1,000 years and 5,000 km) in square brackets. Continent fixed effects: indicators for Asia, Europe, Africa, North America, South America and Oceania. Geographic controls: average temperature, precipitation and cloud coverage; distance to the coast, to waterways, to the closest volcano and fault line and terrestrial distance to Addis Ababa; terrain ruggedness and elevation; malaria prevalence; soil potential caloric yield; absolute latitude; south; major habitat type and homeland size decile indicators. Columns using the Seshat data employ the same covariates except for temperature, precipitation and major habitat type (absolute latitude and south are collinear with the fixed effects). Ethnic controls: major-crop-type indicator. Controls Seshat: past and distance-weighted values for population density, administrative levels, hierarchical complexity, writing and text types, geometrical measurements, the use of calendars and money and infrastructure types, polity's continuity dummy, relationship with supra-national entities and peak century.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Lastly, in contrast to the strong association between solar eclipses and development, alternative triggers of curiosity provide us with conflicting results: distance to fault lines and volcanoes often change the sign of the result, which also tends to not be significant. The destruction inflicted by these is one possible explanation, as it imposes an economic burden on societies experiencing them that slows down the process of development.[53]

2.2. *Human Capital and Technology*

The main hypothesis of this work links curiosity and economic development through human capital and technological improvements. That is, as individuals exert a cognitive effort to understand solar eclipses, they become better at thinking and gain human capital, which allows for better technology. Furthermore, interest in eclipses can itself propel the development of new technologies. Tables 3 and 4 present the results of our analysis of these aspects, focusing on the nexus between solar eclipses and human capital and solar eclipses and technology, respectively.

Table 3 combines three sources of information to portray a coherent relationship between solar eclipses and human capital. Columns (1) and (2) approximate human capital through the playing of *Strategy Games* and the development of *Writing* using information from the Ethnographic Atlas.[54] For these outcomes, we estimate an econometric model based on (1) using OLS, with the full set of controls discussed above and clustering SEs at the region level.[55] Columns (3)–(5) incorporate information derived from folktales (Michalopoulos and Xue, 2021a,b). To assess human capital levels, column (3) focuses on *Eclipse Explanations* and column (4) on the frequency with which concepts related to *Calendars* appear in tales. Column (5) provides a more straightforward approach, relating solar eclipses to the frequency with which words related to *Thinking* appear in myths.[56] We estimate columns (3)–(5) using a Poisson model.[57] These regressions follow the same principles outlined above regarding controls and clustering, with the additional controls discussed previously.[58] Lastly, columns (6)–(9) use data from the Seshat database and focus on the development of *Writing*, *Text* typologies, *Calendars* and *Geometrical Measurements*, respectively. Throughout these specifications, we only employ the most-removed predecessor polity fixed effects and present SEs clustered at the century level and accounting for temporal and spatial autocorrelation.

The results are by and large coherent with our hypothesis and indicate a positive relationship between eclipses and human capital. More specifically, except for column (6), in all specifications the coefficient associated with the number of solar eclipses is positive and significant. Thus, a 1% increase in the number of solar eclipses increases the probability of an ethnic group playing games of strategy or having developed a writing system by 0.23 and 0.40, respectively. Compared

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[53] However, some specifications imply a positive effect of destructive events on growth—for instance, in column (2) of Table 2. This result is compatible with the mechanism we propose insofar as more frequent volcanic eruptions or earthquakes might erode economic progress, while sporadic ones operate by increasing curiosity.

[54] Written languages are coded in the Standard Cross-Cultural Sample, which explains the sample size reduction seen in column (2).

[55] The choice of OLS over a probit model does not impact the results. However, due to data limitations, it is not possible to estimate a probit model with writing as the dependent variable.

[56] Michalopoulos and Xue (2021a,b) provided additional keywords related to thinking: think and rethink. The latter is connected to the idea that repeated exposure to events permits refining previous hypotheses, and results using this as the dependent variable are very similar to those we discuss in the paper. This is not the case for the former, however.

[57] A negative binomial model provides similar results. However, because convergence issues arise, for consistency, we prefer to use a Poisson model throughout.

[58] See Section 1.1 and footnote 32.

Table 3. Solar Eclipses and Human Capital.

	Ethnographic Atlas		Folklore			Seshat Database			
	Strategy Games (1)	Writing (2)	Eclipse Explanation (3)	Calendar Related (4)	Thinking Related (5)	Writing (6)	Texts (7)	Calendar (8)	Geometrical Measurements (9)
Solar eclipse (log)	0.228	0.400	0.330	0.185	0.070	0.010	0.010	0.016	0.018
	(0.062)***	(0.134)***	(0.113)***	(0.085)**	(0.038)*	(0.018)	(0.008)	(0.006)**	(0.010)*
						[0.015]	[0.008]	[0.006]***	[0.009]**
Distance to volcano (log-km)	−0.007	0.028	−0.126	−0.065	0.004				
	(0.023)	(0.039)	(0.076)*	(0.023)***	(0.018)				
Distance to fault line (log-km)	0.004	0.006	0.206	0.009	0.043				
	(0.015)	(0.051)	(0.075)***	(0.026)	(0.014)***				
Volcanic eruptions (log)						0.000	−0.000	−0.001	−0.002
						(0.001)	(0.001)	(0.001)	(0.001)
						[0.001]	[0.001]	[0.001]	[0.001]**
Fixed effects	Continent	Continent	Continent	Continent	Continent	Polity	Polity	Polity	Polity
Time fixed effects	No	No	No	No	No	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Controls Seshat	No	No	No	No	No	Yes	Yes	Yes	Yes
R^2/pseudo-R^2	0.665	0.524	0.095	0.214	0.415	0.927	0.958	0.965	0.948
Observations	346	122	918	918	918	448	448	448	448

Notes: This table presents the results of regressions linking the impact of eclipses on human capital at the ethnic-group level in columns (1)–(5) and at the polity level in columns (6)–(9). Columns (1) reports the findings for the playing of *Games of strategy* while column (2) focuses on *Writing*. Column (3) relates solar eclipses to *Eclipse Explanation* as recorded in folklore. Columns (4) and (5) focus on the prevalence of words related to the concepts of *Calendar* and *Think*. These regressions feature robust SEs clustered at the regional level. Column (6) re-estimates the impact of solar eclipses on the development of *Writing* using data from the Seshat database, column (7) focuses on *Text* typologies and column (8) reviews their effect on the development and use of a *Calendar*, while column (9) focuses on *Geometrical Measurements*. Columns (6)–(9) use the most-removed predecessor polity identifier. Columns (1), (2) and (6)–(9) are estimated by OLS, column (3) follows an ordered probit model and columns (4) and (5) a Poisson model. Columns using the folklore data include an additional regressor, as indicated in footnote 32. These regressions feature robust SEs clustered at the polity level in brackets and accounting for time and spatial autocorrelation (1,000 years and 5,000 km) in square brackets. Continent fixed effects: indicators for Asia, Europe, Africa, North America, South America and Oceania. Geographic controls: average temperature, precipitation and cloud coverage; distance to the coast, to waterways, to the closest volcano and fault line and terrestrial distance to Addis Ababa; terrain ruggedness and elevation; malaria prevalence; soil potential caloric yield; absolute latitude; south, major habitat type and homeland size decile indicators. Columns using the Seshat data employ the same covariates except for temperature, precipitation and major habitat type (absolute latitude and south are collinear with the fixed effects). Ethnic controls: major-crop-type indicator. Controls Seshat: past and distance-weighted values for population density, administrative levels, hierarchical complexity, writing and text types, geometrical measurements, the use of calendars and money and infrastructure types, polity's continuity dummy, relationship with supra-national entities and peak century. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4. *Solar Eclipses and Technology.*

| | Ethnographic Atlas | | Seshat Database | | Ashraf and Galor (2011) | | | | |
	Tasks (1)	Tech. (2)	Money (3)	Infrastructure (4)	Tech. Index (5)	Non-agri. Tech. Index (6)	Communication Tech. (7)	Industrial Tech. (8)	Transportation Tech. (9)
Solar eclipse (log)	0.103 (0.039)***	0.070 (0.034)*	0.003 (0.020) [0.018]	0.022 (0.009)** [0.008]***	0.125 (0.034)***	0.162 (0.041)***	0.683 (0.132)***	0.879 (0.360)**	0.047 (0.041)
Distance to volcano (log-km)	−0.026 (0.012)**	−0.004 (0.014)							
Distance to fault line (log-km)	−0.014 (0.009)	−0.003 (0.016)							
Volcanic eruptions (log)			−0.001 (0.002) [0.002]	−0.001 (0.001) [0.001]	−0.087 (0.019)***	−0.110 (0.024)***	−0.320 (0.082)***	−0.631 (0.194)***	−0.111 (0.028)***
Fixed effects	Continent	Continent	Polity	Polity	Country	Country	Country	Country	Country
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	No	No	No	No	No
Ethnic	Yes	Yes	No	No	No	No	No	No	No
Controls Seshat	No	No	Yes	Yes	No	No	No	No	No
R^2/pseudo-R^2	0.097	0.668	0.928	0.932					
Observations	738	112	448	448	292	292	292	292	292

Notes: This table presents the results of regressions linking the impact of eclipses on technology at the ethnic-group level in columns (1) and (2), at the country level in columns (3) and (4) and at the polity level in columns (5)–(9). Column (1) reports the findings for the number of *Tasks*, while column (2) focuses on *Technological Complexity*. Column (1) adds the number of surveyed tasks as an additional regressor. These regressions feature robust SEs clustered at the regional level. Column (3) relates solar eclipses to *Money*, while column (4) focuses on *Infrastructure*. Columns (5)–(9) employ several technological indices: a generic *Technological Index* in column (5), with column (6) using the same index, but *excluding agricultural technology*; column (7) focuses on *Communication* technology, column (8) on *Industrial* technology and column (9) on *Transportation* technology. Columns (3) and (4) use the most-removed predecessor polity identifier, while columns (5)–(9) use country fixed effects. Column (1) follows the negative binomial model, columns (2)–(4) are estimated by OLS and columns (5)–(9) follow a panel censored model. These regressions feature robust SEs clustered at the polity level in brackets and accounting for time and spatial autocorrelation (1,000 years and 5,000 km) in square brackets. Continent fixed effects: indicators for Asia, Europe, Africa, North America, South America and Oceania. Geographic controls: average temperature, precipitation and cloud coverage; distance to the coast, to waterways, to the closest volcano and fault line and terrestrial distance to Addis Ababa; terrain ruggedness and elevation; malaria prevalence; soil potential caloric yield; absolute latitude; south, major habitat type and homeland size decile indicators. Columns using the Seshat data employ the same covariates except for temperature, precipitation and major habitat type (absolute latitude and south are collinear with the fixed effects). Ethnic controls: major-crop-type indicator. Controls Seshat: past and distance-weighted values for population density, administrative levels, hierarchical complexity, writing and text types, geometrical measurements, the use of calendars and money and infrastructure types, polity's continuity dummy, relationship with supra-national entities and peak century. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

to the corresponding averages (0.21 and 0.21), the change in these probabilities has economic significance. However, similar specifications in columns (6) and (7) using the Seshat data only display positive, but non-significant coefficients.[59]

Other measures of human capital similarly increase with the number of eclipses. Most notably, column (3) indicates a better understanding of solar eclipses as the phenomenon becomes more prevalent. This is a relevant result that speaks directly to our theory. We posit that people devote mental resources to the understanding of eclipses. Thus, more refined theories closer to reality should ensue from more intense pondering. Column (3) indicates that this is indeed the case: a 1% increase in the number of solar eclipses increases by 7.26% the probability of having an elaborate explanation for the phenomenon. Similarly, if we boost the number of eclipses from the 10th to the 90th percentile of the distribution for all ethnic groups, on average, the probability of having no explanation for the phenomenon decreases from 69% to 56%.

Columns (4) and (8) indicate a greater abundance of words related to the concept of a *Calendar* in folktales and a more intense development of actual calendars among societies more exposed to eclipses.[60] Related to the idea that eclipses stimulate curiosity and quicken thinking, column (5) indicates a higher frequency of terms related to *Thinking* when the number of eclipses increases, with an associated marginal effect of 0.24 more tales on this topic for each additional eclipse. Lastly, column (9) clearly indicates that geometry tends to develop more as solar eclipses increase, which is in line with the idea that geometry is a useful tool for predicting eclipses.

Table 4 presents our results regarding how solar eclipses contribute to technological development.[61] Column (1) measures technological sophistication by counting the number of *Tasks* listed in the Ethnographic Atlas, which we estimate using a negative binomial regression.[62] Column (2) refines this crude measure using data from Eff and Maiti (2013) and considers how different activities interrelate. Because this index takes on multiple values, we estimate how eclipses affect it using OLS. In both cases, regressions follow (1) and we cluster SEs at the region level. Columns (3) and (4) employ proxies of technological development as presented in the Seshat database: the monetary system in use (*Money*) and the type of *Infrastructure* built. The econometric specification in this case is the same as in the corresponding columns of Table 3. Columns (5)–(9) introduce multiple indicators of technological level gathered at the country level (Ashraf and Galor, 2011). Column (5) targets technology in general, column (6) focuses on non-agricultural technology and columns (7)–(9) focus on specific sectors: communications, industry and transportation. Regressions feature country and time fixed effects, effectively exploiting the panel dimension of the data. Furthermore, because the data have clearly defined upper and lower limits, we estimate these columns using a censored model.

Overall, the results indicate greater technological development for societies that experienced more solar eclipses, lending additional credence to our hypothesis and providing a secondary channel linking these and development. Column (1) provides evidence of a greater number of activities in societies with more eclipses, which reflects the operation of a more complex productive structure to meet the society's needs. Although this measure is relatively coarse, for

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[59] One possible explanation for the lack of results in column (7) is that, different from other outcomes, it is difficult to establish a classification for text typologies.

[60] As previously discussed, even though calendars may appear unrelated to human capital, the creation of these instruments requires an awareness of celestial regularities and their exploitation.

[61] We note that a more advanced technology could directly result from exposure to eclipses—for instance, developing precision instruments to track the Moon—or indirectly from human capital. Since we are ultimately interested in growth, we do not disentangle these two effects.

[62] This regression controls for the number of surveyed tasks, which differs across ethnic groups.

Table 5. *Solar Eclipses and Curiosity.*

	Folklore		Wikidata	
	Eclipse Related	Curious Related	Scientific Occupation	
	(1)	(2)	(3)	(4)
Solar eclipse (log)	0.234	0.446		
	(0.068)***	(0.151)***		
Distance to volcano	−0.038	−0.019		
(log-km)	(0.017)**	(0.048)		
Distance to fault line	−0.020	0.162		
(log-km)	(0.024)	(0.081)**		
Solar eclipse (0/1)			0.072	0.040
			(0.029)**	(0.017)**
Volcanic eruptions (0/1)			0.048	0.029
			(0.075)	(0.039)
Fixed effects	Continent	Continent	City	City
Time fixed effects	No	No	Yes	Yes
Geography	Yes	Yes	No	No
Ethnic	Yes	Yes	No	No
Weights	No	No	Sample	Population
R^2/pseudo-R^2	0.284	0.369	0.170	0.068
Observations	918	915	150,260	150,260

Notes: This table presents the results of regressions assessing the impact of eclipses on curiosity at the ethnic-group level in columns (1) and (2) and at the individual level in columns (3) and (4). Column (1) reports the findings for the occurrences of words related to *Eclipse* in folktales, while column (2) focuses on the word *Curious*. These regressions feature robust SEs clustered at the regional level. Columns (3) and (4) relate eclipses to having a *Scientific Occupation,* using data from Wikidata with SEs clustered at the country-century level. Columns (1) and (2) follow a Poisson model, and columns (3) and (4) are estimated by OLS. Column (3) weights observations using data-driven weights, while column (4) employs world population estimates. Columns using the folklore data include an additional regressor, as indicated in footnote 32. Continent fixed effects: indicators for Asia, Europe, Africa, North America, South America and Oceania. Geographic controls: average temperature, precipitation and cloud coverage; distance to the coast, to waterways, to the closest volcano and fault line and terrestrial distance to Addis Ababa; terrain ruggedness and elevation; malaria prevalence; soil potential caloric yield; absolute latitude; south, major habitat type and homeland size decile indicators. Ethnic controls: major-crop-type indicator. ** $p < 0.05$, *** $p < 0.01$.

each one-percentage-point increase in eclipses, the number of tasks increases by 0.31 above an average of 2.96. Column (2) indicates that, as the number of eclipses increases, not only does the society participate in more tasks, but these tasks are also of greater complexity. Although the coefficient is small, the increase is economically meaningful insofar as this variable takes values across a small range, with a maximum of 2.59. Column (4) corroborates this point, indicating that the infrastructure becomes more complex.[63] Thus, in general, solar eclipses stimulate technology both at its intensive and extensive margins. Finally, columns (5)–(9) indicate that, in general, technology tends to improve throughout all domains, except for transportation.[64]

2.3. *Curiosity*

Our argument hinges on the assumption that solar eclipses are a powerful trigger of human curiosity. Table 5 presents results regarding this using information on folklore in columns (1) and (2), and individual occupations in columns (3) and (4). More specifically, column (1) focuses on the number of terms related to *Eclipse* appearing in folktales. Arguably, if eclipses are considered

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[63] We can only show a positive effect of solar eclipses on the monetary system.

[64] We note a negative and significant effect of actual volcanic eruptions on technological development that is very coherent across specifications.

impressive, the number of eclipses a society sees should correlate with their relative importance in tales. Column (2) extends this idea and introduces the number of words related to *Curious*. Again, if inexplicable phenomena trigger curiosity and the exploration of ideas, such activities should become more relevant and be encoded in myths to transmit them to future generations.[65] The estimation procedure for columns (1) and (2) repeat the procedure outlined for the Ethnographic Atlas. Columns (3) and (4) employ individuals' occupations derived from Wikidata, and relate the choice of a *Scientific* career to the observation of a total solar eclipse from the age of 5 to 15. We estimate an OLS model controlling for country and century fixed effects, and we cluster SEs at the country-century level.[66] The difference between columns (3) and (4) is the weights: the former computes them based on the sample, while the latter uses world population records to construct them.

We first note that ethnic groups incorporate about 1.09 more concepts related to this phenomenon into their tales when the number of events they witness increases by 1% (the sample average is 4.63). Likewise, shifting ethnic groups from the 10th to the 90th centile of the eclipse distribution increases the number of predicted mentions of eclipses in folklore from 4.04 to 5.38. This result lends credence to our assumption that total solar eclipses are a relevant phenomenon; otherwise, they would not feature as part of folktales. The results in column (2) are similar: a 1% increase in the number of eclipses increases the number of words related to curiosity in folkloric tales by 0.11. Although this may seem negligible, in general, curiosity-related words are not common in folkloric tales, averaging only 0.86 at the society level. Once this is considered, the marginal effect becomes much more relevant, representing around 13% of the sample average.

Columns (3) and (4) focus on the individual-level effect of eclipses in terms of curiosity. These columns indicate that individuals who spotted an eclipse between the ages of 5 and 10 are about 7.19% and 3.96% more likely to become scientists in adulthood. As a reference, 8.62% of sampled individuals followed a scientific career. Although surprising, this result is compatible with our hypothesis: people exposed to an inexplicable event become more curious and have a desire to understand. Related, one can reasonably expect a lingering impact of solar eclipses on curiosity as the involved mechanics become better understood. To test this possibility, we run *unweighted* regressions comprising all individuals born before a given time, repeating the process for each century. Because the number of individuals in our database increases with time, doing so places more importance on the most recent cohort entering the regression. Thus, this procedure enables us to study the temporal evolution of the impact of solar eclipses on scientific occupations.[67] Figure 3 illustrates the results, indicating that, as time advances, the probability of a child who saw a total eclipse choosing a scientific occupation converges towards its average.[68] Nevertheless, solar eclipses remain meaningful until around the seventh century, and there is a small resurgence of their importance during the Renaissance period.[69]

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[65] The folklore data present two related terms: 'curiously' and 'curiosity'. Using the first, we obtain similar results, but not with the latter.

[66] Replacing country fixed effects for city fixed effects and adjusting the SEs accordingly does not modify the conclusions.

[67] Alternatively, one could run separate regressions for each century. However, the reduced number of observations limits this approach. Thus, although our method does not capture the exact effect during a given period, it allows for a larger sample size.

[68] Online Appendix Figure C.16 displays binned scatterplots relating the observation of a solar eclipse during childhood to having a scientific occupation.

[69] The regression corresponding to the year 600 includes individuals born between –1600 and 600, and the coefficient we compute incorporates the average effect for that entire sample. Thus, it is possible to have a nil effect among individuals specifically born in the seventh century.
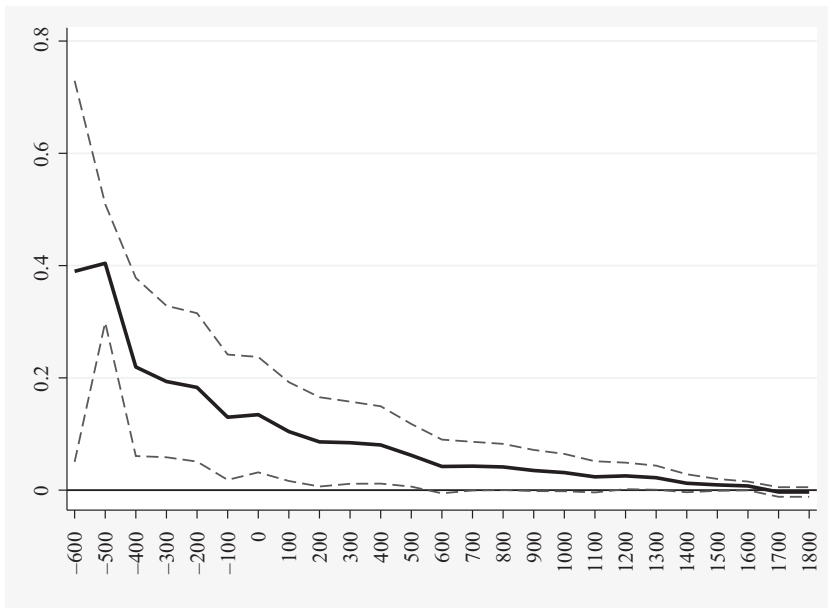
Fig. 3. *Solar Eclipses and Curiosity.*
Notes: This figure represents the association between observing a total solar eclipse during childhood (ages 5–15) and having a *Scientific Occupation*, using data from Wikidata. The thick line reports the average effect of eclipses for all people born before the date indicated on the horizontal axis. The underlying regressions follow (2), but are unweighted.

3. Robustness

3.1. *Lunar Eclipses*

In line with our hypothesis, the previous results support the idea that inexplicable (harmless) phenomena can promote growth through curiosity. Similar effects may be reasonably expected of lunar eclipses, despite these being less impressive and more elusive as they happen at night. Online Appendix Tables C.1–C.5 repeat the main regressions of the paper, introducing lunar eclipses. In each case, panel A replaces total solar eclipses for total lunar eclipses, while panel B incorporates both types of eclipse to compare the relative strength of each.

In general, replacing solar eclipses by lunar eclipses provides results very much aligned and compatible with our hypothesis. Except for cases using the Seshat database, the new results corroborate the association between eclipses and development and validate that human capital and technology are plausible avenues through which the aforementioned relationship could be operating. The relative failure of the Seshat data to reproduce the previous results is not as critical as it may seem, as most polity borders do not change or do so only slightly. Because lunar eclipses are visible from half of the Earth, a relatively constant area implies a relatively constant number of lunar eclipses, which are absorbed by the polity fixed effects.[70] However, this drawback becomes a virtue when using the Ethnographic Atlas because, indirectly, the introduction of lunar eclipses

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[70] This issue also casts doubts on the validity of the results using data from Ashraf and Galor (2011), because of the fixed effects we employ.

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partly controls for area, thus reassuring us that the results using cross-sectional data are not due to size differences.

Similarly, the apparent inability of lunar eclipses to improve the understanding of the phenomena (column 3 of Online Appendix Table C.3) requires some clarification. Indeed, a careful reading of the folklore data turns a potentially devastating result into a coherent one. First, the process resulting in an eclipse differs between solar and lunar eclipses. In the first, the Moon clearly blocks the Sun, and thus both bodies interact. However, the Sun does not directly intervene in lunar eclipses: these happen at night. Second, folklore data record tales wherein eclipses result from the interaction between the Sun and the Moon, for instance, because they are mating. Hence, lunar eclipses cannot enter this body of oral tradition, and this is captured by the non-significant coefficient.

Generally, when we simultaneously analyse the two types of eclipses, the results restore the importance of solar eclipses to the detriment of lunar ones. As previously mentioned, this result follows from the characteristics of lunar eclipses, which are less impressive and noticeable. In this sense, a strong effect arising only from solar eclipses is compatible with our theory. In summary, as demonstrated by the positive and significant coefficients associated with lunar eclipses, inexplicable events are likely to promote economic development. Moreover, this set of results favours the idea that the more mysterious an event is, the more it promotes thinking.

3.2. *Area*

A concern when using cross-sectional data is that surface area may affect the estimates of economic development. Indeed, a mechanical relationship exists between area and the number of solar eclipses. If, at the same time, societies inhabiting a larger area require a more complex organisation, we may be confounding the effect of eclipses with the latter. Thus, Online Appendix Tables C.6 and C.7 propose some additional regressions to further mitigate this problem. First, panel A drops ethnic groups at the top and bottom 5% of the surface area distribution, which reduces the possibility of outliers driving the results. Panel B follows a different strategy, replacing the decile-level fixed effects for ten fixed effects based on k-means of area, effectively creating groups with a similar surface area. Lastly, panels C and D directly add controls for the logarithm of area to our baseline specification, in the latter case including its third-degree polynomial.[71] Overall, the different strategies to better account for area do not challenge our previous conclusions.

Online Appendix C presents additional robustness checks with respect to area. First, we run quantile regressions to reduce the possibility of the results being driven by outliers. Next, we show robustness to a different specification using eclipses per unit of surface area, together with eclipses and surface area as regressors. Online Appendix C details how to properly introduce this term and its interpretation. Moreover, introducing the logarithm of area in lieu of area-decile fixed effects does not qualitatively alter our main conclusions. Lastly, we predict the number of eclipses based on homeland area and use these predictions as the main variable in a set of regressions following the baseline approach.[72] Doing so allows us to dissociate the effect of area from that of curiosity, because predicted eclipses only embody the former. The coefficients associated with predicted eclipses are smaller and far from those we obtain when using the actual number of eclipses.

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[71] We prefer area-decile fixed effects over sheer size because the latter could result from human capital accumulation.
[72] See Online Appendix Tables C.8–C.11 and Figure C.1, respectively.

3.3. *Religion*

In spite of the above evidence, exposition to inexplicable phenomena could operate through channels other than curiosity. In particular, individuals may turn to religion to seek answers or soothing, which could confound our estimates if religion interacts with development. Squicciarini (2020) documented lower levels of human capital among the most religious people, while Noren-zayan (2013) proposed that god creation facilitated cooperation.[73] Moreover, Bentzen (2019) indicated higher levels of religiosity among people residing in earthquake-prone areas, because it provides a coping mechanism. If part of this is due to the search for a rationale, a similar effect may exist for solar eclipses.

Table 6 takes on this issue and shows that solar eclipses are not related to religion. First, column (1) reports results regarding religious complexity, using data from the Ethnographic Atlas. These data classify ethnic groups with respect to their high gods, which may be absent, not active in human affairs, active in human affairs, but not supporting morality or active in human affairs and supporting morality. Next, columns (2)–(4) approximate the importance of religion by counting the number of concepts related to *Religion*, *Religious* and *Pray* that appear in folktales. Lastly, columns (5) and (6) use individual-level data to relate experiencing a total eclipse of the Sun in childhood to the pursuit of a religious occupation.

Starting with column (1), the results indicate a positive and significant correlation between the number of eclipses and more complex religious systems. Thus, in principle, religion could be a mediating factor. However, this statement must be qualified in light of other results. First, columns (2)–(4) suggest that religion does not vary across ethnic groups because of eclipses, contradicting the previous findings. Additionally, columns (5) and (6) indicate that individuals who observed a total solar eclipse as children are not more likely to practise religious occupations.[74] An alternative interpretation of god complexity may reconcile these findings. In particular, Dunbar (2003) and Shariff *et al.* (2009) proposed that complex high gods must be supported by cognitively advanced individuals. Such an explanation is compatible with the previous results relating more frequent eclipses to human capital.[75]

In summary, even though the idea that mysterious events could advance religion is persuasive, the results in Table 6 do not support this. If anything, solar eclipses are neutral with respect to religion. Moreover, once we consider the types of societies we are interested in, with many lacking high gods, the idea that religion could foster growth becomes more dubious.

3.4. *Placebo*

Our hypothesis hinges on the assumption that solar eclipses incentivise curiosity, prompting people into thinking. The evidence presented above is, in general, compatible with this line of thought. However, to increase our confidence in the estimations, as placebo tests, we verify whether solar eclipses display a similar association with ideas and concepts unrelated to human capital and thinking. However, the argument that solar eclipses contribute to the development

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[73] Although an opposition between religion and science existed in Christianity, we cannot know the types of links that could exist between the two among pre-modern ethnic groups. Considering that a large share of societies lack major gods and a relevant fraction have inactive gods that do not interact with people, one would expect a weak relationship, if any.

[74] Furthermore, Figure 4 indicates this to be the case in all centuries.

[75] In light of the research documenting both positive and negative externalities of religion on growth, we note that further controlling for high gods in regressions akin to those in columns (1) and (2) of Table 1 broadly indicates no effect of the former on development. The only exception is for the most complex types of gods, which positively affect growth, but only when the dependent variable is *Population Density*. These results are available from the authors upon request.

Table 6. *Solar Eclipses and Religion.*

| | Ethnographic Atlas | Folklore | | | Wikidata | |
| | High Gods | Religion Related | Religious Related | Pray Related | Religious Occupation | |
	(1)	(2)	(3)	(4)	(5)	(6)
Solar eclipse (log)	0.714 (0.165)***	0.011 (0.019)	−0.405 (0.309)	−0.313 (0.313)		
Solar eclipse (0/1)					−0.003 (0.011)	−0.004 (0.009)
Fixed effects	Continent	Continent	Continent	Continent	City	City
Time fixed effects	No	No	No	No	Yes	Yes
Geography	Yes	Yes	Yes	Yes	No	No
Ethnic	Yes	Yes	Yes	Yes	No	No
Weights	No	No	No	No	Sample	Population
Pseudo-R^2	0.267	0.731	0.309	0.376	0.157	0.126
Observations	599	918	918	918	150260	150260

Notes: This table presents the results of regressions relating the impact of eclipses on religion at the ethnic-group level in columns (1)–(4) and at the individual level in columns (5) and (6). Column (1) focuses on high-god typology. Columns (2)–(4) focus on the prevalence of words related to the concepts of *Religion, Religious* and *Pray*. These regressions feature robust SEs clustered at the regional level. Columns (5) and (6) relate eclipses to having a religious occupation, using data from Wikidata with SEs clustered at the country-century level. Column (1) follows an ordered probit model, columns (2), (5) and (6) are estimated using OLS and columns (3) and (4) follow a Poisson model. Column (5) weights observations using data-driven weights, while column (6) employs global population estimates. Columns using the folklore data include an additional regressor, as indicated in footnote 32. Continent fixed effects: indicators for Asia, Europe, Africa, North America, South America and Oceania. Geographic controls: average temperature, precipitation and cloud coverage; distance to the coast, to waterways, to the closest volcano and fault line and terrestrial distance to Addis Ababa; terrain ruggedness and elevation; malaria prevalence; soil potential caloric yield; absolute latitude; south, major habitat type and homeland size decile indicators. Ethnic controls: major-crop-type indicator. *** $p < 0.01$.
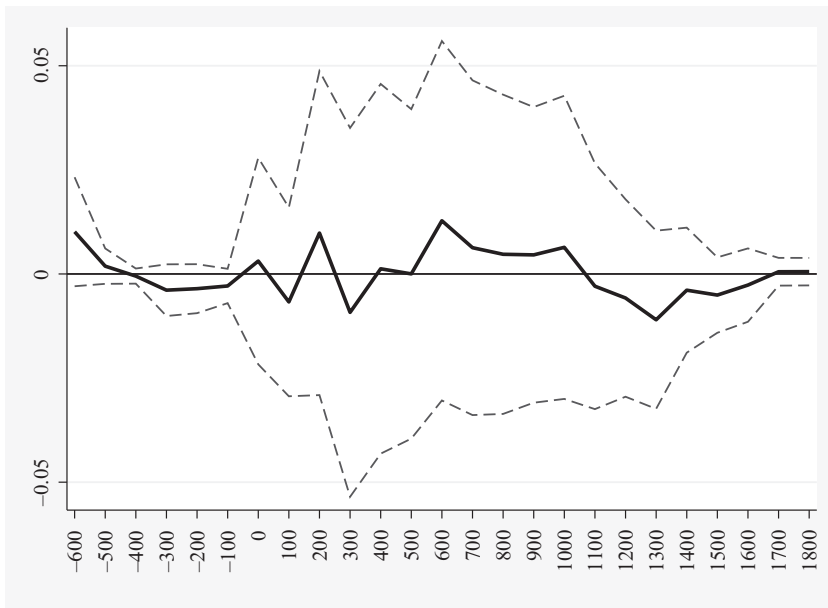
Fig. 4. *Solar Eclipses and Religion.*
Notes: This figure represents the association between observing a total solar eclipse during childhood (ages 5–15) and having a *Religious Occupation*, using data from Wikidata. The thick line reports the average effect of eclipses for all people born before the date indicated on the horizontal axis. The underlying regressions follow (2), but are unweighted.

of human capital implies that a multiplicity of concepts may stem from the observation of eclipses. For example, horses appear more frequently in the stories of ethnic groups that have seen more eclipses. This may be the result of people becoming sedentary, adopting farming and domesticating this animal, which reflects higher human capital and invalidates 'horse' as a placebo. This caveat guides our selection of concepts, which we limit to three categories: meteorological events, inanimate objects and colours.

Columns (1) and (2) of Table 7 present the results when we measure the prevalence of words related to *Clouds* and *Lightning* in ethnic folktales. Columns (3) and (4) are devoted to *Rock* and *Sand*, and columns (5) and (6) refer to the colours *White* and *Purple*. We believe that our choice of concepts is sufficiently neutral.[76]

The results reveal a lack of association between the prevalence of total solar eclipses and these different concepts appearing in folklore, and we can interpret the lack of significant associations as reinforcing our assumption. In this sense, the placebo regressions confine the role of solar eclipses to the promotion of curiosity.

3.5. *Other Results*

We devote part of Online Appendix C to tackling additional concerns. First, a sceptical reader might question the need for such an extensive set of controls in the regressions featuring data

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[76] The regression focusing on lightning accounts for lightning frequency.

Table 7. *Placebo Tests.*

| | Folklore | | | | | |
| | Meteorology | | Inanimate | | Colours | |
	Cloud (1)	Lightning (2)	Rock (3)	Sand (4)	White (5)	Purple (6)
Solar eclipse (log)	−0.383	0.100	−0.001	−0.111	−0.028	−0.547
	(0.237)	(0.103)	(0.058)	(0.155)	(0.131)	(0.421)
Fixed effects	Continent	Continent	Continent	Continent	Continent	Continent
Geography	Yes	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.249	0.249	0.426	0.384	0.346	0.755
Observations	918	918	918	918	918	913

Notes: This table presents the results of placebo regressions relating the eclipses and the occurrence in folktales of words unrelated to economic growth. Columns (1)–(6) track the number of folktales involving the concepts *Cloud*, *Lightning*, *Rock*, *Sand*, *White* and *Purple*, respectively. These regressions feature robust SEs clustered at the regional level. All regressions follow a Poisson model, except for that of column (6), which is estimated using a probit model. Columns using the folklore data include an additional regressor, as indicated in footnote 32. Continent fixed effects: indicators for Asia, Europe, Africa, North America, South America and Oceania. Geographic controls: average temperature, precipitation and cloud coverage; distance to the coast, to waterways, to the closest volcano and fault line and terrestrial distance to Addis Ababa; terrain ruggedness and elevation; malaria prevalence; soil potential caloric yield; absolute latitude; south, major habitat type and homeland size decile indicators. Ethnic controls: major-crop-type indicator.

from the Ethnographic Atlas. Although their inclusion has been guided by the growth literature, Online Appendix Figures C.2–C.4 display the coefficient obtained when covariates are introduced one by one. In general, it does not appear that any specific one is particularly relevant to obtain our main results.

Second, Figure 3 shows that solar eclipses generated more curiosity in the past, when the phenomenon was less understood. Guided by this insight, we analyse the cumulative effect of solar eclipses using the Ethnographic Atlas and the folklore data. More specifically, we run regressions increasing the cut-off year for solar eclipses: first considering only those between 2000–1500 BCE then extending this to 2000–1000 BCE, etc. Online Appendix Figure C.5 displays the results, which exhibit a concave curve indicative of decreasing marginal returns. This result is in line with the more pronounced effect obtained further in the past regarding individuals' careers. In addition, in Online Appendix Figure C.6 we also investigate how solar eclipses were related to scientific discoveries in Greece and India.

4. Conclusion

Considering the central role of human capital in economics, little is known about its origins. This paper studies curiosity as one of its possible determinants, focusing on the Malthusian regime, and contributes to our understanding of comparative development among pre-modern societies. In particular, we argue that pre-modern societies more exposed to inexplicable phenomena devoted more mental resources to unravelling these mysteries, thereby exercising cognitive abilities and gaining a comparative advantage in thinking and in human capital. In light of the unified growth theory, such efforts should be reflected in technological levels, as well as in economic development.

Lacking precise information on curiosity, we approximate this by focusing on total solar eclipses as one major type of inexplicable natural phenomena. Total solar eclipses present three

characteristics distinguishing them from other equally uncanny events: they are harmless, well distributed across the Earth and localised. Using a large selection of development proxies from the Ethnographic Atlas and the Seshat database, we first document that societies more exposed to solar eclipses grew more. Next, in line with our hypothesis, we verify deeper and more intricate thinking among peoples more exposed to eclipses. Likewise, technological complexity increases as well. Finally, we are able to show that total solar eclipses increase curiosity both at the social and individual levels.

In summary, this research sheds light on the early origins of human cognition and contributes to our understanding of growth among societies that have not yet mastered science. In particular, we highlight the importance of curiosity as a natural predecessor to human capital accumulation and how the latter is related to economic prosperity in the long run.

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Additional Supporting Information may be found in the online version of this article:

Online Appendix
Replication Package

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