

Treatment of missing data determined conclusions regarding moralizing gods

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Q1 Whitehouse, et al.¹ used the Seshat archaeo-historical databank² to argue that beliefs in moralizing gods appear in world history only after the formation of complex ‘megacities’ of around one million people. However, inspection of the data they used shows that 61% of the data points on moralizing gods in the Seshat databank are missing values, mostly from smaller populations of less than one million people. In their analysis, the authors re-coded these data points to signify the absence of belief in moralizing gods. When we confine the analysis to only the extant data, or instead use various standard imputation methods, the reported finding is reversed: moralizing gods precede increases in social complexity. Our reanalyses suggest that the reported ‘megacities threshold’ for the emergence of moralizing gods is an artefact of the decision to re-code all missing data as known absences of moralizing gods.

Figure 1 illustrates the Seshat data for the 12 key world regions examined using statistical tests in Whitehouse, et al.¹. What the authors describe as the ‘first appearance’ of moralizing gods occurs only after writing or literate observers (Extended Data Fig. 1), and is almost always preceded by a series of unknown values (documented as ‘NA’ in the data), indicating no evidence that moralizing gods were present or absent. Only one observation in the entire Seshat database—from the middle Yellow River valley in China—reports a known absence of moralizing gods in a world region before their ‘first appearance’.

In total, 61% ($n = 490$) of all observations of belief in moralizing gods used in the statistical tests in Whitehouse, et al.¹ were initially labelled ‘unknown’ or ‘suspected unknown’ in the Seshat dataset (Extended Data Fig. 2). Review of the authors’ R scripts shows that they handled this problem with the moralizing gods variable by treating all cases of missing data as known absences of moralizing gods (0 or FALSE) both in their t -tests (supplementary code folder 04, line 39) and logistic regression (supplementary code folder 06, line 48). The resulting correlation between missing data and absence of a moralizing god is $r = 0.97$, an almost-perfect correspondence (Supplementary Methods 1.2).

These crucial decisions about the treatment of missing data were not reported in Whitehouse, et al.¹. Previous work using ethnographies limited such inferences only to cases where there are detailed accounts of a society’s religious beliefs, but moralizing gods were not mentioned³ (Supplementary Methods 1.4). By contrast, the four Seshat variables used to define moralizing gods, either as moralizing high gods (MHG) or any of three categories of behavioural supernatural punishment (BSP), are all labelled ‘unknown’ or ‘suspected unknown’ in the Seshat databank for 490 of 801 historical observations used in the study.

Including inferred data points from historical eras without direct evidence or substantive information can have large effects on statistical results, especially if unknown values constitute the majority of the dataset. To confirm this, we revised the authors’ logistic regressions using three standard approaches for missing data: analysis only on the complete cases, sampling from the known observations, and Laplace’s principle of indifference^{4–6}. For each result, we find a comparable probability of moralizing gods’ appearance at much smaller social complexity scores than the megacities threshold of 0.6 described by Whitehouse et al.¹ (approximately 0 in all three reanalyses; Fig. 2a, Supplementary Fig. 5, Supplementary Tables 3, 4). These Bayesian models also permit prediction in eras without data, allowing for the probable emergence of moralizing gods between 600 and 1,400 years before the ‘first appearance’ recorded in the Seshat dataset (Fig. 2b, Supplementary Fig. 3).

Further, because the definition of moralizing gods used by Whitehouse, et al.¹ requires written evidence (Extended Data Fig. 1), small, non-literate populations and older historical eras are disproportionately represented among the unknown values (Fig. 1, Extended Data Fig. 2). Inferring that all such unknown eras lack certain religious beliefs therefore produces a powerful forward bias, a methodological artefact that pushes estimates of the appearance of those beliefs to a much later date. For example, historical reconstructions based on Polynesian ethnography indicate that supernatural agents who punish moral transgression probably existed in Hawai’i well before contact, but the first appearance of Hawaiian moralizing gods reported in the dataset in ref. ¹ coincides with the arrival of Europeans to write down those beliefs (Supplementary Methods 2.1).

To test whether the megacities threshold preceding the first appearance of moralizing gods was susceptible to a forward bias, we reanalysed the Seshat data for the 12 key world regions. Whitehouse, et al.¹ report that the average increase in social complexity declined after the first appearance of moralizing gods when comparing the period of seven centuries before and after their appearance ($t = -4.87$, $P < 0.001$, $n = 82$), concluding that belief in these gods follows initial social complexity growth. However, adjusting the reported first appearance of moralizing gods in each region back by one century—the smallest time unit in the analysis—reverses this pattern; moralizing gods now precede the marked rises in social complexity ($t = 3.44$, $P < 0.001$, $n = 84$). This reversal happens for a reason consistent with the presence of a forward bias; as with Hawai’i, the first appearance of moralizing gods in six regions (Deccan, Kachi Plain, Kansai, Nigerian Inland Delta,

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	Years until first appearance of moralizing god											
	-1000	-900	-800	-700	-600	-500	-400	-300	-200	-100	0	100
Deccan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	NA
Kachi Plain	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1
Kansai		NA	1	1								
Konya Plain	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	
Latium	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	
Middle Yellow River valley	NA	NA	NA	NA	NA	NA	NA	NA	0	1	1	
Niger Inland Delta	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	
Orkhon Valley	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	
Paris Basin	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	
Sogdiana	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	
Susiana	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	NA	
Upper Egypt	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	

Fig. 1 | Moralizing gods across 12 key regions. Here, '1' indicates moralizing gods are known to be present in the century-by-century data and '0' indicates that they are known to be absent. NA corresponds to 'unknown' or 'suspected unknown' moralizing god data in the original dataset¹. Generally, moralizing gods appear in Seshat simultaneously with, or after, the appearance of writing

(green), contrasting with ethnographic records of moralizing gods in non-literate societies (Extended Data Fig. 1, Supplementary Methods 1.4). Only one of the Seshat world regions includes a known absence of moralizing gods preceding a known presence (Middle Yellow River Valley (red)).

Orkhon Valley and Sogdiana) coincides with the arrival of conquerors or missionaries with well-documented religious beliefs. Importantly, Whitehouse et al.¹ also ascribed properties of conquerors to the conquered regions, leading to rapid and unrealistic swings in population size immediately before the reported first appearance of moralizing gods. For example, the populations of Deccan, Sogdiana and the Kachi Plain increased from a few thousand to 18–22 million within the span of a single century, producing a sudden, threefold increase in social complexity preceding the apparent arrival of moralizing gods (Extended Data Fig. 3b). To mitigate these drivers of forward bias, we excluded regions affected by mission or conquest, which yielded more gradual increases in social complexity in the remaining six regions (Extended Data Fig. 3d). Performing the same tests as Whitehouse et al.¹, on this reduced dataset revealed no support for differing rates of increase in social complexity seven centuries before and after the reported

first appearance of moralizing gods ($t = -1.34, P = 0.188, n = 42$). This gradualism is consistent with over a century's worth of archaeological evidence pointing to a stepwise co-evolution of religious and political institutions⁷. A shift in the first appearance of moralizing gods back 100 years on this reduced dataset yielded no distinct difference ($t = -0.46, P = 0.647, n = 42$) and a backwards shift in their appearance by 300 years (still a conservative estimate, given Fig. 2b) once again reverses the reported result; moralizing gods precede major increases in social complexity ($t = 2.71, P = 0.010, n = 42$; see Supplementary Table 1 for analyses on the dataset spanning ± 20 centuries).

Together, these reanalyses cast serious doubt on the main conclusions in Whitehouse, et al.¹ that moralizing gods appear only after rapid increases in social complexity globally. Given the problems with preservation of evidence for religious beliefs in the historical record, we conclude that the reported megasociety threshold is an artefact of the

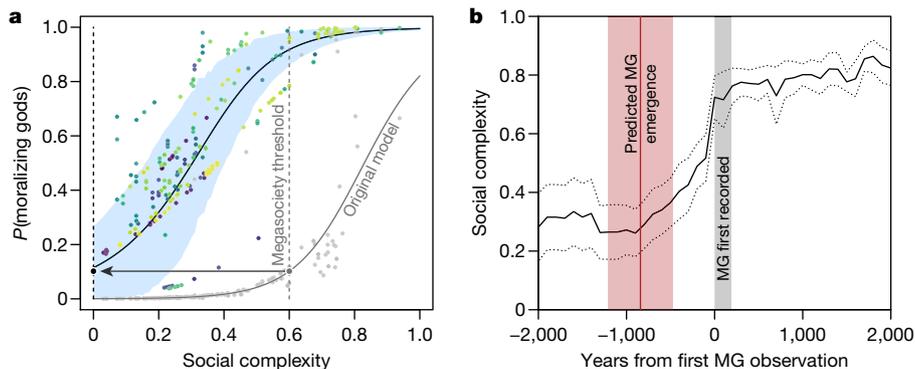


Fig. 2 | Comparison of the original logistic regression model and a reanalysis removing unknown outcomes. In the original regression model¹, missing outcome data was coded as if moralizing gods were absent, whereas our reanalysis removes these missing data. **a**, Estimated relationship between the probability of moralizing gods being observed ($P(\text{moralizing gods})$) and social complexity, with distance and language similarity covariates set to empirical mean values, fit on the original dataset (NA recoded as 0; grey line) and a reduced dataset in which missing values are removed (black line; blue shading indicates 89% highest posterior density interval). Mean $P(\text{moralizing gods})$ for the 490 historical observations with unknown outcome values are

shown as points from the original model (grey) and grouped by 'natural geographical area' in the revised model (each natural geographical area is assigned a different colour). The arrow indicates equivalent social complexity levels for the $P(\text{moralizing gods})$ megasociety threshold in Whitehouse, et al.¹. **b**, Time series showing mean social complexity over time for 2,000 years before and after the appearance of moralizing gods (figure 2a from ref. ¹), estimating forward bias only from known (non-NA) observations, with the inclusion of mean and 95% confidence interval for the predicted first emergence of moralizing gods (MG), approximately 958 ± 210 years (mean \pm s.e.m.) before the first observations in the Seshat database.

decision to recode 61% of cases from missing data to known values, all indicating that moralizing gods are absent.

Reporting summary

Further information on experimental design is available in the Nature Research Reporting Summary linked to this paper.

Data availability

Supplementary data are available at <https://github.com/babeheim/moralizing-gods-reanalysis>. All software is freely available under Creative Commons License CC BY-NC-SA 4.0. Source materials are available at <http://seshatdatabank.info>.

Code availability

Re-analysis code is available at <https://github.com/babeheim/moralizing-gods-reanalysis>. All software is freely available under Creative Commons License CC BY-NC-SA 4.0.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at <https://doi.org/10.1038/s41586-021-03655-4>.

1. Whitehouse, H., et al. Complex societies precede moralizing gods throughout world history. *Nature* **568**, 226–229 (2019).
2. *Seshat: The Global History Databank* (Evolution Institute & Seshat Project, 2015); <http://seshatdatabank.info/>
3. Watts, J. et al. Broad supernatural punishment but not moralizing high gods precede the evolution of political complexity in Austronesia. *Proc. R. Soc. Lond. B* **282**, 20142556 (2015).
4. Little, R. J. A. & Rubin, D. B. *Statistical Analysis with Missing Data* (John Wiley & Sons, 2014).
5. McElreath, R. *Statistical Rethinking: A Bayesian Course with Examples in R and Stan* (Chapman and Hall/CRC, 2020).
6. Gelman, A. & Hill, J. *Data Analysis Using Regression and Multilevel/hierarchical Models*. (Cambridge University Press, 2007).
7. Wheatley, P. *The Pivot of the Four Quarters: A Preliminary Enquiry into the Origins and Character of the Ancient Chinese City* (Edinburgh University Press, 1971)

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Author contributions R.S., B.G.P., M.M., M.L., J.H., R.D.G., B.B. and Q.A. designed the reanalysis. R.S., M.L., B.G.P. and B.B. performed the re-analyses. R.S., M.L. and B.G.P. reviewed code. E.S. and M.W.M. reviewed and vetted historical coding. All authors wrote the manuscript.

Competing interests R.D.G., J.H., M.M., M.W.M., E.S. and R.S. are involved in the Database of Religious History (DRH) project, another freely available online historical database.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41586-021-03655-4>.

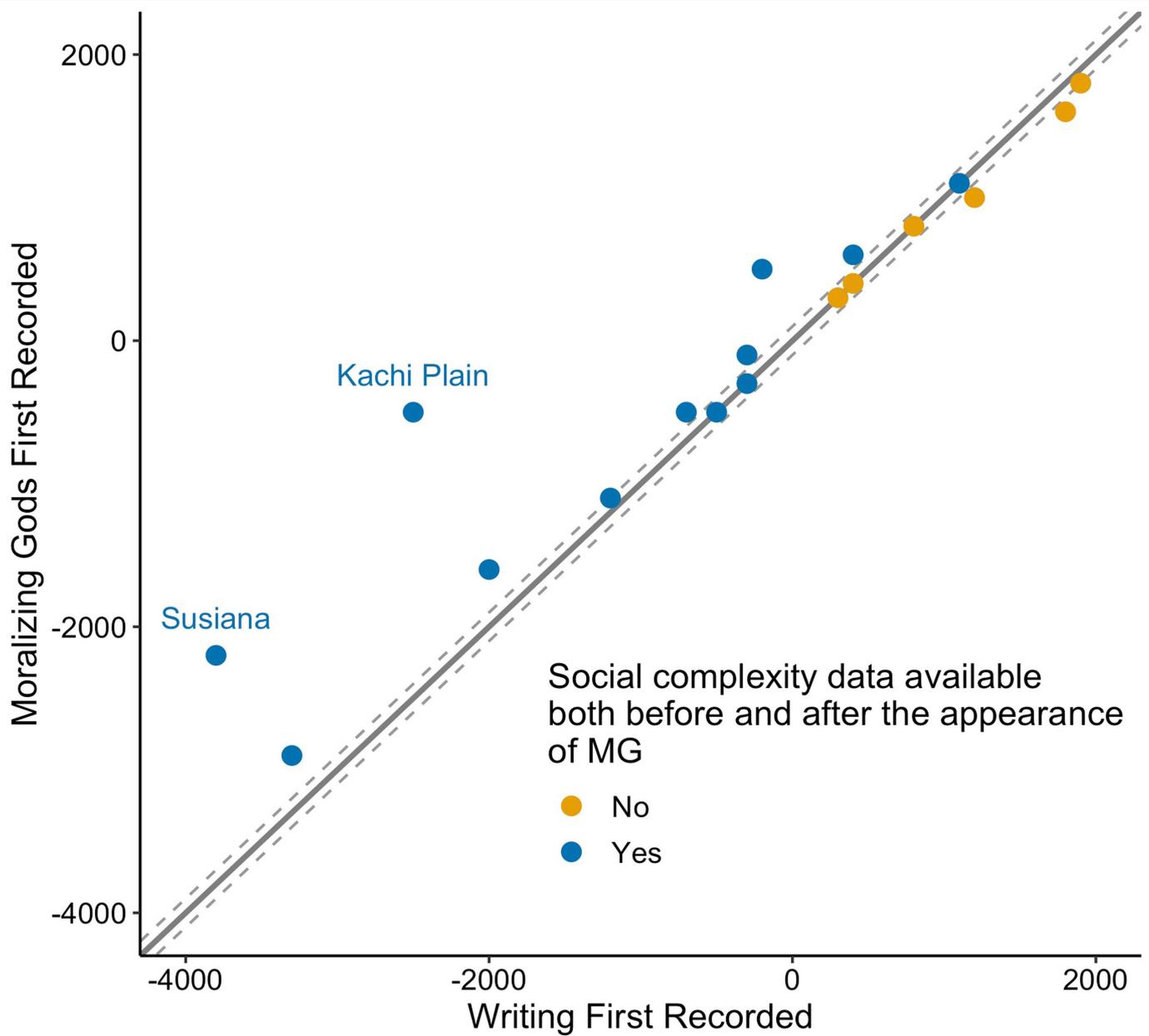
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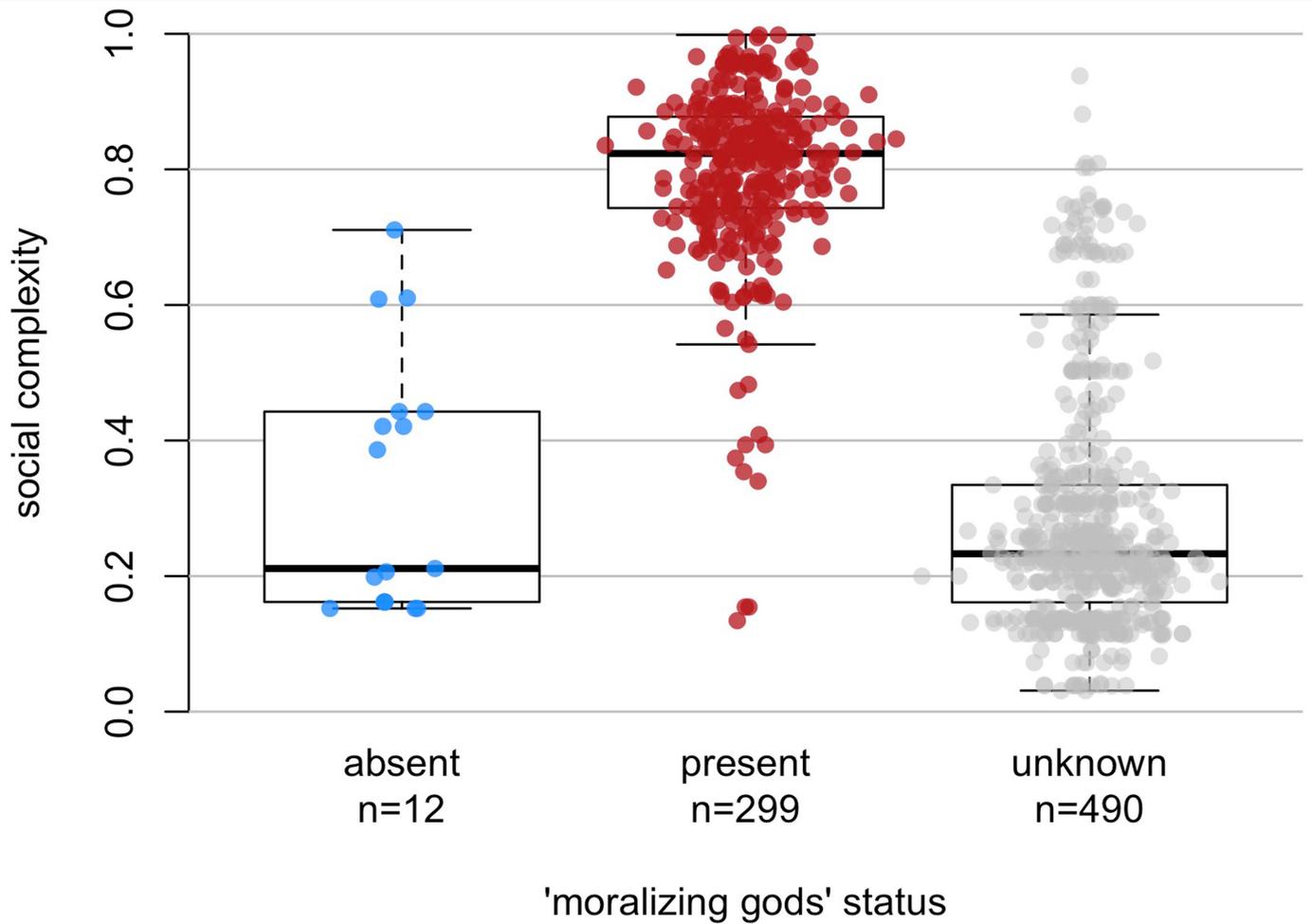
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Matters arising



Extended Data Fig. 1 | The first appearance of writing and moralizing gods across NGAs. The solid line indicates when writing and moralizing gods (MGs) are first recorded in the same century, and the dashed lines show when writing appeared 100 years before moralizing gods and when moralizing gods appeared 100 years before writing. NGAs are coloured by whether social complexity data are available both before and after the appearance of moralizing gods or not. Only natural geographic areas with social complexity

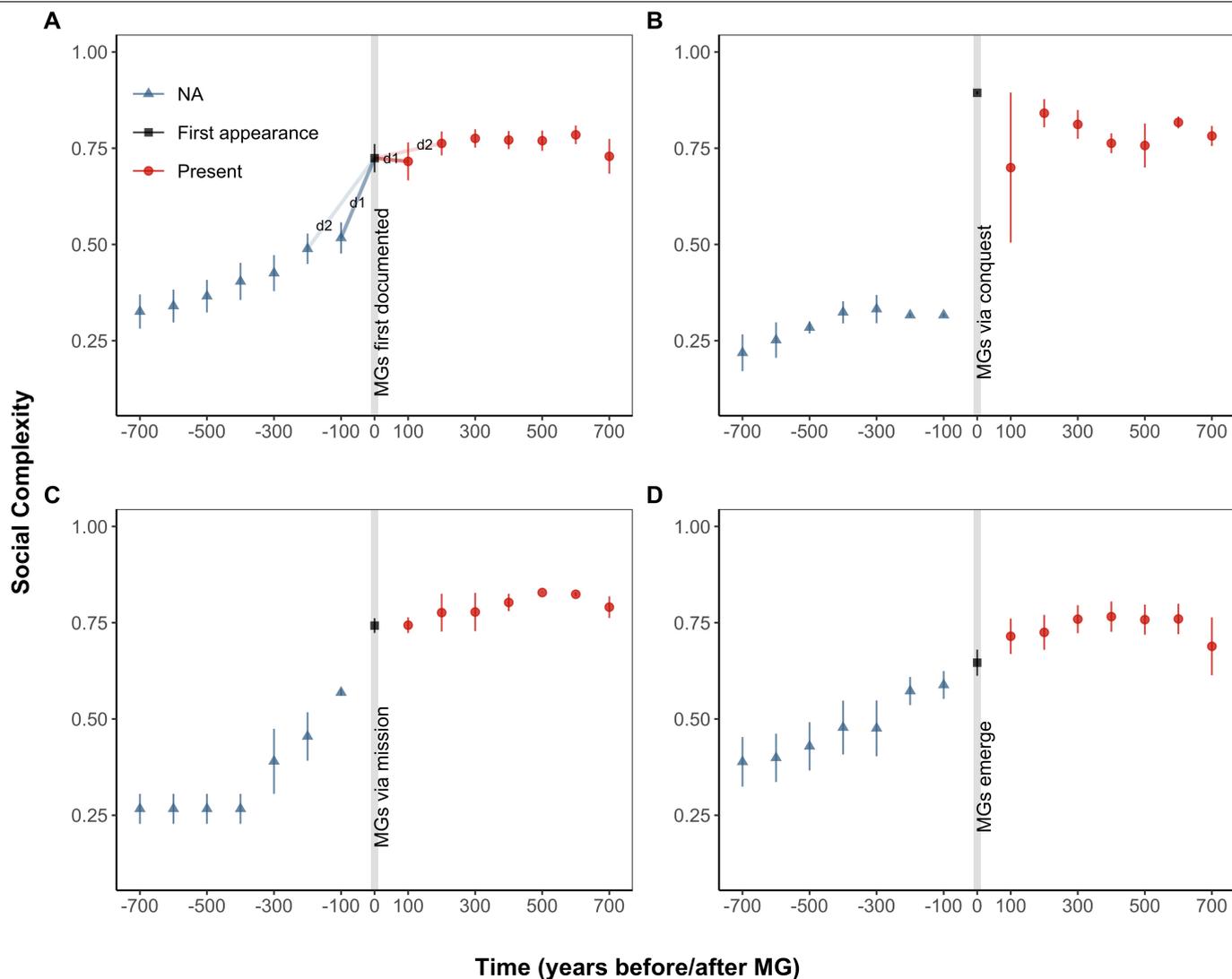
data available both before and after the appearance of moralizing gods were included in the analysis (and only these natural geographic areas are shown in Fig. 1). It must be noted that while writing first appears at 2500 BC in the Kachi Plain, it is absent for the subsequent two polities in the dataset, and does not reappear until 300 BC – the same time as the first appearance of moralizing gods.



Extended Data Fig. 2 | Distribution of social complexity score by 'moralizing gods' outcome status. Before statistical analyses were performed in Whitehouse, et al.¹, all 'unknown' or 'suspected unknown' (NA) cases were treated as moralizing gods 'absent' (0) without explicit description

in the manuscript. In box plots centre line shows median, box limits indicate upper and lower quartiles and whiskers span 1.5× interquartile range). $N = 801$ observations.

Matters arising



Extended Data Fig. 3 | Social complexity before and after the appearance of moralizing gods. Dots represent mean social complexity as calculated by Whitehouse, et al.¹ (a combination of population and territory size, infrastructure, hierarchy, and other factors, standardized between 0 and 1) collapsed across natural geographical area. Data are mean \pm s.e.m. The shading of lines connecting the dots in **a** reflects the weight that the difference (d_1, \dots, d_7 ; on d_1 and d_2 are shown) between the social complexity at time point n and time point 0 in the t -test analysis performed by Whitehouse, et al.¹ (that is, differences in social complexity are highest around time 0, hence driving the forward bias). Note that the increase in social complexity from time point -100 to 0 is coded as pre-moralizing gods, while the complexity often arrives via

conquest or mission together with moralizing gods. **a**, The 'first appearance' of moralizing gods (MGs) in the archaeo-historical records follows a sharp increase (39%) in social complexity in the 12 geographical areas. **b**, The sharp increase in social complexity just before the appearance of moralizing gods is partially caused by ascribing properties of conquerors to the conquered regions in the Deccan, Kachi Plain and Sogdiana regions. **c**, Similarly, regions receiving moralizing gods via mission (Kansai, Niger Inland Delta and Orkhon Valley) experience a sharp increase in social complexity. **d**, The remaining six natural geographical areas where moralizing gods were not first recorded through conquest by a larger empire or through mission show a steady rise in social complexity.

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Data collection Secondary analysis on public data; no software was used.

Data analysis R (v3.5.3), with the following R packages: rstan (2.18.2), glmmTMB (0.2.3), glmmADMB (0.8.5), rethinking (1.88); supplementary packages listed at github.com/babeheim/moralizing-gods-reanalysis

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Behavioural & social sciences study design

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Study description	Quantitative reanalysis of longitudinal macro-historical datasets at the level of regional polities using regression-discontinuity, t-test, and hierarchical, generalized linear model designs.
Research sample	Existing dataset using the Seshat database file "exportdat.csv" reported in Whitehouse, et al. (2019) DOI: 10.1038/s41586-019-1043-4, scraped on 10 January 2018. Data units are individual centuries for 28 world geographic areas from roughly 4,000 BCE to 2,000 CE, coding demographic, technological, geographic, political, and religious information for that region. In total, N = 801 such observations are used in logistic regression analyses, and a subset of 12 world regions at multiple time horizons are used for the beta, t, and discontinuity tests.
Sampling strategy	N/A - secondary re-analysis of existing, published dataset.
Data collection	N/A - secondary re-analysis of existing, published dataset.
Timing	N/A
Data exclusions	Century-wide data were excluded in pre-determined time horizons of seven centuries in the beta regression and discontinuity tests for 12 world regions. Century-wide data with missing outcome variables (n=465) were excluded or imputed before logistic regression modeling according to three imputation methods described in text.
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