LETTER

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Greater post–Neolithic wealth disparities in Eurasia than in North America and Mesoamerica

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How wealth is distributed among households provides insight into the fundamental characters of societies and the opportunities they afford for social mobility[1,2]. However, economic inequality has been hard to study in ancient societies for which we do not have written records[3,4], which adds to the challenge of placing current wealth disparities into a long-term perspective. Although various archaeological proxies for wealth, such as burial goods[5,6] or exotic or expensive-to-manufacture goods in household assemblages[7], have been proposed, the first is not clearly connected with households, and the second is confounded by abandonment mode and other factors. As a result, numerous questions remain concerning the growth of wealth disparities, including their connection to the development of domesticated plants and animals and to increases in sociopolitical scale[8]. Here we show that wealth disparities generally increased with the domestication of plants and animals and with increased sociopolitical scale, using Gini coefficients computed over the single consistent proxy of house-size distributions. However, unexpected differences in the responses of societies to these factors in North America and Mesoamerica, and in Eurasia, became evident after the end of the Neolithic period. We argue that the generally higher wealth disparities identified in post-Neolithic Eurasia were initially due to the greater availability of large mammals that could be domesticated, because they allowed more profitable agricultural extensification[9], and also eventually led to the development of a mounted warrior elite able to expand polities (political units that cohere via identity, ability to mobilize resources, or governance) to sizes that were not possible in North America and Mesoamerica before the arrival of Europeans[10,11]. We anticipate that this analysis will stimulate other work to enlarge this sample to include societies in South America, Africa, South Asia and Oceania that were undersampled or not included in this study.

We use house size as a proxy for household wealth, because it is often archaeologically visible and integrates embodied, relational and material aspects of wealth[12] (Supplementary Table 1). Specifically, we calculated Gini coefficients for house-size distributions in a sample of 63 sites or groups of sites from a single archaeological culture that are contemporaneous within the available temporal precision, selected in part for the quality of preservation, investigation and reporting (Fig. 1 and Supplementary Table 2). The archaeological contexts sampled from the Old World range from around 11,000 to about 2,000 years ago (plus one recent set of !Kung San encampments), and in the Americas, from around 3,000 to about 300 years ago. The contexts that we discuss therefore considerably pre-date those early modern societies that are usually the oldest for which quantitative assessments of inequality are attempted—and such estimates are with few exceptions[5] based on income not wealth[3,13]. Unlike most previous analyses, our sample includes a number of non-European cases, including China and pre-Columbian North America and Mesoamerica.

Ethnographic analogy suggests that, except for sedentary hunter-fishers in areas of high productivity, wealth disparities were probably low among ancient hunter-gatherers[4]. Logically, wealth disparities cannot accumulate within lineages until mechanisms for transmission of wealth across generations (including transfers and assortment or positive feedback effects) become common, as is much more likely among sedentary societies. Indeed, in keeping with their generally greater pedestrian residential mobility, less wealth is typically transmitted across generations in hunter-gatherer and horticultural societies than in agricultural or pastoral societies[12].

The type of wealth transmitted in societies with different economic systems tends to vary according to the type of wealth that is most prominent. Among hunter-gatherers and horticulturalists, embodied wealth (with proxies including grip strength, body weight, reproductive success and hunting success) and relational wealth (number of exchange or sharing partners, number of allies in conflict and size of kin networks) are more prominent, and more likely to be transmitted across generations, than material wealth, such as livestock, land and tools. Material wealth accumulation and transmission are most common in agricultural and pastoral societies[14].

Evidence that house size provides a reliable estimate for household wealth comes not only from ethnographic documentation (Supplementary Table 1), but also from comparisons of our estimates of Gini coefficients in ancient societies of various types with analyses made using different proxies for contemporary and recent societies of these same types (Methods). In general, we find that our house-size-based Gini coefficients for hunter-gatherers are slightly lower than those estimated in other ways. Our estimates are about the same as a series of independent measurements for horticultural societies, but are also lower for agricultural societies.

As expected, the hunter-gatherers in this sample exhibit low Gini indices (wealth differences) using the house-size proxy (median = 0.17); the horticulturalists' Gini wealth measurements of 0.27 are markedly higher and those for agricultural societies are the highest (median = 0.35; Fig. 2a). In Fig. 3a, we plot the Gini coefficients based on house-size distributions through time by hemisphere. Although there is considerable overlap, the tendency for most of the

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Figure 1 | General location of sites/societies analysed. See Supplementary Table 2 for details. The base map was obtained from Natural Earth.

more recent Old World coefficients to exceed most of those in the New World was not anticipated.

Wealth differentials tend to increase as societies grow in size and increase in sociopolitical scale[4,15,16]. This tendency is generally visible in our sample (Fig. 2b). Therefore, one possible explanation for the differences in Old World and New World Gini coefficients in our sample is differential representation of political scale by hemisphere.

The association between political scale and hemisphere in our sample is slight ($\chi^2 = 7.594$, degrees of freedom (d.f.) $= 4$, $P = 0.108$; Fig. 2b and Supplementary Table 3). 'Local groups' are over-represented and 'big man collectivities' under-represented in the Old World sample (our use of these terms follows ref. 17); this could lower the Gini coefficients for the Old World relative to the New World. This therefore cannot explain the generally higher Gini coefficients that we identified in the Old World.

Another sample-representation factor that might influence these results is variation by hemisphere for the type of political regimes among the states. Contemporary nations with more autocratic regimes tend to exhibit higher levels of inequality than more democratic regimes[1,18]. We classified the states in our sample on a three-value ordinal scale, from collective to autocratic, following guidelines from ref. 19.

A marginally significant relationship exists between political strategy and hemisphere among the states in our sample ($\chi^2 = 5.10$, d.f. $= 2$, $P = 0.078$; Supplementary Table 4). The largest contribution to this association is the over-representation of collectively organized states in the Old World. Once again, this should tend to decrease, not increase, the Old World Gini coefficients relative to those from the New World.

To understand the true source of the hemispheric differences, it is helpful to plot the sites and societies in our sample relative to the local appearance of domesticated plants (Fig. 3b, Supplementary Table 2 and Methods). In Fig. 3b, the x axis (Δyears) represents the difference in date between the houses for which the Gini coefficients are calculated, and the time of the local arrival or development of domesticated plants.

Figure 3b reveals a similar trajectory for wealth differentials in the Old and New Worlds until approximately Δ2,500. Although the New World sample begins relatively earlier and exhibits slightly higher initial wealth disparities due to the inclusion of some sedentary hunter-gatherers, Gini coefficients in both series increase from levels typical of hunter-gatherers to levels more typical of small-scale agriculturalists by Δ1,800. Sites such as Grewe in the Early Pioneer Hohokam of Central Arizona and Jianxin in the middle–late Dawenkou of the Shandong province, North China, which are near contemporaries by this temporal estimate, exhibit similar wealth disparities.

After the period represented by these two sites, however, Old World societies continued to develop increased wealth disparities whereas these disparities remained steady or declined in North America and Mesoamerica. In Mesopotamia, excavated houses of the Old Babylonian period ($n = 106$) yield a Gini coefficient of 0.40. In this case, we can draw on ancillary information not used to compute the Gini coefficients that we report by noting that coefficients computed

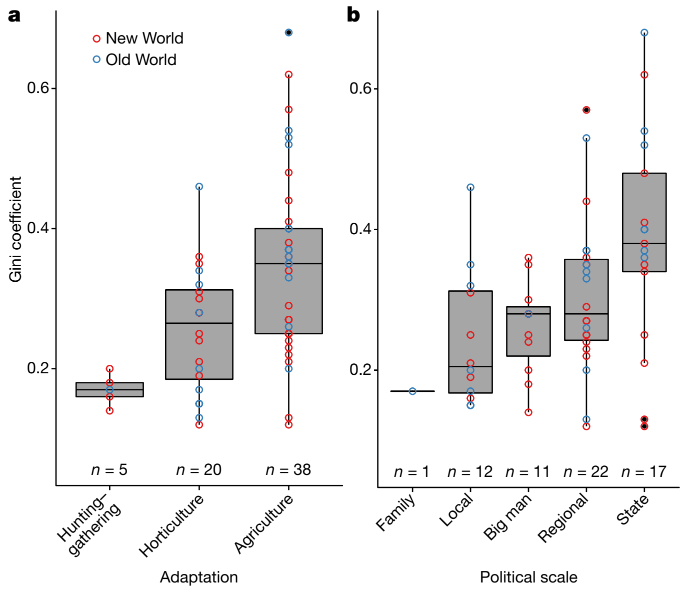

Figure 2 | Median Gini coefficients in the sample vary by adaptation type and political scale. a, Gini coefficients by adaptation type (following ref. 12); $n = 63$. Hunting–gathering includes mobile foragers and more sedentary complex hunter-gatherers. **b**, Gini coefficients by political scale (following ref. 17); $n = 63$.

from house sizes described in contemporaneous texts are higher (0.46), whereas coefficients computed from contemporaneous house-size prices reported in texts are very similar to those computed from excavation-based house-size distributions (0.38 for Nippur and 0.41 for Ur)[20].

These can be contrasted with the near-contemporaneous (Δyears) Xolalpan phase (AD 400–500) of Teotihuácan, one of the largest cities in ancient Mesoamerica. A high degree of urban planning, the lack of a very large royal palace, and the high dominance of intermediate-sized houses yield a markedly low Gini of 0.12 (ref. 21). Archaeologists increasingly consider this site to represent the capital of a 'collective' polity[22].

To explain the divergence of the Gini trajectories in the Old and New Worlds after Δ2,500, when New World Gini coefficients had stopped increasing, we focus on the agricultural extensification made possible by domesticated draft animals that were not available in the New World[9]. Although increasing agricultural production in areas such as southern Mesopotamia and Egypt required irrigation, in many other areas, such as northern Mesopotamia and Europe, plow animals acted as a multiplier for human labour[23] and enabled the preparation of a much larger area for sowing than a farming family could have cultivated by hand. Because the use of manure is likely to be highest in plots immediately surrounding settlement areas[24], the importance of agricultural extensification for urbanization in these areas is demonstrated by a significant negative relationship between the degree to which cereals were manured (inferred from grain δ^{15}N values) and site size beginning in the Late Chalcolithic period (around 4000 calibrated (cal.) BC)[25]. In addition to their contribution to farming extensification, large domesticated mammals also produced valuable manure and a number of 'secondary products', such as milk and fibre[26].

Agricultural extensification in turn had consequences. First, it is likely that only richer households could maintain draft animals[27]. Those households could profit from higher production and from renting labour of their animals to others, strengthening the correlation between wealth and income. Extensification probably increased agricultural surpluses averaged across all households in a society, raising the maximum attainable inequality[16] or the inequality possibility frontier[13]. Finally, extensification is land-hungry, eventually resulting, in the Old World, in a class of landless peasants that was larger than in the pre-Columbian Americas. These processes increased inequality by operating on both

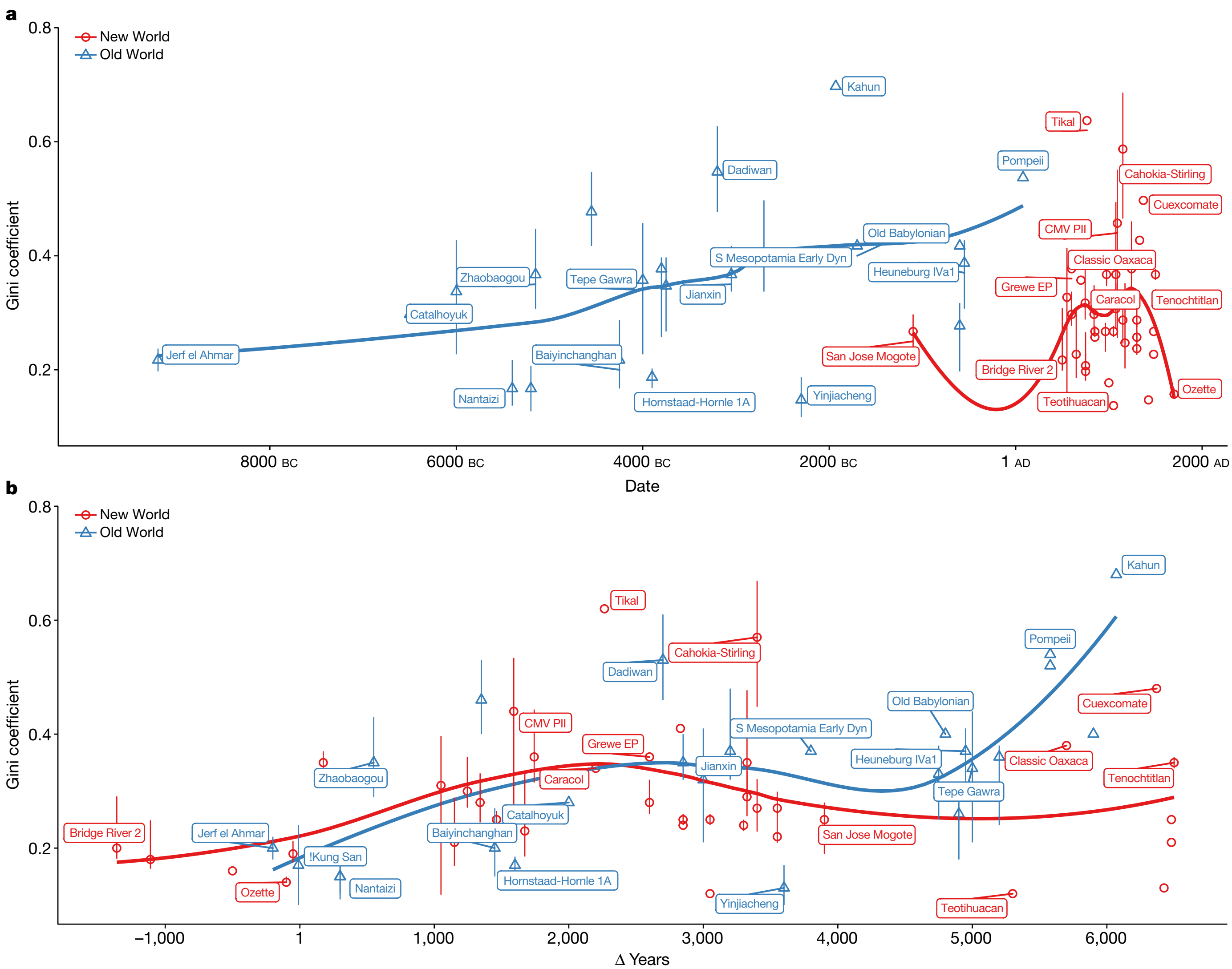

Figure 3 | Robust regression (using locally weighted scatterplot smoothing) of Gini coefficients on sample dates. a, Coefficients by absolute date of sample (calibrated BC/AD ^{14}C, tree-ring date or calendar date); $n=62$; !Kung San was excluded. **b**, Coefficients by Δyears (date of sample − date of the local appearance of domesticated plants); $n=63$. S Mesopotamia Early Dyn, Southern Mesopotamia Early Dynastic; CMV PII, Central Mesa Verde region Pueblo II.

ends of the wealth distribution, increasing the holdings of the rich while decreasing those of the poor.

We note, however, that wealth differentials in the Chinese cases here, even though they did not benefit from animal traction until the late third millennium BC[28], are generally in line with samples from the Near East and Europe. This suggests that 'food on the hoof' was also important in creating wealth disparities. We presume that even before the arrival of traction animals, unequal numbers of animals (pigs) were maintained by contemporaneous households in these societies, consistent with some empirical evidence[29,30].

Shortly after Δ3,000 many Eurasian societies developed bronze metallurgy and horse-mounted warfare. The emergence of a new mounted warrior elite contributed directly to higher Gini coefficients given their large rich houses and indirectly through territorial conquests that greatly increased polity scale[11]. Horses and pack animals (including camels in some areas) were potent offensive weapons[31] allowing successful polities to expand further than was possible in the New World. All 30 of the largest states and empires between 3000 and 600 BC were in the Old World[10].

In fact, post-Δ3,000 Eurasian societies expanded their wealth differentials through increases in demographic scale in ways that were not available for societies in North America and Mesoamerica. Greater wealth differentials are more strongly associated with increasing settlement size, regional population size and regional population density in the Old World than in the New World (Supplementary Table 5). Although explaining these differences in scaling behaviour is not our primary objective, it seems likely that they are connected with more economic specialization and long-distance exchange, in conjunction with lower frictions for long-distance transport by wheeled vehicles and more efficient water transportation in the Old World. The differential availability of large mammals that could be domesticated in the Old and New Worlds seems to have had diverse and far-reaching implications for the differing trajectories of societies in these two hemispheres.

The highest modelled wealth Gini coefficients in our Old World sample (0.48 at around AD 1, Fig. 3a; 0.60 at around Δ6,000, Fig. 3b) are similar to contemporary values for the Slovak Republic (0.45) and Spain (0.58)[32], although lower than for China (0.73)[33] or the United States in 2000 (0.80)[34]. (Substantial differences in the methods used by these studies need to be kept in mind.) More research is needed to determine how reliable the proxy of house size is as a measure for wealth in contemporary societies; we do know that housing wealth makes up about one half of household net worth in the United States[35] and about 70 per cent in China[33]. Even given the possibility that the Gini coefficients constructed here may underestimate true household wealth disparities, it is safe to say that the degree of wealth inequality experienced by many households today is considerably higher than has been the norm over the last ten millennia.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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Supplementary Information is available in the online version of the paper.

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METHODS

Sample. Of necessity this is a non-probabilistic sample of archaeological contexts. Sites that are not preserved, discovered, excavated and adequately reported cannot be included. Hunter-gatherer camps have poor preservation and low discoverability and are therefore underrepresented, and there are likewise preservation biases against earlier compared to later sites. Our sample is further limited by the necessity of having experts identify and interpret appropriate contexts, because we require that the Gini coefficients are constructed over penecontemporaneous households. Both the judgment of contemporaneity and of what constitutes a household require expert interpretation. Several areas (notably South America, South Asia, Oceania and Africa) are unrepresented or underrepresented and as a result we consider this a pilot study. Since South American camelids were useful for transport but not for traction, measuring the degree of wealth differentiation there will be especially helpful for determining the causes of the wealth differentiation in Eurasia. Eventually, wealth trajectories should be derived separately for all major world regions.

The !Kung San were removed from Fig. 3a as unrepresentative of the contemporary world, although they were retained in all other analyses.

Comparisons with contemporary and recent Gini coefficients. The Gini coefficients that we report, based on house-size distributions, are generally in line with recent calculations for living and recent societies of these types. Gini coefficients computed on various types of wealth among five societies of hunter-gatherers averaged to 0.25 (ref. 36); among four horticultural societies to 0.28 (ref. 37); and in eight agricultural societies to 0.44 (ref. 38). These are the average of the averages for each social type, unweighted by ethnographers' perceptions of the most important category for each type. In comparison, our median Gini estimates for such societies computed over house-size distributions are 0.17, 0.27 and 0.35, respectively (Fig. 2a). This suggests that Gini coefficients calculated from house-size distributions scale in the expected direction and are reasonable in overall magnitude, although they may underestimate household wealth inequality in hunter-gatherer and agricultural societies.

As another check for our method, a subset of our authors[5] developed 131 estimates of household material wealth inequality from archaeological and historical sources. In contrast to the approach here, they used a variety of proxies, processed to make them as comparable as possible. Their sample and ours overlap for several societies, but usually in those cases the Gini calculations are based on the same proxy of house size, and therefore the values are similar. In four cases reviewed in Supplementary Table 6, Gini coefficients are estimated for the same or similar contexts using different bases. This sample is too small to draw firm conclusions, but it suggests that Gini coefficients based on distributions of burial goods may be much higher than those based on house-size distributions. More research is needed to determine whether these should be considered different dimensions of a single multivariate concept, or whether one should be preferred over another for specific uses. Here we have chosen to develop and interpret a single consistent proxy.

Statistical analyses and graphics. No weighting by number of households per data point was performed in any of the graphics or analyses. Gini computations were performed so as to be unbiased for small sample sizes[39]. Confidence intervals calculated by us in Fig. 3 are 80%, produced by at least 1,000 bootstrap replicates, and are bias corrected. In cases where Gini values were taken from the literature, there are usually no confidence intervals and the mechanics of computation are usually unknown. Loess (locally weighted scatterplot smoothing) regression lines in Fig. 3 were generated using an alpha (or span) of 0.5, yielding fits that seemed to be the most interpretable balance between rough and smooth.

The interpretations in the text as to which cells contribute most to the lack of fit in Supplementary Tables 3, 4 are based on the magnitudes of the cell χ^2 contributions.

The measurements of demographic scale on which Gini coefficients are regressed (Supplementary Table 5) draw on a number of sources, derived independently for their areas by each data contributor (Supplementary Table 2). Site population in households is the most straightforward and was often estimated by the original excavator. Nevertheless, credible estimates are lacking for 25 cases. For regional population in households, each data contributor was asked to derive sizes of regions that were traditional in their areas or that made sense because of the availability of existing population estimates. Regional population sizes are lacking for 18 cases. In the analyses reported in Supplementary Table 5, Gini coefficients were regressed on the $\log_{10}$ of the demographic analyses, rather than on the raw values, to compensate for right skew.

Our use of Δyears as a measurement of time relative to the local arrival or development of Neolithic lifestyles is inspired by studies of the Neolithic demographic transition[40,41]. This convention is useful for putting temporally transgressive changes across large areas on a common footing, and in our case makes it possible to directly compare the rate and magnitude of changes in household wealth inequality in the two hemispheres. The timing of arrival or local development of domesticated plants is a little problematic for the American Bottom (Cahokia) region. We could have used the date for the local arrival of maize (around AD 700) for the calculation of Δyears. Instead, we used the date at which the Eastern Agricultural Complex became locally well-established, around 3800 BP (about 2250 cal. BC)[42]. Using this date (instead of the maize arrival date) does not markedly change the shape of the fitted line for the New World in Fig. 3b, but delays by about 300 Δyears the point at which the fitted line for the Old World exceeds that for the New World.

Central Mexican Gini data are reported in ref. 21, except for the Aztec capital Tenochtitlan, which was calculated here for the first time. We use the 'social tables' approach[43], as adapted by ref. 21 for archaeology. We posit four social categories. The consensus population of Tenochtitlan (212,500) is apportioned among these four categories as follows: (1) imperial family: 1 household of 200 persons; (2) other nobles: 293 households with a mean household size of 15; nobles, including the royal family, are assumed to comprise 2% of the city's population[21]; (3) wealthy commoners: 1,486 households of 7 persons, or a total of 5% of the commoner population; and (4) other commoners: 28,236 households of 7 persons.

The imperial palace was 25,425 m^2 (ref. 44). House sizes for the other categories are derived from the area of houselots in Tenochtitlan in the early colonial period. This dataset was assembled by E. Calnek[45], who calculated rectified area measurements of the total size of houselots from 16th century maps in the Archivo General de la Nación, Ramo Tierras, in Mexico City. Houselot size has three modes, which are taken to match the three non-imperial categories (Supplementary Table 7). We tried two approaches for calculating Gini coefficients on these data. For method 1, we simply took the category means and multiplied them by the number of households in that category, then calculated Gini coefficients over that pseudo-population (which thus had only four distinct values). That yielded a Gini of 0.13. For method 2, we repeatedly generated random, normally distributed pseudo-populations of houselot sizes in each size category using the mean and standard deviation of that category. For the 'commoner' category, we truncated the population distribution at 52 m^2, the mean of the five smallest houselots in that category. This approach yielded a mean Gini = 0.302, $s = 0.003$, across the multiple determinations, each based on a different pseudo-population derived from the parameters above. We prefer the second method and use that here.

Data availability. The full dataset is provided as Supplementary Table 2.

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☐ Initial submission ☐ Revised version ☒ Final submission

Life Sciences Reporting Summary

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Experimental design

1. Sample size

Describe how sample size was determined.	We used all the samples of structures with high-quality preservation, excavation and reporting, and where household use of space could be reconstructed with reasonable assurance, that were personally known to the author(s) responsible for each region.

2. Data exclusions

Describe any data exclusions.	Some regions are not represented because we did not have a regional specialist available. Some samples within regions for which we did have a specialist were excluded because of poor preservation, excavation, recording, or inability to assign households to spaces. In Fig. 3a, the !Kung San data point is eliminated, since it poorly represents diversity in house size in the Old World ca. 1970.

3. Replication

Describe whether the experimental findings were reliably reproduced.	Replication, strictly speaking, is impossible in archaeology. We do believe that our samples are large enough to see that the patterns we note are becoming redundant.

4. Randomization

Describe how samples/organisms/participants were allocated into experimental groups.	No randomization in sample selection was possible, although we used a randomization approach to determine the Gini for Tenochtitlan, as described in the Methods section. Samples were allocated into regions by geography; into temporal periods based on criteria (e.g., tree-ring dates, 14C dates, textual sources) appropriate to each sample; and into groupings based on subsistence regime or political scale based on the expert judgment of the regional specialists

5. Blinding

Describe whether the investigators were blinded to group allocation during data collection and/or analysis.	The regional specialists who provided the Gini coefficients also provided the geographic and temporal assignments, and the allocation into subsistence regimes and political scales, for the sample(s) for which they were responsible. However, they did this independently of each other, and prior to the pattern-seeking exercises described in this paper were undertaken. Our main result (the greater post-Neolithic wealth disparities in the Old World) was not recognized by any of the authors when these assignments were made and the Gini coefficients calculated.

Note: all studies involving animals and/or human research participants must disclose whether blinding and randomization were used.

6. Statistical parameters

For all figures and tables that use statistical methods, confirm that the following items are present in relevant figure legends (or in the Methods section if additional space is needed).

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement (animals, litters, cultures, etc.)
☒	☐	A description of how samples were collected, noting whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	A statement indicating how many times each experiment was replicated
☐	☒	The statistical test(s) used and whether they are one- or two-sided (note: only common tests should be described solely by name; more complex techniques should be described in the Methods section)
☐	☒	A description of any assumptions or corrections, such as an adjustment for multiple comparisons
☐	☒	The test results (e.g. *P* values) given as exact values whenever possible and with confidence intervals noted
☐	☒	A clear description of statistics including central tendency (e.g. median, mean) and variation (e.g. standard deviation, interquartile range)
☐	☒	Clearly defined error bars

See the web collection on statistics for biologists for further resources and guidance.

Software

Policy information about availability of computer code

7. Software

Describe the software used to analyze the data in this study.	We used R and R Studio for all graphics and analyses, invoking various libraries depending on the analysis. No custom computer code was employed, beyond the minimum necessary to generate the figures.

For manuscripts utilizing custom algorithms or software that are central to the paper but not yet described in the published literature, software must be made available to editors and reviewers upon request. We strongly encourage code deposition in a community repository (e.g. GitHub). *Nature Methods* guidance for providing algorithms and software for publication provides further information on this topic.

Materials and reagents

Policy information about availability of materials

8. Materials availability

Indicate whether there are restrictions on availability of unique materials or if these materials are only available for distribution by a for-profit company.	n/a

9. Antibodies

Describe the antibodies used and how they were validated for use in the system under study (i.e. assay and species).	n/a

10. Eukaryotic cell lines

a. State the source of each eukaryotic cell line used.	n/a
b. Describe the method of cell line authentication used.	n/a
c. Report whether the cell lines were tested for mycoplasma contamination.	n/a
d. If any of the cell lines used are listed in the database of commonly misidentified cell lines maintained by ICLAC, provide a scientific rationale for their use.	n/a

Animals and human research participants

Policy information about studies involving animals; when reporting animal research, follow the ARRIVE guidelines

11. Description of research animals

Provide details on animals and/or animal-derived materials used in the study.	n/a

Policy information about studies involving human research participants

12. Description of human research participants

Describe the covariate-relevant population characteristics of the human research participants.

n/a