Coin hoards speak of population declines in Ancient Rome

Peter Turchin[a,1] and Walter Scheidel[b]

[a]Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT 06269; and [b]Department of Classics, Stanford University, Stanford, CA 94305

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In times of violence, people tend to hide their valuables, which are later recovered unless the owners had been killed or driven away. Thus, the temporal distribution of unrecovered coin hoards is an excellent proxy for the intensity of internal warfare. We use this relationship to resolve a long-standing controversy in Roman history. Depending on who was counted in the early Imperial censuses (adult males or the entire citizenry including women and minors), the Roman citizen population of Italy either declined, or more than doubled, during the first century BCE. This period was characterized by a series of civil wars, and historical evidence indicates that high levels of sociopolitical instability are associated with demographic contractions. We fitted a simple model quantifying the effect of instability (proxied by hoard frequency) on population dynamics to the data before 100 BCE. The model predicts declining population after 100 BCE. This suggests that the vigorous growth scenario is highly implausible.

census data | civil war | demography | mathematical model | preindustrial society

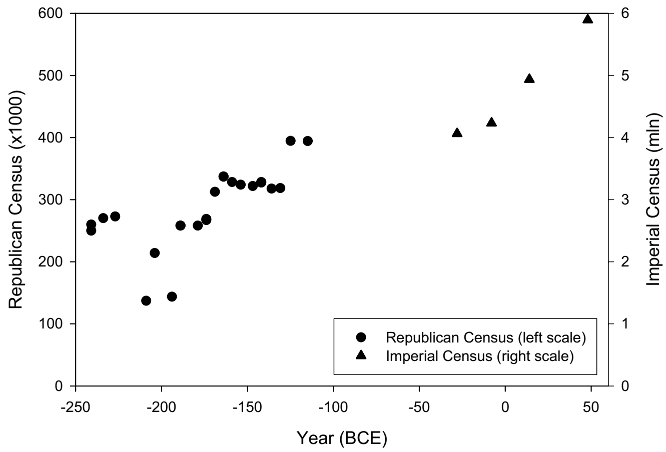

Fig. 1. Census data (1).

Population size and its change over time are defining characteristics of human societies. Our appreciation of the military and fiscal potential of a given state and our reconstructions of economic growth and decline critically depend on demographic variables. We cannot hope to understand how historical states functioned unless we are able to obtain at least a rough estimate of their population numbers. Yet the scarcity of reliable statistics from premodern societies can make it difficult to ascertain even the correct order of magnitude, let alone track change over time. Moreover, in those rare cases in which serial census data do exist, translating them into viable estimates is no trivial task. Roman historians, for example, have been unable to agree on how to interpret an abrupt jump in recorded census tallies that occurred during the first century BCE.

The "Low Count" Vs. "High Count" Controversy. During the Republican period (fifth to first centuries BCE), adult male Roman citizens were liable to conscription and taxation and entitled to vote in popular assemblies. These rights and obligations required periodic registration of the citizens and their assets. For this purpose state officials conducted censuses of adult male citizens at relatively short intervals, usually every 5 years. From the middle of the third to the end of the second centuries BCE, the attested numbers gradually (and noisily) rose from around 200,000 to close to 400,000 (Fig. 1). By contrast, three censuses organized by the first emperor Augustus in 28 BCE, 8 BCE, and 14 CE document a population that increased from 4–5 million, while a later census recorded 5.9 million in 48 CE (Fig. 1). One reason for this discontinuity is uncontroversial. At the end of the Social War (91–89 BCE) the Roman state granted citizenship to its peninsular Italian allies. According to the estimate of Peter Brunt (1:97), this mass enfranchisement approximately tripled the number of Roman citizens. The subsequent extension of citizenship to the inhabitants of Italy north of the Po River in 49 BCE increased the total by a number equivalent to a quarter of the post-89 BCE tally (1:117). Together, these expansions account for <40% of the observed increase in the census totals, and we are left to explain a 2- to 3-fold increase of the Roman citizen population during the century before the first Augustan census.

One solution is to assume that the Augustan population counts reflect a shift from the registration of adult male citizens to that of the entire citizenry including women and minors (1, 2); given the probable age structure of the Roman population, this ought to have approximately tripled the official tally. However, this putative shift is not mentioned in the sources, and this thesis—known as the "low-count" hypothesis—has been criticized because it implies a net decline in the free Italian population during the first century BCE and logically presupposes urbanization and military participation ratios that are high by comparative historical standards (3–5). The principal alternative—or "high-count" hypothesis—is to assume that the identity of the census population did not change (3, 6–9). This notion poses a serious challenge to modern narratives of Roman history that are commonly (although usually implicitly) predicated upon acceptance of the "low-count" scenario. As one of us has observed, if the "high count" were correct, much of Roman history would have to be rewritten (10). More generally, the presence of a very large population in ancient Italy would imply levels of economic output that were extremely high by premodern standards and thereby require sweeping reconsideration of the performance potential of premodern economies. For this reason alone, this controversy is of great importance far beyond the field of Roman History.

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[1]To whom correspondence should be addressed. E-mail: peter.turchin@uconn.edu.

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There are three major arguments against the "high-count" hypothesis. First, it implies a total Italian population of nearly 20 million by the late first century CE (5, 10). In peninsular Italy, a corresponding population density was not attained until the mid-nineteenth century, when New World crops had already begun to make a significant contribution to farm output. Second, ancient evidence of massive slave imports numbering in the millions during the last 2 centuries BCE and of rapid increases in the cost of military labor in the first century BCE is consistent with strong demand for labor that is hard to reconcile with the notion of strong natural population growth as implied by the "high-count" hypothesis (5, 11). Third, the century before the establishment of a stable monocratic regime by Augustus (130–30 BCE) was characterized by violent conflict: slave rebellions (including the famous Spartacus uprising), the Social War between Romans and their Italian allies, and several periods of civil war, as well as a host of lesser-instability events. Unlike the wars of the Roman Republic during the second century BCE that took place outside Italy proper, many of these later conflicts were internal in the sense that they either took place on Italian soil or drew large numbers of Italians into combat outside the region. Historical evidence indicates that such high levels of sociopolitical instability tend to be associated with demographic contractions. Thus, a recent analysis of quantitative historical data shows that sociopolitical instability is a good predictor of population change in early modern England and France, in the middle and late Roman Empire (the period following the one on which our article is focused), and in ancient and medieval China (see Tables S1 and S2). Conversely, the "high-count" hypothesis requires us to accept that vigorous population growth could occur in the context of recurrent internecine wars.

Quantifying the Effect of Instability on Population Growth. Can this argument be made quantitative? So far scholars on both sides of the debate have relied on traditional historical methods: careful reading of the sources and close (but ultimately impressionist) scrutiny of the validity of individual pieces of information and the plausibility of competing claims, supplemented by inferences from comparative evidence. Here, we propose an approach that is similar to the methods used in the natural sciences. Our approach is based on an empirical model of the relationship between population dynamics and internal warfare.

We start from the premise that the census data can be treated as a signal reflecting real population dynamics, although contaminated by large amounts of noise. Faulty transmission of numbers across the ages is one source of error. For example, two different ancient authorities report totals of 250,000 and 260,000 for the census of 241 BCE (1, page 13). We do not attempt to determine which number is correct and include both into the database. The second source of error is that the recorded numbers can be expected to have undercounted the actual population: no census is perfect, not even in modern times. Brunt generally reckoned with an undercount of 10% (1, page 61), yet the actual margin of error probably varied with time. We model both sources of error as a stochastic process.

In addition to population data we also need a variable that quantifies the dynamics of internal warfare. Michael Crawford (12) observes that the temporal distribution of coin hoards in Italy reflects with high accuracy the dynamics of warfare in this region (Fig. 2). The reasons for this correlation are not hard to fathom. People tend to hide their valuables in times of violence and danger. Emergency hoards would later be recovered by the owners unless they had been killed or driven away. As a result, the greater the intensity of warfare, the more hoards are left in the ground to be discovered by archaeologists. For this reason, the time-specific deposition rate of hoards serves as an index of internal instability caused by violent conflict and dislocation. The pattern observed in Fig. 2 shows no correlation with the

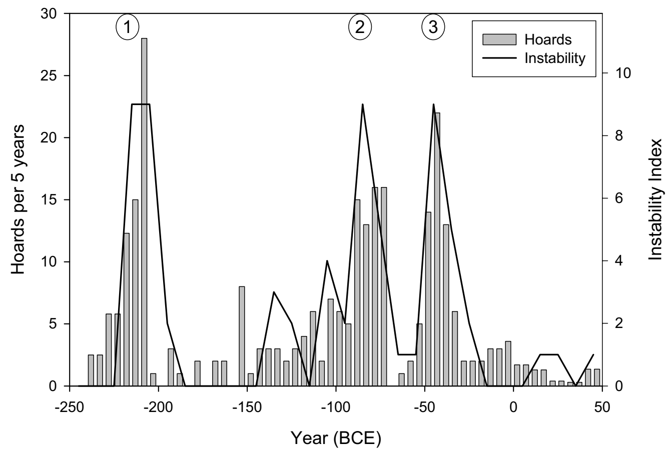

Fig. 2. Temporal distribution of coin hoards (12) compared with the instability index. The circled numbers indicate period of intense internal warfare: 1. Second Punic War; 2. Social War, civil war between Marius and Sulla, and Spartacus uprising; 3. Civil wars between Caesar and Pompey, the Second Triumvirate and Caesar's assassins, and Octavian and Antony (see Tables S3 and S4, Fig. S1).

steady growth of the Roman stock of coinage during this period, which suggest that the distribution of coin hoards was not sensitive to changes in the money supply (13, page 109). It deserves attention that in other periods and places internal warfare also appears to be the most important determinant of peaks in the temporal distribution of hoards (ref. 14 and Figs. S2–S6).

To quantify the effect of internal warfare on population dynamics we fitted a simple model to the census and coin hoard data:

$$N_{t+\Delta t} = N_t + (r_0 - gW_t)N_t\Delta t \qquad [1]$$

Here, N_t is the number of citizens in year t, W_t is the intensity of internal warfare (measured by the number of hoards), and Δt is the time step, taken to be 1 year. Eq. **1** is simply a discrete version of the exponential growth model, $N_{t+\Delta t} = N + r_t N_t \Delta t$, in which the per capita growth rate, r_t, is assumed to be a linear function of war intensity. Parameter r_0 is the maximum rate of population growth (when conditions are peaceful) and g measures warfare's depressing effect on population growth. The model is very simple, indeed simplistic; however, when data are scarce and corrupted by large amounts of noise we do not enjoy the luxury of fitting complex models with many parameters.

To determine the relative plausibility of the "high-count" vs. "low-count" hypotheses we first estimated the model parameters on the data series before 100 BCE, before the enfranchisements and the possible shift in the identity of the censused, postulated by the "low-count" hypothesis (see *Methods*). Although the model is simple, the fitted trajectory successfully captures the major trends in the census data: the short-lived population increase before the Second Punic War, demographic contraction during the war, and sustained population growth in the second century BCE (Fig. 3*A*). The worst deviations between the fitted trajectory and data are the two data points for 209 and 194 BCE, which are marred by difficulties of conducting census during the War with Hannibal and large numbers of Romans stationed outside Italy after the war.

Next, we used the model to predict the trajectory after 100 BCE using the hoard data but not the censuses. Thus, our procedure for testing the two hypotheses is not in any way circular: we fitted the model on one set of data, and tested the hypotheses on another, separate one. The result is unambiguous

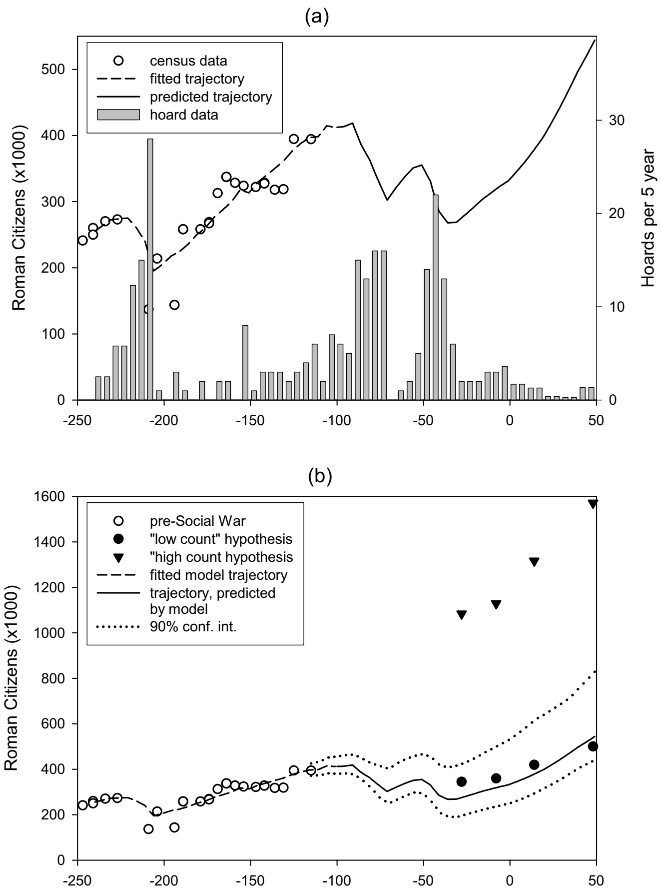

Fig. 3. Results of testing the "high-count" versus "low-count" hypotheses. The hollow circles represent the census numbers during the third and second centuries BCE (before the enfranchisement of the Italian allies). The triangles indicate what the numbers of citizens would have been following the assumptions of the "high-count" hypothesis if there had been no enfranchisements, a group we label "original citizens." These numbers are obtained by dividing the early imperial census numbers by 3.75 to account for the enfranchisement. The solid circles indicate the number of "original citizens" under the "low-count" hypothesis. They are obtained by dividing the "high-count" tallies by 3.1, assuming that men aged 17+ accounted for approximately 32% of the population to account for the postulated shift of census coverage from adult males to all citizens. (*A*) Fitting the model on the pre-100 BCE data and projecting trajectory for the post-100 BCE period. (*B*) Comparing the projected trajectory with the "high-count" and "low-count" hypotheses.

(Fig. 3*B*): given the high level of internal warfare in Italy during the first century BCE, the population trajectory postulated by the "high-count" hypothesis is highly implausible. The population totals associated with the "low-count" hypothesis, in contrast, closely match the predicted values.

Conclusion

Our quantitative and empirically tested model speaks strongly against the assumption of robust natural population growth in Roman Italy in the first century BCE and thus offers further support for the "low-count" hypothesis. Our results are clearly inconsistent with the predictions of the "high count" hypothesis and consequently fail to support the notion of pronounced Roman economic and demographic exceptionalism. More generally, our results indicate that a formal approach combining modeling and data analysis (even if our model was very simple) can compensate for the scarcity of reliable statistics from premodern societies.

Methods

Sources of Data. The transmitted census totals were taken from Brunt (1). Where sources report different totals we give both numbers. The list of internal warfare incidents is taken from Turchin and Nefedov (14), which in turn is based on Sorokin (15). Both population and instability data are tabulated in *SI Text*.

Quantifying Instability from Narrative Sources. Instability index (with which the frequency of coin hoards is compared in Fig. 2) was constructed in the following way. We divided the whole period into decades (240–231 BCE, 230–221 BCE, …, 41–50 CE). The Instability Index is the number of years within each decade that was in an instability event. For example, in the decade of 220–211 BCE, the years 218–211 were part of the Second Punic War, thus the Instability Index for the decade is 8.

Coin Hoard Frequency. Three compilations of Roman Republican coin hoards have been published (16–18). Because each author used different criteria for hoard inclusion and dating, there is some variation in the temporal distributions of hoards among the lists. We capitalized on this variation to estimate how robust our results are to variant methods in compiling hoard lists, and found that using different compilations changed the predicted population trajectory only by 2.5%–3.5% (see *SI Text*). Therefore, for the period of 240–1 BCE we use the Crawford list, as it is the only one that includes third century BCE hoards. For hoards buried between 1 and 50 CE, see *SI Text*.

Fitting the Model to Data. Model (1) was fitted to the data by the trajectory matching method (19). Let C_t be the number of citizens counted in the census conducted in year t, and H_t the number of hoards from year t. Assuming that the number of hoards is a good proxy for internal warfare, W_t, we have the model: $N_{t+1} = N + (r_0 - \gamma H_t)N_t$ (where Δt was set equal to 1 year). Parameter γ is the product of g in Eq. **1**. and the coefficient of proportionality between H_t and W_t. Given values of N_0 (the initial number of people), r_0, and γ we iterate the model forward to generate predicted values N_1, N_2, and so on. Next we calculate a measure of goodness of fit, the sum of squared deviations between N_t and C_t (this approach assumes that measurement errors follow the Gaussian distribution). Finally, we use a nonlinear minimization routine that selects those values of N_0, r_0, and γ for which the sum of squared deviations is the smallest—these are the best-fitting parameters of the model.

Note that our model focuses entirely on the effect of sociopolitical instability on population dynamics, whereas our previous work indicated that instability and population dynamics are linked by dynamical feedback loops (20, 21). Feedback between dependent and independent variable (two-way causality) does not mean that we have to deal with the statistical problem of *endogeneity*, because in our case it is not the W_t and N_t variables that are correlated. Instead, it is the *rate of change* of one variable that is influenced by another. As explained in Turchin (22), it is possible to quantify the dynamical feedbacks between both variables by regressing their rates of change on the values of variables. An application of this approach to several datasets, documenting both population and instability dynamics, is given in (21).

Estimating the 90% Prediction Interval. The 90% prediction interval was estimated by the bootstrap (23). The major source of error is the transmitted census totals, of which we have 24 data points (see Table S5*A*). We constructed "bootstrapped" dataset by sampling from the actual data "with replacement;" that is, some data points may end up in the bootstrapped set more than once, while others will not be chosen. The 24 bootstrapped data points were fitted with model (1) in exactly the same way as the actual data, and the values of estimated parameters noted. We then repeated the procedure 1,000 times. For each of one thousand bootstrapped parameter sets we iterated the model forward to 50 CE. To obtain the 90% prediction interval for each time step, we discarded the highest 5% and the lowest 5% predicted values (the prediction interval is indicated with the dotted line in Fig. 3*B* of the main publication).

Estimating the Ratio of Adult Males to the Total Population. Using Model South Males Level 3, $e_0 \approx 25$, $r = 0$ (24, page 449) we estimated that men aged 17+ accounted for approximately 32% of the population. Thus, the ratio of adult males to the total population is 1:3.1.

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