SOCIAL SCIENCES

Smithian growth in a nonindustrial society

Scott Ortman[1,2]* and José Lobo[3]

A defining feature of the contemporary world is economic growth, and the most frequently cited cause is technological change, especially with respect to energy capture and information processing. This framing masks the potential for economic growth in nonindustrial societies, but there is growing evidence for episodes where the material conditions of life did improve in the preindustrial past. Here, we explore a potential mechanism behind these improvements. We use settlement scaling theory to distinguish agglomeration-driven from technology-driven growth, and then we apply this framework to archaeological evidence from the Pre-Hispanic Northern Rio Grande Pueblos of New Mexico, USA. Results suggest that agglomeration-driven or "Smithian" growth was the dominant factor behind improvements in the material conditions of life over time in this society. We also summarize evidence that this growth took place in the context of a stable regional population, declining levels of inequality, and increasingly inclusive social institutions.

INTRODUCTION

A defining feature of the contemporary world is economic growth, understood as sustained increases in a society's material output per capita. Recent perspectives on this process attribute it primarily to increases in energy capture and information processing driven by technology (*1*, *2*). These capacities have increased rapidly since the onset of the industrial revolution, and this has led many to conclude that economic growth was therefore negligible in earlier periods (*3*, *4*). However, it is increasingly clear that many past societies did, in fact, generate substantial per capita increases in material outputs (*5*), energy capture rates (*6*), farming surpluses (*7*), consumption rates (*8*), and wealth accumulation (*9*), with proposed explanations for these trends ranging from technological progress (*10*, *11*) to institutional structures (*9*), urbanization (*12*), and expanding trade networks (*13*–*15*). Studies have also noted that economic growth is but one manifestation of a more general process of development involving improvement in material well-being (*6*, *16*).

Given the growing body of evidence indicating that material well-being did improve in the past, it is useful to recall that one of the original theorists of economic growth (Adam Smith, who lived and worked in a preindustrial society) proposed a growth mechanism based on population size, exchange, and the (economic) division of labor that explains how economic growth can occur even in the absence of technological change (*17*). Unfortunately, it has been difficult to isolate "Smithian growth" empirically using contemporary data, and as a result, this mechanism tends to be overlooked in discussions of social and economic policy. Here, we suggest a two-part strategy for overcoming this problem. First, we use the settlement scaling framework to distinguish agglomeration-driven from technology-driven growth. Then, we examine time series data that show that per capita outputs increased over time, but population growth and technological change were both very slow. In this situation, the settlement scaling framework predicts that growth will exhibit a specific relationship with agglomeration (i.e., the social concentration of individuals in physical space), and we show that this is, in fact, what the evidence reveals.

[1]Department of Anthropology, University of Colorado Boulder, Boulder, CO 80309-0233, USA. [2]Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501, USA. [3]School of Sustainability, Arizona State University, Tempe, AZ 85287, USA.
*Corresponding author. Email: scott.ortman@colorado.edu

It is a common misperception that archaeological data are not useful for the study of economic development because they derive from smaller and simpler societies than those of recent times. [By development, we mean improvement in the material conditions of life in a society (*6*).] We suggest here that, on the contrary, these features are helpful in that they allow one to more readily isolate specific mechanisms of interest. In the contemporary world, evidence of Smithian growth is difficult to separate empirically because urbanization, population, and technology are all changing rapidly and simultaneously. A focus on small-scale societies of the past, where most interaction was face-to-face, movement was pedestrian, and technological change was relatively slow, allows one to observe the productivity effects of agglomeration much more readily (*18*). Our strategy thus illustrates an important way that studies of past societies known through archaeology can contribute to the overall science of socioeconomic development; namely, the smaller societies of the past can be used in a way analogous to the model systems used in other fields. In the biological sciences, for example, model systems such as *Caenorhabditis elegans*, *Escherichia coli*, fruit flies, and mice provide direct insight into fundamental processes because of their relative simplicity. We suggest that past societies known through archaeology can do the same for the social sciences.

Smithian growth

There is no specific section of *The Wealth of Nations* (*19*) that presents a fully developed model of economic growth, but observations and arguments regarding conditions that facilitate increased labor productivity are interspersed throughout the book (*20*). Smith observed that specialization made possible through the division and coordination of labor can generate substantial increases in individual-labor productivity, and that specialization is also stimulated by increases in the size of domestic markets (effectively, increases in population size) or the amount of trade. Both phenomena are captured in Smith's famous dictum "That the Division of Labour is Limited by the Extent of the Market." Smith attributed the productivity gains generated from an enhanced division of labor (i.e., one that extends beyond the family) to the efficiency gains from the increased intellectual and manual deftness of each worker through "learning by doing" and the reduction in the number of times individuals have to switch between tasks (*3*, *17*, *21*). The classic Smithian account was later augmented by noting that specialization and the concentration of producers facilitate—through copying, imitation, and social learning—the transmission and accumulation of minor innovations resulting from attempts at improving standard procedures (*22*, *23*). All these insights came to constitute the foundations for a theory of economic growth that is largely independent of research and development (R&D)–driven technological change (*24*–*26*).

The standard interpretation of Smith's famous dictum is that larger markets support larger levels of production, which, in turn, demand increasing separation of this production into discrete components and an increasing concentration of individuals on specific tasks. A sociologically richer interpretation, which is not restricted to market economies, is that the extent of the division of labor is related to the number of individuals who interact with each other in meeting their needs. The division of labor is not only about the vertical integration of specialized tasks but also about the distribution of tasks in networks that facilitate learning, knowledge flow, and the integration (recombination) of information (*27*). Furthermore, the conditions necessary for learning by doing are not restricted to modernity. Even in ancient societies, individuals engaged in specialized productive tasks (making pottery, weaving textiles, making hunting tools, gathering edible plants, etc.) and would have had the opportunity to learn from and improve upon each other's way of performing these tasks.

Smithian growth is a manifestation of the effects of increased market (population) size and interaction rates for socioeconomic organization, the diversity of tasks and tools, and productivity (both individual and group level). From this perspective, the phenomenon of the division and coordination of labor emphasizes information and communication in networks. Although these phenomena are of long-standing interest to anthropologists, archaeologists, sociologists, and economists (*28*–*32*), measuring the consequences of Smithian growth in contemporary economies is far from straightforward due to the confounding effects of technological change. Below, we illustrate one means of doing so.

Settlement scaling and growth

In this section, we show that a theoretical framework known as settlement scaling theory (SST) incorporates and formalizes the mechanism of Smithian growth and provides a framework for isolating its effects. The basic models and empirical evidence in support of SST have been presented in previous publications (*27*, *33*–*35*). Here, we focus on its connection with growth dynamics.

Piketty (*36*) observes that economic growth "… always includes a purely demographic component and a purely economic component, and only the latter allows for an improvement in the standard of living." But an interacting population blurs the distinction between demographic and "economic" effects (*37*). A fundamental axiom of SST is that per capita productivity is proportional to the average interaction rate among individuals (the degree k of an individual's undirected socioeconomic network), given the frictional effects of distance. This notion, that increasing productivity derives from the concentration and intensification of social interaction, is the basic idea behind economic models of agglomeration effects, from lowered transaction costs to increased complementarities in production to knowledge spillovers (*2*, *38*–*40*). Together with the assumption that human social networks involve as much mixing as is possible (including weak ties), given spatial constraints, the aggregate (extensive) output of a strongly interacting population in a settlement can be written as

$$Y_i(N_i, t) = \frac{G(t)\,[N_i(t)]^2}{A_{ni}(t)} * e^{\varepsilon_i(t)} \tag{1}$$

where $Y_i(N_i, t)$ is the aggregate output (a socioeconomic rate) of a given settlement Y_i with resident population N_i at time t, $[N_i(t)]^2 \approx N_i(t) * (N_i(t) - 1)$ is the total number of links (interactions) that are possible within that population, $A_{ni}(t)$ is the area over which interactions occur in that population, $G(t)$ represents the range of social and technological factors (common to all settlements) that convert these interactions into output, $e^{\varepsilon_i(t)}$ captures the range of influences unique to each city that lead to a deviation of productivity in any given settlement from the average expectation. Statistically, the $\varepsilon(t)$ term accounts for deviations in each city from the expected (power-law) scaling relationship. We represent this deviation as an exponential so that it will take the form of a Gaussian random variable following natural log transformation (see below).

Equation 1 can be simplified by expressing $A_{ni}(t)$ in terms of $N_i(t)$. We accomplish this in several steps (subscripts, errors, and time are omitted below to simplify the notation). First, we consider the balance of costs and benefits for individuals when they interact from the perspective of a spatial equilibrium. In the case of a small and amorphous settlement, the cost for a person to interact with others is largely set by the energetic cost of traversing the maximum distance between individuals, which is given by $c = \mu A^{1/2}$ (where μ is the energetic cost of movement and A is the circumscribing area), and the benefit of the resulting interactions is given by $y = \hat{g}\, a_0\, lN/A$ (where $\hat{g}$ is the average productivity of an interaction, a_0 is the average distance at which interaction occurs, l is the average length of the path taken by an individual, and N/A is the average population density of the settlement). Implicit here is the assumption, foundational to the social sciences, that human effort is bounded and needs to be allocated based on benefits and costs. In the context of moving in physical space, this implies that individuals move about, or explore, only portions of the space in which their social interactions are embedded (*41*). Setting $c = y$ (balancing costs with benefits) and simplifying, one arrives at

$$A(N) = (G/\mu)^{2/3} N^{2/3} = a N^{2/3} \tag{2}$$

where $G = \hat{g}\, a_0\, l$ and $a = (G/\mu)^{2/3}$. Thus, the area circumscribing a settlement grows proportionately to the settlement population raised to the 2/3 power such that larger settlements become progressively denser. Note also that the prefactor of this relationship varies in accordance with the productivity of interactions and with transportation costs but is independent of population.

Second, we consider how the interaction area changes as settlements become larger and more organized. In organized settlements, interaction occurs through movement along an access network of roads, paths, and other public spaces as opposed to straight paths. We assume that the expansion of this interaction infrastructure follows the expansion of concentrated population so that the space devoted to the access network ρ is added in accordance with the current population density, $\rho = (N/A)^{-1/2}$, such that the total area of the access network $A_n \sim N\rho = A^{1/2}N^{1/2}$. Substituting $aN^{2/3}$ for A in this equation, based on Eq. 2, then leads to (with subscripts and time added back in)

$$A_{ni}(t) \sim a(t)^{1/2} N_i(t)^{5/6} \quad (3)$$

Equation 3 indicates that the area over which interaction occurs in a settlement grows proportionately to the settlement population raised to the 5/6 power. We can now replace $A_{ni}(t)$ in Eq. 1 with $a(t)^{1/2}N_i(t)^{5/6}$ from Eq. 3 and simplify, leading to

$$Y_i(N_i, t) = Y_0(t)\,[N_i(t)]^{\beta} * e^{\varepsilon_i(t)} \quad (4)$$

with β = 7/6. Equation 4 suggests that as settlements increase in population, their average aggregate socioeconomic rates grow proportionately to population raised to the β power. It also suggests that per capita rates are given by

$$y_i(N_i, t) = Y_0(t)\,[N_i(t)]^{\delta} * e^{\varepsilon_i(t)} \quad (5)$$

which implies increasing per capita productivity in accordance with population raised to the $\delta = \beta - 1 = 1/6$ power. Together, Eqs. 4 and 5 imply that there are increasing returns to scale such that more populous settlements are more productive per capita simply due to the network effects of individuals interacting regularly in space.

Next, we consider the effects of increasing settlement population for labor specialization (subscripts and time once again omitted for simplicity). We posit that to persist an individual requires access to a certain range of outputs, broadly construed, to satisfy their needs, and these must be met through either individual effort or social interaction. These outputs, in turn, are the results of a set of functions, F, determined by the interplay of technology and culture. As a result, $F = k(N) \times d(N)$, where $k(N)$ is the average connectivity (degree per capita) in a settlement of population N, $d(N)$ is the average functional diversity (tasks per capita) in that settlement, and F is a constant independent of N. This relation shows that, with increasing social connectivity, individuals have the opportunity to specialize in a decreasing range of functions d such that the product $F = k(N) \times d(N)$ is constant. In this scenario, increasing connectivity enables decreasing functional diversity and increasing functional specialization (i.e. division of labor), so given that Eq. 5 implies $k(N) = K(N)/N = k_0N^{\delta}$, then $d(N) = (F/k_0)N^{-\delta}$. As a result, functional diversity per capita (specialization^{-1}) is

$$d(N_i(t)) = (F/k_0(t))\,[N_i(t)]^{-\delta} \quad (6)$$

and the total functional diversity is

$$D(N_i(t)) = (F/k_0(t))\,[N_i(t)]^{1-\delta} * e^{\varepsilon_i(t)} \quad (7)$$

This relation specifies that the range of productive activities performed by individuals in a settlement is proportional to its population raised to the 1 − δ power. This, in turn, implies that, on average, the range of activities performed by an individual is proportional to the population raised to the −δ power. This means that new activities are added more slowly than people, and as a result, settlements become more connected and diverse as they grow in size, but with each individual becoming increasingly specialized.

These models capture and formalize the Smithian growth mechanism by relating increases in average per capita productivity directly to increases in per capita specialization. This specialization is, in turn, stimulated by increasing connectivity due to the concentration of people in space that emerges from the spatial equilibrium of interaction-dependent costs and benefits. We next show that this framework incorporates Smithian growth into the overall pattern of economic growth in a society. We first take the natural logarithm of Eq. 4 to express it as a linear function

$$\ln[Y_i(N_i, t)] = \ln[Y_0(t)] + \beta \ln[N_i(t)] + \varepsilon_i(t) \quad (8)$$

Then, we express this result in terms of the ensemble average across all settlements

$$\langle \ln[Y(t)] \rangle = \ln[Y_0(t)] + \beta \langle \ln[N(t)] \rangle \quad (9)$$

where the ensemble averages are defined as

$$\langle \ln[Y(t)] \rangle = \frac{1}{N_s} \sum_{i=1}^{N_s} \ln Y_i(N_i, t) \quad (10a)$$

and

$$\langle \ln[N(t)] \rangle = \frac{1}{N_s} \sum_{i=1}^{N_s} \ln N_i(t) \quad (10b)$$

and where N_s refers to the total number of settlements. Because, by definition, $\langle \varepsilon_i(t) \rangle = 0$, it can be dropped from the ensemble average. Equation 9 indicates that the average log output of settlements in a system at a particular time is the sum of the log-baseline productivity in that society (which incorporates nonrivalrous technology) and the average log-settlement population multiplied by the scaling exponent β = 7/6. One can also think of Eq. 9 as representing the center of the data in a scatterplot relating $ln[N_i(t)]$ to $ln[Y_i(N_i, t)]$, the log of settlement size versus the log of settlement output for individual settlements, the average relation of which is given by Eq. 8 (minus the error term), a line with slope β, and intercept $ln[Y_0(t)]$. Note also that Eq. 10a implies that the total log-output of the society is given by $N_s * \langle ln[Y(t)] \rangle$.

Last, we can differentiate both sides of Eq. 9 to convert it to a growth equation

$$\frac{d\langle \ln Y \rangle}{dt} = \frac{d(\ln Y_0)}{dt} + \beta \frac{d\langle \ln N \rangle}{dt} \rightarrow \gamma_{\langle Y \rangle} = \gamma_{Y_0} + \beta \gamma_{\langle N \rangle} \quad (11)$$

Equation 11 states that the growth rate of mean settlement output is the sum of the growth rate of baseline productivity and the growth rate of the mean settlement population multiplied by β = 7/6. This relationship illustrates that overall economic growth can be decomposed into growth in baseline productivity γ_{Y0}, which is driven by the variety of technologies that affect movement costs and interaction benefits, and Smithian growth $\beta\gamma_{\langle N \rangle}$, which is driven by increases in settlement population (market size) and its associated network effects (division of labor).

The settlement scaling framework leads to an analytical strategy for distinguishing these two forms of growth empirically using time series data for the population sizes and socioeconomic rates of settlements in a regional system. First, one can plot $ln[N_i]$ versus $ln[Y_i]$ by time period and use regression to estimate the slope and intercept of the relationship for each period. A prediction of the framework is that the slope β of the fit line will be consistent across periods and should be within the range of statistical tolerance of 7/6. Second, one can examine the movement of the center and the intercept $ln[Y_0(t)]$ from one period to the next to distinguish the contribution of technology- and agglomeration-driven growth to the overall growth rate. In contemporary societies, these time series analyses typically reveal a changing intercept of the scaling relation and a movement of the center along the fit line due to the combined effects of urbanization and technological progress (*42*). However, in cases where technology was static, our framework predicts that the intercept of the fit line $ln[Y_0]$ will be constant such that $\gamma_{\langle Y \rangle} \propto \beta\gamma_{\langle N \rangle}$ across periods. In this circumstance, all growth will be attributable to the Smithian mechanism. In the following section, we illustrate that this situation can occur, and may have been typical of preindustrial societies, using archaeological time series data from the Pre-Hispanic U.S. Southwest.

MATERIALS AND METHODS

We examine measures of settlement population and material outputs in the society encountered by 16th century CE Spanish explorers in the northern Rio Grande drainage of what is now New Mexico, USA. Previous research demonstrates that this society took shape ca. 1250 CE as people moved into the region from elsewhere (*43*). Between that time and the imposition of Spanish colonialism in the 17th century, the Native American Pueblo inhabitants of this region coalesced into larger settlements, produced and exchanged pottery more widely, developed substantial trade networks with neighbors to the east, and experienced lowered rates of interpersonal violence (*18*, *44*). These changes occurred in the context of a relatively stable regional population (ca. 35,000 people) from 1300 to the mid-1500s, after which European-introduced diseases began to take a toll (*45*, *46*). There is evidence for the development of increasingly inclusive social institutions during this period (*44*, *47*), but there is no evidence for substantial change in technology related to transport, energy capture, or information processing. Also, although the first permanent Spanish settlement was established in 1598, Spanish introductions and impositions only began to affect the Pueblo economy in a substantial way in the mid-1600s, the end point of this investigation (*48*). Throughout the period of this investigation, all movement was pedestrian (there were no beasts of burden), travel was limited to use-developed trails, the same crops were grown using the same techniques, the same domestic animals were kept (dogs and turkeys), the same set of tools were made, and information was exchanged only orally or via visual culture.

The archaeological record of this region is especially well known due to a long history of archaeological research, high surface visibility of archaeological remains, cultural resource management work related to private development and federal land management, the persistence of vibrant Pueblo communities in the region, and a precise ceramic chronology that supports a chronological resolution of 30 to 65 years. As part of the Village Ecodynamics Project, the lead author and associates compiled information for settlements in this society from the literature, governmental agency databases, and archival sources (Fig. 1) (*18*, *49*). The assembled databank includes the beginning and end dates of occupation at individual archaeological sites or portions thereof (these are referred to as habitation components), the number of rooms associated with each component, the floor areas of excavated or otherwise visible rooms, and, when available, amounts of pottery and chipped-stone debris in tabulated samples of artifacts.

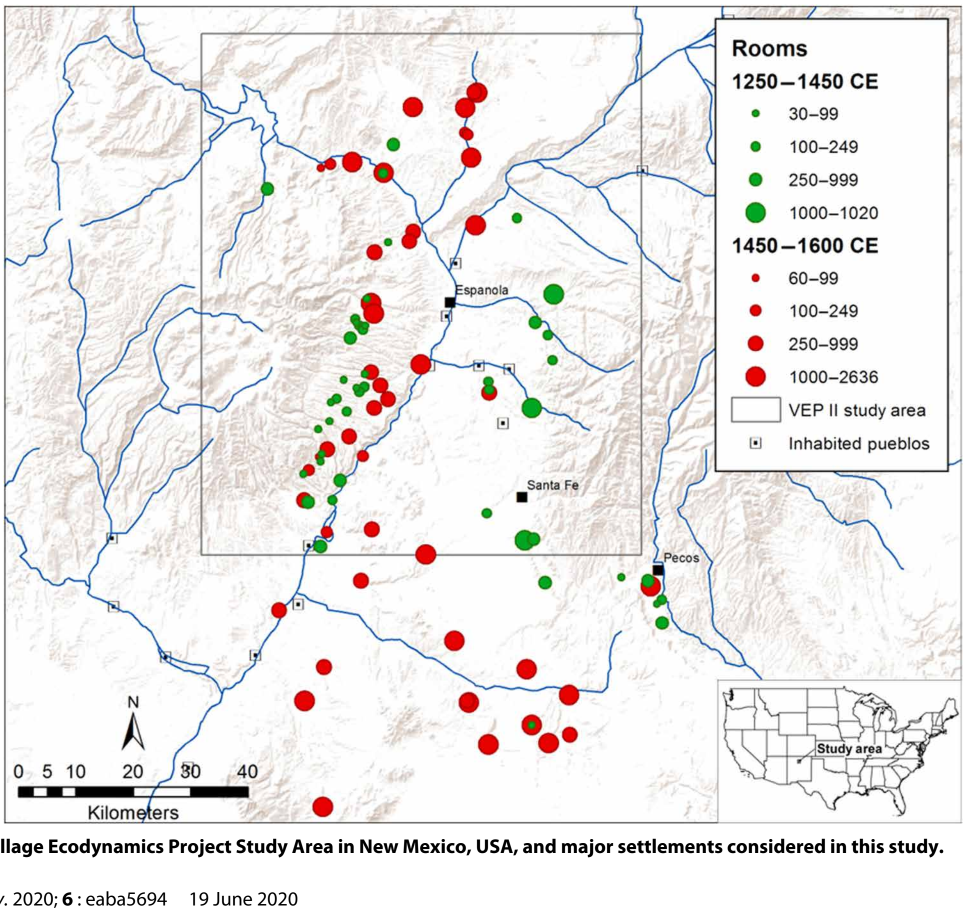

Fig. 1. Location of the Village Ecodynamics Project Study Area in New Mexico, USA, and major settlements considered in this study.

Many of the analyses below rely on population estimates derived through a procedure known as uniform probability density analysis. As discussed in (*49*), this procedure produces estimates of the number of people who resided in a habitation component during each of a series of time periods based on its architectural footprint and associated pottery assemblage (or a logistic growth model over the occupation span when a pottery assemblage is not available). The method first estimates the maximum number of people who could have lived within the architectural footprint of a component based on the extent of architectural remains. Then, it computes a probability density function based on the relative frequencies of pottery dating from various time periods in the associated artifact assemblage (or a logistic growth function). Last, it assumes that the maximum population coincides with the period of peak probability of occupation and scales the off-peak populations proportionately. The resulting estimates are probabilistic in nature (they are not census counts), but they incorporate both living space and trash accumulations and thus follow current best principles for regional demographic reconstruction in archaeology (*50*). In this case, the results allow us to examine the distribution of population during each of a series of 10 time periods between 1250 and 1650 CE. Figure S1 presents rank-size distributions of settlement populations (habitation components) for the Northern Rio Grande Pueblo settlement system during each of these periods. This distribution became increasingly non-Zipfian over time, indicating a strong agglomeration trend in a context where there was an upper limit on the maximum settlement size. As a result, the mean of the log of settlement size changed much more than the log of the maximum settlement size over time. This is important because the settlement scaling framework suggests that Smithian growth is driven by increases in the former and not the latter, and in this case, the latter was relatively stable.

We also examine three socioeconomic measures to investigate growth dynamics. Because these measures draw on the total accumulation of artifacts and architecture at each habitation component over its occupation span, we assign these measures to the end date of the final period of occupation for each component. The first measure is the ratio of potsherds derived from painted fine-ware serving vessels to potsherds derived from utility-ware cooking vessels. This measure builds from previous research on artifact accumulations in archaeology, which emphasizes connections between trash accumulation, people, and time (*51*, *52*). These studies have concluded that cooking vessels are "low-income-elasticity goods" that are used, wear out, and accumulate at consistent rates per household, thus providing an index of person-years of occupation. (In economics, income elasticity of demand indicates how the quantity of a good consumed by a household varies as the household income increases.) Serving vessels, in contrast, are high-income-elasticity goods for which one would expect demand to increase along with rates of socializing with food and status display. As a result, the accumulation rate of fine-ware potsherds would be expected to covary with living standards. Because the denominator of the fine-ware to utility-ware ratio is an index of person-years, and the numerator represents the same time interval, the ratio is an index of the per capita accumulation rate of fine-wares. In addition, because these accumulations are of fragments from broken vessels, the accumulation rate is also a consumption rate (*8*).

The second measure is the average floor area of rooms associated with a component. Several studies in archaeology have shown that house area is related to household possessions and food stores, and that the distribution of house sizes is a reasonable proxy for "income" and "wealth" distributions (*53*). This is because, in ancient societies, all wealth took the form of tangible goods that took up space. House area is therefore also a high-income-elasticity good reflecting household possessions. Although it is difficult to distinguish house boundaries in Northern Rio Grande Pueblo settlements, the sizes of individual rooms can often be determined through excavation or surface survey, and previous research suggests that a reasonable conversion is one resident per room (*49*). Given this, room area is a reasonable measure of possessions per person. We therefore use the mean room area as a per capita measure that is also correlated with living standards. (Along these lines, we note that the correlation between the fine-ware to utility-ware ratio and the mean room area, averaged by time period, is $r = 0.399$.)

Last, the third measure is the ratio of chipped-stone fragments to utility-ware potsherds in samples for which both were collected and tabulated. Unlike service wares, which accumulate because of consumption, chipped-stone debris accumulates as a by-product of the production of chipped-stone tools. The ratio of chipped-stone fragments to utility-ware potsherds represents the relative stone tool production rate per capita, and we consider it to be a proxy for the division of labor. This interpretation builds from the fact that stone tools are also low-income-elasticity items. In a society where households are isolated and self-sufficient, there is no division of labor above the household level. As a result, each household must produce all the tools they need to use themselves. As these households become more connected, however, individuals have more opportunity to get the tools they need through their social contacts. As a result, the tools that exist are used more intensively, and fewer tools will be needed overall. This implies that the average individual will not need to spend as much time making stone tools, and the community's tool needs can be met by a decreasing fraction of people producing these tools. The net result will be a stone tool production rate that increases more slowly than the population, at the same rate as the division of labor expands.

Table 1 presents numerical summaries of the data we examine (the source data are available at https://core.tdar.org/project/392021/social-reactors-project-datasets), and Fig. 2 presents a summary of economic change over time using several of these measures. Figure 2A shows that the mean settlement size grew much more strongly than the size of the largest settlement between 1250 and 1650 CE, and that the total regional population was relatively stable between the late 1200s and the mid-1500s. Figure 2B shows that the mean ratio of fine-ware to utility-ware sherds across sites for which tallies are available increased fairly consistently from the late-1200s to at least the mid-1500s, with notably less precise estimates beginning in the 1400s due to the decreasing number (but larger size) of inhabited sites, and a potential decline (with a wide confidence band due to the small number of components for which assemblage data are available) beginning in the later 1500s. This index provides evidence for increasing per capita consumption of painted serving vessels over time. Last, Fig. 2C is generally consistent with a slowly increasing house size over time, with estimates for the 13th century being especially imprecise due to the small number of components from which room sizes are available. The notes associated with Table 1 show that increases over time in all three measures are statistically significant. Overall, these summaries are consistent with previous research that suggests consistent long-term improvement in material living standards in this society from the time it initially formed until it was disrupted by Spanish colonization in the 17th century.

Because two different indexes of living conditions show long-term growth trends that correspond with an agglomeration trend, we use the settlement scaling framework to assess the sources of this growth. The first step is to convert site-level fine-ware to utility-ware ratios, mean room areas, and chipped stone to utility-ware ratios to indexes that reflect settlement-level consumption, household possessions, and productive diversity. We convert the potsherd ratio to an extensive consumption index by multiplying it by the maximum population estimate for that settlement, which is the room count. We convert the mean room area into a possessions index by first assuming that, as living standards improve, half of the gains will go into larger room sizes and the other half will go into additional rooms. This implies that the square of the mean room area should provide a good index of possessions per capita, and the product of this number and the maximum population estimate then converts this intensive index to an extensive one. Last, we convert the chipped stone to utility-ware ratio to an extensive measure of productive diversity by once again multiplying this ratio by the room count.

RESULTS

Figure 3 presents scaling analyses of the relationship between maximum settlement size and consumption, possessions, and productive diversity. In these plots, habitation components are color-coded to show broad time intervals, and the centers of the data for each of the 10 time periods are shown in yellow. The ordinary least-squares best-fit line across all periods is also shown, and the associated regression results are presented in table S1. The high r^2 values derive from autocorrelation effects in index construction, but there is nothing inherent in these procedures that would force the observed estimates of β to approach the values predicted by SST. Yet, this is what happens in all three cases. The point estimates of β for the two output measures are within 0.021 and 0.008, respectively, of the predicted value of 7/6 from Eq. 4, and the point estimate of β for the diversity measure

Table 1. Summary data for the Northern Rio Grande Pueblo area, 1250–1650 CE.

Period (CE)	1200–1250	1250–1280	1280–1315	1315–1350	1350–1400	1400–1450†	1450–1515	1515–1550	1550–1600	1600–1650†
Occupied sites	1540	1684	1586	810	703	561	445	410	228	36
Est. population	9699	20,225	26,862	31,398	35,417	37,211	35,180	25,763	19,369	8490
Mean site size (room count)*	13	24	34	69	98	151	232	243	239	283
Mean of ln[site size]‡	1.9	2.14	2.68	2.92	3.17	3.48	3.68	3.67	4.47	4.99
Largest site (room count)	623	700	1018	2179	1862	2833	2636	2272	2317	990
Sites with pottery tallies	10	9	11	68	36	26	7	6	11	5
Mean ratio fine/utility sherds§	0.35	0.369	0.447	0.611	0.806	1.447	1.569	0.896	1.029	1
SD ratio	0.17	0.284	0.254	1.083	1.212	2.482	1.513	0.903	0.469	0.63
Sites with chipped-stone data	7	5	2	15	7	9	1	2	3	6
Mean ratio chipped stone/utility sherds	0.6	0.642	0.895	0.411	0.748	0.391	0.152	0.644	0.577	0.33
SD ratio	0.32	0.383	0.555	0.575	0.877	0.542	N/A	0.083	0.491	0.3
Measured rooms	22	45	193	540	177	248	377	421	154	1382
Sites with measured rooms	5	8	21	63	12	8	5	11	8	4
Mean room area (m^2)‖	6.6	6.32	5.54	5.31	6.18	6.51	6.99	7	6.32	8.55
SD area	2.73	1.88	1.54	1.39	1.9	1.14	1.32	1.6	2.14	1.65
Gini coefficient (room areas)	0.28	0.178	0.166	0.233	0.188	0.202	0.154	0.164	0.204	0.19

*The mean number of rooms inhabited at each site during each period [from (*49*)]. †Throughout this paper, the data for these periods are averages of results for two periods encompassing 1400–1450 CE and 1600–1650 CE, respectively, in (*49*). ‡Linear fit: $\langle \ln [N_t] \rangle = (0.006 \pm 0.0007)t - (6.958 \pm 0.9633)$, analysis of variance (ANOVA) $F(1,8) = 108.8$, $P < 0.0001$, $r^2 = 0.923$. §For three chronological groups of log-transformed observations (pre-1280, 1280–1450, and 1450–1650 CE), ANOVA $F(2,193) = 13.995$, $P < 0.0001$. ‖For three chronological groups of log-transformed observations (pre-1280, 1280–1450, and 1450–1650 CE), ANOVA $F(2,148) = 11.162$, $P < 0.0001$.

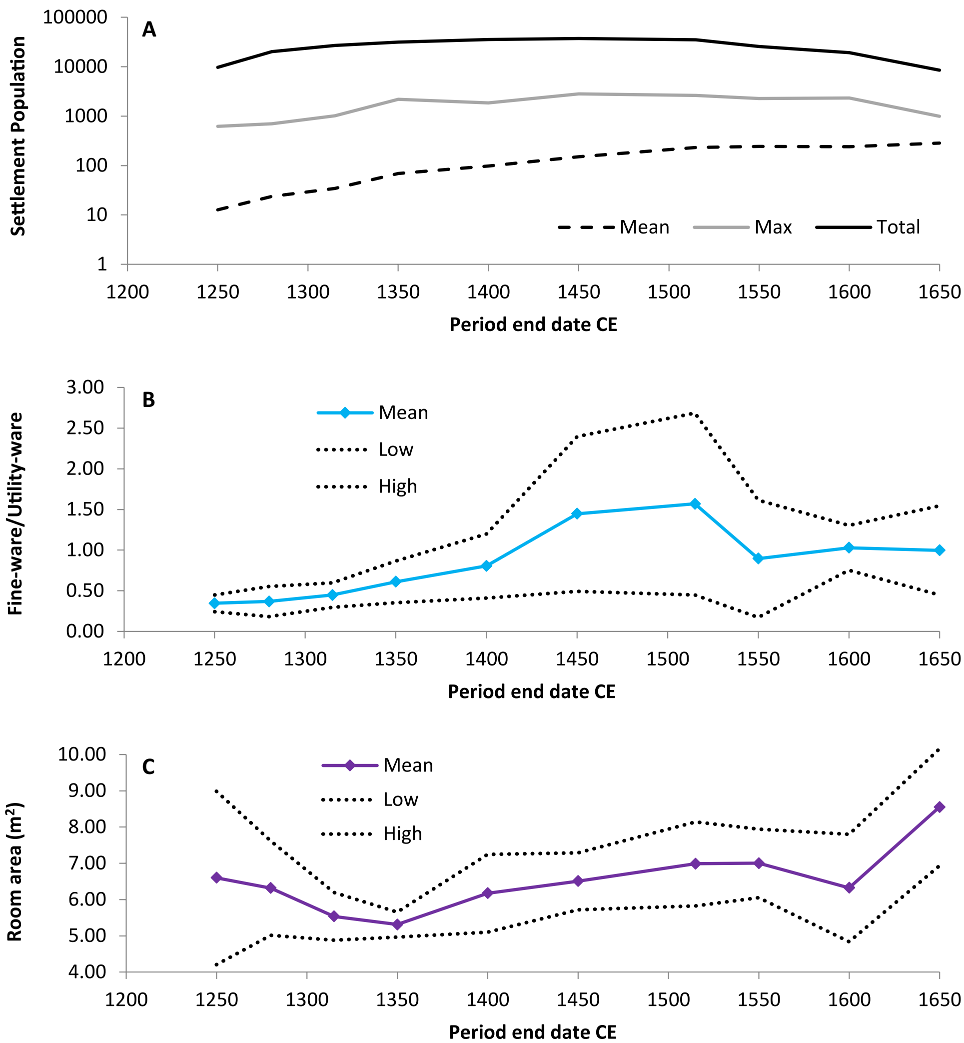

Fig. 2. Summary of economic change in the Northern Rio Grande Pueblo region. All three time series show statistically significant increases over time, as explained in Table 1: (**A**) settlement population, (**B**) ratio of fine-ware to utility-ware sherds, and (**C**) mean room area. Dotted lines represent 95% confidence intervals surrounding the mean estimates by period.

is within 0.012 of the predicted value of 5/6 from Eq. 7. In addition, the 95% confidence intervals of all three estimates easily encompass the predicted values, and the predicted values are within one standard error of the point estimate in all cases. These results provide strong evidence that larger settlements in this society, which were associated with larger local markets, experienced increasing returns to scale in consumption and possessions, and decreasing returns in productive diversity, at rates that are predicted by our framework. In addition, all three plots suggest no significant change in the intercept of the scaling relation over time. In all three cases, the centers of the data for each of the 10 time periods are close to the global fit line. This is consistent with previous research that suggests limited technological change during the period of interest.

Consistency in baseline economic outputs can be shown more directly by tracing the intercept of the scaling relation $ln[Y_0(t)]$ for consumption and possessions, which can be estimated from the center coordinates and Eq. 9. (For the productive diversity, index sampling by period is too sparse for these additional analyses.) The center coordinates and estimated intercepts for the consumption and possessions index by time period are presented in table S2, the time series of the intercepts are plotted in Fig. 4A, and the relationship between period end date and intercept for each index is summarized in table S3. The regressions demonstrate that there is no relationship between time and intercept for either index. In both cases, the estimated correlation between the two variables comfortably includes zero, the regression is not significant, and the intercepts essentially fluctuate around a constant value, except for a negative perturbation in both indices in the early 1300s. These results reinforce the conclusion that there was little change in the energetics of social interaction over time in this society.

The fact that $ln[Y_0(t)]$ was effectively constant for the consumption and possessions indices over time implies that improvements in material living standards in this society were due exclusively to agglomeration via the Smithian growth mechanism such that $\langle ln[Y(t)]\rangle \propto \beta\langle ln[N(t)]\rangle$. Because of partial sampling, small samples, and the fact that we have associated the accumulated data for each habitation component with a single time period, there are likely errors in our estimates of $\langle ln[Y(t)]\rangle$ and $\langle ln[N(t)]\rangle$ that translate into errors in the associated growth rates, $\gamma_{\langle Y\rangle}$ and $\gamma_{\langle N\rangle}$. Still, the strong relationship between population and the consumption and possessions

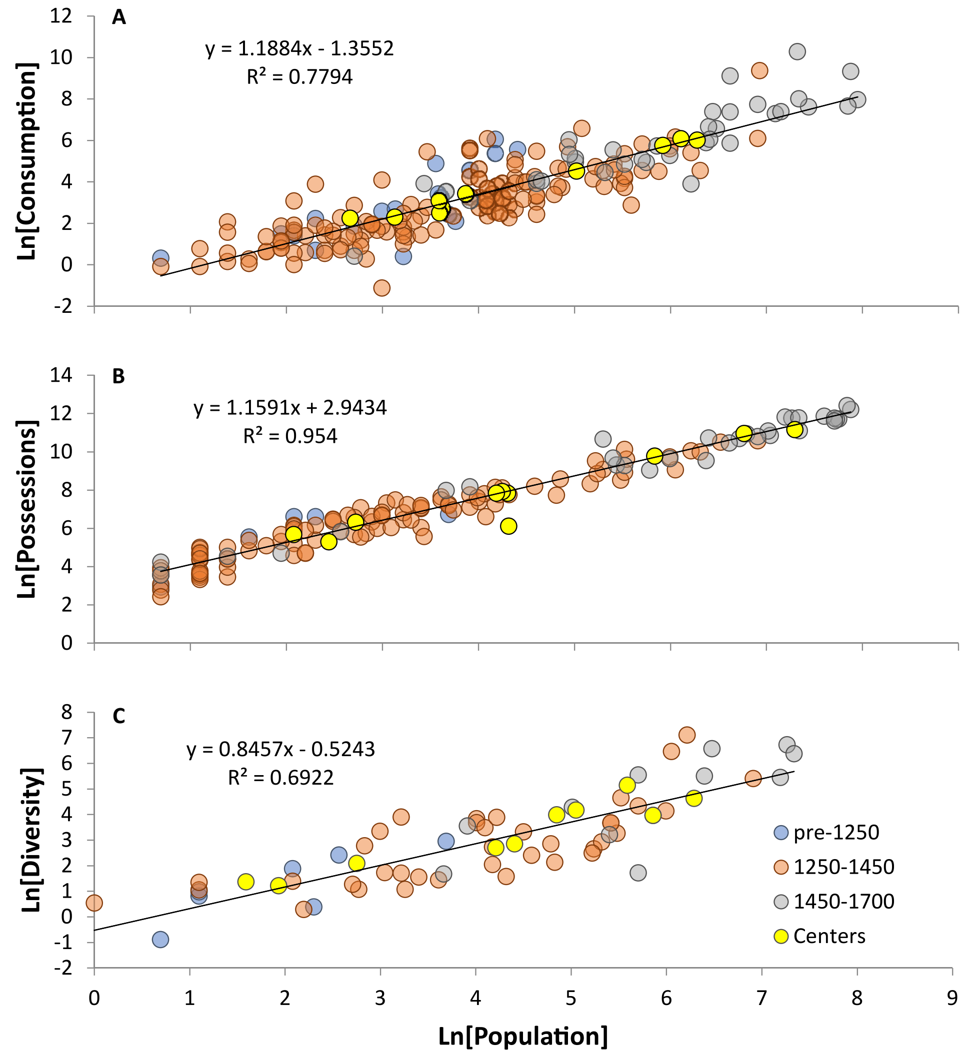

Fig. 3. Settlement population and economic indicators in the Northern Rio Grande Pueblo Region. Panels show relationships for indices of consumption (**A**), personal possessions (**B**), and the division of labor (**C**). Symbols reflect chronological groups, and yellow circles are the centers of the data for each time period. Note that for all three indices, there is evidence of increase in both settlement size and the relevant socioeconomic rate over time, but the data series follows a single scaling relation. For full regression results, see table S1.

indices at the settlement level, regardless of time, suggests that sampling errors in $\langle ln[Y(t)]\rangle$ and $\langle ln[N(t)]\rangle$ will covary such that $\langle ln[Y(t)]\rangle \propto \beta\langle ln[N(t)]\rangle$ should still obtain. That this is the case is shown in Fig. 4B, which shows the movement of the center of each index over time and illustrates that the slope of the best-fit line to these data is $\beta \cong 7/6$ in each case. This result reinforces our contention that Smithian growth at the societal level is simply the integration of the growth in individual settlements across an agglomerating regional population.

The scaling results thus suggest that it is reasonable to estimate the overall economic growth rate in this society using $\gamma_{\langle Yt\rangle} = \beta\gamma_{\langle Nt\rangle}$. This calculation is presented in Fig. 5A, using the data series for $\langle ln[N(t)]\rangle$ from Table 1, which represents all the major settlements and most of the minor settlements in this system. This figure shows that Northern Rio Grande Pueblo society generally experienced positive growth, at rates of a fraction of a percent, for most of its history. In addition, it experienced one period of stagnant or slightly negative growth in the mid-1500s and two periods of pronounced positive growth: one in the period immediately following a population influx from the northwest in the late 1200s (*43*), and a second from the late 1500s through the mid-1600s. The effects of infectious diseases introduced by the Spanish may be responsible for the mid-1500s period of stagnation, but Spanish colonialism is not likely responsible for the later growth episode, as Spanish presence only became permanent in 1598 and substantial impacts are most apparent from the mid-1600s (*45*, *54*).

DISCUSSION

We have shown that SST incorporates and formalizes the growth mechanism first hypothesized by Adam Smith and leads to an analytical strategy for distinguishing technology-driven growth from agglomeration-driven growth. We then applied this approach to time series data for settlement populations and three economic indicators for a small-scale nonindustrial society where regional population growth and technological change were minimal over a 4-century

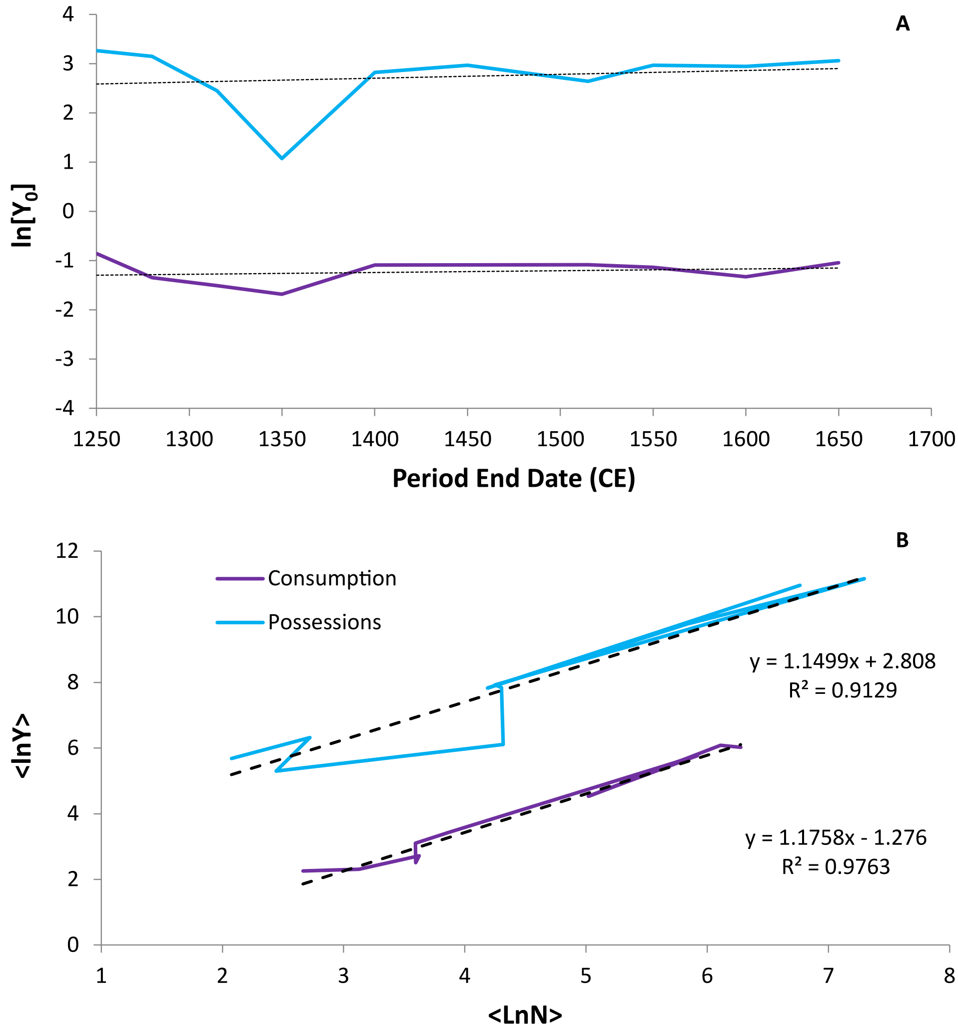

Fig. 4. Scaling relationships through time. (**A**) Scaling intercept for the consumption index (purple) and possessions index (blue) through time; the intercept is estimated using the center coordinates for each period (see table S2 and Eq. 9); note that there is no temporal trend in these data (see table S3). (**B**) Movement of the center of agglomeration versus consumption (purple) and possessions (blue) over time; note that, in both cases, the centers gradually progress up a single scaling relation with slope $\beta \cong 7/6$, consistent with Eq. 9 in the case of constant technology.

period. Material living conditions clearly improved over time in this society, and we were able to show that these improvements can be attributed entirely to the Smithian mechanism. Results suggest that the Puebloan society of the Northern Rio Grande Region of New Mexico, USA experienced consistent and sustained growth, at a long-term average of 0.8% per year, for a several centuries-long period of development. As a result, there was an approximate fourfold increase in the standard of living between 1250 and 1650 CE.

At the same time, room area distributions suggest that there was no relationship between economic growth and increasing inequality. The Gini coefficients of these distributions by time period (Table 1), which we argue reflect levels of inequality in material possessions, suggest a long-term average of about 0.2, relatively low in comparison to other New World societies of similar scale and technology (*53*), and if anything, these coefficients show a declining trend over time (Fig. 5B). Recent perspectives from economic history suggest that economic growth in the absence of redistribution of private gains inexorably leads to increasing inequality (*36*). If so, the fact that inequality did not increase with growth in Northern Rio Grande Puebloan society hints at the presence of redistributive social norms and/or institutions. On a more general level, this finding suggests that there is no necessary relationship between Smithian growth and increasing inequality.

We also note that, in order for a stable population to agglomerate into fewer, larger settlements over time, many existing settlements must be vacated. One can view this process of internal migration away from existing built infrastructure and capital improvements in agricultural land toward a smaller number of growing settlements where agglomeration economies were enhanced as a form of creative destruction—an additional process that is often cited in discussions of economic growth (*55*, *56*). Along these lines, studies of population history across the Northern Rio Grande Pueblo region have found evidence for migration flows to and from specific settlements and regions over time (*18*, *44*, *49*). Thus, an important ingredient of Smithian growth, at least in the context of a stable population, is reduced barriers to internal migration. A form of creative destruction would appear to be a necessary by-product.

Our results suggest that the proximate cause of economic growth in this society was increases in the average level of agglomeration,

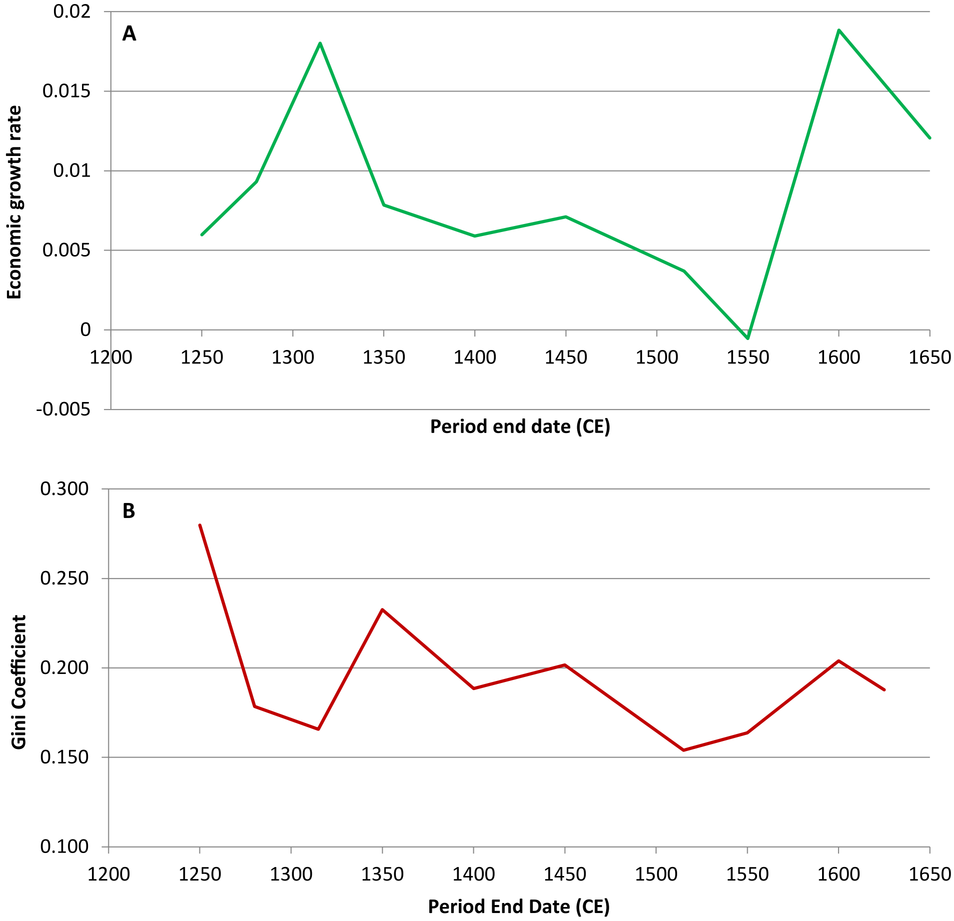

Fig. 5. History of economic growth and inequality in the Northern Rio Grande Pueblo area. (**A**) economic growth rates; (**B**) Gini coefficients. Growth rates are average per year over each period, estimated from $\langle[lnN(t)]\rangle$ across all inhabited sites (see Table 1 and Eq. 11). Gini coefficients are based on the distribution of room areas during each period (see Table 1).

social connectivity, and productive diversity over time, as specified by the settlement scaling framework. Because physical technology was constant over the period of interest, these changes must have been stimulated by factors that supported the peaceful long-term coexistence of larger numbers of people in settlements. Several researchers (*9*, *55*, *56*) have suggested that increasingly inclusive social institutions can have these effects, and we note that there is abundant evidence for the development of such institutions in this case. Changes in the rate and distribution of interpersonal violence (*47*), community architectural plans (*44*), redistributive rituals (*57*), and cultural discourses (*44*) all suggest an evolution away from kin-based institutions and toward institutions that supported place-based, regional group identities and a strong communal ethic. We also note that these cultural changes seem to have coincided with the formation of Northern Rio Grande Pueblo society, as studies of comparable data from earlier periods in other parts of the U.S. Southwest have found lower and more unstable levels of agglomeration and higher levels of interpersonal violence (*44*). These cultural changes thus appear to represent the ultimate drivers of growth in this case. Smithian growth can therefore be seen not merely as a mechanism to achieve economic growth, narrowly defined, but more broadly as a set of conditions and interactions facilitating social development and, concomitantly, improvements in material well-being (*6*).

Examining episodes of socioeconomic development in the past helps one see an important explanatory distinction between the social interactions that generate economic growth (i.e., increases in material output brought about by productivity increases) and the productivity-enhancing effects of energy converters and other technologies in which these relationships are embedded at any given time. While energy capture and technology are very important in determining a society's level of material development, social interactions are the fundamental substratum that generates this improvement by stimulating increased specialization and exchange, leading to improvement in the material conditions of life. Focusing on the scale and pace of socioeconomic development associated with the Industrial Revolution can obscure the fundamental role that social interactions and their supportive institutions play in causing sustained (albeit modest) improvements in physical well-being across different technological settings (*58*).

The archaeological data used in this investigation come from a small-scale, nonindustrial society, with all the caveats this entails. The scale of Pre-Hispanic Northern Rio Grande Pueblo society was modest even relative to other preindustrial civilizations, from ancient Greece and Rome to China and Egypt, Mesoamerica, and the Andes. Despite all this, we find that archaeological data from this society are useful for investigating the mechanisms of economic growth because they provide a means of controlling for population growth and technological change, thus isolating the effects of population agglomeration. When this is done, the effects of agglomeration for growth are much clearer than they often are in contemporary data, where population growth, agglomeration, and technological change are all occurring simultaneously (*59*, *60*). Archaeological evidence can thus be seen to play a surprising and important role in the overall effort to develop a scientific understanding of economic growth and socioeconomic development.

The results presented here reinforce recent work that argues that archaeological evidence has great untapped potential for research on contemporary issues and is especially important for the study of urbanization (*35*). In this case, they show that, when holding technology constant, increases in per capita productivity are not driven by the total population, or the population size of the largest settlement, but by changes in the average level of agglomeration across settlements. Our results also indicate that there is no necessary relationship between Smithian growth and increasing inequality. Given this, important areas for additional research on economic growth, especially in the developing world, include exactly how culture and institutions stimulate or hinder the agglomeration process, and how these arrangements reduce the coupling between economic growth and increasing inequality. Our results also suggest that it would be profitable to investigate whether the relationships observed here are apparent in other settings where agglomeration occurred in the context of stable population and physical technology. It may also be profitable to identify potential cases of technology-driven growth in the context of stable population and agglomeration, although whether this scenario has happened in human history, or is even feasible, is at this point an open question.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/6/25/eaba5694/DC1

REFERENCES AND NOTES

1. R. J. Barro, X. Sala-i-Martin, *Economic Growth* (MIT Press, ed. 2, 2004).
2. C. I. Jones, P. M. Romer, The new kaldor facts: Ideas, institutions, population, and human capital. *Am. Econ. J. Macroecon.* **2**, 224–245 (2010).
3. J. Mokyr, in *Handbook of Economic Growth*, P. Aghion, S. Durlauf, Eds. (North Holland, 2006).
4. E. A. Wrigley, Energy and the English Industrial Revolution. *Philos. Trans. R. Soc. A* **371**, 1–10 (2013).
5. R. Fouquet, S. Broadberry, Seven centuries of European economic growth and decline. *J. Econ. Perspect.* **29**, 227–244 (2015).
6. I. M. Morris, *The Measure of Civilization: How Social Development Decides the Fate of Nations* (Princeton Univ. Press, 2013).
7. W. T. Sanders, J. R. Parsons, R. S. Santley, *The Basin of Mexico: Ecological Processes in the Evolution of a Civilization* (Academic Press, 1979).
8. W. M. Jongman, in *Cambridge History of Capitalism, Volume I: From Ancient Origins to 1848*, L. Neal, J. G. Williamson, Eds. (Cambridge Univ. Press, 2014), pp. 75–100.
9. J. Ober, *The Rise and Fall of Classical Greece* (Princeton Univ. Press, 2015).
10. K. Greene, Technological innovation and economic progress in the ancient world: M. I. Finley re-considered. *Econ. Hist. Rev.* **53**, 29–59 (2000).
11. V. Smil, *Energy in Nature and Society: General Energetics of Complex Systems* (The MIT Press, 2008).
12. A. Bowman, A. Wilson, Eds., *Settlement, Urbanization and Population* (Oxford Univ. Press, 2011).
13. G. Algaze, *Ancient Mesopotamia at the Dawn of Civilization* (University of Chicago Press, 2008).
14. P. Temin, *The Roman Market Economy* (Princeton Univ. Press, 2012).
15. J. G. Manning, *The Open Sea: The Economic Life of the Ancient Mediterranean World from the Iron Age to the Rise of Rome* (Princeton Univ. Press, 2016).
16. N. Nunn, The historical roots of economic development. *Science* **367**, eaaz9986 (2020).
17. M. Kelly, The dynamics of Smithian growth. *Q. J. Econ.* **112**, 939–964 (1997).
18. S. G. Ortman, K. E. Davis, in *Reframing the Northern Rio Grande Pueblo Economy*, S. G. Ortman, Ed. (University of Arizona Press, 2019), vol. 80, pp. 1–16.
19. A. Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (Metalibri Digital Library, 2007).
20. W. J. Stull, The urban economics of Adam Smith. *J. Urban Econ.* **20**, 291–311 (1986).
21. H. Barcai, A formal outline of the Smithian growth model. *Q. J. Econ.* **83**, 396–414 (1969).
22. K. J. Arrow, The economic implications of learning by doing. *Rev. Econ. Stud.* **29**, 155–173 (1962).
23. P. Auerswald, S. Kauffman, J. Lobo, K. Shell, The production recipes approach to modeling technological innovation: An application to learning by doing. *J. Econ. Dynam. Control* **24**, 389–450 (2000).
24. G. J. Stigler, The division of labor is limited by the extent of the market. *J. Pol. Econ.* **59**, 185–193 (1951).
25. G. Grossman, E. Helpman, Product development and international trade. *J. Pol. Econ.* **97**, 1261–1283 (1989).
26. R. M. Solow, *Learning from 'Learning by Doing': Lessons for Economic Growth* (Stanford Univ. Press, 1997).
27. L. M. A. Bettencourt, Impact of changing technology on the evolution of complex informational networks. *Proc. IEEE* **102**, 1878–1891 (2014).
28. E. Boserup, *Population and Technological Change: A Study of Long-Term Trends* (University of Chicago Press, 1981).
29. R. L. Carneiro, The transition from quantity to quality: A neglected causal mechanism in accounting for social evolution. *Proc. Natl. Acad. Sci. U.S.A.* **97**, 12926–12931 (2000).
30. A. W. Johnson, T. K. Earle, *The Evolution of Human Societies: From Foraging Group to Agrarian State* (Stanford Univ. Press, ed. 2, 2000).
31. E. Durkheim, *The Division of Labor in Society* (The Free Press, 1984).
32. K. J. Arrow, in *The Return to Increasing Returns*, J. M. Buchanan, Y. J. Yoon, Eds. (The University of Michigan Press, 1994), pp. 69–84.
33. L. M. A. Bettencourt, The origins of scaling in cities. *Science* **340**, 1438–1441 (2013).
34. S. G. Ortman, A. H. Cabaniss, J. O. Sturm, L. M. Bettencourt, The pre-history of urban scaling. *PLOS ONE* **9**, e87902 (2014).
35. J. Lobo, L. Bettencourt, M. E. Smith, S. Ortman, Settlement scaling theory: Bridging the study of ancient and contemporary urban systems. *Urban Stud.* **57**, 731–747 (2019).
36. T. Piketty, *Capital in the Twenty-First Century* (Harvard Univ. Press, 2014).
37. E. W. F. Peterson, The role of population in economic growth. *SAGE Open* **7**, 1–15 (2017).
38. E. L. Glaeser, H. D. Kallal, J. A. Scheinkman, A. Shleifer, Growth in cities. *J. Pol. Econ.* **100**, 1126–1152 (1992).
39. E. L. Glaeser, J. A. Scheinkman, A. Shleifer, Economic growth in a cross-section of cities. *J. Monet. Econ.* **36**, 117–143 (1995).
40. R. Hausmann, C. A. Hidalgo, The network structure of economic output. *J. Econ. Growth* **16**, 309–342 (2011).
41. L. Alessandretti, P. Sapiezynski, V. Sekara, S. Lehmann, A. Baronchelli, Evidence for a conserved quantity in human mobility. *Nat. Hum. Behav.* **2**, 485–491 (2018).
42. L. M. A. Bettencourt, Towards a statistical mechanics of cities. *C. R. Phys.* **20**, 308–318 (2019).
43. S. G. Ortman, *Winds from the North: Tewa Origins and Historical Anthropology* (University of Utah Press, 2012).
44. S. G. Ortman, in *The Archaeology of Human Experience*, M. Hegmon, Ed. (American Anthropological Association, 2016), pp. 74–94.
45. E. M. Barrett, *Conquest and Catastrophe: Changing Rio Grande Pueblo Settlement Patterns in the Sixteenth and Seventeenth Centuries* (University of New Mexico Press, 2002).
46. A. F. Ramenofsky, The problem of introduced infectious diseases in new mexico, A.D. 1540-1680. *J. Anthropol. Res.* **52**, 161–184 (1996).
47. T. A. Kohler, S. G. Ortman, K. E. Grundtisch, C. M. Fitzpatrick, S. M. Cole, The better angels of their nature: Declining violence through time among prehispanic farmers of the pueblo southwest. *Am. Antiq.* **79**, 444–464 (2014).
48. A. F. Ramenofsky, K. L. Schleher, *Change and Stability: The Archaeology and History of Pueblo San Marcos, New Mexico* (University of New Mexico Press, 2017).
49. S. G. Ortman, Uniform probability density analysis and population history in the northern rio grande. *J. Archaeol. Method Theory* **23**, 95–126 (2016).
50. R. D. Drennan, C. A. Berrey, C. E. Peterson, *Regional Settlement Demography in Archaeology* (Eliot Werner Publications, 2015).
51. M. D. Varien, B. J. Mills, Accumulations research: Problems and prospects for estimating site occupation span. *J. Archaeol. Method Theory* **4**, 141–191 (1997).
52. M. D. Varien, S. G. Ortman, Accumulations research in the southwest united states: Middle-range theory for big-picture problems. *World Archaeol.* **37**, 132–155 (2005).
53. T. A. Kohler, M. E. Smith, A. Bogaard, G. M. Feinman, C. E. Peterson, A. Betzenhauser, M. Pailes, E. C. Stone, A. M. Prentiss, T. J. Dennehy, L. J. Ellyson, L. M. Nicholas, R. K. Faulseit, A. Styring, J. Whitlam, M. Fochesato, T. A. Foor, S. Bowles, Greater post-neolithic wealth disparities in eurasia than in north and mesoamerica. *Nature* **551**, 619–622 (2017).

54. M. J. Liebmann, J. Farella, C. I. Roos, A. Stack, S. Martini, T. W. Swetnam, Native American depopulation, reforestation, and fire regimes in the Southwest United States, 1492-1900 CE. *Proc. Natl. Acad. Sci. U.S.A.* **113**, E696–E704 (2016).
55. D. Acemoglu, J. A. Robinson, *Why Nations Fail: The Origins of Power, Prosperity and Poverty* (Crown Business, 2012).
56. D. C. North, J. J. Wallis, B. R. Weingast, *Violence and Social Orders: A Conceptual Framework for Interpreting Recorded Human History* (Cambridge Univ. Press, 2009).
57. R. I. Ford, in *Ortiz, Alfonso, ed. New Perspectives on the Pueblos* (University of New Mexico Press, 1972), pp. 1–17.
58. J. L. van Zanden, B. van Leeuwen, Persistent but not consistent: The growth of national income in Holland 1347-1807. *Explor. Econ. Hist.* **49**, 119–130 (2012).
59. R. Jedwab, D. Vollrath, Urbanization without growth in historical perspective. *Explor. Econ. Hist.* **58**, 1–21 (2015).
60. J. V. Henderson, Urbanization and economic development. *Ann. Econ. Financ.* **4**, 275–341 (2003).

Acknowledgments: We thank K. E. Davis for assistance in compiling the room area and artifact assemblage data analyzed in this paper and L. Bettencourt for discussions. **Funding:** Portions of this research were supported by grants from the James S. McDonnell Foundation (#220020438) and the NSF (CNH-0816400). **Author contributions:** S.O.: conceptualization, methodology, formal analysis, investigation, data curation, writing, review and editing, and visualization; J.L.: conceptualization, methodology, investigation, writing, and review and editing. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data needed to evaluate the conclusions in the paper are present in the paper and/or Supplementary Materials. The raw data files are available at https://core.tdar.org/project/392021/social-reactors-project-datasets. Additional data are available from the authors upon request.

Submitted 16 December 2019
Accepted 8 May 2020
Published 19 June 2020
10.1126/sciadv.aba5694

Citation: S. Ortman, J. Lobo, Smithian growth in a nonindustrial society. *Sci. Adv.* **6**, eaba5694 (2020).

Science Advances

Smithian growth in a nonindustrial society

Scott Ortman and José Lobo

Sci Adv **6** (25), eaba5694.
DOI: 10.1126/sciadv.aba5694

Science Advances (ISSN 2375-2548) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title *Science Advances* is a registered trademark of AAAS.