The Origins of Inequality: Insiders, Outsiders, Elites, and Commoners
Author(s): Gregory K. Dow and Clyde G. Reed
Source: *Journal of Political Economy*, Vol. 121, No. 3 (June 2013), pp. 609-641
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/10.1086/670741

# The Origins of Inequality: Insiders, Outsiders, Elites, and Commoners

Gregory K. Dow

*Simon Fraser University*

Clyde G. Reed

*Simon Fraser University*

Hereditary economic inequality is unknown among mobile foragers, but hereditary class distinctions between elites and commoners exist in some sedentary foraging societies. With agriculture, such stratification tends to become more pronounced. We develop a model to explain the associations among productivity, population, property rights, and inequality. Using Malthusian dynamics, we show that regional productivity growth leads to enclosure of the best sites first, creating inequality between insiders and outsiders. Hereditary elite and commoner classes subsequently arise at the best sites. Food consumption becomes more unequal and commoners become poorer. These predictions are consistent with a wide range of archaeological evidence.

## I. Introduction

Mobile foraging groups exhibit a minimal amount of economic inequality. There may be differences in work tasks and food consumption based

Leanna Mitchell provided exceptional research assistance. We are grateful for comments from our colleagues at Simon Fraser University, participants at the Workshop on the Emergence of Hierarchy and Inequality hosted by the Santa Fe Institute in February 2009, and participants at the Second Conference on Early Economic Developments held at Simon Fraser in July 2009. We would also like to thank two anonymous referees and two editors at this *Journal* for extensive comments on earlier drafts. Funding was provided by the Human Evolutionary Studies Program at Simon Fraser and the Social Sciences and Humanities Research Council of Canada. All opinions are those of the authors.

[*Journal of Political Economy,* 2013, vol. 121, no. 3]

on age and sex, and bands may occupy territories of unequal value, but there are no hereditary class distinctions. Anthropologists have studied societies of this kind in the Kalahari Desert, Australia, Southeast Asia, Amazonia, and the Arctic (Kelly [1995] 2007).

Sedentary foraging societies are more diverse. Some are relatively egalitarian, but others display considerable inequality both across and within communities, and they may be divided into hereditary elite and commoner classes. Examples of the latter type include societies on the northwestern coast of North America prior to European contact (Ames and Maschner 1999). With agriculture, such inequality tends to become more pronounced and is usually based on elite control over land (Johnson and Earle 2000).

We develop a theory to explain the associations among (*a*) rising productivity, (*b*) rising population, and (*c*) rising inequality. The key exogenous variable in our model is the productivity of labor in food acquisition. Population, property rights, and inequality are endogenous. The link between points *a* and *b* results from Malthusian dynamics. When productivity improves, food per capita rises in the short run. However, the productivity gains are eventually absorbed through population growth in the long run, with regional food per capita returning to a constant long-run level.

The link between points *b* and *c* results from endogenous property rights. Our starting point is a region in which many identical agents have free mobility across many food acquisition sites. These sites vary in quality because of water availability, soil fertility, and other factors. If the number of agents at a site exceeds a critical mass, outsiders can expect to be driven off or killed by the insiders. This deters further entry and transforms open-access land into an exclusive resource.

The causal mechanism leading to inequality runs as follows. In a world of open access, food consumption is equal because agents receive their average products, which are identical across sites because of free mobility. The same equilibrium condition implies that population density must be highest at the best sites. Productivity growth results in population growth, and eventually the agents at the best sites become numerous enough to close those sites to further entry. The insiders at closed sites share food equally. The insiders at all closed sites are better off than outsiders who remain in the commons, and insiders at higher-quality sites are better off than those at lower-quality sites. Further growth in productivity and population leads to enclosure of lower-quality sites. Regional inequality rises, and agents in the commons become increasingly impoverished.

When productivity and population are sufficiently high, stratification emerges at the best sites and then spreads across the region. At the stratified sites, elites hire outside labor at a wage equal to food per person in the commons. Thus the marginal product of labor in the stratified sector is equal to the average product in the open sector. Members of the elite receive both an implicit wage and land rent.

One key simplifying assumption is that a fixed number of food producers is needed to close a site. There are no specialized guards or warriors. In our formal analysis we treat the required number of people as a parameter that is invariant across sites and over time. In practice, however, this number could vary with terrain, with the technology used to repel outsiders, with natural shocks affecting the value of the site, or with external events that encourage entry attempts by outsiders.

A second simplifying assumption is that the number of children for an adult is proportional to the adult's food income. With identical proportionality factors across agents, this implies that income distribution does not influence aggregate population growth. It also implies that average income is fixed in the long run, so if someone is made better off by a change in parameters, then someone else must be made worse off.

Our model has implications for mobility between the elite and commoner classes. In long-run equilibrium, parents have just enough children to replace themselves at an aggregate level. However, the elite at stratified sites have more children than are needed for replacement. We assume that in each generation, the children of the previous insiders at a site form a new insider group according to birth order. After the critical mass needed for exclusion has been reached, any further offspring are expelled from the site. This implies that all the elite agents at a stratified site have elite parents; thus, the elite is hereditary. Institutional rules other than birth order could also be used to ensure sufficient downward mobility from the elite to the commoner class.

The formal structure of the model applies equally to foraging and agricultural societies. Our model is also general in an institutional sense: while we assume that elites hire commoners by paying them a wage, one could easily reformulate the model to have commoners pay land rent to the elite. The only requirement is that commoners must be free to leave their current sites. For brevity we omit consideration of slave societies.

The rest of the paper is organized as follows. Section II discusses the creation of property rights during the California gold rush. Although this case differs in some ways from the small-scale foraging and agricultural societies on which we focus later, it shows how property rights can emerge in the absence of the state and helps to motivate some of the assumptions used in our formal model.

Section III develops a short-run model in which a given regional population is allocated across sites, and property rights are endogenously determined at each site. Section IV introduces an aggregate production function for the region as a whole and identifies the distortions associated with property rights issues. Section V combines Malthusian population dynamics with the aggregate production function to define long-run equilibrium and investigate the adjustment path toward this equilibrium. Section VI shows that when some sites are closed, higher productivity ($a$) makes commoners poorer, ($b$) raises the Gini coefficient for the region, and ($c$) leads to hereditary elites.

We turn to empirical evidence in Section VII. After a general discussion, we review archaeological data on the emergence of inequality in Southwest Asia, Europe, Polynesia, and the Channel Islands off the coast of California. In each case, we argue that the data are consistent with our theory. Section VIII summarizes our results. Section IX closes with a discussion of related literature from archaeology, anthropology, and economics, with an emphasis on the ways in which our framework differs from other contributions. Proofs of all formal propositions are available in the online Appendix.

## II. The California Gold Rush

When the California gold rush started in 1848, mineral rights were held by the US government (all information is from Umbeck [1981]). However, enforcement proved impossible because of high rates of desertion from the military. From 1848 to 1866 open access prevailed, except at sites where property rights were created endogenously.

Miners foraged for gold using simple technologies involving little human capital. The exclusion technology was based only on numbers of miners. Miners would wait a short period after a discovery at a site had been made public before allocating gold land. At that point, a majority vote would be held, and early arrivers would be allowed to stay while late arrivers would be compelled to leave. The values of the claims of the insiders were then equalized.

To maintain their exclusive mining rights, miners were required to be present at the mining site and to work their claims a specified number of days per week. Miners were collectively required to enforce each other's mining rights. Failure to comply with these rules led to expulsion from the site. Although all miners were well armed, there is little evidence of violence in the goldfields. There is also no evidence that specialized gunfighters were hired or that unusual abilities in the use of violence were important.

The population of miners was perhaps 800 in May 1848 and had grown to over 100,000 a year later. Early in this process, there is no evidence that any sites were closed. Individuals or small teams worked under open-access conditions. Population densities were higher at better sites (often, those closest to water supplies).

By 1849, contracts between miners show that exclusive mining rights had arisen at some sites. These contracts describe explicit responsibilities for group enforcement of property rights. The inequality in the goldfields through 1866 was insider-outsider, in the sense that some groups of miners had more valuable sites and thus higher per capita incomes. It never involved stratification among miners at an individual site, except in a few instances in which miners hired local Native Americans to search for gold. In 1866 the US Congress passed legislation that ended the need for self-enforcement by the miners.

This narrative captures several features of our formal model, including (*a*) many sites of heterogeneous quality within a region, (*b*) initial conditions of open access, (*c*) creation of group property rights when local population densities became high enough, (*d*) a low cost of property right enforcement after a critical mass of agents was reached, (*e*) little difficulty with free-rider problems among insiders at a site, (*f*) no specialization with respect to violence, and (*g*) roughly equal endowments of human and physical capital among the agents. The main difference from our framework is that we treat population growth as a Malthusian response to rising productivity, while in the goldfields population grew rapidly through in-migration.

Putting the latter point aside, we believe that small groups of hunter-gatherers or agriculturalists would most likely have cooperated to defend territories using generally available weapons (clubs, spears, bows and arrows) much as the gold miners did and that the number of insiders would have been the key variable in deterring potential intruders. While our model does not deal with coalitions of intruders (i.e., warfare), it should be noted that coalitions of gold miners did not engage in warfare over mining sites.

## III. Short-Run Equilibrium

At an individual production site, food output (in calories) is $\theta s L^{\alpha}$, where $\theta > 0$ reflects regionwide climate, technology, and resources; $s > 0$ is the quality of the site; $L \geq 0$ is labor used for food production; and $0 < \alpha < 1$. The input of land is normalized at unity. Variations in site quality reflect local environmental factors such as terrain, good soil, availability of fresh water, or favorable hunting and gathering opportunities.

Each individual agent is negligible relative to the number of agents at the site as a whole. An agent is endowed with a unit of time, which is used for food production. We ignore leisure. Any agent at the site can migrate to another site and obtain a quantity of food $w$. There is an infinitely elastic supply of outsiders who will enter the site if they are not excluded and can obtain more than $w$ by doing so.

A group of $d$ or more food producers can cooperate to prevent outsiders from appropriating land at the site. This is an automatic by-product of food production and does not have an opportunity cost (exclusion involves deterrence rather than building a fence or patrolling a perimeter). The weapons used to defend a site are readily available to all. Deterrence fails whenever there are fewer than $d$ agents at the site, and in this case outsiders will enter if it is profitable to do so.

Let $n$ be the number of agents born at the site. There are two ways in which a group of size $d$ may arise. If $n \geq d$, a subset of size $d$ is determined by birth order. This core group, called *insiders*, appropriates all of the land at the site. The other $n - d$ agents become *outsiders* and have no land endowment. Alternatively, if $n < d$, those born at the site fall short of the number needed for exclusion. But if enough outsiders are attracted to the site, exclusion occurs after the first $d - n$ agents have arrived from other sites.

Next, consider a region with a continuum of production sites. Physical mobility among sites is costless, but the agents cannot leave the region because of natural barriers such as deserts, mountains, or oceans. Site qualities are distributed uniformly on the interval $s \in [0, 1]$. Let $n(s)$ be the number of people born at a site of quality $s$. Define the short run as a period in which the total regional population $N \equiv \int_0^1 n(s)\,ds$ does not change. We take this to be one human generation (about 20 years).

For a given regional population $N$, labor is allocated across sites as follows. A *short-run equilibrium* (SRE) for a given $N > 0$ is a wage $w > 0$ and a density function $L(\cdot)$ defined on the interval [0, 1] with $N = \int_0^1 L(s)\,ds$ such that

*a.* if $L(s) < d$, then $w = \theta s L(s)^{\alpha-1}$;
*b.* if $L(s) \geq d$, then
  i. $L(s)$ maximizes $\theta s L^{\alpha} - w(L - d)$ subject to $L \geq d$ and
  ii. $r(s) \equiv \theta s L(s)^{\alpha} - wL(s) \geq 0$.

Part *a* states that all sites where exclusion is impossible must have the same food per capita $w$, which is equal to the average product of labor. Because mobility is costless, these sites must be equally attractive in equilibrium. We call such sites *open* and refer to the set of all open sites as the *commons.*

Part *b* describes sites where insiders can exclude outsiders. We call such sites *closed.* At these sites the $d$ insider agents choose some number of outsiders $L - d \geq 0$ who are admitted to the site and allowed to produce food there. We assume that the methods used to exclude outsiders can also be used to prevent them from appropriating land after they are admitted. Any outsiders allowed to produce food at the site receive the wage $w$.

When $L = d$ so that no outsiders are admitted, we say that the site is closed but *unstratified.* When $L > d$, the site is both closed and *stratified.* In the latter situation, we distinguish between the *elite* (the insiders who control access to land) and the *commoners* (the hired outsiders who have no land claim and receive the wage $w$). Commoner labor does not contribute to entry deterrence.

Condition $b$(i) in the definition of SRE requires that when a site is closed, the number of hired agents be chosen to maximize the net food income of the insider group. The resulting food is shared equally among the $d$ landowners, so that each receives $w + [\theta s L(s)^\alpha - wL(s)]/d$. Condition $b$(ii) requires that the land rent $r(s) \equiv \theta s L(s)^\alpha - wL(s)$ obtained at a closed site be nonnegative. Otherwise, the insiders would be better off abandoning the site and moving to the commons themselves.

Landowners in the stratified sector maximize profit, and thus at every site in this sector the marginal product of labor is equal to the wage. The wage, in turn, is equal to the average product of labor in the commons. At a site that is closed but unstratified, the marginal product of labor at the site is below the average product in the commons, so it is unprofitable for insiders to employ outsiders.

We prove the existence and uniqueness of SRE in three steps. First, we consider an arbitrary wage $w$ and characterize the property rights and labor inputs that must occur at each site in an SRE. This is done in lemma 1 below. The main result is that there are quality bounds $s^a$ and $s^b$ with $0 < s^a < s^b$ such that sites with qualities below $s^a$ are open, sites of intermediate quality are closed but unstratified, and sites with qualities above $s^b$ are both closed and stratified. Lemma 2 establishes the converse: a wage and a density function that satisfy the conditions of lemma 1 and clear the labor market are an SRE.

Finally, proposition 1 shows that equating labor demand with the labor supply $N$ yields a unique equilibrium wage. This wage determines a unique set of property rights through lemma 1. Because the definition of SRE involves only the ratio $x \equiv w/\theta$ rather than $w$ and $\theta$ separately, in this section we fix $\theta$ and work with the normalized wage $x$.

LEMMA 1. Choose an arbitrary normalized wage $x \equiv w/\theta > 0$. Let $L(\cdot, x)$ be a density function that satisfies conditions $a$ and $b$ in the definition of SRE for the given $x$. Define $s^a(x) \equiv xd^{1-\alpha}$ and $s^b(x) \equiv (x/\alpha)d^{1-\alpha}$.

*a*. If $s < s^a(x)$, then $L(s, x) = (s/x)^{1/(1-\alpha)} < d$ (open sites).
*b*. If $s^a(x) \leq s \leq s^b(x)$, then $L(s, x) = d$ (unstratified sites).
*c*. If $s^b(x) < s$, then $L(s, x) = (\alpha s/x)^{1/(1-\alpha)} > d$ (stratified sites).

Lemma 1 shows that for any wage level, a commons must exist. If $x$ is high enough that $1 < s^a(x)$, all sites are in the commons. At intermediate wage levels we have $0 < s^a(x) \leq 1 \leq s^b(x)$, where at least one of the latter inequalities is strict. Inferior sites are open and superior sites are closed, but no sites are stratified. If the wage is low enough that $0 < s^a(x) < s^b(x) < 1$, all three sectors exist, with the best sites both closed and stratified.

The latter case is illustrated in figure 1. The density $L(\cdot, x)$ showing labor input as a function of site quality is rising in the open sector, is flat on the interval where insiders do not use hired labor, and is rising again in the stratified sector. The areas $D_O(x)$, $D_I(x)$, $D_E(x)$, and $D_C(x)$ under the density curve show the total labor input (i) at open-access sites, (ii) by insiders at unstratified sites, (iii) by elites at stratified sites, and (iv) by commoners at stratified sites, respectively.

LEMMA 2. Choose any $N > 0$. A normalized wage $x$ and a density function $L(\cdot, x)$ that satisfy conditions $a$, $b$, and $c$ in lemma 1 form an SRE if and only if $N = \int_0^1 L(s, x)\,ds$.

Lemma 2 shows that an equilibrium can be found by associating each normalized wage with the corresponding density function from lemma 1, computing the area under this density as in figure 1, and then varying the wage until the total area under the density curve is equal to the regional population $N$. This procedure gives the following results.

PROPOSITION 1 (Short-run equilibrium). Define $Q \equiv (1 - \alpha)/(2 - \alpha)$, $N^a \equiv Qd$, $N^b \equiv 2Qd$, $x^a \equiv d^{\alpha-1}$, and $x^b \equiv \alpha d^{\alpha-1}$. Let the labor demand function be $D(x) \equiv \int_0^1 L(s, x)\,ds$, where $L(s, x)$ is obtained from lemma 1.

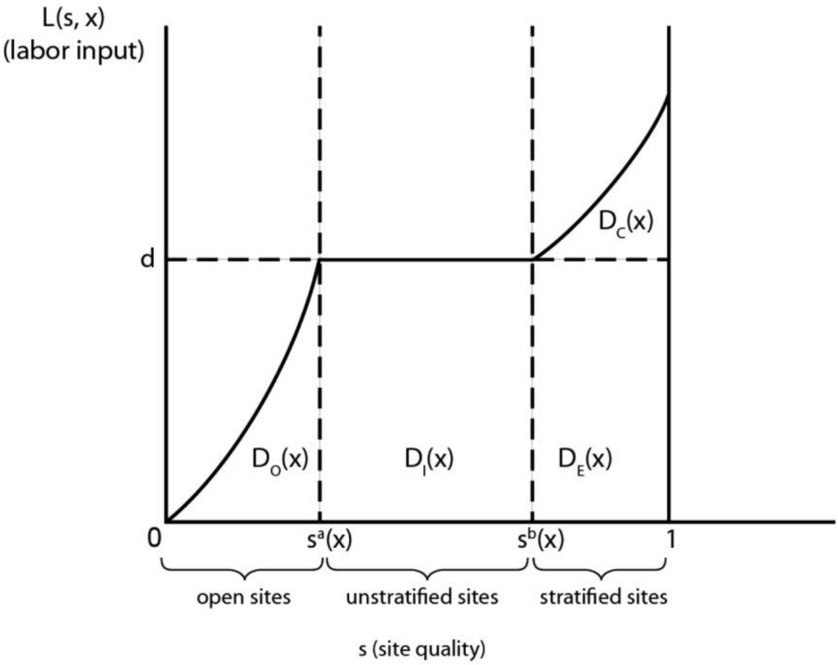


FIG. 1.—Labor input as a function of site quality for a fixed normalized wage $(x)$. $x = w/\theta$, where $w$ is the nonnormalized wage and $\theta$ is the productivity of food production; $d$ is the minimum labor input needed to exclude outsiders; and $D_O(x)$, $D_I(x)$, $D_E(x)$, and $D_C(x)$ show the total labor input at open-access sites, by insiders at unstratified sites, by elites at stratified sites, and by commoners at stratified sites, respectively.

*a.* $N < N^a$ implies $x^a < x$ and $D(x) = Qx^{-1/(1-\alpha)}$.
*b.* $N^a \leq N \leq N^b$ implies $x^b \leq x \leq x^a$ and $D(x) = d - xd^{2-\alpha}/(2-\alpha)$.
*c.* $N^b < N$ implies $x < x^b$ and $D(x) = Q[xd^{2-\alpha}/\alpha + (\alpha/x)^{1/(1-\alpha)}]$.
*d.* The labor demand function $D(x)$ is continuously differentiable with $D'(x) < 0$ for all $x > 0$. Also, $\lim_{x\to 0} D(x) = \infty$ and $\lim_{x\to\infty} D(x) = 0$.
*e.* For each $N > 0$, there is a unique $x > 0$ such that $D(x) = N$. The combination of this normalized wage and the associated labor allocation $L(\cdot,\ x)$ from lemma 1 form a unique SRE for the given $N$. The equilibrium wage $x(N)$ is continuously differentiable with $x'(N) < 0$, $\lim_{N\to 0} x(N) = \infty$, and $\lim_{N\to\infty} x(N) = 0$.

Figure 2 shows the relationships among the regional population $N$, the wage, and the property rights regime. The downward-sloping labor demand curve $D(x)$ is obtained from proposition 1, and the population $N$ gives a vertical supply curve for labor. At low population levels, the wage is high and all sites are open, because even the best sites fail to reach the threshold $d$. Population growth leads to a falling wage. Beyond $N^a$, the best sites become closed. Further population growth leads to

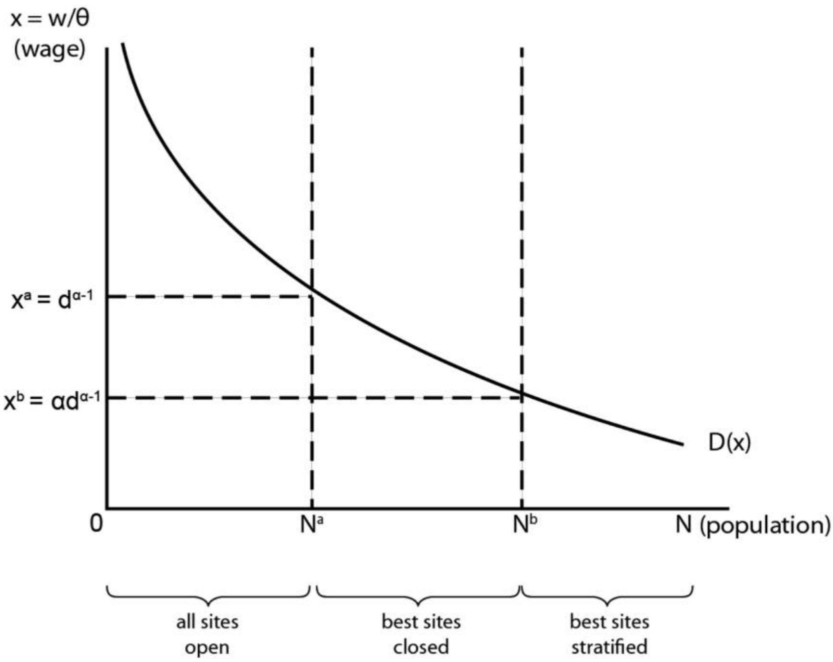


FIG. 2.—Normalized wage and property rights as a function of regional population. $w$ is the nonnormalized wage, $\theta$ is the productivity of food production, $d$ is the minimum labor input needed to exclude outsiders, $\alpha$ is the output elasticity for food production, and $D(x)$ is the demand for labor.

more enclosures in order of decreasing site quality. Beyond $N^b$, the best sites are both closed and stratified.

## IV. The Aggregate Production Function

Before considering long-run equilibrium, we need to develop some ideas about aggregate output. Suppose first that all sites are open. Owing to the constant elasticity of output, equalizing the average product of labor across sites is the same as equalizing the marginal product of labor ($\mathrm{MPL} = \alpha\mathrm{APL}$). Therefore, labor is allocated efficiently. But if some sites are closed, a distortion occurs because labor input is constant on $[s^a(x), s^b(x)]$ while site qualities are not, so marginal products are unequal. If some sites are stratified, a second distortion arises because the marginal product of labor at such sites is equal to the average product at open sites. Here we study the implications for regional output.

Total food output for the region is

$$Y = \int_0^1 \theta sL(s, x)^\alpha ds, \tag{1}$$

where the labor allocation $L(\cdot, x)$ satisfies lemma 1 and the equilibrium wage is derived from $D(x) = N$ in proposition 1. Thus the aggregate production function becomes

$$Y(N) = \int_0^1 \theta sL[s, x(N)]^\alpha ds \tag{2}$$

or

$$Y(N) = \phi[x(N)], \tag{3}$$

where $\phi(x) = \int_0^1 \theta sL(s, x)^\alpha ds$.

Proposition 2 (Aggregate production function). As in proposition 1, let $Q \equiv (1-\alpha)/(2-\alpha)$, $N^a \equiv Qd$, $N^b \equiv 2Qd$, $x^a \equiv d^{\alpha-1}$, and $x^b \equiv \alpha d^{\alpha-1}$.

*a.* $N < N^a$ implies $x^a < x$ and $\phi(x) = \theta Q x^{-\alpha/(1-\alpha)}$.
*b.* $N^a \leq N \leq N^b$ implies $x^b \leq x \leq x^a$ and $\phi(x) = \theta[x^2 d^{2-\alpha}(Q - 1/2) + d^\alpha/2]$.
*c.* $N^b < N$ implies $x < x^b$ and $\phi(x) = \theta Q[x^2 d^{2-\alpha}(1+\alpha)/2\alpha + (\alpha/x)^{\alpha/(1-\alpha)}]$.

The function $\phi(x)$ is continuously differentiable with $\phi'(x) < 0$ for all $x > 0$. The function $Y(N) = \phi[x(N)]$ is continuously differentiable with $Y'(N) > 0$ for all $N > 0$.

COROLLARY TO PROPOSITION 2.

*a.* $N < N^a$ implies $Y(N) = \theta N^\alpha Q^{1-\alpha}$.

*b.* $N^a \leq N \leq N^b$ implies $Y(N) = (\theta d^\alpha/2)[1 - \alpha(2-\alpha)(1 - N/d)^2]$.

*c.* There is a population level $N^c > N^b$ such that (i) $Y''(N) > 0$ for $N^b < N < N^c$, (ii) $Y''(N^c) = 0$, and (iii) $Y''(N) < 0$ for $N > N^c$.

*d.* For any fixed $\theta > 0$, $Y(N)/N$ is continuously differentiable and decreasing, with $\lim_{N\to 0} Y(N)/N = \infty$ and $\lim_{N\to\infty} Y(N)/N = 0$.

Figure 3 shows the production function $Y(N)$. This function is increasing and has a continuous marginal product, but its second derivative is discontinuous at $N^a$ and $N^b$. In the population interval $N < N^a$, all sites are open and there are no distortions. Output has a Cobb-Douglas form as in part *a* of the corollary, where $Q$ can be interpreted as the endowment of quality-adjusted land for the region as a whole. In the range $N^a < N < N^b$, higher-quality sites are closed and labor input is constant at $d$ across these sites. In this interval $Y(N)$ is below the dashed continuation of the Cobb-Douglas function from part *a*.

When $N^b < N$, the highest-quality sites become stratified. This creates a further distortion because the marginal product of labor is not equalized between the open and stratified sectors. As indicated in figure 3,

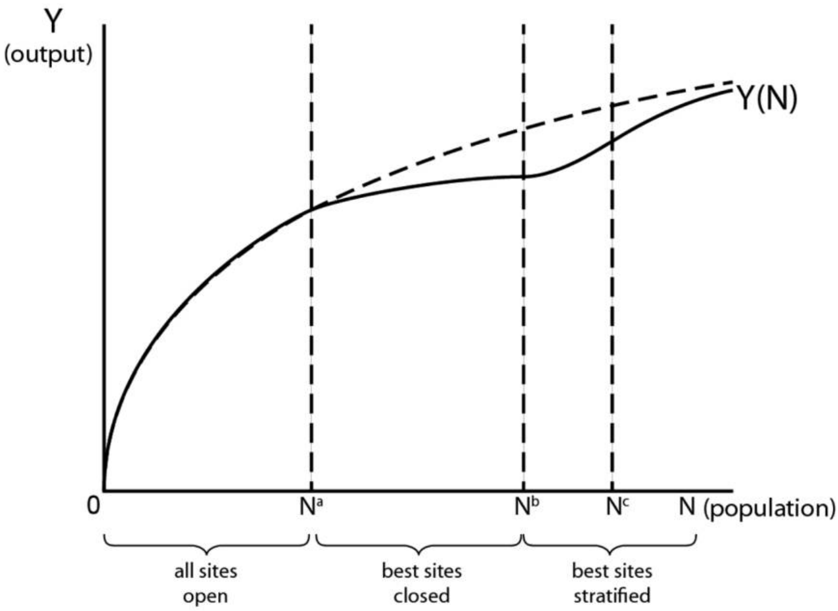


FIG. 3.—Aggregate production function. $N^c$ is the population level at which the production function changes from convex to concave.

for population levels near $N^b$ the production function is convex. The rising marginal product results from the shifting property rights boundaries between the open and closed sectors as well as the unstratified and stratified sectors. The curve $Y(N)$ has an inflection point at $N^c$ and then returns to concavity. At very high population levels almost all sites are stratified, marginal products are equal at almost all sites, and $Y(N)$ approaches the dashed Cobb-Douglas curve in figure 3.

Aggregate per capita food $Y(N)/N$ is globally decreasing in total population $N$, as indicated in part *d* of the corollary. This occurs because the usual tendency for average product to decline at each individual site outweighs the property rights effects responsible for the nonconcave portion of $Y(N)$.

## V. Long-Run Equilibrium

Population is endogenous in the long run. Each adult in period $t$ has children who survive to become adults in period $t+1$. Adults from period $t$ die at the end of that period. The number of children for an individual is equal to the parent's food income multiplied by a constant $\gamma > 0$. This relationship arises because fertility is an increasing function of food, because childhood mortality is a decreasing function of food, or both.

We assume that $\gamma$ is identical for all adults, so the aggregate number of new adults in period $t+1$ is $\gamma Y_t$, where $Y_t$ is regional food output in period $t$. Let $N_t$ be the population of adults in period $t$ for the region as a whole. The dynamics for the region are given by $N_{t+1} = \gamma Y(N_t; \theta)$, where $Y(N; \theta)$ is the aggregate production function from Section IV with the productivity parameter $\theta$ included as an explicit argument. In a long-run equilibrium we always have $Y(N; \theta)/N = 1/\gamma$. This is the Malthusian feature of the model: as long as the demographic parameter $\gamma$ is constant, every long-run equilibrium yields the same food per capita at the regional level. A permanent increase in productivity ($\theta$) is thus absorbed in the long run through higher population rather than higher food per person.

A *long-run equilibrium* (LRE) for a fixed $\theta > 0$ is defined to be a population $N > 0$, a density function $L(s)$ with $N = \int_0^1 L(s)\,ds$, and a normalized wage $x \equiv w/\theta > 0$ such that the conditions for short-run equilibrium are satisfied, and in addition $Y(N; \theta)/N = 1/\gamma$.

PROPOSITION 3 (Long-run equilibrium).

*a*. For each $\theta > 0$ there is a unique LRE population $N(\theta) > 0$.
*b*. $N(\theta)$ is continuously differentiable and increasing, with $\lim_{\theta\to 0} N(\theta) = 0$ and $\lim_{\theta\to\infty} N(\theta) = \infty$.
*c*. There are productivity levels $0 < \theta^a < \theta^b$ such that

i. $0 < \theta < \theta^a$ implies $0 < N(\theta) < N^a$. All sites are open.
ii. $\theta^a \le \theta \le \theta^b$ implies $N^a \le N(\theta) \le N^b$. There is a threshold $s^a(\theta) \in (0, 1]$ such that all sites with $s \in [0, s^a(\theta))$ are open and all sites with $s \in [s^a(\theta), 1]$ are closed. No sites are stratified.
iii. $\theta^b < \theta$ implies $N^b < N(\theta)$. There is a threshold $s^a(\theta) \in (0, 1)$ such that all sites with $s \in [0, s^a(\theta))$ are open and all sites with $s \in [s^a(\theta), 1]$ are closed. There is also a second threshold $s^b(\theta) \in (s^a(\theta), 1)$ such that all sites with $s \in (s^b(\theta), 1]$ are stratified.

The boundaries $s^a(\theta)$ and $s^b(\theta)$ are continuously differentiable and decreasing with $\lim_{\theta\to\infty} s^a(\theta) = 0$ and $\lim_{\theta\to\infty} s^b(\theta) = 0$.

*d*. The (nonnormalized) LRE wage $w(\theta)$ is continuously differentiable. For all $\theta \le \theta^a$, $w(\theta) = 1/\gamma$. For all $\theta > \theta^a$, $w(\theta)$ is decreasing with $w(\theta) < 1/\gamma$.

The results in proposition 3 are illustrated in figure 4. The ray from the origin with slope $1/\gamma$ is identical in all three graphs. The only distinction among the cases involves the productivity parameter $\theta$, which is low in figure 4*A*, intermediate in figure 4*B*, and high in figure 4*C*. The values of $N^a$ and $N^b$ are independent of $\theta$. In each case the LRE is unique because the aggregate average product of labor $Y(N;\ \theta)/N$ is globally decreasing in $N$ (see part *d* of the corollary in Sec. IV).

Figure 4*A* shows the case in which $0 < \theta < \theta^a$ and $0 < N(\theta) < N^a$. The ray from the origin with slope $1/\gamma$ intersects the production function $Y(N;\ \theta)$ at a population less than $N^a$. All sites are open because $N(\theta) < N^a$. Figure 4*B* shows the case in which $\theta^a < \theta < \theta^b$ and $N^a < N(\theta) < N^b$. Because the production function $Y(N;\ \theta)$ has now shifted up, the ray from the origin and $Y(N;\ \theta)$ intersect at a higher value of $N$. Owing to the larger population, the best sites are closed, although none are stratified. Finally, figure 4*C* shows the case in which $\theta^b < \theta$ and $N^b < N(\theta)$. Here the productivity $\theta$ is high enough to support a long-run population above $N^b$, and accordingly the best sites are stratified.

We conclude this section with a brief description of the process through which the system converges to an LRE for a fixed $\theta$. This is shown in figure 5. We start from an initial population $N^0$ with a corresponding output $Y^0$. Suppose that $N^0$ is below the long-run population $N^*$. The output $Y^0$ determines the adult population $N^1$ in the next generation through $N^1 = \gamma Y^0$. This implies that the point $(N^1, Y^0)$ lies on the ray from the origin with slope $1/\gamma$. The point $N^1$ yields the output $Y^1$ through the production function, and so on. The arrows show the process by which the system converges monotonically to the point $(N^*, Y^*)$. The same dynamics apply in reverse starting from a population above $N^*$.

In later sections, two distinct thought experiments will be considered. In the first case, we start from an LRE involving a low productivity

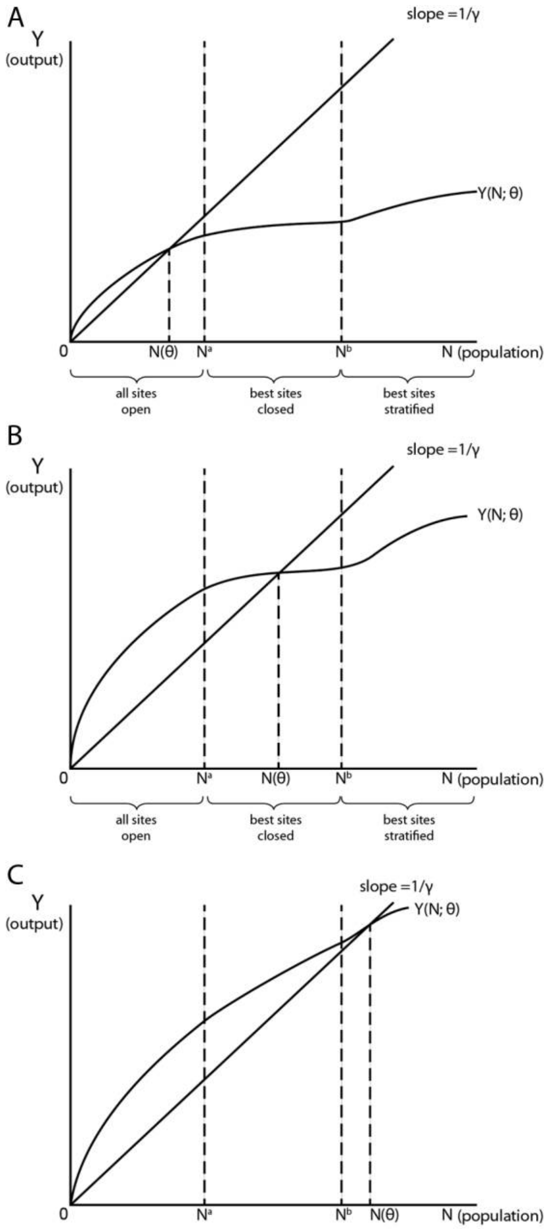


Fig. 4.—*A*, Long-run equilibrium with low productivity. The productivity level $\theta$ is low enough to yield an equilibrium population $N(\theta)$ such that all sites are open. *B*, Long-run equilibrium with intermediate productivity. The productivity level $\theta$ yields an equilibrium population $N(\theta)$ such that the best sites are closed but not stratified. *C*, Long-run equilibrium with high productivity. The productivity level $\theta$ is high enough to yield an equilibrium population $N(\theta)$ such that the best sites are stratified.

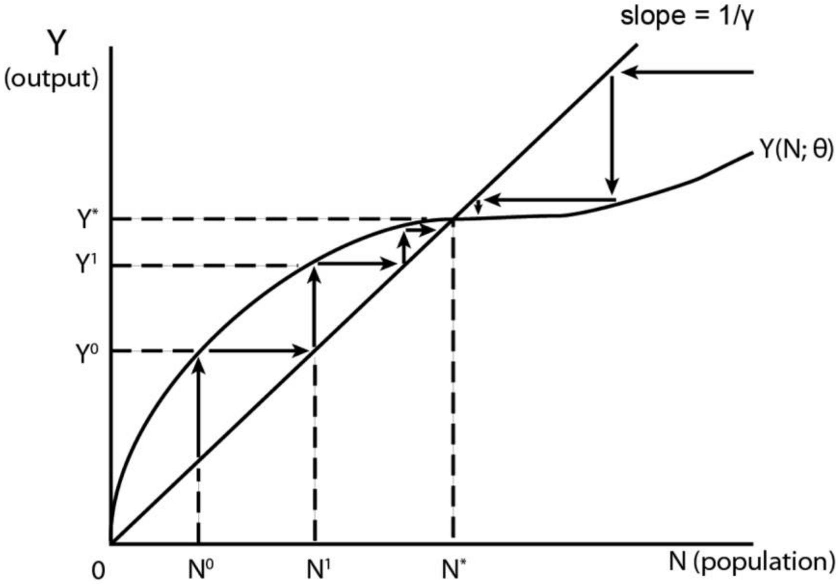


FIG. 5.—Monotonic convergence to a long-run equilibrium. For a fixed productivity level $\theta$, the arrows show the adjustment path from a low initial population $N^0$ and output $Y^0$ to the long-run equilibrium population $N^*$ and output $Y^*$. The adjustment path from a high initial population is shown by the reverse arrows.

level $\theta^*$ and a low population $N^*$. For example, $N^*$ might be associated with an open-access LRE as shown in figure 4*A*. We then consider a discrete permanent jump in productivity to $\theta^{**} > \theta^*$. Depending on $\theta^{**}$, the new LRE may yield insider-outsider inequality without stratification as in figure 4*B* or it may involve stratification as in figure 4*C*. In either situation, the dynamics of the convergence process are qualitatively the same as in figure 5.

The second thought experiment involves continuous productivity growth at a rate that is slow compared with the rate at which population adjusts. In this case, it would be a reasonable approximation to assume that population is always near (though not exactly equal to) the LRE level $N^*$ associated with current productivity $\theta^*$. We can then use the results from proposition 3 to study the comparative static effects of $\theta$ on $N$ and $w$.

## VI. Poverty, Inequality, and Demography

*Poverty.*—The least-well-off agents are those receiving the wage $w$, either in the commons or at stratified sites (if any). The dynamics of poverty can be studied using the thought experiments described at the end of Section V. We start in each case from an LRE with productivity $\theta^*$ and population $N^* = N(\theta^*)$.

First, consider a permanent productivity increase to $\theta^{**} > \theta^*$ in period 0. We want to examine the dynamics of the wage along the adjustment path leading to the new LRE $(\theta^{**}, N^{**})$. The immediate effect of the productivity shock is to raise the SRE wage $w^0$ to a level such that $w^0/\theta^{**} = w^*/\theta^*$. This follows from the fact that the ratio $x \equiv w/\theta$ is determined solely by $N$ in the short run, and the initial population $N^*$ remains in place. The result is $w^0 > w^*$, so the short-run effect of a positive productivity shock is always to alleviate poverty by making commoners better off.

Along the adjustment path, we have an increasing population $(N^0, N^1, \ldots)$, where $N^0 = N^*$ and the sequence converges to $N^{**}$. Because population is rising, the ratio $x = w/\theta^{**}$ is falling owing to the downward-sloping labor demand curve. The new productivity level $\theta^{**}$ is constant throughout the adjustment process, and so the nonnormalized wage sequence $(w^0, w^1, \ldots)$ is decreasing.

Whether the final wage $w^{**}$ in the new LRE is above or below the initial wage $w^*$ depends on $\theta^{**}$. If the new productivity level is consistent with universal open access $(\theta^{**} < \theta^a)$, then $w^* = w^{**} = 1/\gamma$ from proposition 3($d$). The effect of the productivity shock is to make everyone better off along the adjustment path, with eventual convergence back to the previous Malthusian level of food per capita. On the other hand, if $\theta^{**} > \theta^a$ so that some sites are closed in the new LRE, proposition 3($d$) implies $w^* > w^{**}$. In the long run the poor become worse off through the closure of more sites and the contraction of the commons.

The second thought experiment involves a gradual improvement in productivity from $\theta^*$ to $\theta^{**}$, where we ignore short-run adjustments and focus on the long-run wage $w(\theta)$. Again proposition 3($d$) gives a straightforward verdict. As long as $\theta$ is low enough to maintain universal open access, the wage remains constant at $w(\theta) = 1/\gamma$. However, once $\theta > \theta^a$ so that some sites are closed, further productivity growth reduces the wage and leads to worsening absolute poverty.

*Inequality*.—Here we address two separate issues: inequality within a given site and inequality for the region as a whole. First consider an individual stratified site. The total number of agents is $L$, where $L - d$ are commoners and $d$ are members of the elite. Each commoner receives the wage $w$ and each elite agent receives $w + r(s)/d$, where $r(s) > 0$ is the land rent at a site of quality $s$. The Lorenz curve consists of two line segments, one for each class of agents (for brevity the graph is omitted).

The Gini coefficient for a stratified site reduces to $G = (1 - \alpha)[1 - d/L(s, x)]$, where $L(s, x)$ is the optimal labor input from lemma 1($c$) and $\alpha$ and $d$ are fixed parameters. In a given SRE, one can compare Gini coefficients across stratified sites. Because $L(s, x)$ is an increasing function of $s$, better sites have more inequality. One can also compare the same site across SREs with different values of $x$. A fixed site has more inequality in the SRE in which population $N$ is higher, or equivalently $x$ is lower, because then the elite hires more commoners at the site. As $N$ goes to infinity and $x$ goes to zero, $L(s, x)$ goes to infinity for any fixed $s$, and the Gini approaches $1 - \alpha$. This is the share of food output that would go to landowners in a perfectly competitive equilibrium, as we will explain in connection with proposition 4 below.

We turn next to the effect of population on regional inequality. When $N < N^a$ so that all sites are open, there is no inequality. In what follows, we assume $N > N^a$ so that some sites are closed. A Lorenz curve $y(z)$ for this case is shown in figure 6. The horizontal axis $z$ refers to the fraction of the total population whose food income falls below some given level, and the vertical axis $y$ refers to the fraction of total food income received by this subset of agents.

The Lorenz curve has two segments. First, there is a linear portion involving the worst-off agents, who receive the wage $w$ either in the commons or through employment at stratified sites. This group makes up a

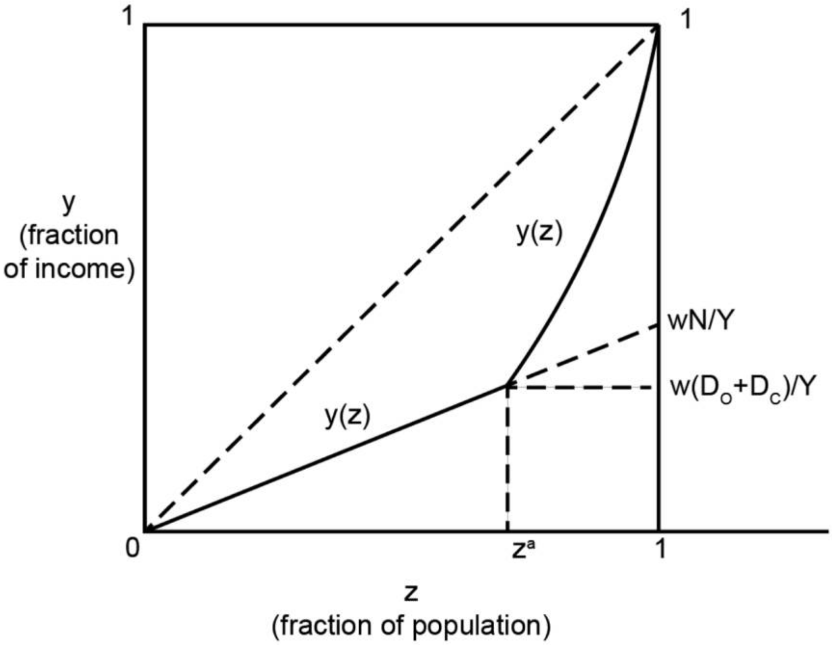


FIG. 6.—Lorenz curve $y(z)$ for a fixed population when some sites are closed. $w$ is the (nonnormalized) wage, $N$ is population, $Y$ is regional output, $D_O$ is total labor input at open-access sites, $D_C$ is total commoner labor at stratified sites, and $z^a$ is the fraction of agents in the region who receive only wage income.

fraction $z^a \equiv (D_O + D_C)/N$ of the population and determines the Lorenz curve on the interval $[0, z^a]$. The slope of this segment is $wN/Y$, which is direct plus imputed labor cost as a fraction of total food output. The nonlinear segment of the Lorenz curve beyond $z^a$ involves agents who receive land rent. This part of the curve is derived as follows.

An insider or elite agent at a site of quality $s$ receives the income $w + r(s)/d$, where $w$ is the imputed value of the agent's time, $r(s)$ is land rent, and $d$ is the number of insider agents. For any income level above $w$, there is some fraction of the population $z > z^a$ receiving that income or less. This group includes all commoners, as well as insiders who occupy sites at or below a quality cutoff $s(z)$ given by

$$s(z) = 1 - (1 - z)N/d \qquad \text{for } z^a \leq z \leq 1. \tag{4}$$

The total rent $R(z)$ appropriated by the bottom $z$ of the population is

$$\begin{aligned} R(z) &\equiv 0 \qquad \text{for } 0 \leq z \leq z^a, \\ R(z) &= \int_0^{s(z)} r(s)\,ds \qquad \text{for } z^a \leq z \leq 1, \end{aligned} \tag{5}$$

where $r(s) \equiv 0$ for the open sites $s \in [0, s^a)$ and $r(s) = \theta s L(s)^\alpha - wL(s) \geq 0$ for the closed sites $s \in [s^a, 1]$. In the latter case, $L(s)$ is the optimal labor input from Section III. This is equal to $d$ for unstratified sites, with $L(s) > d$ for stratified sites (if any).

For a fixed $N > 0$, the Lorenz curve $y(z)$ is given by

$$y(z) = (1/Y)[wNz + R(z)]. \tag{6}$$

The Gini coefficient is twice the area between the 45-degree line and the Lorenz curve, or

$$G = 2\left[1/2 - \int_0^1 y(z)\,dz\right]. \tag{7}$$

For $z = 1$, the right-hand vertical axis in figure 6 shows the division of income across classes of agents. The fraction of total food going to commoners is $w(D_O + D_C)/Y$, the fraction going to insiders and elites as imputed wages is $w(D_I + D_E)/Y$, and the fraction going to the latter two groups as land rent is $1 - wN/Y$.

Proposition 4 (Inequality). Consider the short-run equilibria for populations $N_1$ and $N_2$. Let $N^a < N_1 \leq N^b$ so that $N_1$ generates insider-outsider inequality. Let $N_1 < N_2$, where $N_2$ may generate either insider-outsider ($N_2 \leq N^b$) or elite-commoner ($N^b < N_2$) inequality.

*a.* The Lorenz curves satisfy $y_1(z) > y_2(z)$ for all $0 < z < 1$ and the Gini coefficients satisfy $G_1 < G_2$.

*b*. Let $G(N)$ be the Gini for the population $N$. Then $G(N^b) = (2 - \alpha)(1 - \alpha^2)/3(2 + \alpha + \alpha^2)$ is the upper bound for insider-outsider inequality and the lower bound for elite-commoner inequality. Furthermore, $G(\infty) = 1 - \alpha$.

Part *a* shows that starting from insider-outsider inequality, population growth always leads to a higher Gini. Indeed, we have Lorenz curve dominance: when $N$ rises, the fraction of income $y(z)$ for the worst-off $z$ of the population falls at every $0 < z < 1$. This is true whether the society remains in an insider-outsider regime or shifts to an elite-commoner regime at $N_2$. Although the Gini is not necessarily increasing in $N$ throughout the elite-commoner range, it must increase within the insider-outsider range.

The absolute productivity $\theta$ drops out of the Gini coefficient and is irrelevant for proposition 4. The only parameters that influence inequality are the elasticity $\alpha$ and the exclusion threshold $d$. Part *b* shows that any elite-commoner equilibrium has higher inequality than any insider-outsider equilibrium. The boundary value $G(N^b)$ is inversely related to $\alpha$ because when food output is more responsive to labor, commoners are paid more and land rents become less significant as a source of inequality.

The limit result for $G(\infty)$ follows from the fact that when the population is large, almost all agents are commoners, and almost all commoners are employed at stratified sites. The property rights distortions discussed in Section IV become negligible, and the aggregate production function is approximately described by part *a* of the corollary to proposition 2. As a result, the slope of the linear part of the Lorenz curve in figure 6 is approximately the labor share $\alpha$ that would arise in a competitive economy. Because the boundary $z^a$ in figure 6 approaches one, the area under the Lorenz curve approaches $\alpha/2$, and (7) gives a Gini of $1 - \alpha$. Thus in a large elite-commoner society, the Gini is equal to the output share that would go to landowners in a perfectly competitive economy.

No assumptions about the long run are used in proposition 4. However, suppose that a society starts from LRE with insider-outsider inequality. If better climate or improved food production technology stimulates population growth, this must increase inequality both along the adjustment path and in the new LRE. Higher productivity does not directly cause higher inequality; the two variables are linked only through the channel of Malthusian population dynamics.

*Demography*.—The definition of LRE in Section V ensures that at the regional level, each generation of agents produces exactly enough children to replace itself. However, agents with high incomes produce more children than are needed to replace themselves, while agents with low incomes produce fewer children than are needed. The following proposition relates site quality to reproduction.

PROPOSITION 5 (Demography). Consider a long-run equilibrium with $\theta^a < \theta$ so that some sites are closed. Landless agents produce too few offspring to replace themselves. The site quality $s^r \equiv d^{1-\alpha}/\theta\gamma$ satisfies $s^a < s^r < \min\{1, s^b\}$. Insiders with $s \in [s^a, s^r)$ do not fully replace themselves, insiders with $s = s^r$ exactly replace themselves, and insiders with $s \in (s^r, 1]$ more than replace themselves.

Whenever there is inequality, the poorest agents have an income too low to permit demographic replacement. Insiders at sites with quality near $s^a$ have rents near zero and must also fail to replace themselves. On the other hand, insiders at the best sites ($s = 1$) must more than replace themselves in order to maintain a steady-state population for the economy as a whole. Since land rent is an increasing function of site quality, there is an intermediate value $s^r$ at which insiders remain in demographic equilibrium.

Recall from Section III that when the number of agents born at a site ($n$) exceeds the number needed to close the site ($d$), the latter group is selected by birth order while the remaining $n - d$ agents are excluded. Proposition 5 shows that all stratified sites have downward mobility in the sense that some children of the elite are excluded from elite status. These agents go to an open site or are hired at a stratified site.

There is also downward mobility at high-quality unstratified sites (those with $s^r < s \leq s^b$) because some children of insiders do not become insiders themselves. However, at lower-quality unstratified sites (those with $s^a \leq s < s^r$), the number of children $n$ born to insiders is less than $d$. As discussed in Section III, in this case $d - n$ commoners enter the site, and at that point the insiders become sufficiently numerous to block further entry.

## VII. Empirical Evidence

Anatomically modern humans have existed for about 190,000 years (McDougall, Brown, and Fleagle 2005). For most of that time, groups remained small, occupied relatively large territories at low densities, and frequently moved to follow resources. Technological innovation was sporadic, with long periods of stagnation (Dow and Reed 2011). Our theory predicts that inequality should be minimal under such conditions.

Climate change around 13,000 years ago triggered a shift toward agriculture in Southwest Asia and probably elsewhere (Dow, Reed, and Olewiler 2009). By 11,600 years ago, the Holocene brought a better mean climate and lower variance across temperate parts of the northern hemisphere (Richerson, Boyd, and Bettinger 2001). Over several millennia, better technology and a benign environment led to substantial productivity growth. As our theory predicts, the result was increasing population density, appropriation of the best sites by insiders, and eventually inequality between elites and commoners at the best sites.

This broad portrait is consistent with inferences about nutrition and health from skeletal remains. Boix and Rosenbluth (2006) survey archaeological data on skeletons with reference to height (correlated with nutrition during childhood and adolescent growth spurts) and other health indicators (e.g., bone lesions due to anemia or infections, incomplete tooth enamel formation, and loss of bone mass). The authors use dispersion measures to proxy for economic inequality. They find a low incidence of inequality in hunter-gatherer societies, increased inequality with the rise of agriculture, and a strong positive correlation between population density and inequality.

We turn next to a series of regional case histories for Southwest Asia, Europe, Polynesia, and the Channel Islands of California. These examples are chosen mainly because they have been intensively studied by archaeologists and reflect a variety of food acquisition strategies that include terrestrial foraging, farming, and fishing.

*Southwest Asia.*—This region is of special interest as one of the first in which sedentary lifestyles emerged after the last glacial maximum. It is also notable as the region in which agriculture first evolved. Before agriculture, during a period that lasted about 1,500 years and ended around 13,000 BP (calendar years before the present), the climate was mild and rainfall was plentiful. At this time the region was occupied by early Natufians, who were largely sedentary foragers. Price and Bar-Yosef (2012, 151) note that there is evidence for "the existence of corporate groups that controlled important resources," a sign that insider-outsider inequality may have been present. Evidence from mortuary practices at specific sites also suggests the presence of stratification (Kuijt and Prentiss 2009; Price and Bar-Yosef 2012). This is not surprising from the standpoint of our theory because excellent climatic conditions led to abundant natural resources, high productivity, high regional population, and sedentism at the best sites.

Around 13,000 years ago, climate change throughout the northern hemisphere brought a temporary return to Ice Age conditions known as the Younger Dryas, which lasted over 1,000 years. During this period many settlements were abandoned, sedentary lifestyles were replaced by mobile foraging in large parts of Southwest Asia, and skeletal data indicate a regionwide decline in nutritional levels, health status, and population (Smith 1991; Mithen 2003). Coinciding with this period of decline, mortuary practices show a complete absence of stratification (Kuijt and Prentiss 2009). This is consistent with our theory but in reverse. Owing to the substantial decline in regional productivity, population fell, sedentism was largely replaced by mobile foraging, and inequality was eliminated through a return to open-access conditions.

When climate recovered after the Younger Dryas, cultivation became widespread and population grew rapidly (information in this paragraph is from Price and Bar-Yosef [2012]). Over the next millennium or two, as plant and animal domestication developed, evidence for insider-outsider inequality includes uneven distribution of exotic materials across sites (155). The evidence for elite-commoner inequality includes unequal house sizes within communities (155), as well as unequal distribution of grave goods (158–59). Again, this sequence of events is consistent with theoretical expectations.

*Europe.*—Domesticated plants and animals spread across the European continent from pristine origins in Southwest Asia (all information is from Shennan [2008]). Before the arrival of agriculture, hunter-gatherer population densities were very low throughout Europe, except for coastal or riverine areas with rich aquatic resources. The first farming in central Europe was associated with the "Linear Pottery Culture," or LBK in its German acronym. LBK culture arose around 5600–5500 BC near modern Hungary and Austria and spread rapidly westward. As this occurred, populations rose quickly to new plateaus in Germany, Poland, and Denmark. Agricultural colonization proceeded in a patchwork fashion in which the best locations were settled first.

Shennan argues that "the growth in population should have led to a growth of inequality between territory-holding units as successively poorer settlement sites were occupied" (2008, 323). In our terminology, this represents insider-outsider inequality. The evidence that this did in fact occur comes from data on differences in house sizes, tools, and domestic animal bones. There is also evidence that inequality within settlements (what we would call elite-commoner inequality) increased, as indicated by a growing frequency of small houses relative to large ones. The fact that houses of the same types were rebuilt in the same places suggests that socioeconomic status was inherited.

Cemetery data indicate that the earliest LBK settlements "present a picture of relatively egalitarian societies" (Shennan 2008, 323). However, later cemeteries have a few graves, including some child graves, with markedly richer burials than others. Shennan argues that the cemeteries represented "an ancestral claim to territory in the face of increasing competition" (324). Other evidence suggests the emergence of patrilineal corporate groups that controlled prime locations and whose senior members had larger houses.

The connections to our theory are fairly straightforward. Agricultural technology provided an abrupt productivity increase, which then triggered an upward adjustment of population in the regions where farming was introduced. One complication is that much of this population growth may have come from LBK migrants rather than from demographic expansion by hunter-gatherer groups who adopted agriculture. In our model, the arrival of people who already had agricultural technology would only accelerate the adjustment to a new long-run equilibrium without changing the outcome. The sequence of relatively egalitarian LBK societies followed by insider-outsider and elite-commoner inequality, along with evidence for hereditary elite status, clearly fits our theoretical expectations.

*Polynesia.*—The islands of Polynesia differ widely in size, climate, topography, soil fertility, and ecosystems. All Polynesian societies are descended from a common ancestral culture based on domesticated plants and animals, hunting, foraging, and fishing. A diverse set of societies evolved in the millennia before European contact. On small atolls with land areas less than 10 square kilometers and populations below 1,000 individuals, groups typically had weak chiefs and an egalitarian ethic. On large volcanic islands with higher populations, inequality was often quite pronounced (Younger 2008).

The island chains with the sharpest divisions between landowning elites and landless commoners prior to European contact are generally agreed to include Hawaii, Tonga, and the Society Islands, with Hawaii as the most extreme case. Sahlins (1958, 11–12) adds Samoa to this list, and Goldman (1970, 20–21) adds Mangareva. Of the 10 island chains for which data are available, the four with the highest population densities per unit of arable land are Hawaii, Tonga, the Society Islands, and Samoa (Kirch 1984, 37, 98). These are also the island chains with the best endowments of natural resources (Sahlins 1958, 126–30; Kirch 1984). These cross-section observations on productivity, population, and inequality are broadly consistent with our expectations. We turn next to the dynamics of inequality for the particular cases of Tonga and Hawaii.

For Tonga, the first phase of human occupation occurred during 950–700 BC and probably involved intensive foraging activity (all information is from Burley [2007]). The population may have reached 600–700 by the end of this period. A second phase, which occurred between 700 BC and AD 400, involved wider dispersal of population over the landscape. In this period, marginal islands were occupied and small hamlets were replaced by village-sized complexes. Burley says that this shift was associated with a "fundamental transformation in economy" (193) involving intensive dryland farming, which may have resulted from depletion of indigenous birds, iguana, shellfish, and other species. Burley estimates that with dryland agriculture, a theoretical carrying capacity of about 34,000 people would have been reasonable (185). He also estimates that by AD 400, population had reached about half this level, or roughly 17,000 people (196).

The third phase of Tongan social evolution starts around 400, but observations are scarce until about 950, when a dynastic chiefdom appeared. This chiefdom arose on the island with the most arable land and highest population. By 1200, this dynasty had gained full control of its home island, and by 1450 it was waging a campaign for unified control of the entire Tongan chain. Burley comments, "what is important from a demographic perspective is the emergence of this integrated polity as a theoretical response to and probable correlate of population pressure as carrying capacity limits were being reached" (2007, 197). Under this new political and economic structure, earlier hamlets and villages disappeared, and commoners worked on estates owned by chiefly lineages.

Hawaii's founding population has been estimated at fewer than 100 people, who arrived sometime during AD 800–1000 (Kirch 2010, 126–29). The initial settlements occurred in a few ecologically favorable locations, primarily on the islands of Oahu and Kauai. During 1100–1500, the population doubled about every one to two generations. This growth was focused first in areas suitable for irrigated taro pond fields (Oahu, Kauai, and Molokai) between 1200 and 1400. In this phase, "irrigation works were developing in lockstep with the exponential rise in population" (145). A later growth phase involved intensive dryland sweet potato farming (Maui and Hawaii). This agricultural system became widespread circa 1400. Around 1500, the rate of population growth slowed dramatically. Kirch suggests that the expansion of dryland farming into areas that were marginal for rainfall increased mortality. The transition to a slowly growing or stable population occurred over about one century (139).

By the late 1400s, "virtually all of the agriculturally suitable landscapes across the archipelago [were] settled and territorially divided" (Kirch 2010, 174). Kirch believes that a ruler on the island of Oahu dating to about 1490 was the first to institute "a formal system of hierarchical land divisions" and a regularized collection of tribute (92). Dryland agriculture on Maui and Hawaii took longer to develop but led to "highly formalized garden plots and territorial boundaries" by 1600–1650 (153). Archaic states had arisen by this time and continued through European contact in 1778. At the latter date, the population of the island chain was roughly 400,000 (130).

Late Hawaiian society was not based on continuous gradations of rank defined by kinship but instead involved "distinct named, endogamous classes of persons" (Kirch 2010, 34). The elite were internally ranked by descent, while the commoners were forbidden to keep genealogical records beyond the level of grandparents (72–73). The elite controlled land and gave commoners access to it in exchange for tribute and labor services. In one area, about half of all food output went to the elite (68).

In both the Hawaiian and Tongan cases, a small founding population eventually achieved a period of rapid population growth, followed by convergence to demographic equilibrium. In general, locations were settled in order of their ecological favorability, and stratified social institutions first appeared in high-quality areas. The availability of good agricultural land led to a high precontact population density, and the result was a high degree of inequality between elite and commoner classes. This is consistent with our analysis in Section V of the adjustment path from a low initial population with open access to a high equilibrium population with stratification.

*The Channel Islands.*—The northern Channel Islands include three main islands (Santa Cruz, Santa Rosa, and San Miguel) located off the coast of southern California (information in this section is taken from overlapping research in Kennett [2005], Kennett et al. [2009], and Winterhalder et al. [2010], except where noted). The first residents were hunter-gatherers who depended heavily on the rich marine environment for food. Site quality varied with terrain, the presence of kelp zones, and watershed size. The qualities of potential coastal village locations have been ranked using a geographic information system, with site rankings based solely on environmental variables and independent of archaeological findings. Each island has multiple sites of varying quality.

The single-piece fishhook made from shell was developed between 2500 and 2100 BP. Prior to 1500 BP, communities expanded slowly. First- and second-ranked habitats were filled in during this period, with sites settled in order of quality. The bow and arrow was introduced between 1500 and 1300 BP. After 1500 BP, the population grew rapidly and local densities increased as people nucleated into villages. Between 1500 and 1300 BP, third- and fourth-ranked habitats came into use, resulting in the occupation of all viable locations. This period marked the end of open access at the best sites, which was replaced by competition among communities and unequal control of local resources. By 1300 BP, there was an increase in lethal violence involving projectile points. It is likely that defense was a public good fostering corporate group formation.

Insider-outsider inequality in the period after 1500 BP can be inferred from the skeletal evidence of Lambert and Walker (1991). *Cribra orbitalia* is a condition that develops as part of a child's response to anemia. On the basis of comparison of contemporaneous skeletal remains, the frequency of *cribra orbitalia* was lowest on the California mainland, below 30 percent on Santa Cruz (largest of the northern Channel Islands and rich in diverse plants and animals), noticeably higher on Santa Rosa (an island of intermediate size), and over 70 percent on San Miguel (a small isolated island with a shortage of fresh water and terrestrial resources). Because movement among the islands was not physically difficult, these substantial health differences suggest that residents of lower-quality sites did not enjoy free access to higher-quality sites.

After 1300 BP, there was further development of new fishing tackle and advances in fishing technology related to plank canoes and toggling harpoons. Fish bones from midwater, deep-ocean, and open-ocean habitats became increasingly common in faunal assemblages. Plank canoes also facilitated the exploitation of comparative advantage between the islands and the mainland. After 1300 BP, there is evidence of large-scale craft specialization on the islands, as well as significant trading of ground stone from the islands for goods such as acorns from the mainland. In the period between 1300 and 650 BP, population continued to increase, apparently because the new technologies and associated trading opportunities outweighed the effects of adverse climate events such as droughts (see Kennett et al. 2009, 310; Winterhalder et al. 2010, 471).

Clear social inequality, inferred from burial practices, emerged by around 650 BP. At the time of first contact with Europeans two centuries later, there were around 3,000 people on the Channel Islands living in at least 22 villages, which varied in their size and sociopolitical importance. The society was ranked and included hereditary chiefs whose kinship system was patrilineal and patrilocal, and who often married into chiefly families on the mainland. The majority of people had a matrilineal and matrilocal kinship system.

This history is consistent with our theory. Prior to 1500 BP, regional population was low relative to the availability of good sites, there were no restrictions on entry into high-quality sites, and thus there is no evidence of inequality. As population increased during 1500–1300 BP, entry to the best sites was restricted, marginal sites were occupied, and insider-outsider inequality becomes archaeologically visible. During 1300–650 BP, productivity gains involving fishing, hunting, and trade supported further population growth, which led to elite-commoner inequality with hereditary elite positions.

## VIII. Summary

We have developed a theory that connects rising labor productivity with rising population density and inequality. In particular, our framework links inequality with the emergence of exclusive property rights to land. The model applies equally well to mobile foragers, sedentary foragers, and agriculturalists. It accounts both for the emergence of inequality within a society over time and for variation in inequality across societies. In Section VII, we argue that data from archaeology and anthropology support the theory.

Specific results include the following. When regional population is low enough, there is no inequality because universal open access prevails.

As regional population rises, insider-outsider inequality emerges first, followed by elite-commoner inequality. In the insider-outsider range, population growth always leads to a higher regional Gini coefficient. Any elite-commoner equilibrium has a higher Gini than any insider-outsider equilibrium. In a large elite-commoner society, the Gini is roughly equal to the output share that would go to landowners in a perfectly competitive economy. These results depend only on regional population and therefore apply to any short-run equilibrium, including those along the adjustment path toward long-run equilibrium. Inequality does not depend directly on productivity, but it is linked to productivity in the long run by Malthusian population dynamics.

A positive productivity shock from nature or technology must make the poorest agents better off in the short run. If the resulting long-run population remains compatible with open access, then all agents are better off along the adjustment path and eventually return to their original standard of living. But if the productivity improvement leads to the closure of some sites in the long run or some sites were already closed in the initial equilibrium, increased productivity eventually makes commoners worse off through the closure of more sites and the contraction of the commons.

In a long-run equilibrium with stratification, elite agents inherit their positions from their parents. The same holds true for insiders at high-quality unstratified sites. Insiders at lower-quality unstratified sites must recruit outsiders in each generation to preserve their property rights. Commoners do not replace themselves demographically, so this class is partly maintained by downward mobility from elite and insider groups.

The aggregate production function shows how property rights affect allocative efficiency as population rises. Owing to our Cobb-Douglas functional form, open access yields an efficient allocation of labor. After some sites are closed, output falls below its theoretical maximum because marginal products of labor are not equated across closed sites. When population crosses into the elite-commoner range, another distortion arises because the marginal product of labor at stratified sites is equal to the average product in the commons. At very high population levels, almost all sites are stratified and almost all labor is paid its marginal product. As a result, aggregate output approaches its theoretical maximum, although with inequality both across and within sites.

## IX. Related Literature

We conclude with a review of related literature from archaeology, anthropology, and economics. The following discussion highlights ways in which our analysis differs from other theories about the emergence of property rights and inequality.

There is a large literature in archaeology and anthropology on inequality in small-scale societies (see Price and Feinman 1995, 2012). Some authors attribute inequality to ideological or cultural factors, and our approach has little connection with that branch of the literature. Others focus on economic variables such as natural resources, technology, and population. Kirch (2010, 190–201), for example, combines a production function for agriculture with Malthusian population dynamics to explain the evolution of inequality in Hawaii. This is clearly in the spirit of our approach.

Kelly (2007, chap. 8) observes that most hunter-gatherer societies are relatively egalitarian, with only a few that have substantial inequality. The latter societies have several characteristics in common, including highly predictable natural resources, high population densities, large settlement sizes, perimeter defense, and tightly controlled resource ownership. There is typically a hierarchical class structure based on descent. According to Kelly, population density is the key proximate cause of inequality among hunter-gatherers, with sedentism and storage technology as supporting factors.

Arnold (1993, 1995) surveys a wide range of anthropological explanations for the emergence of inequality in hunter-gatherer societies. Her main argument is that aspiring elites can gain control over household labor in times of environmental or social stress. In particular, she argues that a negative climate shock around 700–800 BP in the Channel Islands led to greater importation of food from the mainland and enabled elites to gain control over the production of canoes as well as beads needed for export. But as noted in Section VII, population continued to rise in the Channel Islands during this period, which suggests that the adverse climate events were more than offset by technological progress and expanded trade opportunities. Our explanation, in which ongoing population growth led to site closures and rising stratification within sites, avoids reference to mechanisms of monopoly power and labor control that are difficult to observe archaeologically.

Kennett et al. (2009) offer an explanation for the emergence of stratification that has some overlap with our own: both stress the role of heterogeneous production sites, demographic change, constraints on mobility, and competition over scarce resources. Kennett et al. see rising population density as a source of social stress that allows some (dominant) individuals to shape institutions in a way that leads to stratification. They argue that this is more likely when productivity differences across sites are large and geographic or social barriers inhibit migration. In our approach, by contrast, we assume that all individuals are identical with respect to preferences and abilities. Unlike Kennett et al., we emphasize the endogenous nature of population, the development of mobility constraints through the endogenous creation of property rights, and the idea that insider-outsider inequality is a necessary precursor to stratification.

Gilman (1981) argues for an explanation of stratification in Bronze Age Europe based on the importance of site-specific capital investments, high exit costs, and the use of force by "protectors" who exacted tribute from other agents at the site. Webster (1990) argues instead that incipient control over labor through patron-client relationships was a more important causal factor leading to stratification in prehistoric Europe than control over nonhuman wealth or natural resources such as land. We discussed a more recent view of early European stratification by Shennan (2008) in Section VII, which we believe lends support to our theoretical framework based on control over land.

Johnson and Earle (2000) develop a general theory of human social evolution that runs from foraging bands to local groups, chiefdoms, and eventually the agricultural state. Using many case studies from anthropology, they argue that population and technology were the prime movers behind this evolutionary process and that economic stratification was one of the principal consequences. Our perspective differs by having technology as the key driving force, with population responding through Malthusian mechanisms.

Another influential view from outside economics is that of Diamond (1997), who argues that inequality results from rising productivity and population combined with a constraint involving social cohesion. Diamond asserts that in societies with thousands of individuals, conflicts among individuals and groups can no longer be resolved through kinship ties alone. The continued existence of such societies required transfer of coercive power to a chief, which led to the emergence of inequality.

Borgerhoff Mulder et al. (2009) develop an economic model of inequality in small-scale societies (see *Current Anthropology* [2010] for detailed empirical analysis and critical discussion). In their approach, households are exposed to random shocks to their wealth in each period. Greater transmission of wealth from parents to offspring increases steady-state inequality by magnifying the effects of these shocks. The key prediction is that hunter-gatherer and horticultural societies should have lower inequality than pastoral and agricultural societies because the latter rely more on material assets (animals and land) that can easily be passed to children. This prediction is consistent with observed Gini coefficients. Borgerhoff Mulder et al. offer important insights into the differences in steady-state inequality across societies. However, they do not address the endogeneity of property rights or the evolution of stratification in prehistoric societies.

Several economists have theorized about the evolution of property rights to land in prehistoric societies. North and Thomas (1977), for example, argue that foragers had open access to resources that were subject to depletion through overharvesting. Population growth made this problem more severe and motivated the development of communal property rights over land, which in turn made agriculture attractive.

De Meza and Gould (1992) assume that agents choose whether or not to enforce private ownership claims on resource sites. Our model resembles theirs in having many resource sites with costless mobility among sites. However, they assume that there is a fixed cost of enclosing a site, while we assume that group property rights are a costless by-product of food acquisition when insiders are sufficiently numerous.

Baker (2003) seeks to explain why foraging societies have varying land tenure institutions. The explanatory variables include resource density and predictability, as well as production and conflict technology. The model involves strategic interactions between insiders and outsiders, where groups must decide how much of their endowed territory to defend and whether they will intrude on territories defended by others.

Rowthorn and Seabright (2010) develop a model of property rights that applies to agriculturalists during the Neolithic transition. They cite evidence showing that increased productivity in early farming was associated with lower levels of health and nutrition. In their model this is explained by an increase in resources allocated to the defense of crops and land from outside groups.

Bowles and Choi (2011) study the coevolution of agriculture and property rights. In their view, foraging bands exercised communal control over land. Under agriculture, this was replaced by individual property rights over land, livestock, and other resources. The onset of the Holocene made agriculture more attractive. The result was a positive feedback loop in which decreased ambiguity of resource possession under agriculture reinforced individual property rights, and individual rights encouraged agriculture.

Our theory differs from those of North and Thomas (1977), de Meza and Gould (1992), Baker (2003), Rowthorn and Seabright (2010), and Bowles and Choi (2011) in several ways. First, these authors study the creation of group or individual property rights over land but not the emergence of inequality across or within social groups. Second, Baker (2003) restricts attention to foraging societies, North and Thomas (1977) and Bowles and Choi (2011) study the coevolution of property rights and agriculture, and Rowthorn and Seabright (2010) assume an agricultural transition. Our theory applies to both foraging and agricultural societies, while explaining why inequality tends to rise as agriculture spreads. Finally, unlike these authors, we endogenize population.

Rowthorn, Guzmán, and Rodríguez-Sickert (2013) develop a model of a region in which some societies are egalitarian while others are stratified. The number of societies of each type is exogenous. Stratified societies have two classes: food producers and warriors. Membership in a class is fixed and hereditary. The warriors own land and use specialized weapons that are not available to food producers. In long-run equilibrium, warriors have higher food incomes than food producers because their children are more expensive. However, on the basis of utility at birth, warriors may be either better or worse off than food producers. Rowthorn et al. address several issues we do not, including the specialization of some agents in military activity, the use of force to appropriate land, and the possibility of rebellion by commoners. They do not address insider-outsider inequality or explain the origins of stratification. By contrast, in our model the sites that are open, closed, and stratified are determined endogenously, and an agent is always better off being a member of the elite. We also include downward mobility from the elite into the commoner class. Although it is not part of their formal model, Rowthorn et al. offer a verbal discussion of downward mobility that is consistent with our analysis.

## References

Ames, Kenneth M., and Herbert D. Maschner. 1999. *Peoples of the Northwest Coast: Their Archaeology and Prehistory*. London: Thames & Hudson.

Arnold, Jeanne E. 1993. "Labor and the Rise of Complex Hunter-Gatherers." *J. Anthropological Archaeology* 12:75–119.

———. 1995. "Social Inequality, Marginalization, and Economic Process." In *Foundations of Social Inequality*, edited by T. Douglas Price and Gary M. Feinman, 87–103. New York: Plenum.

Baker, Matthew J. 2003. "An Equilibrium Conflict Model of Land Tenure in Hunter-Gatherer Societies." *J.P.E.* 111 (1): 124–73.

Boix, Carles, and Frances Rosenbluth. 2006. "Bones of Contention: The Political Economy of Height Inequality." Manuscript, Dept. Politics, Princeton Univ.

Borgerhoff Mulder, M., et al. 2009. "Intergenerational Wealth Transmission and the Dynamics of Inequality in Small-Scale Societies." *Science* 326 (October 30): 682–88.

Bowles, Samuel, and Jung-Kyoo Choi. 2011. "The Holocene Revolution: The Co-evolution of Agricultural Technologies and Private Property Institutions." Manuscript, Santa Fe Inst.

Burley, David V. 2007. "Archaeological Demography and Population Growth in the Kingdom of Tonga." In *The Growth and Collapse of Pacific Island Societies: Archaeological and Demographic Perspectives*, edited by Patrick V. Kirch and Jean-Louis Rallu, 177–202. Honolulu: Univ. Hawai'i Press.

*Current Anthropology*. 2010. "Intergenerational Wealth Transmission and Inequality in Premodern Societies." Special issue, 51 (1).

de Meza, David, and J. R. Gould. 1992. "The Social Efficiency of Private Decisions to Enforce Property Rights." *J.P.E.* 100 (3): 561–80.

Diamond, Jared. 1997. *Guns, Germs, and Steel: The Fate of Human Societies*. New York: Norton.

Dow, Gregory K., and Clyde G. Reed. 2011. "Stagnation and Innovation before Agriculture." *J. Econ. Behavior and Org.* 77 (3): 339–50.

Dow, Gregory K., Clyde G. Reed, and Nancy Olewiler. 2009. "Climate Reversals and the Transition to Agriculture." *J. Econ. Growth* 14 (1): 27–53.

Gilman, Antonio. 1981. "The Development of Social Stratification in Bronze Age Europe." *Current Anthropology* 22 (1): 1–23.

Goldman, Irving. 1970. *Ancient Polynesian Society*. Chicago: Univ. Chicago Press.

Johnson, Allan, and Timothy Earle. 2000. *The Evolution of Human Societies*. 2nd ed. Stanford, CA: Stanford Univ. Press.

Kelly, Robert L. [1995] 2007. *The Foraging Spectrum: Diversity in Hunter-Gatherer Lifeways*. Repr. New York: Percheron.

Kennett, Douglas J. 2005. *The Island Chumash: Behavioral Ecology of a Maritime Society*. Berkeley: Univ. California Press.

Kennett, Douglas J., Bruce Winterhalder, Jacob Bartruff, and Jon M. Erlandson. 2009. "An Ecological Model for the Emergence of Institutionalized Social Hierarchies on California's Northern Channel Islands." In *Pattern and Process in Cultural Evolution*, edited by Stephen Shennan, 297–314. Berkeley: Univ. California Press.

Kirch, Patrick V. 1984. *The Evolution of the Polynesian Chiefdoms*. New York: Cambridge Univ. Press.

———. 2010. *How Chiefs Became Kings: Divine Kingship and the Rise of Archaic States in Ancient Hawai'i*. Berkeley: Univ. California Press.

Kuijt, Ian, and Anna Marie Prentiss. 2009. "Niche Construction, Macroevolution and the Late Epipaleolithic of the Near East." In *Macroevolution in Human Prehistory: Evolutionary Theory and Processual Archaeology*, edited by Anna Marie Prentiss, Ian Kuijt, and James Chatters, 253–71. New York: Springer.

Lambert, Patricia M., and Phillip L. Walker. 1991. "Physical Anthropological Evidence for the Evolution of Social Complexity in Coastal Southern California." *Antiquity* 65:963–73.

McDougall, I., F. H. Brown, and J. G. Fleagle. 2005. "Stratigraphic Placement and Age of Modern Humans from Kibish, Ethiopia." *Nature* 433 (February 17): 733–36.

Mithen, Steven. 2003. *After the Ice: A Global Human History, 20,000–5000 BC*. London: Weidenfeld & Nicolson.

North, Douglass C., and Robert Paul Thomas. 1977. "The First Economic Revolution." *Econ. Hist. Rev.* 30 (2): 229–41.

Price, T. Douglas, and Ofer Bar-Yosef. 2012. "Traces of Inequality at the Origins of Agriculture in the Ancient Near East." In *Pathways to Power: New Perspectives on the Emergence of Social Inequality*, edited by T. Douglas Price and Gary M. Feinman, 147–68. New York: Springer Science+Business Media.

Price, T. Douglas, and Gary M. Feinman, eds. 1995. *Foundations of Social Inequality*. New York: Plenum.

———. 2012. *Pathways to Power: New Perspectives on the Emergence of Social Inequality*. New York: Springer Science+Business Media.

Richerson, Peter J., Robert Boyd, and Robert L. Bettinger. 2001. "Was Agriculture Impossible during the Pleistocene but Mandatory during the Holocene? A Climate Change Hypothesis." *American Antiquity* 66 (3): 387–411.

Rowthorn, Robert, Ricardo Andrés Guzmán, and Carlos Rodríguez-Sickert. 2013. "The Economics of Social Stratification in Premodern Societies." *J. Math. Sociology*, forthcoming.

Rowthorn, Robert, and Paul Seabright. 2010. "Property Rights, Warfare and the Neolithic Transition." Working Paper no. 654 (November), Inst. d'Economie Industrielle.

Sahlins, Marshall. 1958. *Social Stratification in Polynesia*. Seattle: Univ. Washington Press.

Shennan, Stephen. 2008. "Population Processes and Their Consequences in Early Neolithic Central Europe." In *The Neolithic Demographic Transition and Its Consequences*, edited by Jean-Pierre Bocquet-Appel and Ofer Bar-Yosef, 315–29. New York: Springer Science+Business Media.

Smith, P. 1991. "Dental Evidence for Nutritional Status in the Natufians." In *The Natufian Culture in the Levant*, edited by Ofer Bar-Yosef and F. R. Valla, 425–33. Ann Arbor, MI: Internat. Monographs Prehistory.

Umbeck, John R. 1981. *A Theory of Property Rights with Application to the California Gold Rush*. Ames: Iowa State Univ. Press.

Webster, Gary S. 1990. "Labor Control and Emergent Stratification in Prehistoric Europe." *Current Anthropology* 31 (4): 337–66.

Winterhalder, Bruce, Douglas Kennett, Mark Grote, and Jacob Bartuff. 2010. "Ideal Free Settlement of California's Northern Channel Islands." *J. Anthropological Archaeology* 29:469–90.

Younger, Stephen M. 2008. "Conditions and Mechanisms for Peace in Precontact Polynesia." *Current Anthropology* 49 (5): 927–34.