Supplementary Information for

"The coevolution of farming and private property during the early Holocene"

Samuel Bowles and Jung-Kyoo Choi

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1. Evidence.

1.1 Productivity of labor in farming and foraging

Measures of energetic output per hour of labor can be computed for a few forager populations and for some cultivars farmed under conditions and using technologies that may have characterized farming at the time of the agricultural revolution (1). Comparison of caloric returns for foraging wild species and for cultivation requires that account be taken of the following differences. While seasonal variation in resource availability and delayed return production are present and storage is possible to some extent by those foraging wild species, the extent of storage is considerably greater for those who cultivate rather than forage. The reduced diversity of sources of nutrition among farmers gives rise to far greater seasonal and annual risk. Estimates must therefore take account of losses during storage, time delay, and risk exposure. Table S1 below give estimates of the calories per hour of labor (including that involved in processing and storage). Data are for cereals only due to the lack of the comparable data on non-cereal cultivars of the first farmers (such as avocado, bottle gourd and squash.)

Table S1. Mean caloric returns per hour of total labor (c*) for wild and cultivated species with adjustments for risk and (for cultivation) land abundance and delayed returns. (Standard deviations in parentheses). The estimates relevant to an individual's initial decision to engage in some farming (line 2) entail no greater risk for the farmer than for the forager. The estimates relevant to average reproductive output for a group of farmers (line 3) account for the greater risk exposure of farmers. The *p*-value for the difference between the wild and cultivated c* distributions are from the Wilcoxon rank-sum test (not affected by the possibly exaggerated returns in the Great Basin prehistoric data). (The Welch-Satterthwaite difference in means *t*-test (unequal sample variances) gives (for the three rows in order): t = 2.33, 2.38 and 2.39. Source: (1)

Estimate	*Cultivated* (1)	*Wild* (2)	*p* value (for Δ wild-cultivated)	*Ratio* (1)/(2)
1. No risk or time delay adjustment	1041 (152)	1662 (590)	0.005	0.63
2. Decision: forager risk only and subjective delay	954 (147)	1628 (578)	0.0003	0.59
3. Evolution: risk and reproductive delay	951 (139)	1628 (578)	0.0003	0.58

1.2 Temperature and climate data

Temperature data. Differences in temperature (Centigrade) are about 1.2 times the difference in the $\delta^{18}O$ signal shown in Fig. S1 (2). The data indicate that changes in mean temperature as great as 8 degrees (C) occurred over time spans as short as two centuries. By way of comparison, the Little Ice Age that devastated parts of early modern Europe experienced a fall in average temperatures of one or two degrees, and the dramatic warming of the last century raised average temperatures by one degree, comparing the unprecedentedly hot 1990s with a century earlier (3, 4). The variability of climate during the late Pleistocene required high levels of geographical mobility, which was an impediment to any substantial investments in tree crops or field preparation or even stores and storage facilities. The scale and pace of climate change is truly extra ordinary: for example $\delta^{18}O$ signals from sea cores indicate that between 25 and 60 ka, variations in sea surface temperature of $3^{o} – 5\ ^{o}C$ occurred over periods of 70 years or less in the Santa Barbra Basin, California (5) (sea surface temperatures today are about this different between the Santa Barbara Basin and northern Vancouver Island). Think about the frequency of moves and the distances that early humans may have traveled. A change of 9 degrees Centigrade in the course of a millennium appears to have been common prior to the Holocene. That's the difference in the average daily temperature in Cape Town and Mombasa 4 thousand kilometers to the north. While humans and the wild species on which they depended could of course adapt to a few degrees change in temperature, we infer that the distances covered and frequency of moves must discouraged the kinds of investment that farming requires.

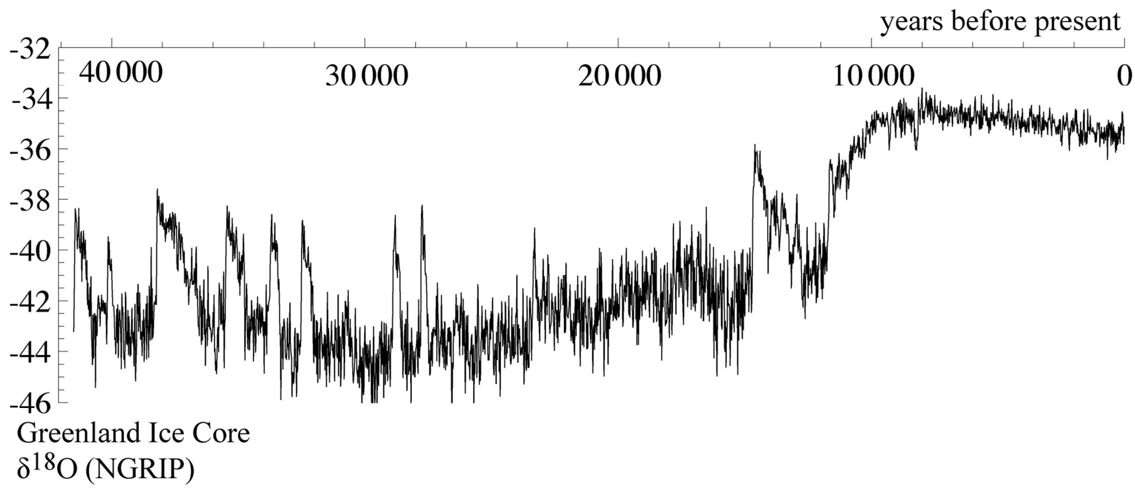


Fig. S1. Late Pleistocene and Holocene climate. Greenland ice core data used in the main text

1. 3. Private property in forager and farming societies.

In (6) we provide further evidence for the empirical claims made in the paper and in particular the claim that the private property rights that farming required—the assurance that an individual or family could exclude others from appropriating the results of their labor in cultivation and animal tending – were for the most part absent among foragers (mobile hunter gatherers) at the end of the Pleistocene. The sources upon which we have relied are (7-38).

The main archaeological and ethnographic evidence is the fact that by comparison with small scale farmers who can allocate surpluses to privately owned storage, foragers redistribute a substantial fraction of the food and other economic resources acquired by their own labor to others beyond the nuclear family, along with the widely held inference that, according to Boehm: “the great majority of … prehistoric foragers would still have today’s main pattern, meaning that they lived in mobile, flexible, and egalitarian multifamily units.” (7) (p.88)

We have collected evidence on the fraction of the food acquired by family members (measured in calories) that a family retains for its own use rather than being consumed by others in both foraging and horticultural societies. The mean of the four estimates of family retention rates for foragers is 0.295 and of the five estimates for horticulturalists is 0.644. (The difference in means is significant at $p< 0.001$.)

But a family can expect that those receiving transfers will reciprocate, that is transfer something in return *as a result of* the initial transfer that is above and beyond the amount that would have resulted from family ties, genetic relatedness, propinquity and other influences on sharing . A more adequate measure of the amount retained would be 1 – (fraction transferred)(1-reciprocation rate), where the reciprocation rate is defined as the fraction of the quantity transferred from family A to family B that is reciprocated in transfers from B to A, controlling for other influences on transfers of food such as geographical proximity and kinship. The means after adjusting for reciprocation are 0.360 and 0.740 for the foragers and the horticulturalists, respectively. Sources: Ache (forest) (29); Yora (30); Aka (24, 31); Hiwi (32); Rakoiwa, Krishisiwa and Bisaasi (1986 and 1987) (33); Ye’kwana (34).

2. The model of within-group interaction

2. 1. Choice of technology: Farming vs. foraging

An individual may be either a hunter-gatherer or a farmer. A hunter-gatherer obtains V_h by foraging. A farmer’s product is acquired by a prior investment of an amount z, resulting in a subsequent gross product of (using the subscript a to refer to farming or agriculture) $V_a^G = rz$, where r is a measure of the returns to the farmer’s investment that varies inversely with climatic volatility (see Fig. S8.) The net payoff of the farmer (after subtracting the cost of investment) would be $V_a = rz - z$ if the product is not taken by others or $-z$ if the product is taken by others. Thus the expected payoff to farming may be less or greater than V_h depending on climatic conditions and the prevalent property rights. Note even if the productivity of the two economies is identical ($V_h = V_a$) the farmer is more vulnerable than the forager to losses through hostile challenges over their product because the farmers' crop (rz) exceeds the foragers' prey (V_h) by the magnitude of the farmer's prior investment, z. We set V_h =1, r =1.5, z=2 (i.e., V_a^G=3 and V_a =1) for our benchmark simulations reported in Fig. 2 in the text. The benchmark returns to farming investment r =1.5 is adjusted downward according to climatic conditions so that realized returns are $r - \theta$ (see Section 8).

2. 2. Pairing and play

Once a player obtains V_h or V_a^G depending on his technology, he plays the bourgeois-sharer-civic game with a randomly chosen partner twice; one game over the distribution of his product and the other game over the distribution of his partner's product. Each player has one of the behavioral strategies described below and summarized in Table S2.

2. 3. The sharer and bourgeois strategies

The first behavioral type, the sharer, concedes half of the product to the other, or the whole product if the other claims it (similar to the dove in the hawk dove game). Bourgeois individuals claim the entire product if it is in their possession; if not they act like a sharer. A non-possessing bourgeois may engage in contests with another bourgeois if the possession of the product is contestable, which occurs with probabilities that depend on whether the product is farmed (μ_a) or foraged (μ_h). The loser of the contest bears a cost, while the winner claims the product (V). We let $\mu_h > \mu_a$ because farmed plants and animals and the land that supports them are more easily demarcated and defended than most foraged products, due to the greater productivity of land devoted to domesticated species. In our benchmark model of the forager economy we let μ_h =1 so a bourgeois will contest any claim of individual possession (under these conditions, bourgeois is thus identical to hawk in the hawk- dove game).

2. 4. The civic strategy

A civic individual shares when he meets either sharers or other civics. Being paired with anyone claiming the whole product, all the civics attempt to punish him. They succeed with probability f, in which case the civic obtains the entire product and distributes it equally to all civics; if unsuccessful, which occurs with probability (1- f), all the civics bear the cost $\frac{C}{(1-\alpha-\beta)n}$, where n is the number of civics, and α and β are the within group frequencies of sharers and bourgeois, respectively (i.e., $1-\alpha-\beta$ is the frequency of civics). The probability of civics successfully punishing an individual claiming the entire product (f) is increasing in their numbers (Fig. S2) according to:

$$\mathrm{f}=\frac{[(1-\alpha-\beta)n+0.5n-v]^{\gamma}}{[(1-\alpha-\beta)n+0.5n-v]^{\gamma}+[n-(1-\alpha-\beta)n-0.5n+v]^{\gamma}}$$

where v and γ are a center value and exponent of the winning function. The following figure depicts this probability (when v =8; γ =5). In this case, the civic successfully punishes with probability 0.5 if the number of civic in a group is equal to 8.

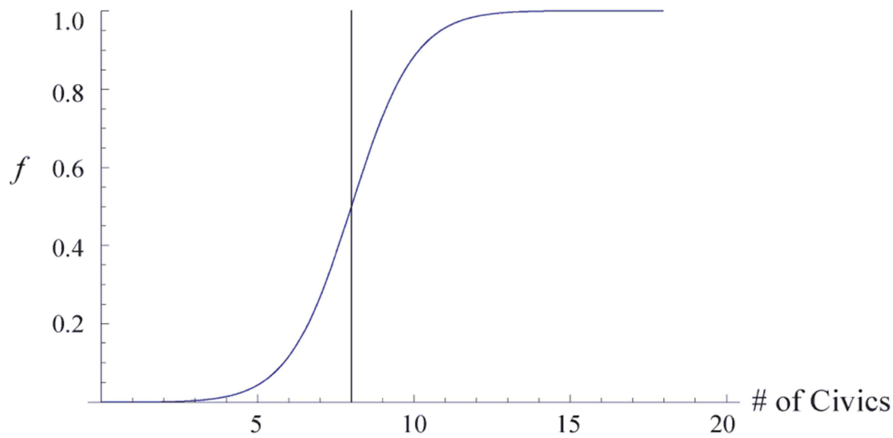


Fig. S2. The probability of successfully punishing an individual claiming the entire product. Successful punishment of a group member claiming the entire product depends on both the numbers willing to contest the claim and the legitimacy of their objection in the eyes of others. We take the number of civics in the population to be a measure both of the degree to which the target is outnumbered, and the legitimacy of the punishment.

Table S2. Actions taken by the row player when paired with the column strategy

	Bourgeois	*Sharer*	*Civic*
Bourgeois	If possessor, claims the entire product, if not concedes it	If possessor, claims the product, if not concedes it	If possessor, claims the product, if not concedes it
Sharer	If paired with a possessor, concedes the product	Shares the product equally	Shares the product equally
Civic	If paired with a possessor (who claims the entire product) seeks (jointly with other civics, if any) to contest the bourgeois' claim	Shares the product equally	Shares the product equally

2.5 Payoffs

With these assumptions, we have the payoff matrices described below. The following payoff matrices are for the games when a farmer meets a farmer, when a farmer meets a forager, when a forager meets a farmer, and when forager meets a forager, respectively.

Table S3. Row Player's payoff

(Recall that when a pair meets, they play two games, one over the product of each of the two parties. Expressions in red are the row's payoff of the game over row's product and those in black are the row's payoff of the game over column's product. We assume $\mu_a = 0$, $\mu_h = 1$, and $V_a^G = rz$)

(a) When a farmer meets a farmer

	Bourgeois	*Sharer*	*Civic*
Bourgeois	$[V_a^G - z] + [0]$	$[V_a^G - z] + \left[\frac{1}{2}V_a^G\right]$	$[-fC + (1-f)V_a^G - z] + \left[\frac{1}{2}V_a^G\right]$
Sharer	$\left[\frac{1}{2}V_a^G - z\right] + [0]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_a^G\right]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_a^G\right]$
Civic	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{fV_a^G - (1-f)C}{(1-\alpha-\beta)n}\right]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_a^G\right]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_a^G\right]$

(b) When a farmer meets a forager

	Bourgeois	*Sharer*	*Civic*
Bourgeois	$[V_a^G - z] + \left[\frac{1}{2}(V_h - C)\right]$	$[V_a^G - z] + [V_h]$	$[-fC + (1-f)V_a^G - z] + [-fC + (1-f)V_h]$
Sharer	$\left[\frac{1}{2}V_a^G - z\right] + [0]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_h\right]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_h\right]$
Civic	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{fV_h - (1-f)C}{(1-\alpha-\beta)n}\right]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_h\right]$	$\left[\frac{1}{2}V_a^G - z\right] + \left[\frac{1}{2}V_h\right]$

(c) When a forager meets a farmer

	Bourgeois	*Sharer*	*Civic*
Bourgeois	$\left[\frac{1}{2}(V_h - C)\right] + [0]$	$[V_h] + \left[\frac{1}{2}V_a^G\right]$	$[-fC + (1-f)V_h] + \left[\frac{1}{2}V_a^G\right]$
Sharer	$[0] + [0]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_a^G\right]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_a^G\right]$
Civic	$\left[\frac{fV_h - (1-f)C}{(1-\alpha-\beta)n}\right] + \left[\frac{fV_a^G - (1-f)C}{(1-\alpha-\beta)n}\right]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_a^G\right]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_a^G\right]$

(d) When a forager meets a forager

	Bourgeois	*Sharer*	*Civic*
Bourgeois	$\left[\frac{1}{2}(V_h - C)\right] + \left[\frac{1}{2}(V_h - C)\right]$	$[V_h] + [V_h]$	$[-fC + (1-f)V_h] + [-fC + (1-f)V_h]$
Sharer	$[0] + [0]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_h\right]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_h\right]$
Civic	$\left[\frac{fV_h - (1-f)C}{(1-\alpha-\beta)n}\right] + \left[\frac{fV_h - (1-f)C}{(1-\alpha-\beta)n}\right]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_h\right]$	$\left[\frac{1}{2}V_h\right] + \left[\frac{1}{2}V_h\right]$

The followings are the explanation on some entries of the payoff matrices.

- The case where an individual (row player) who is a bourgeois farmer meets a bourgeois farmer (the upper-left cell in Table S3 (a)). The row player keeps his/her product because the row's farmed product is not contestable and the column player (bourgeois) respects the row's ownership. Therefore row's net payoff is $V_a^G - z$. (the first bracket in red). Because the column player is also a farmer, his/her product is not contestable. The row player respects his/her partner's ownership and receives 0 from the game over his partner's product (the second bracket in black).
- The case where an individual (row player) who is a civic farmer meets a bourgeois farmer (the lower-left cell in Table S3 (a)). The row's farmed product is not contestable. The column player (bourgeois) respects the row's possession of the product because he/she knows that the row is the owner. In response the row player (civic) is willing to concede a half of the product and enjoy the other half for him/herself. Therefore the row player receives $V_a^G/2 \, - z$ (the first bracket in red). And the column player refuses to share because he/she is a bourgeois and attempts to defend his/her whole product. There are $n(1-\alpha-\beta)$ civics, they successfully punish the column player with probability f (see Fig. S2), in which case all the civics share the column player's gross product (V_a^G since the column player is a farmer), or lose the fight with probability $1-f$, in which case they bear the cost (the second bracket in black).
- The case where a bourgeois farmer meets a bourgeois forager (the upper-left cell in Table S3 (b)). The farmer (row player) can successfully keep his/her whole product because the farmed product is not contestable and his/her bourgeois partner would not claim it, which gives the row player $V_a^G - z$ (the first bracket in red). However the row player claims the partner's product because it is foraged product (note that a bourgeois simply behaves like an aggrandizer if the product is contestable). Therefore there will be a conflict and both will get $(V_h - C)/2$ (the second bracket in black).
- The case where a bourgeois forager meets a bourgeois forager (the upper-left cell in Table S3 (d)). Both will behave like aggrandizers because both products are contestable. Therefore each one will receive $(V_h - C)/2$.
- The case where a civic forager meets a bourgeois forager (the lower-left cell in Table S3 (d)). The bourgeois forager will attempt to grab the civic's product because the civic's product is contestable. All the civics in the group collectively punish the bourgeois for

his/her aggrandizing behavior. The collective punishment is successful with probability f, in which case all the civics share the product among themselves; otherwise they bear the cost of conflict (the first bracket in red). Since the bourgeois forager's product is also contestable and the bourgeois refuses to share it, another collective punishment is imposed on the bourgeois. The collective punishment of the civics is successful with probability f and the civic-forager receives the payoff shown in the second bracket in black.

3. Strategy updating with conformism and group contests

After all games have been played, each member is paired with a cultural model, possibly a teacher, religious leader, successful hunter or farmer, or competitor. This pairing process reflects the way the group socializes its members. If the model and the member are of the same type, the member simply retains his trait. If the two have different traits, then the member compares his payoff from this period to the model's payoff, and switches to the model's trait if the model's payoff is higher.

Members in a group which lost an intergroup contest are paired with a cultural model from the winning group and update their strategy through the process described above. Between-group interaction occurs once every generation. An intergroup contest occurs when one of the two is sufficiently likely to win, reflecting the fact that as with other primates, evenly matched human groups seek to avoid costly conflicts (39). We assume that when group *i* is randomly paired with group *j* and has a contest with probability *d* where $d=|\pi_i - \pi_j|/(\pi_i + \pi_j)$. When a contest occurs, the group with a higher average payoff wins with probability 0.5 + 0.5d. Further we assume that each member in the losing group loses 3 payoff units, and this score is added to each member in the winning group.

The pairing rule will introduce conformism to the transmission process if each member of the more numerous type within a group is more likely to be drawn to be a cultural mode than would occur by chance. To allow for this, we let the probability that a sharer will be drawn a cultural model be

$$\frac{\alpha^\eta}{\alpha^\eta + \beta^\eta + (1-\alpha-\beta)^\eta}$$

where η (>1) is a measure of conformist biased cultural transmission. The probability that a bourgeois or a civic is drawn for the cultural model pool is calculated in similar fashion, that is by the same expression but with β^{η} in the numerator rather than α^{η} and similarly for the civics. Fig. S3 illustrates the biased assignment of models to members if there are just two types in the population; for $\eta > 1$, the bias is conformist, with larger groups contributing proportionally more to the pool of cultural models. For $\eta = 1$ the pairing of members and cultural models is random. (For $\eta < 1$ the bias is anti-conformist, larger groups contributing proportionally fewer to the pool; we do not consider this case).

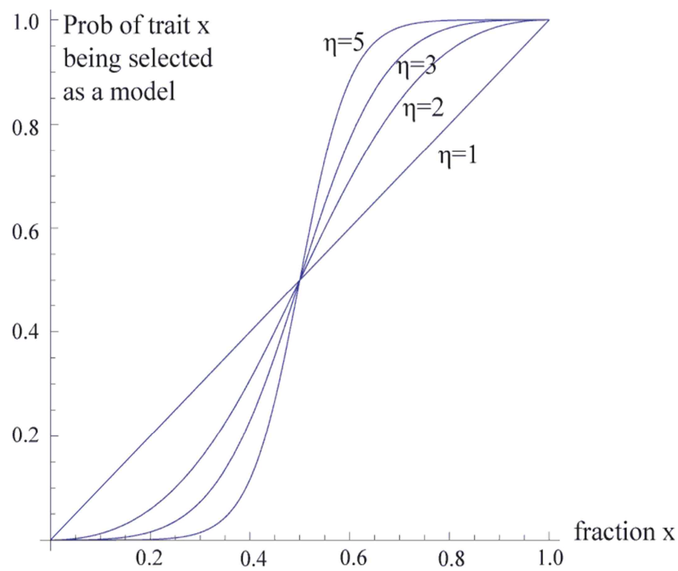


Fig. S3. Biased assignment of models to members when there are two types in the population. In the cultural updating process individuals are assigned to cultural models, but types that are numerically prevalent in a group are more than proportionally likely to be cultural models (teachers, influential elders, religious leaders).

4. Replicator dynamics (in a foraging economy)

To calculate the dynamics (without conformism), we assume a payoff monotonic updating process (behavioral-technology types with higher than average payoffs increase their share of the population.). We suppose every member in a group is a hunter-gatherer, so that we have $V = V_h$ and $\mu = \mu_h = 1$. Let π^B, π^S and π^C be the expected payoff to bourgeois, sharer and civics, respectively, and π^S be the average payoff of the group. Let α, β, and $1 - \alpha - \beta$ be the within-group frequency of sharer, bourgeois and civics, respectively. Then we have the following replicator dynamics.

$$d\alpha/dt = \alpha(\pi^S - \bar{\pi}) \text{ and } d\beta/dt = \beta(\pi^B - \bar{\pi})$$

where

$$\pi^S = \alpha(V/2) + \beta \cdot 0 + (1-\alpha-\beta)(V/2)$$
$$\pi^B = \beta(V-C)/2 + \alpha V + (1-\alpha-\beta)[(\alpha+\beta)V + (1-\alpha-\beta)(-C)]$$

and

$$\bar{\pi} = \beta\pi^B + \alpha\pi^S + (1-\alpha-\beta)\pi^C$$

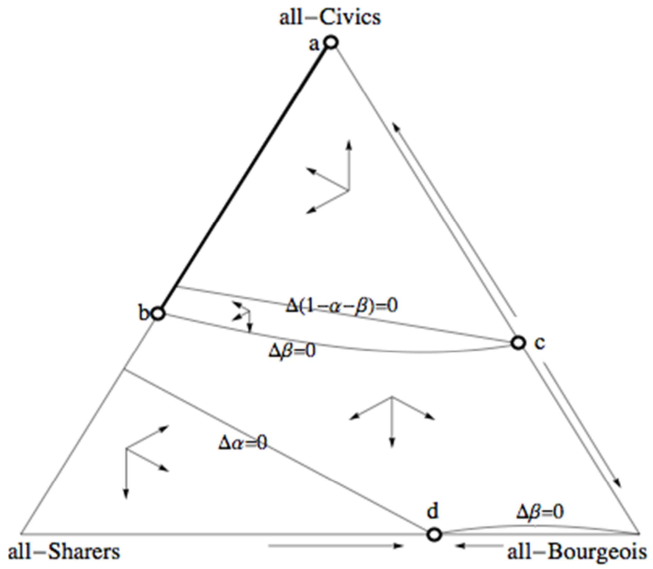


Fig. S4. Within-group dynamics in a foraging economy. The coordinates of a point in the simplex sum to 1 and give the fractions of the population composed of the three behavioral types. For example at point **b** slightly more than half of the population are sharers and the rest are civics (there are no bourgeois). The vectors (arrows) indicate the direction of movement in the regions defined by the loci along which α and β (the fractions, respectively of sharers and bourgeois), and $1-\alpha-\beta$ (the fraction of civics) are stationary, assuming that the group has not lost a contest with another group and that conformist assignment of cultural models is absent. The vectors show that the sharer-bourgeois equilibrium (point **d**) is self-correcting (asymptotically stable) while the all-civic equilibrium (point **a**) is not (it is only neutrally stable, i.e. subject to drift). Thus beginning at **a,** drift may propel a population along the left edge of the simplex towards point **b**, where the number of civics is just sufficient to repel any invading bourgeois. Beyond **b** a group member switching by chance to the bourgeois strategy (or a bourgeois immigrant) will do better than others in the group, and the population will then be carried to point **d**.

The stationary and stable states of this dynamic are the all-civic group and a mixed group of bourgeois and sharers. These two states give two alternative idealized representation of the forager livelihood and institutions with the first representing a relatively conflict free social system and the second representing a breakdown of order with conflict arising over the possession of valued goods. To understand the dynamics of these societies we need to explore the entire state space. Due to migration among groups and behavioral experimentation there will always be a few bourgeois individuals present in the group with all civics. Also there will be an occasional civic in the in a group composed mostly of sharers and bourgeois types. The population state of bourgeois and sharers is stable (self-correcting) because when civics are few they often bear the costs of the many contests with the aggrandizing bourgeois in which they engage (and which they lose because they are few in number). Hence they receive low payoffs and are not emulated in the updating process. Similarly, when civics are common, the occasional bourgeois types will not proliferate, as they will lose the many contests with civics that occur, while civics rarely bear the costs of contests with a bourgeois type (there are few bourgeois so there is little occasion for punishing, and the numerous civics rarely lose).

But a mixed population of sharers and civics may be unstable because when there are few civics present, aggrandizing individuals will proliferate, carrying the population to the sharer-bourgeois stationary state. In our simulations under Pleistocene conditions (that is where virtually all are foragers) groups composed of a mix of shares and civics occasionally are invaded by bourgeois types carrying the group to the neighborhood of the sharer-bourgeois state. But the lower average payoffs in this state due to contestability of foraged products then result in these groups losing conflicts with groups predominantly made up of sharers and civics, resulting in the restoration of substantial fractions of civics and sharers and few bourgeois types.

5. Benchmark parameter values

Table S4. Parameter values

Parameter	*Value*	*Parameter*	*Value*
Group size per generation (n)	20	Group interaction	Every generation
Migration rate (m)	0.2	Contestability of hunter-gathered product (μ_h)	1
Behavioral experimentation (ε)	0.25	Contestability of Farmed product (μ_a)	0
Level of conformism (η)	2	Farming productivity (r)	1.5
Hunter-gatherer product (V_h)	1	Farming investment (z)	2
Cost of losing a conflict (C)	1.5	Farmer's net product (V_a)	1

Sensitivity to alternative parameter values is estimated in Section 10. The rationale for these benchmark parameter values follows. Group size and migration rates are consistent both with ethnographic and genetic evidence as summarized in (40) and (41). The levels of conformism and behavioral experimentation are not estimated, but appear to be plausible. The hunter-gatherer product is a normalization. The cost of conflict is chosen to ensure that the underlying game takes the Hawk Dove form. The rationale for the two contestability parameters is provided in the text (see Fig. S10 panels B and C for sensitivity to alternative values). Net agricultural product is set equal to the productivity of hunter gatherers; in the simulations this is endogenously adjusted downward reflecting the effects of weather volatility (see Section 8 below particularly Fig. S8). Agricultural investment, which implies a capital to net output ratio in farming of 2 is calibrated from a farming production function reflecting what for early Holocene Europe is called the Neolithic package. The capital stock is composed of stored cereals and goats, with the latter contributing one third of the livelihood of the family, using data on seeds and storage from (1) and effective lifetime for the livestock of 5 years, possibly resulting in an underestimate of the capital output ratio for the herding component production. The non livestock portion of the capital may also be underestimated due to the exclusion of tools. A larger capital output ratio in farming, by raising the farmer's vulnerability to contestation, could be offset by more intermediate values of the contestability parameters (which would reduce the forager-farmer differences in vulnerability) without affecting the underlying economic mechanisms at work in the model.

6. Aggrandizers: A gangster path to the Holocene revolution?

Another path has been proposed, one that proceeds through simple taking and defending of goods by aggrandizers, who (if their defense is effective) would then have the incentives to engage in a delayed return activity such as agriculture. This so-called "gangster" variant of the Holocene revolution seems quite unlikely, however. We captured its dynamics in the model of the forager economy in which property rights are always contested $\mu_h = 1$ so that the bourgeois is just a gangster who claims and fights for resources of others. But in our simulations such 'gangsters' rarely proliferate and when they do their success is short lived. The reason why the bourgeois strategy eventually succeeded is that it attenuated conflicts among would be aggrandizers by recognizing the possession rights of others, once the domestication process reduced the contestability and contestability of possession. An aggrandizer strategy might succeed had we assumed strongly asymmetric fighting ability and the inability of those with less ability to form effective coalitions. But we did not explore this possibility

7. Algorithm structure

The code was written in Borland C++ Builder. The simulation algorithm is as follows. A schematic representation of our model appears in Fig. S5.

A. Create 30 groups and 20 agents in each group.
   a. Initially, all the agents are civic hunter-gatherers.
B. Within-group Interaction (bourgeois-sharer-civic game with hunted/gathered product or agricultural product, see Section 2.)
C. Group Interaction
   a. Between-group interaction occurs once every generation. Group i is randomly paired with group j and has a contest with probability d where $d=|\pi_i - \pi_j|/(\pi_i + \pi_j)$. When a contest occurs, the group with a higher average payoff wins with probability 0.5 + 0.5d.
   b. Each member in the losing group loses 3 payoff units, and this score is added to each member in the winning group.
D. Updating
   a. In a winning group: Each member meets a cultural model, where the model is chosen non-randomly (η >1) from the winning group.
   b. In a losing group: Each member meets a cultural model, where the model is chosen non-randomly from the winning group.
   c. Behavioral experimentation occurs for each individual during the strategy updating with probability ε. If experimentation occurs, the behavioral strategy and the technology choice are drawn randomly from the entire strategy set. If experimentation does not occur the individual updates according to the best response dynamic described above.
E. Migration
   a. With probability m=0.2 each individual is selected for a migrant pool from which individuals are allocated to a randomly selected destination group.
F. Repeat B-E for a specified number of generations.

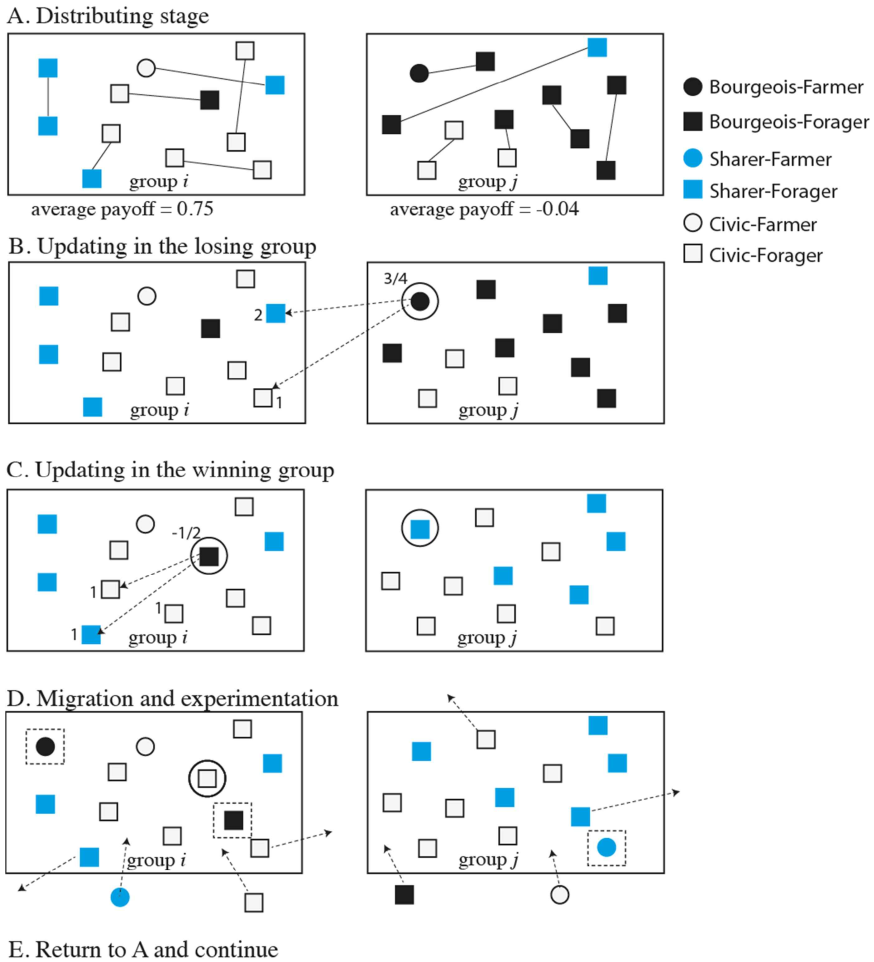


Fig. S5. Distribution, group competition, and updating. Two pre-dominantly forager groups are represented by the rectangles, populated by individuals who differ in technology (the shape of the object) and their behavioral type (its color). In the top panels (**A**) individuals are randomly paired with others in their group in the distribution stage either conceding, sharing, claiming, or contesting the claims of others. This determines their payoffs. In the next set of panels (**B**) the two groups have had a contest, the left group had higher average payoffs and has prevailed, and the loser group's members update their type. One updating individual is shown paired with two models (one for updating behavior, one for updating technology) from the winning group (along with their payoffs from the distribution stage). Payoffs for all of the pairings shown are given (with explanation) in Table S3. As a result of the payoff differences, the updating person converts from a bourgeois farmer to sharer hunter gatherer (shown by the circle in the right hand C panel). Then (left hand **C**) members of the winning group (on the left) are paired with models from their own group, and update their types accordingly. Finally (**D**) random migration into and from both groups occurs, along with random experimentation of types (the dashed rectangles). This sketch does not fully represent our simulation algorithm (e.g. the simulations there are 30 groups each with 20 members of a given generation, and all group members update in every generation.)

8. Calibrating farming productivity using climate data.

The calibration is based on two pieces of information: estimates of the productivity of farming relative to foraging in the early Holocene (1) and uncontroversial inferences from climate and other data that conditions during the previous 30 thousand years were exceptionally farming-unfavorable (42). Among the data supporting the second point (in addition to the extraordinary temperature variations over less than century long time scales described above in Fig. S1) is evidence that the total organic carbon stored terrestrially (a measure of photosynthesis) during the period just prior to the Holocene was 41% of the levels during the Holocene (using estimates based on the highest available resolution (43)). The two big facts that we represent in the model are thus that farming, were it to have occurred during the Pleistocene, would have been very unproductive and would have been more productive during the Holocene but still not as productive as foraging.

In this section we show two things: (a) that the productivity levels of farming and foraging generated by the climate data were calibrated to fall within plausible ranges in light of the data and (b) that the main results are unaffected by plausible variations in the relevant productivity ratio (see Fig. S9 below).

We used the data on climate volatility to predict movements in levels of farming productivity in the late Pleistocene and Holocene so as to generate long term averages consistent with the our direct estimates mentioned two paragraphs above. This calibration then automatically generated climate-driven temporal variation in the relative productivities over the entire 40 thousand year period. The average productivity of farming relative to foraging in the Holocene is based on the data in Table S1 (1). To generate plausible values for this ratio we used the estimates for caloric productivity of foraging and farming (5 and 15 respectively in number) to generate 75 pairs representing the productivity ratio for some particular location of a sub population. The resulting distribution is shown in Fig. S7.

The time series of the ratio of farming to foraging productivity that we used for the simulations reported in Fig. 2 of the text was generated in the following way (summarized in Fig. S6).

1. *Climate volatility*. From the Greenland ice core data we calculated the maximum difference in the δ^{18}O signal during 5 generations (i.e., the maximum δ^{18}O signal minus the minimum of δ^{18}O signal during 5 generations) and smoothed the series by using 200-year (10 generations) backward moving average. For any particular year, this number

(which we denote w) is a measure of the climate variability experienced by the previous ten generations. (Because the NGRIP ice core data are binned in 20 year intervals we also defined a generation as 20 years.)

2. *Farming productivity*. We use data on the relative productivity of farming and foraging to calculate θ, the disadvantage of farming due to the temperature volatility calibrating the generating function so that on average farming is 86 percent as productive as foraging in the Holocene and 35 percent as productive during the Pleistocene. For this calibration, we used $\theta = (0.45 - w)/5$ for our benchmark simulation.
3. *The productivity ratio*. In the simulation, the agricultural gross output is $rz - z$ where r is a measure of the productivity of the farmer's investment and z is a prior investment for farming. We apply the disadvantage of farming due to the temperature volatility, θ, to r, so that the gross productivity of farming becomes $(r - \theta)$. The productivity of farming (net of investment costs) is thus: $(r - \theta)z - z$; and because the productivity of foraging is normalized to 1, this is also equal to productivity ratio of the farming to hunting.

Fig. S6. Calibration structure.

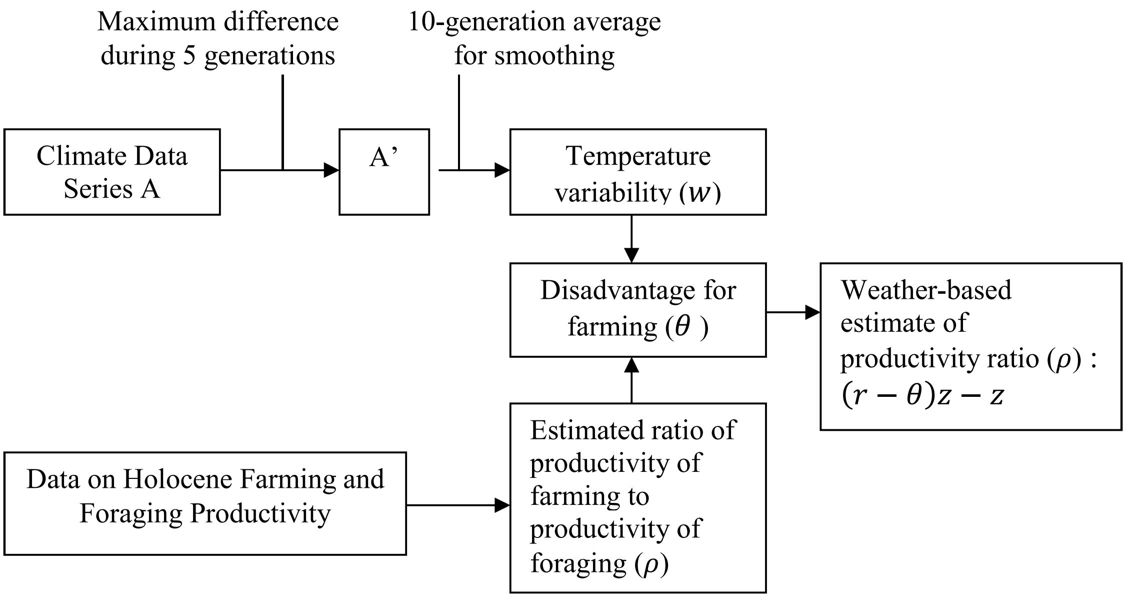


Fig. S7. Simulated distribution of the relative productivity of farming and foraging under early Holocene conditions. Source: methods described in text, data from (1). The arrows indicate the average productivity ratios generated by our weather data (given by $(r-\theta)z-z$ where θ is the weather-determined estimated average disadvantage of farming.)

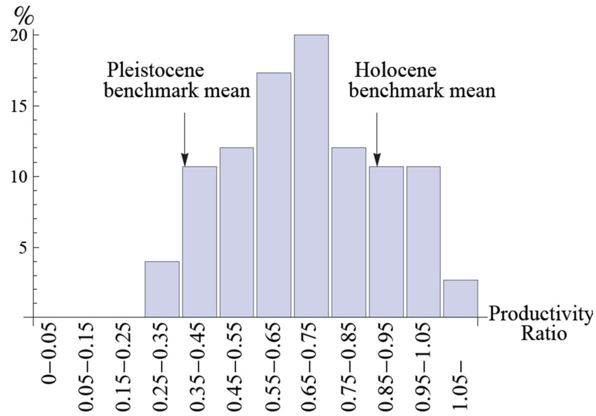
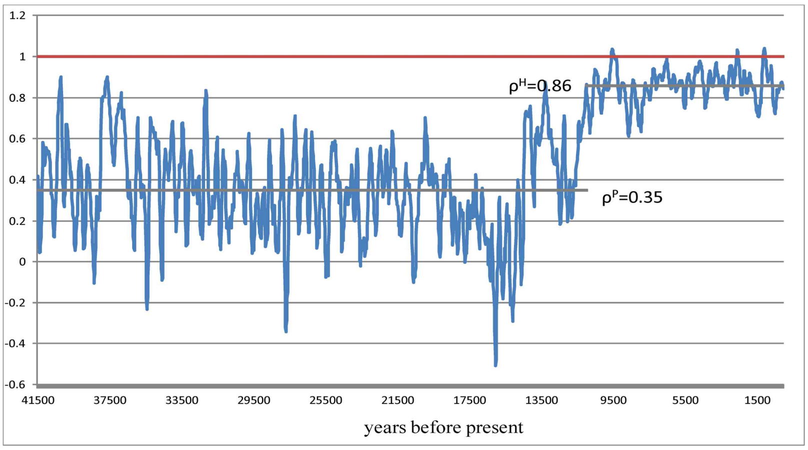


Fig. S8. Climate-induced variation in agricultural productivity relative to foraging. Shown is the ratio of the products acquired by farming (assuming that the products are not contested) to the products acquired by foraging (i.e., V_a/V_h). This ratio is determined entirely by the weather volatility shown in text Fig. 2. In the figure ρ^{P} and ρ^{H} are, respectively, the ratio of productivity of farming to the productivity of the foraging during the late Pleistocene and the Holocene.

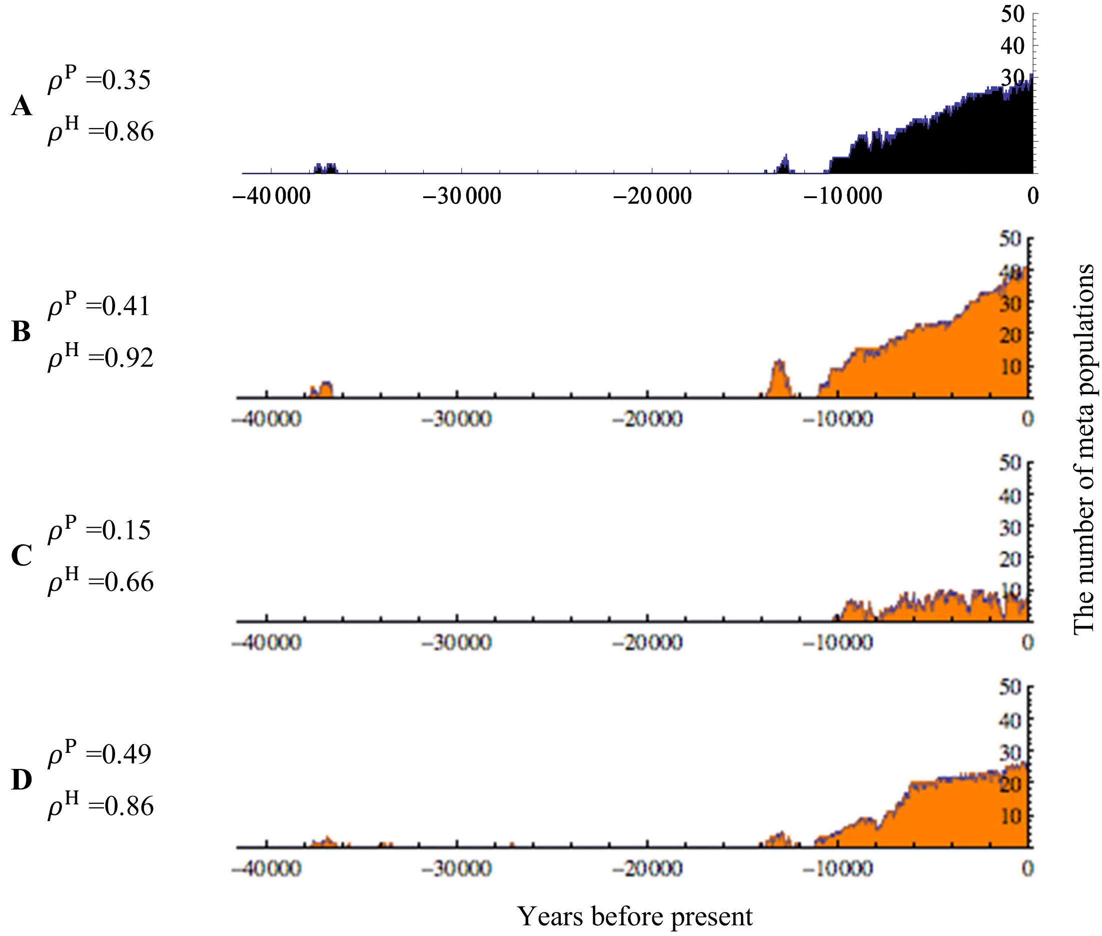


9. Sensitivity of simulation results to alternative productivity calibrations

In our baseline simulations the average ratio of farming productivity to foraging productivity in the Holocene is 0.86 and in the Pleistocene 0.35. We also experimented with simulations (shown below) in which the Holocene productivity ratio (farming to foraging) was 0.92 and 0.66. These are shown in Fig. S9.

Fig. S9 Panel B shows that a calibration that raises the relative productivity of farming has limited effect (modestly increasing the number of transitions in the Holocene without affecting the Pleistocene period). Panel C (remarkably) shows that farming and private property emerge even when farming during the Holocene is just two thirds as productive as foraging. In this set of a thousand implementations of the simulation (equivalent to a thousand independent populations) 10 populations made an independent to farming and private property, or about the actual number of such transitions in the archaeological data. Thus what we call the Holocene revolution could have occurred despite farming productivity being approximately inferior as our estimates indicate. Finally Panel D shows a modest increase in the farming productivity ratio that has no effect on the Pleistocene period.

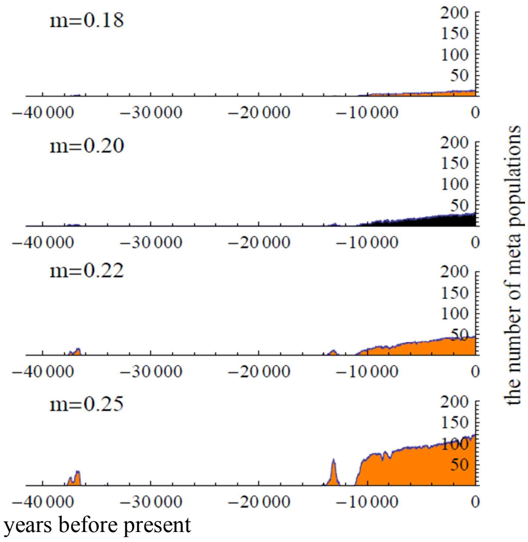
Fig. S9. Simulation runs under alternative assumptions concerning the relationship of climate to the relative productivity of farming and foraging. Shown in each panel are for each time period the number of populations (of the thousand populations simulated) in which half of the population or more are bourgeois farmers. Panel A is our benchmark for ease of reference. In the figure ρ^{P} and ρ^{H} are, respectively, the ratio of productivity of farming to the productivity of the foraging during the late Pleistocene and the Holocene. Source: see text.



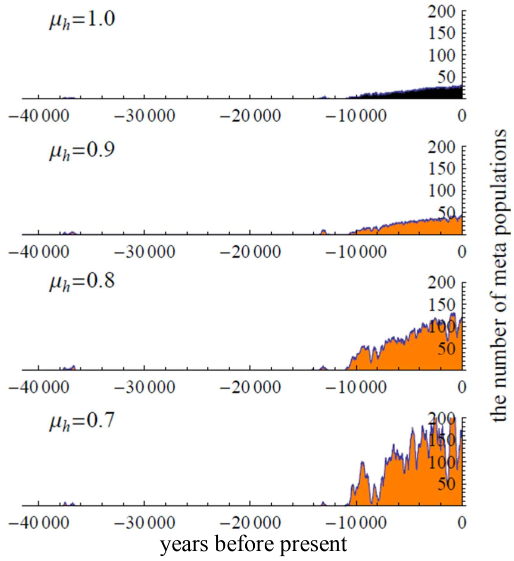
10. Robustness checks for the remaining parameters.

The remaining robustness tests appear in Fig. S10.

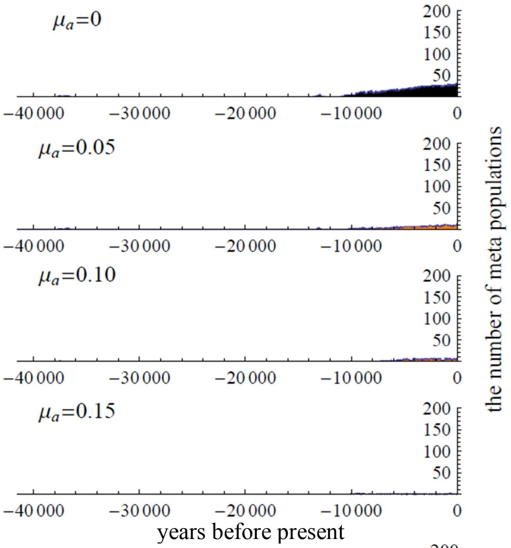
Fig. S10. Simulation runs under alternative parameter values. Shown in each panel are for each time period the number of populations in which half or more of the population are bourgeois farmers of a thousand simulations of a population under the parameters indicted (all other parameters are at their benchmark values). These simulations may be compared to the results in Fig. 2 of the main text, which are reproduced in each panel in black for ease of reference.



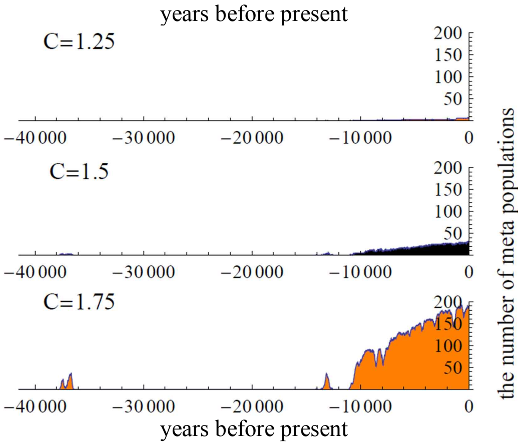
A. Rate of random migration per generation. Higher levels of migration tend to accelerate the emergence of farming because the effect is to reduce the force of group competition (because migration makes groups more similar) and this weakens the process that stabilizes the forager-hunting technical-institutional equilibrium. When $m = 0.18$, there are a total of 14 transitions to farming and private property at the end of the period. Migration is random (the so called island model) meaning that with probability m an individual is relocated in a randomly selected subpopulation (including the current one). Typically observed migration is highly non-random (most migrants go to a few nearby sub-populations) and thus is much less effective in equalizing group compositions (41, 44, 45). Based on evidence from the Aland Islanders, the !Kung, and circumpolar Eurasian hunter-gatherers (46) we estimate that our benchmark random migration rate (0.2) corresponds to an empirical rate of migration of from 0.3 to 0.6.



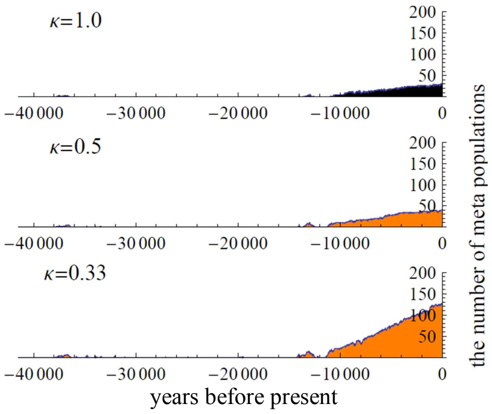
B. Contestability of foraged products, bourgeois strategy. We assume that farmed species are not contested by non-possessing bourgeois individuals, but that hunted or gathered species are. Some hunting and gathering groups establish family based property rights over wild species (which may be acquired in particular locations). To explore the sensitivity of our results to this forager property rights scenario we consider reductions in the contestability of possession of wild species (that is, partial property rights). The effect is to facilitate the emergence of private property and hence farming. Note the property rights first scenario that characterizes many transitions occurs in our benchmark simulations even under the least favorable possible conditions, namely that foraged products are entirely contestable.



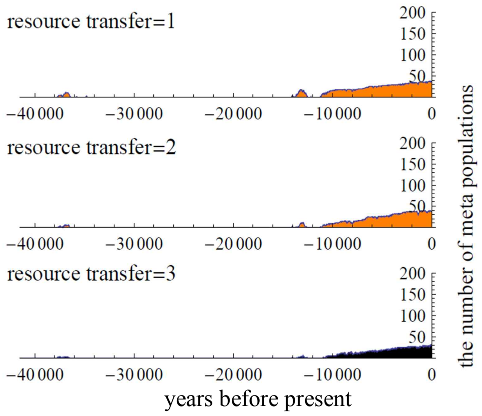
C. Contestability of farming products, bourgeois strategy. In our benchmark simulations we assumed that farmed goods were not contested by bourgeois individuals; foraged goods were contested, as were farmed goods in civic-bourgeois interactions, leading to high levels of property rights contestation in the benchmark (see Section 11). Here we allow bourgeois farmers to contest each other's private property, with the following frequencies and resulting transitions.
Benchmark μ_a=0, resulting in 31 transitions; μ_a=0.05, 10 transitions; μ_a=0.10, 5 transitions; μ_a=0.15, 1 transition.



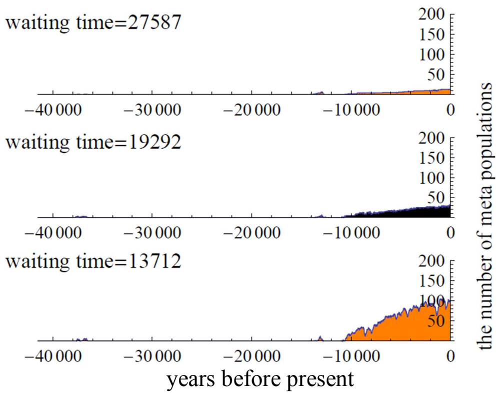
D. Cost of losing a conflict within group. The greater the cost of losing a conflict the stronger will be the selective forces working against groups with some bourgeois members but that have highly contestable property rights. This occurs when groups are engaged primarily in hunting. As a result, the larger is this cost, the more beneficial is the adoption of farming (which reduces contestability of goods and hence diminishes the number of conflicts). As a result higher values of C result in earlier and more frequent independent emergences of farming and private property. When C = 1.25, by the end of the period there are 6 transitions to farming and private property.



E. Probability of a between group conflict per generation. In the simulations group conflicts result in resource transfers and the assignment of winning group cultural models for the cultural updating process of the next generation of the losers. Both contribute to loser populations becoming more like winner populations. Less frequent group conflicts will weaken one of the mechanisms stabilizing the forager equilibrium, resulting in both earlier and more extensive emergences of farming. Based on evidence of the substantial extent of mortality in between forager group conflict (47) we think that a once per generation conflict scenario is not an overestimate. In any case the results are very similar when conflicts are half this frequent and not qualitatively affected by even a greater reduction in conflict.



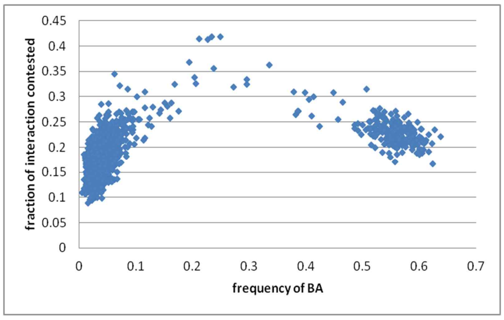
F. Resource transfer from losing to winning group. The larger is this transfer, the more powerful is the advantage of foraging groups in competition with farming groups (average payoffs in foraging groups are almost always higher than in farming groups due to the productivity advantages of foraging wild species and the costs of within group conflicts when property rights are contestable). But the results vary only slightly with variations in this parameter, suggesting that plausible reductions in the stakes of group competition have little effect.



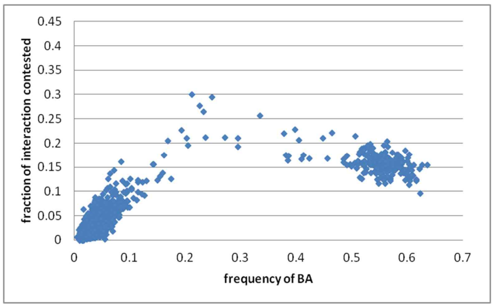
G. Expected waiting time for half of a group of hunters to become farmers by random experimentation. Random experimentation creates diversity among groups and over a sufficiently long time period will convert a group, for example, of all hunters to a group with equal numbers of farmers and hunters. We use the waiting time for such a transition as our measure of the extent of experimentation. In our benchmark case in each period a hunter will try farming with a probability equal to 12.5 % and for group of 20 individuals per generation the expected waiting time for the transition mentioned above is 19292 generations (the expected waiting time is the reciprocal of the probability that in a given period 10 or more previously forager group members will switch to farming by random experimentation, calculated from the binomial distribution.)

11. Contested private property within groups

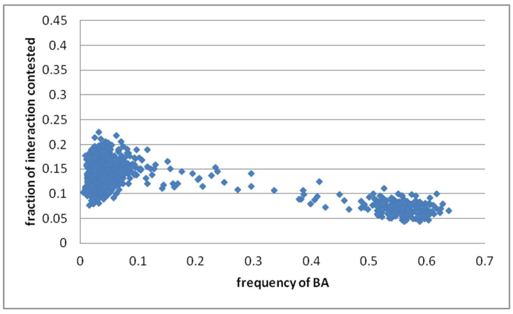
Within-group contests over economic resources occur frequently both because punishers always contest bourgeois attempts to exclude others from the use of resources and bourgeois contest other bourgeois' claims on resources when those resources are contestable (which is always the case with foraged resources). Fig. S11 shows that the degree of contestation is modest when bourgeois farmers are either very few or very many; intermediate fractions of bourgeois farmers which occur during transitions from forager to farmer societies generate substantial levels of property rights conflict within groups, because (as explained in the text) during these transitions there is no widely held convention for the management of conflict and the nature of the economic resources – including a substantial fraction of wild species – makes private property claims contestable.



(a) all interactions



(b) interactions between bourgeois individuals



(c) interactions between bourgeois and civic individuals

Fig. S11. Fraction of all interactions that are result in contests. Contests occur between bourgeois and punisher individuals, and between bourgeois individuals when property rights are contestable. Each point gives average across the 30 groups of the contested fraction of interactions for the population average of the fraction of bourgeois farmers in the population. The data are from benchmark implementations of the simulation in which cultivated resources and domesticated animals possessed by a bourgeois farmer are not contested by other bourgeois individuals. Contestation levels are greater but simulation results are qualitatively similar in simulations in which contestation of farmed resources by bourgeois individuals occurs (See Fig. S10 panel C).

12. The Holocene transition in the Levant

Table S5 adapted from (48) presents the data referred to in the text. The evidence for harvesting and processing wild cereals by the early Natufians is very strong and for cultivation proper not as strong. Bar Yosef for example refers to Natufians as “perhaps the earliest farmers”

(49), while Unger-Hamilton concludes that "the evidence favors the notion that cereals were being cultivated in the Early Natufian" Additional evidence is found in (50-53).

Table S5. The advent of farming and the changing nature of storage: Levant , 14,500 BP to 8,700 BP. Source: From (48) and other sources (54-56) Slightly different dating of the Natufian periods is used in (54)

Periods	*Economy*	*Storage*	*Interpretation*
Early & Late Natufian ca. 14500-11700 BP	Intensive collection and some cultivation of wild plant resources; intensive hunting of wild species (esp. gazelle, possibly communally); no evidence of husbandry	Indirect evidence for some very limited storage.	Relatively unrestricted access
Pre-Pottery Neolithic A ca. 11,700-10,500 BP	Collection and some cultivation of wild plant resources; possible domestication of some plants; intensive hunting of wild species; no evidence of husbandry	Dedicated storage silos (wild plants) outside in public (and possibly inside) of residential units	Relatively unrestricted access.
Middle Pre-Pottery Neolithic B ca. 10,500 – 9,250 BP	Collecting and cultivating wild plant resources; in some places wide range of domesticates; hunting, domestication of goat-sheep	Dedicated storage outside and inside residential units; moderate volume	Restricted access
Late Pre-Pottery Neolithic B & PPNC ca. 9,250 – 8,700 BP	Reliance on a restricted range of domesticated plants; hunting, increased reliance on goats, sheep, pigs cows.	Dedicated separate rooms; high volume	Restricted access

13 Demographic advantages of farming and the Neolithic Demographic Transition (NDT)

Based on fraction of immature individuals in cemeteries dating from the early Holocene, the reproductive advantages of sedentary living may have raised the rate of population increase from barely above zero to about 1.3% per annum at its peak (57) followed by declines and subsequent fluctuation, with "a slower tempo of change in the epicenters [of the advent of farming] than in the secondary transition zones."(54). The NDT most likely witnessed an increase in fertility and that "mortality rose almost in concert with fertility and not after a long delay."(58) The peak rate was not sustained over the long period and it seems likely that farmers' populations grew at the rate typical of pre-industrial populations or somewhere between 0.1 and 0.2 percent annually. While capable of growing at well over 2 per cent per annum, forager population (averaged over long periods) during the Pleistocene may have been stationary it appears to have been positive growth rates appear to have been the case during the Holocene. Thus the NDT might have given the communities that took up farming and its associated property rights at most an advantage of about one percentage point (at its peak). The increase in the rate of population growth from "forager" to "farmer" levels appears to have been extraordinarily protracted. But suppose that the change in growth rates from about 0.3 to 1.3 took place exponentially over just a millennium (54). Then it would take 382 years before the "farmer" population exceeded 1.2 of the forager population, had they had similar populations at the outset.

Works cited

1. Bowles S (2011) The cultivation of cereals by the first farmers was not more productive than foraging. *Proc. Natl. Acad. Sci. USA* 108(12):4760-4765.
2. Johnsen SJ, Dansgaard W, & White JWC (1992) The origin of Arctic precipitation under present and glacial conditions. *Tellus B41*: 452-468.
3. Mann M, Bradley M, & Hughes M (1998) Global-scale temperature patterns and climate forcing over the past six centuries. *Nature* 391(April):779-787.
4. McManus J, Oppo D, & Cullen J (1999) A 0.5 million-year record of millennial-scale climate variabilty in the North Atlantic. *Science* 283:971-975.
5. Hendy I & Kennett J (2000) Dansgaard-Oeschger cycles and the California Current System. *Paleoceanography* 15(1):30-42.
6. Bowles S & Choi J-K (2012) *The Origin of Private Property* (Santa Fe Institute)).
7. Boehm C (2012) *Moral origins: Social selection and the evolution of virtue, altruism, and shame* (Basic Books, New York) p 424.
8. Soffer O (1985) Subsistence Practices and Durationof Occupation in the Late Valdai. *The Upper Paleolithic of the Central Russian Plain*, (Academic Press, London, UK), pp 249-353.
9. Stoffer O (1989) Storage, sedentism and the Eurasian Palaeolithic record. *Antiquity* 63:719-732.
10. Waguespack N (2002) Caribou sharing and storage: refitting the Palangana site. *Anthropological Archaeology* 21:396-417.
11. Peterson N & Taylor J (1998) Demographic transition in a hunter-gatherer population: the Tiwi case, 1929-1996. *Australian Aboriginal Studies* 1998(1):11-27.
12. Hart C & Pilling A (1960) *The Tiwi of North Australia* (Holt Reinhart and Winston, New York).
13. Schulting R (1995) *Mortuary Variability and Status Differentiation on the Columbia-Fraser Platteau`* (Archaeology Press, Simon Fraser University, Burnaby).
14. Bekar C & Reed C (2011) Land markets and inequality: Evidence from medieval England. in *Simon Fraser University*.
15. Woodburn J (1982) Egalitarian Societies. *Man* 17:431-451.
16. Knauft BM (1991) Violence and Sociality in Human Evolution. *Current Anthropology* 32(4):391-428.
17. Binford L (2001) *Constructing Frames of Reference: An Analytical Method for Archeological Theory Using Hunter-Gatherer and Environmental Data Sets* (University of California Press, Berkeley).
18. Kaplan H, Hill K, Lancaster J, & Hurtado AM (2000) A theory of human life history evolution: diet, intelligence, and longevity. *Evolutionary Anthropology* 9(4):156-184.
19. Winterhalder B (1990) Open field, common pot: Harvest variability and risk avoidance in agricultural and foraging societies. *Risk and uncertainty in tribal and peasant societies*, ed Cashdan EA (Westview, Boulder), pp 67-89.
20. Kelly RL (1995) *The foraging spectrum : diversity in hunter-gatherer lifeways* (Smithsonian Institution Press, Washington) pp xvi, 446.
21. Dyson-Hudson R & Smith EA (1978) Human territoriality: An ecological assessment. *American Anthropologist* 80:21-41.
22. Dowling J (1968) Individual ownership and the sharing of game in hunting socieites. *American Anthropologist* 70:502-507.

23. Wiessner P (1982) Leveling the hunter: constraints on the status quest in foraging societies. *Food and the Status Quest: An Interdisciplinary Perspective*, eds Wiessner P & Schiefenhovel W (Berghahn, Oxford), pp 171-191.
24. Bahuchet S (1990) Food sharing among the Pygmies of Central Africa. *African Study Monographs* 11:27-53.
25. Hawkes K, O'Connell JF, & Blurton-Jones NG (2001) Hadza meat sharing. *Evolution and Human Behavior* 22:113-142.
26. Cashdan EA (1980) Egalitarianism Among Hunters and Gatherers. *American Anthropologist* 82(1):116-120.
27. Wiessner P (1982) Risk, Reciprocity and Social Influences on !Kung San Economics. *Politics and History in Band Societies*, eds Leacock E & Lee R (Cambridge University Press, Cambridge), pp 61-84.
28. Gurven M, Allen-Arave W, Hill K, & Hurtado AM (2001) Reservation food sharing among the Ache of Paraguay. *Human Nature* 12:273-297.
29. Gurven M, Hill K, & Kaplan H (2002) From forest to reservation: Transitions in food sharing among the Ache of Paraguay. *Journal of Anthropological Research* 58:93-120.
30. Hill K & Kaplan H (1989) Population and dry season subsistence strategies of the recently contacted Yora of Peru. *National Geographic Research Report* 5(317-334).
31. Bahuchet S (1991) Les Pygmees d'aujourd'hui en Afrique centrale. *Journal des Africanistes* 61:5-35.
32. Gurven M, Hill K, Kaplan H, Hurtado AM, & Lyles R (2000) Food transfers among Hiwi foragers of Venezuela: Tests of reciprocity. *Human Ecology* 28(2):171-218.
33. Hames R (2000) Reciprocal altrusim in Yanomamo food exchange. *Adaptation and human behavior: An anthropological perspective*, eds Cronk L, Chagnon N, & Irons W (Aldine Gruyter).
34. Hames R & McCabe C (2007) Meal sharing among the Ye'kwana. *Human Nature* 18:1-21.
35. Borgerhoff Mulder M, Bowles S, Hertz T, & others (2009) Intergenerational Transmission of Wealth and the Dynamics of Inequality in Small-scale Societies. *Science* 326:682-688.
36. Kaplan H & Hill K (1985) Food Sharing among Ache Foragers: Tests of Explanatory Hypotheses. *Current Anthropology* 26(2):223-246.
37. Pearson MP (2000) *The Archaeology of Death and Burial* (Texas A&M University Press, College Station, TX).
38. Hayden B (1997) *The Pithouses of Keatley Creek* (Harcourt Brace College Publishers, New York) p 140.
39. Wilson M, Hauser MD, & Wrangham RW (2001) Does participation in intergroup conflict depend on numerical assessment, range location, or rank for wild chimpanzees. *Animal Behavior* 61:1203-1216.
40. Bowles S & Gintis H (2011) *A cooperative species: human reciprocity and its evolution* (Princeton University Press, Princeton) p 254.
41. Gamez SM, Wilkins J, & Bowles S (2012) Cosmopolitan ancestors: Genetic evidence that prehistoric populations were not small and isolated. in *Santa Fe Institute*.
42. Richerson P, Boyd R, & Bettinger RL (2001) Was Agriculture Impossible During the Pleistocene but Mandatory During the Holocene? A Climate Change Hypothesis. *American Antiquity* 66(3):387-411.
43. Beerling DJ (1999) New estimates of carbon transfer to terrestrial ecosystems between the last glacial maximum and the Holocene. *Terra Nova* 11(4):162-167.

44. Rychkov YG & Sheremet'eva VA (1980) The genetics of circumpolar populations of Eurasia related to the problem of human adaptation. *The human biology of circumpolar populations*, ed Milan F (Cambridge U Press, New York).
45. Harpending HC & Jenkins T (1974)!Kung population structure. *Genetic Distance*, eds Crow JF & Denniston C (Plenum, New York).
46. Rogers A & Jorde LB (1987) The effect of non-random migration on genetic differences between populations. *Annals of Human Genetics* 51:169-176.
47. Bowles S (2009) Did Warfare among Ancestral Hunter-Gatherer Groups Affect the Evolution of Human Social Behaviors. *Science* 324:1293-1298.
48. Kuijt I (2011) Home is where we keep our food: The origins of agriculture and late pre-pottery Neolithic food storage. *Paleorient* 37(1):137-152.
49. Bar-Yosef O (1998) The Natufian Culture in the Levant, Threshold to the Origins of Agriculture. *Evolutionary Anthropology* 5(5):159-177.
50. Bellwood P (2005) *First Farmers: The Origins of Agricultural Societies* (Blackwell, Oxford) p 384.
51. Barker G (2006) *The agricultural revolution in prehistory: why did foragers become farmers?* (Oxford University Press, Oxford) p 616.
52. P.C.Anderson (1991) Harvesting wild grains during the Natufian as seen from experimental cultivation and harvest of wild einkorn wheat and microwear analysis of stone tools. *The Natufian Culture in the Levant*, eds Bar-Yosef O & Valla FR (International Monographs in Prehistory, Ann Arbor), pp 521-556.
53. R.Unger-Hamilton (1991) Natufian plant husbandry in the southern Levant and comparison with that of the Neolithic periods: the lithic perspective. *The Natufian Culture in the Levant*, eds Bar-Yosef O & Valla FR (International Monographs in Prehistory, Ann Arbor), pp 483-520.
54. Guerrero E, Naji S, & Bocquet-Appel J-P (2008) The signal of the neolithic demographic transition in the Levant. *The Neolithic Demographic Transition and its Consequences*, eds Bocquet-Appel J-P & Bar-Yosef O (Springer), pp 57-80.
55. Kuijt I & Finlayson B (2009) Evidence for Food Storage and Predomestication Granaries 11,000 Years Ago in the Jordan Valley. *PNAS* 106(27):10966-10970.
56. Wilcox G & Storedeur D (2012) Large scale cereal processing before domestication during the tenth millennium cal BC in northern Syria. *Antiquity* 86:99-114.
57. Bocquet-Appel J-P (2008) The Neolithic Demographic Transition, population pressure, and cultural change. *Comparative Civilizations Review* 58:36-49.
58. Bocquet-Appel J-P (2009) The Demographic Impact of the Agricultural System in Human History. *Current Anthropology* 50(5):657-660.