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Cereals, Appropriability and Hierarchy*

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Abstract

We propose that the development of social hierarchy following the Neolithic Revolution was due to the ability of the emergent elite to appropriate crops from farmers, rather than a result of increased productivity, as usually maintained. Since cereals are easier to appropriate than roots and tubers, we argue that regional variations in the suitability of land for the cultivation of these different crop types can account for differences in the formation of hierarchies and states. Our empirical investigation supports a causal effect of the cultivation of cereals on hierarchy, and the lack of a similar effect of land productivity.

KEYWORDS: *Geography, Hierarchy, Institutions, State Capacity*

JEL CLASSIFICATION NUMBERS: *D02, D82, H10, O43*

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1 Introduction

The transition to agriculture (also known as the Neolithic Revolution) led to profound social changes. Hierarchies and city-states emerged, leading to the development of the great civilizations of antiquity. In Egypt, for example, state hierarchy grew rapidly following the adoption of farming in the Nile Valley. The construction of the great pyramids in the third millennium BCE, illustrates the resulting high state capacity. Other regions of the world, however, followed a very different path: no state institutions emerged in New Guinea, even though agriculture was adopted there at about the same time as in Egypt.[1]

We offer an explanation for this disparity. We posit that the key factor for the emergence of hierarchy was the ability of the elite to appropriate food crops from farmers. Thus, regional variations in the suitability of land for roots and tubers, which are less appropriable, or cereals, which are more appropriable, can account for differences in the formation of hierarchy and related state institutions.

Our proposed mechanism pertains not only to antiquity, but also to agricultural-based societies in the pre-industrial era. Moreover, since the modern transition away from agriculture is protracted, and since social institutions exhibit significant inertia, our theory may contribute to the explanation for persistent differences in current institutions, and towards understanding the root-causes for the underdevelopment of tropical regions that suffer from malfunctioning governments.[2]

In the existing literature, it is generally argued that high farming productivity explains the emergence of hierarchy. High productivity generated a food surplus, which facilitated, through various channels, the emergence of a non-food producing elite. Diamond (1997), for example, attributes the relative backwardness of New Guinea to its low land productivity relative to Eurasia.

We propose that, rather than productivity and surplus, it is the ability to appropriate that explains the emergence of hierarchy.[3] Consider a farming community that cultivates cassava, with

[1]According to Denham (2011), systematic cultivation of bananas, taro and yam in New Guinea occurred ca. 5000-4500 BCE.

[2]Bockstette, Chanda and Putterman (2002), Gennaioli and Rainer (2007), Spolaore and Wacziarg (2013), and Michalopoulos and Papaioannou (2013, 2014) demonstrate that deep rooted pre-colonial institutions affect current institutions and economic outcomes.

[3]We note that the gradual increase in productivity among hunter-gatherers, due to improved hunting techniques and learning by doing, was apparently translated in its entirety to an increase in population density, without leading to surplus or to hierarchy. Since the Neolithic Revolution occurred over several millennia (see Purugganan and Fuller, 2010), along Malthusian lines one could expect that also this gradual increase in productivity could have been easily

annual output above subsistence. Cassava is a perennial root that can be harvested year-round and rots shortly after harvest. It is, therefore, practically impossible to transport cassava for consumption by a distant elite, its dependents or its military.[4] It is thus unlikely that a complex hierarchy could emerge, despite the availability of food surplus: surplus would simply lead to an increase in population.

Consider another farming community that grows a cereal grain with no surplus, where each family's annual produce equals its subsistence needs. Since the grain has to be harvested within a short period and then stored, a visiting tax collector could readily confiscate part of the stored produce. The durability of these cereal grains makes them well suited for transport for the use of a distant elite. Such ongoing confiscation is expected to adversely impact population size, and due to diminishing average product of labor, it will result in total output exceeding the farming population's subsistence needs. The resulting farming surplus is confiscated by the non-farming elite.

The first scenario highlights that had the Neolithic amounted to a transition to the cultivation of roots and tubers only, based on Malthusian considerations the increase in productivity would have been absorbed by increased population. The second scenario demonstrates that surplus isn't a necessary precondition for taxation. It was the elite itself, we argue, that created the food surplus on which it could survive, once the opportunity to confiscate arose.[5] Thus, according to our theory, it is the ability to appropriate that explains the emergence of both the elite and farming surplus. Surplus, in contrast to conventional theory, was not a precondition for hierarchy.

According to our "appropriability" mechanism, the emergence of hierarchy is explained by the vulnerability of the cultivated crops to confiscation.[6] Due to increasing returns to scale in the

dissipated through increased population. Ashraf and Galor (2011) support the applicability of Malthus's theory by demonstrating that technological improvements before the Industrial Revolution had a positive effect on population size but no effect on long run per capita income.

[4] In Appendix A we document these characteristics of cassava and of other roots and tubers. Portability of these crops is hampered also by their bulkiness (due to ca. 70% moisture content) and their vulnerability to spoilage. We support there also our various claims: (i) that reliance on roots and tubers is a major phenomenon in tropical regions; (ii) that roots and tubers are highly productive in the tropics; (iii) that their harvest is in general non-seasonal; and (iv) that after harvest they are significantly more perishable than cereals.

[5] In reality, as in our model below, stored grains are vulnerable to predation not only by tax collectors but also by bandits. If the government employs some of the tax revenue to protect farmers from bandits, it may in fact facilitate a larger population than under banditry (see the model in Appendix C, where we allow for endogenous population).

[6] In addition to their vulnerability to appropriation due to the need of storing grains, cereal producers are vulnerable also to extortion since the long gestation in the field exposes farmers to the threat of arson, and to the possibility

provision of protection, early farmers had to cooperate in order to defend their grains. Once the group size exceeded a few dozen immediate kin, it is unlikely that those who sought security were as forthcoming in financing the protection services they desired. This public-good nature of protection was overcome by the opportunity that stored cereals provided for the elite to appropriate the necessary means. In other words, we propose that the transition to cultivating cereals, created both a demand for protection and the means for providing it. Thus, once the opportunity to expropriate arose, it led to the emergence of complex and hereditary social hierarchy, and eventually the state.

The simplest evidence in support of our theory is that all agriculture-based states, with complex hierarchy, that we know of in human history relied on cereals. The non-emergence of complex hierarchy among hunter-gatherers and among farming societies that did not rely on cereals, we argue, was not because they lived at subsistence, but rather because their staple food was not easily expropriated to feed a would-be elite. That is, we suggest that the fundamental cause for New Guinea's low level of social complexity and for its economic underdevelopment is that farming there relied mostly on tubers (yam and taro, and, since the 17th century, sweet potatoes), for which long-term storage is neither feasible (due to perishability) nor necessary (due to non-seasonality). Farmers' ability to cultivate highly productive crops, that are practically non-appropriable, inhibits both the demand for socially-provided protection and the emergence of protection-providing elite. It is a curse of plenty.

In our formal model a fixed number of farmers can allocate their land between two crops, which we label cereals and tubers.[7] The productivity of the two crops is presumed to differ across geographic locations. We assume that it is possible to tax cereals, though at some cost. For simplicity, we assume that it is impossible to confiscate or tax tubers. As a result, cereals are cultivated only if their productivity advantage over tubers is sufficiently high to compensate for taxation by the state or the risk of loss to bandits.

that violence could be used to deny access to land or water.

[7] For the sake of simplicity, we do not consider the decision to farm or to forage, nor do we allow for endogenous population size. For brevity, we often refer to tubers only, even when implying also roots. What we are really after is a distinction among crops according to their degree of appropriability. We are aware that potatoes for example, have been freeze dried in ancient Peru, and are altogether somewhat storable and not a tropical crop. We also ignore other important food plants such as fruits, vegetables and legumes, and also the role of livestock. To the extent that these are not easily appropriable, we would lump them with tubers.

In the 'anarchy' regime, we assume that non-farmers can be bandits or foragers. Since we assume that bandits are unorganized and cannot credibly commit, their number is determined endogenously, such that the average revenue from theft is equal to the alternative productivity in foraging. The probability that cereals would be stolen is a function of the number of bandits. In the alternative 'hierarchy' regime, crops are protected from bandits, but a portion is taxed by the revenue maximizing elite. We assume that the hierarchical elite can commit to any feasible rate of taxation. To maximize the net tax revenue, the state employs tax collectors such that the marginal tax revenue is no less than their wage, which equals the alternative income from foraging. The state will therefore employ (weakly) less tax collectors than the equilibrium number of bandits under anarchy. Finally, we assume that to be viable and deter bandits, the state incurs some fixed costs.

The main prediction of the model is that a state cannot exist if tubers are sufficiently productive. The potential tax revenue is insufficient, in this case, to cover the fixed cost of forming a government. This result illustrates our claim that it is the relatively high productivity of more appropriable cereals, rather than high agricultural productivity per se, that facilitates the development of hierarchy. The model also suggests that, even though the elite is self-serving, whenever hierarchy exists, it dominates anarchy in welfare terms. As a result, cereal based farming, which renders farmers vulnerable to taxation, leads not only to the development of a state, but contributes also to farmers' welfare. Anarchy is more distortionary than hierarchy for two reasons: First, the state's ability to commit to a lower tax rate that encourages the cultivation of cereals when these are more productive; Second, since the state employs fewer tax collectors than the equilibrium number of bandits under anarchy, the forgone output loss in foraging (due to banditry or to tax collection) is higher under anarchy.[8]

In our empirical investigation we find a positive effect of cereal farming on hierarchy, and no such effect for land productivity. These result are obtained from two alternative datasets with information on social hierarchy: a cross section of societies and a panel of countries. In both cases we use the productivity advantage of cereals over roots and tubers as an instrument for cereal farming. For our cross section analysis we use Murdock's (1967) Ethnographic Atlas on cultural, institutional

[8] We ignore the possibility that the non-benevolent state may contribute further to farmers' welfare, if it contributes directly to agricultural productivity, for example through publicly provided irrigation or the importation of better farming techniques.

and economic features of 1,267 earlier societies from around the world. For our panel data we use the dataset compiled by Borcan, Olsson and Putterman (2014), which is based on present-day boundaries of 159 countries, over the last millennium. We exploit the 'Columbian exchange' as a natural experiment for changes in land productivity and in the productivity advantage of cereals over roots and tubers.

In the next section we review the most pertinent literature. Our model is presented in section 3, and our main empirical results are presented in section 4, where multiple robustness checks are reported in Appendix E. Section 5 concludes.

2 Archeological Evidence and Related Literature

In this section we examine relevant archaeological evidence on the earliest transition to agriculture, and survey related literature that distinguishes between crop types or considers aspect of appropriability. Additional theories that correlate between the Neolithic revolution and hierarchy are reviewed in Appendix B.[9]

Archaeological evidence in the form of dwellings, sickles, grinding stones and storage facilities confirm the idea that the transition to cereal farming was correlated with communal storage and with the emergence of hierarchy. The earliest phase of the transition to agriculture in the Near East is known as the (late) Natufian Age (ca. 12,500-9,500 BCE). Foragers at that time adopted semi-sedentary living and relied in part on collecting wild cereals. However, they did not yet cultivate cereals, which would have required storage.[10] Cereal cultivation by farmer-foragers took place in the next developmental phase, known as Pre-Pottery Neolithic A (PPNA, ca. 9500-8500 BCE). Kuijt and Finlayson (2009) report an important archeological discovery from about 9000 BCE, of a large and elaborate communal storage pit in the Jordan Valley. This reveals that storage was an integral part of the earliest phase of the transition to cereal farming, when wild

[9] Thus, even though we incorporate predation by non-farmers, we refer to the literature on conflict between early farmers and non-farmers in Appendix B – see recently Boix (2015), Dal Bó, Hernández and Mazzuca (2015) and Dow and Reed (2013).

[10] Kuijt (2008) and Price and Bar-Yosef (2010) point out the limited archeological evidence for storage facilities from the Natufian age. Goring-Morris and Belfer-Cohen (2011, p. S200) note that there is no evidence that the Natufians engaged in intentional plant cultivation. The Natufians apparently did not attempt to store grain over the winter, which would have necessitated more permanent, covered and plastered storage facilities to protect the stored grain from spoilage by moisture, insects or rodents.

grains were collected on a large scale and then sown, still without attempts at domestication. This evidence also indicates social cooperation and organization, which we interpret as evidence that hierarchy, developed alongside the gradual intensification of cereal farming and its concomitant storage, rather than that hierarchy followed the transition to agriculture (including domestication) and the presumed availability of surplus.[11]

Our proposed appropriability theory was anticipated to a substantial extent by Taylor (1973) and Testart (1982a, 1982b, 1982c). In a brief and neglected contribution, Taylor contended that the Neolithic revolution ought to be called the "storage revolution." He argued that the cultivation of grains enabled storage, and introduced a threat of theft. He deduced that this pressure forced the incipient agriculturist, as well as hunter-gatherers who practiced storage, into sedentism and to "social control that would assure the horde to its rightful owner," and thus contributed to "the very foundation of civilization."

Testart summarizes extensive anthropological evidence from hunter-gathering societies about a positive association between social inequality and the prevalence of storage of seasonal food sources. His main focus was on early Native Americans in the Pacific Coast of California who relied on seasonal acorns and dried salmon. Testart argued that these societies exhibited inegalitarian, complex social structures similar to those of early cereal farming societies, and attributed the similarity to their reliance on sedentism and storage. Testart briefly dealt also with agricultural societies and clearly distinguished among them between those based on cereals and those based on tubers (1982a, pp. 195-204), suggesting that farming societies that rely on tubers and do not store remain more egalitarian. But his (1982c) unsatisfactory attempt to support this idea empirically, using data from the Ethnographic Atlas (see Section 4) led him to conclude by giving priority to sedentism as the more robust correlate of social inequality, rather than to storage. Our current study complements these seminal contributions. Unlike Testart, our subject matter is hierarchy, rather than inequality. In addition, whereas Testart vacillated with regard to the causal mechanism that relates storage to inequality, we argue for a specific mechanism by which food storage creates vulnerability to expropriation, leading to a demand for protection, and simultaneously facilitating

[11] Somewhat similar large round pits from PPNA were found elsewhere in the Jordan valley and in several sites next to the Euphrates (Mithen et al. 2011; Willcox and Strodeur 2012). These pits are identified as communal structures, serving both for storage and as communal meeting places, possibly for ritual ceremonies.

its supply by the emergent elite.[12]

Tushingham and Bettinger (2013) follow up in seeking to explain why early aboriginal Californians preferred to store acorns, rather than salmon, despite salmon's significant nutritional advantage. They resolve this puzzle by applying Bettinger's (1999) distinction between back-loaded and front-loaded food resources, according to which, acorns are back-loaded since their procurement and storage involves little effort, while their preparation for consumption is very costly, while salmon is front loaded since an opposite cost pattern holds.[13] Tushingham and Bettinger argue that back-loaded resources offered earlier foragers the advantage of a lower probability of loss of caches due to pillage. They identify the key detriment to reliance on stored salmon as: "the possibility that others will rob caches, which mobile foragers are not positioned to protect" (p. 533). In addition to the increased vulnerability of front-loaded sources to theft, they are subject also to loss to "freeloaders" from the inside (p. 534). The authors suggest that the late and rather abrupt transition to salmon intensification among aboriginal Californians occurred once a community reached a threshold size that facilitated on-going protection of the stored dried salmon. That transition coincided with the emergence of permanent villages and with the appearance of plank houses that also functioned as storage facilities.[14] Tushingham and Bettinger do not mention hierarchy or agriculture, but the evidence that they examine and their analysis are perfectly consistent with our appropriability theory and with our proposed mechanism by which vulnerability to appropriation leads to social hierarchy in cereal-dependent farming societies.[15]

Anthropologists who seek to explain the emergence of hierarchy as related to the increased

[12] Testart too mentioned vulnerability to theft: "stored food is the primary object of raids, and it may be stolen, monopolized by men of high status, or made the subject of rent or tribute" (1982b, p. 527; 1982c, p. 351). But in reference to Taylor, he explicitly denied the need to protect stockpiles against theft, arguing that social norms of reciprocity among foragers preclude theft (1982a, p. 31). In fact, in addition to storage and sedentism, he refers also to all the "usual suspects" in the anthropological literature for explaining the emergence of inequality including: high population density, trading activity, prestige, and altered ideology.

[13] Woodburn (1980) offered a somewhat related distinction between delayed return and immediate return food procuring strategies.

[14] A vivid eye-witness depiction of these villages is available in Cook's account of his voyages in the eastern shores of the Pacific Ocean (1784, volume II, book IV).

[15] Chiwona-Karltun et al. (2002) provide an anecdotal illustration of the appropriability theory in a farming setting. They report that women in modern Malawi, and particularly single women, prefer to grow bitter and toxic cassava variants even though these variants require significantly more post-harvesting processing. This pattern is explained as due mostly to the advantages of this extra post-harvest drudgery, which protects these women against thievery, since thieves prefer the non-bitter variant. A Malawian women is quoted: "We grow bitter, toxic cassava because it gives a certain level of food security. If we are to grow sweet cassava, look at our neighbors! Their whole field was harvested by thieves while they slept and now they have no food. Nobody wants to die from hunger."

productivity of farming often distinguish between horticulture and agriculture. The former is typically identified with cultivation in small-scale 'gardens' with hand-held tools, and the latter is defined as employing intensive cultivation, often with the aid of irrigation, the plow, and animal power. Horticulture-based societies are claimed to be associated with low levels of social complexity, and to form a preliminary developmental stage to more productive agriculture which is associated with more complex, hierarchical societies (see Lenski, 1966; Johnson and Earle 2000). From our perspective, though, it isn't the employment of more intensive farming techniques that is the source of greater social complexity, but rather the greater appropriability of the cultivated crops. We note also that horticulture typically involves the cultivation of less appropriable crops, and occurs in the tropics or semi-tropics, and that as such its adoption should be considered as a long-term equilibrium, rather than as a stage in the transition to agriculture, which is almost invariably associated with the cultivation of appropriable cereals.

In a related theory, Scott (2009) explains why states emerged in South East Asia only in the river valleys and not in the highlands by claiming that the tribal hill people were able to resist subjugation by states through adopting foraging and shifting agriculture (another common trait associated with horticulture). According to Scott, states emerged in the lowlands because the option of relying on similar modes of food procurement was not open there, and the cultivation of appropriable rice was the norm.[16]

Using a somewhat analogous distinction to that between horticulture and agriculture (and an empirical approach similar to the one we follow), Alesina, Giuliano and Nunn (2013) distinguish between regions where farmers used handheld tools like the hoe and the digging stick and regions where cereal farmers prepare the soil by employing the plow. They argue that plow-using generated greater gender inequality, and show that it impacted current perceptions of gender roles.

In another related study, Nunn and Qian (2011) show that the adoption of the potato in Europe led to population growth and substantial social changes. They argue that these changes were due to the higher caloric yield of the potato in regions that are highly suitable for its cultivation. Our

[16] Alongside the similarities, there are many differences between Scott's approach and ours. His key distinctions relate to geographic elevation: between hill and valley people, and to the form of cultivation: sedentary vs. shifting, rather than to the choice of the cultivated crop. While his theory may be applied to regions other than South East Asia, it fails totally in the case of South America, where the Incas had a powerful state in the mountains, while no major states emerged in the Amazon valleys.

perspective leads us to offer a complementary mechanism whereby European farmers adopted the potato because it provided them with greater immunity against taxation/theft, and this resulted in growth of the farming population. Consistently with this mechanism, Mcneill (1999, pp 71-72) reports that European farmers long resisted adopting the potato after it reached Europe in the mid-sixteenth century. He reports also that during the Dutch Wars in 1557-1609, "villagers along the route [of the Spanish army] swiftly discovered that by leaving the tubers in the ground and digging them only as needed for their own consumption, they could safely survive even the most ruthless military requisitioning. Foraging parties were unwilling to dig for their food when stores of grain were available in barns."

Similarly, Wiessner and Tumu (1998) report how the sweet potato rapidly became the staple crop in the rugged highlands of New Guinea after it was introduced some 300 years ago, following the Columbian Exchange. Its adoption increased land productivity and generated surplus; but this surplus was transformed into prestige goods (like slaughter of pigs in communal festivals) and substantial population growth, leaving the highland population fractured, characterized by endemic tribal warfare, without any consolidation of power or significant increase in social complexity.

In a related study to the present one, Mayshar, Moav and Neeman (2013) distinguish between areas where farming is more transparent and areas of lower transparency. They associate such transparency to appropriability and claim that the capacity of earlier states to tax depended on the transparency of farming, thus offering an alternative link between geographic attributes and the viability of statehood.[17]

Finally, given our focus on the distinction between tropical and temperate crops, we note that ever since Montesquieu (1748, book 14) asserted that the tropics were backward because people in hot climates tend to be timid and lazy, many scholars (including Diamond, 1997) sought to explain what lies behind the relative underdevelopment of tropical countries.[18]

[17] In another application of the appropriability approach, de la Sierra (2013) employs evidence from the mining regions of the Democratic Republic of Congo to show that a rise in the price of the substance coltan that is produced from bulky and transparent ores led to the monopolization of power and the cessation of conflict between rival armed groups in the coltan rich regions; whereas an increase in the price of gold, which is easier to conceal and is hence less transparent, did not. Similarly, Buonanno et al. (2015) show the effect of a rise in the price of sulphur on the emergence of the Sicilian Mafia.

[18] Sachs, Mellinger and Gallup, (2001), Olsson and Hibbs (2005) and Spolaore and Wacziarg (2013) provide empirical attempts to links income per capita across countries with geographic variables. Nowadays, two main features of the tropics are typically argued to have impeded its development: low agricultural productivity and a high burden of disease. Weil (2007, 2010) finds that the effect of health on growth is rather small and cannot explain the extent of

3 A Model of Cereals and Hierarchy

The basic premise of the model is that regions of the world differ in their productivity of tubers relative to that of cereals. The key difference between the two crops is that tubers, unlike cereals, cannot be expropriated by bandits or by tax collectors. We model farmers' choice of what crop to grow in two different regimes: anarchy and hierarchy, and derive conclusions regarding the circumstances under which hierarchy can emerge.

The economy is populated by a measure one of farmers and a measure N of non-farmers. Our main exogenous variable, $\delta > 0$, measures the productivity advantage of cereals over tubers, or the productivity disadvantage of tubers.[19] The productivity of cereals is normalized to unity: farmers can grow one unit of cereals, or $1 - \delta$ units of tubers, or any linear combination thereof. Hence, a farmer's output is $\beta + (1 - \beta)(1 - \delta) = (1 - \delta) + \beta\delta$, where $\beta \in [0, 1]$ is the fraction of land allocated to cereals and $1 - \beta$ is the fraction allocated to tubers. Output is measured in nutritional units and tubers and cereals are assumed to be perfect substitutes.

The income of non-farmers who engage in foraging is assumed to be constant and denoted: $s > 0$. In a state of anarchy, non-farmers can chose to be bandits who expropriate crops from farmers. In a state of hierarchy, we assume that some non-farmers are hired by the state to serve as tax collectors, and are paid the wage s. We denote by λ the measure of bandits or tax collectors. N is assumed to be larger than the equilibrium level of λ.

3.1 Anarchy

Under anarchy, farmers face a risk of a raid by bandits. A raided farmer loses his cereal crop, but none of his crop of tubers. Farmers are assumed here to be risk neutral.[20] A farmer is facing a raid with probability τ and chooses the fraction of land allocated to cereal, β, to maximize his expected income I:

$$I = (1 - \tau)\beta + (1 - \delta)(1 - \beta) = (1 - \delta) + \beta(\delta - \tau). \tag{1}$$

the gap between tropical and non-tropical countries.

[19] If $\delta \leq 0$ the analysis is trivial: tubers dominate cereals in providing both protection and higher productivity, so that farmers would only grow tubers in equilibrium, and the economy could only be in a state of anarchy.

[20] In Appendix D we show that our results are robust to the introduction of risk aversion.

In selecting β, farmers weigh the productivity advantages δ of cereals over tubers, against the disadvantage, as measured by the expropriation rate τ.

The rate of expropriation, τ, is a function of the measure of bandits λ, $\tau = \tau(\lambda)$. We assume that the function $\tau(\lambda)$ is strictly increasing and strictly concave, and satisfies: $\tau(0) = 0$, $\lim_{\lambda \searrow 0} \tau'(\lambda) = \infty$, $\lim_{\lambda \nearrow \infty} \tau'(\lambda) = 0$ with $\lim_{\lambda \nearrow \infty} \tau(\lambda) = \overline{\tau} \leq 1$.[21] The inverse function of $\tau(\lambda)$, denoted by $\lambda(\tau)$, is therefore strictly increasing, strictly convex, with $\lambda(0) = 0$, $\lim_{\tau \searrow 0} \lambda'(\tau) = 0$ and $\lim_{\tau \nearrow \overline{\tau}} \lambda'(\tau) = \infty$.

Bandits are identical and uncoordinated (if they coordinate they become the ruling elite and the economy shifts to the "hierarchy" equilibrium as described in the following section). Thus a bandit's expected income π is given by the total amount of cereals confiscated from farmers divided by the measure of bandits: $\pi = \tau(\lambda)\beta/\lambda$.

Definition. *Equilibrium consists of a pair (β, τ) such that:*

1. *β maximizes farmers' income I, given the confiscation rate τ;*

2. *given β, non-farmers are indifferent between being foragers or bandits, so that $\pi = s$.*[22]

The last condition can be restated as requiring: $\tau\beta/\lambda(\tau) = s$.

Define a threshold rate δ_A by the implicit relationship:[23]

$$\frac{\delta_A}{\lambda(\delta_A)} = s.$$

δ_A provides the lower bound for the productivity advantage of cereals above which only cereals are grown.[24]

Proposition 1. *The economy under anarchy has a unique equilibrium (β_A, τ_A) that is given by:*

[21] Micro-foundation for the shape of $\tau(\lambda)$ can be obtained by assuming that banditry is time consuming, that bandits are not coordinated, and thus that as their number increases their marginal theft declines due to increased probability of raiding the same farmers.

[22] Our assumptions that $\lim_{\lambda \searrow 0} \tau'(\lambda) = \infty$ guarantee a solution with $\tau > 0$.

[23] We use the subscript A to denote parameters and equilibrium values in a regime of anarchy, and similarly use the subscript H in a state of hierarchy.

[24] Our assumptions on $\tau(\cdot)$ imply that that δ_A is well defined for every $s > 0$. δ_A captures the confiscation rate that will exist in equilibrium if the option to grow tubers is relevant. Thus, tubers are not grown if $\delta \geq \delta_A$.

$$
(\beta_A, \tau_A) = \begin{cases} \left(\frac{\lambda(\delta)s}{\delta}, \delta\right) & if \quad \delta < \delta_A \\ \\ (1, \delta_A) & if \quad \delta \geq \delta_A \end{cases} .
$$

Proof. If $\delta > 0$, an equilibrium with no cereals ($\beta_A = 0$) can be ruled out. This is since in that case $\pi = 0$, leading to $\lambda = 0$ and $\tau = 0$, which would lead to $\beta = 1$, a contradiction. This implies that the equilibrium can only be either mixed ($0 < \beta_A < 1$), where both crops are cultivated; or one with cereals only ($\beta_A = 1$).

If $\delta \geq \delta_A$, so that the productivity disadvantage of tubers is sufficiently high, farmers cultivate only cereals ($\beta_A = 1$), even though this entails a maximal confiscation rate $\tau_A = \delta_A$ and a corresponding maximal number of bandits, $\lambda(\delta_A)$.

In the alternative case $0 < \delta < \delta_A$, the productivity disadvantage of tubers is low. Our assumptions on $\tau(\cdot)$ imply that the confiscation rate, $\tau(\lambda)/\lambda$, or $\tau/\lambda(\tau)$, is monotonically decreasing in τ, from infinity towards zero. Thus, when $\delta < \delta_A$, we have: $\delta/\lambda(\delta) > \delta_A/\lambda(\delta_A) = s$. Hence, there exists a unique $\beta_A \in (0,1)$ such that $\pi_A \equiv \delta\beta_A/\lambda(\delta) = s$. The last condition, in conjunction with the condition $\tau_A = \delta$, defines the combination (β_A, τ_A) in the mixed equilibrium. ■

Income distribution. It follows from Proposition 1 that if cereals' productivity advantage is low ($\delta < \delta_A$) and the equilibrium is therefore mixed, the values of β_A, τ_A and $\lambda_A = \lambda(\tau_A)$ tend to zero when δ tends to zero, and are all strictly increasing in δ. As a result, also the total expected amount of cereals confiscated by bandits, $\tau_A\beta_A$, strictly increase in δ. As (1) reveals, farmers' income in that range is $1 - \delta$, thus decreasing in δ. On the other hand, when the productivity advantage of cereals exceeds the threshold δ_A, all theses variables become independent of the value of δ, with farmers income equaling $1 - \delta_A$. In these two ranges combined, the proposition thus implies that $\tau_A\beta_A$, τ_A and λ_A are all weakly increasing in δ. In turn, even though bandits' welfare is equal to s independently of the value of δ, farmers' welfare weakly decreases with δ.

The effect of the reservation income s. The smaller is s, the larger is the incentive for foragers to engage in banditry. This implies a higher threshold δ_A, meaning that farmers will raise tubers in a wider range of δ. Thus, for values of $\delta > \delta_A$, a lower s reduces farmers' income. However, for

$\delta < \delta_A$, a smaller s has no effect on farmers income, on τ and therefore on λ; it will rather reduce the equilibrium value of β.

Two sources of inefficiency. Denote by Y_0 the maximal possible level of output in the economy, when all farmers cultivate only the more productive cereals (assuming $\delta > 0$) and all non-farmers engage in foraging. This maximal output level is: $Y_0 = 1 + Ns$.

The equilibrium (β_A, τ_A) introduces two deviations from this maximal level of output: the first is due to the possibility that farmers may grow tubers (if their productivity disadvantage is sufficiently small: $\delta < \delta_A$); and the other is due to the forgone output by banditry. This means that equilibrium output is given by:

$$Y = Y_0 - (1 - \beta_A)\,\delta - s\lambda(\tau_A).$$

Inspection of the equilibrium values (β_A, τ_A) reveals that for large values of δ, the only distortion is the loss of output due to bandits being unproductive $s\lambda_A = s\lambda(\tau_A)$, which equals the threshold level δ_A. For small values of δ, the mixed equilibrium implies $\tau_A = \delta$, which makes farmers indifferent between the two crops. It follows from the fact that expected revenue per-bandit is equal to $\tau_A\beta_A/\lambda(\tau_A) = s$ that $s\lambda(\tau_A) = \tau_A\beta_A$, and thus it follows that:

Corollary 1. *The output loss* $(Y_0 - Y)$ *due to an anarchy regime is:*

$$(1 - \beta_A)\,\delta + \lambda_A s = \begin{cases} \delta & if \quad \delta < \delta_A \\ \\ \delta_A & if \quad \delta \geq \delta_A \end{cases}.$$

3.2 Hierarchy

We assume that in a state of hierarchy the elite (the state) chooses its tax policy to maximize its revenue net of the cost of tax collection. In order to facilitate comparison between the regimes of hierarchy and anarchy, we assume that the state has access to the same expropriation technology as bandits. Namely, the state cannot tax tubers, and if it employs a measure λ of tax collectors at cost s per tax collector, it can generate revenue of $\tau(\lambda)\beta$ from the farming sector. In adopting Weber's definition, we also assume that a state has to be able to deter bandits, and thus has to have monopoly power over the use of force. The use of force required to possess such a monopoly over the use of force entails fixed cost $G_0 > 0$.

A key advantage that a state has, in comparison to anarchy, is that it is farsighted and organized, and can thus commit not to expropriate farmers beyond a certain tax rate.[25] That is, the state selects the number of tax collectors to maximize its net revenue, taking into account farmers' response to the implied tax rate. Farmers' freedom to choose to avoid taxation completely by cultivating tubers, implies that the state cannot gain from setting a tax rate higher than δ. Thus, the objective of the state is to choose a tax rate τ, and thus to hire $\lambda(\tau)$ tax-collectors at cost $s\lambda(\tau)$, to maximize its net revenue, subject to the constraint that farmers respond optimally to the tax rate:

$$\max_{\tau \geq 0} R(\tau) = \tau\beta - s\lambda(\tau),$$

subject to

$$\beta = \arg\max_{\beta' \in [0,1]} \left\{ (1-\delta) + \beta'(\delta - \tau) \right\}.$$

Since it is evident that $\beta = 0$ if $\tau > \delta$ and $\beta = 1$ if $\tau < \delta$, we assume that $\beta = 1$ if $\tau \leq \delta$, and note that the state's problem is in fact to choose τ to maximize $\tau - s\lambda(\tau)$, subject to $\tau \leq \delta$. The optimal tax rate under hierarchy is thus: $\tau_H(\delta) = \min\{\delta, \delta_H\}$, where δ_H is the parameter that solves $s\lambda'(\delta_H) = 1$. At the high range of tubers' productivity, where, $\delta < \delta_H$, $\tau_H = \delta$ and $R(\tau_H(\delta)) = \delta - s\lambda(\delta)$, increases in δ. Our assumption that the state is viable only if it sustains an army at a fixed cost $G_0 > 0$ sets a lower limit on net revenue. Thus we assume that these fixed costs are low enough to satisfy: $R(\tau_H(\delta_H)) > G_0$. We also define then the viability threshold $\underline{\delta} < \delta_H$, such that: $R(\tau_H(\underline{\delta})) = G_0$.

We have thus established:

Proposition 2. (i) *If δ is small ($\delta < \underline{\delta}$), then a state cannot exist. (ii) If δ has an intermediate value ($\underline{\delta} \leq \delta < \delta_H$) then the optimal tax rate set by the state is given by $\tau_H = \delta$. (iii) If δ is large ($\delta \geq \delta_H$), then the optimal tax rate is equal to δ_H.*

[25] Another difference between bandits and the state is that bandits confiscate a farmer's entire cereal crop with probability τ, while an organized hierarchy taxes farmers at the rate τ with certainty. If farmers are risk neutral, as assumed here, this difference is unimportant. Below we show that our qualitative results hold also when farmers are risk averse.

Income distribution. Under hierarchy, farmers grow only cereals. Thus, their income is $1-\tau_H = 1-\min\{\delta,\delta_H\}$, which is weakly decreasing in the cereal productivity advantage over tubers δ. Total tax receipts equals τ_H, and the net tax revenue received by the elite, after paying the tax collectors and covering the cost of the army is: $\tau_H - s\lambda(\tau_H) - G_0$. Both the gross and net tax receipts strictly increase in δ up to the threshold δ_H, where they remain constant.

Output Loss. Analogously to the case of anarchy, we define the efficiency loss for hierarchy as the deviation of total output from the maximal potential:

$Y_0 - Y = (1-\beta_H)\,\delta + s\lambda(\tau_H) + G_0$ and since $\beta_H = 1$, $Y_0 - Y = s\lambda(\tau_H) + G_0$. Thus we obtain:

Corollary 2. The output loss $(Y_0 - Y)$ due to hierarchy is:

$$s\lambda(\tau_H) + G_0 = \begin{cases} s\lambda(\delta) + G_0 & if \quad \delta < \delta_H \\ \\ s\lambda(\delta_H) + G_0 & if \quad \delta \geq \delta_H \end{cases}.$$

.

3.3 Anarchy vs. Hierarchy

As explained in the previous section, a state can only exist if tubers are sufficiently unattractive to farmers, that is, if their productivity disadvantage δ is above the threshold $\underline{\delta}$. The comparison between the regimes of anarchy and hierarchy depends on the relationship between the thresholds δ_A, δ_H and $\underline{\delta}$.

Proposition 3. *If δ is small ($\delta < \underline{\delta}$), then only anarchy is possible, with a mixed equilibrium in which $\tau_A = \delta$ and where both cereals and tubers are grown. If δ is high enough for the state to be viable ($\delta \geq \underline{\delta}$), then a hierarchy weakly Pareto dominates anarchy.*

Proof. Because the function $\tau(\cdot)$ is strictly concave, the marginal productivity of tax collectors (or bandits) is lower than the average productivity: $\tau'(\lambda) < \tau(\lambda)/\lambda$ and $\tau'(\lambda(\tau)) < \tau/\lambda(\tau)$. Recall that, $\lambda(\delta_H)$ is defined by $\tau'(\lambda(\delta_H)) = s$ and $\lambda(\delta_A)$ is defined by $\delta_A/\lambda(\delta_A) = s$. It therefore follows from the concavity of $\tau(\cdot)$ that $\delta_H < \delta_A$ and $\lambda(\delta_H) < \lambda(\delta_A)$.

Non-farmers earn the same income s irrespective of the regime. Suppose that $\delta > \underline{\delta}$. On the other hand, the implied tax rate on farmers under anarchy is larger than or equal than the tax rate under hierarchy. In the range where $\underline{\delta} \leq \delta \leq \delta_H$, the tax rate under both anarchy and hierarchy is δ; in the range $\delta_H \leq \delta < \delta_A$ the tax rate under anarchy δ is higher than the tax rate under hierarchy δ_H and in the range $\delta_A \leq \delta$ the tax rate under anarchy is δ_A, whereas under hierarchy it is lower δ_H. Hence, farmers are weakly better off in all cases under hierarchy than under anarchy. Finally, when $\delta > \underline{\delta}$, a hierarchy generates an additional surplus to the elite, since by construction: $\tau - s\lambda(\tau) - G_0 > 0$. ■

Proposition 4. In the range where hierarchy is viable, the economy is more productive under hierarchy than under anarchy.

Proof. From corollaries 1 and 2 we obtain that the difference between total output under hierarchy to that under anarchy is equal to:

$$Y_H(\delta) - Y_A(\delta) = \begin{cases} \delta - s\lambda(\delta) - G_0 & if \quad \delta \in [\underline{\delta}, \delta_H] \\ \delta - s\lambda(\delta_H) - G_0 & \delta \in (\delta_H, \delta_A] \\ \delta_A - s\lambda(\delta_H) - G_0 & \delta > \delta_A \end{cases}.$$

By the definition of $\underline{\delta}$, $R(\underline{\delta}) = \underline{\delta} - s\lambda(\underline{\delta}) = G_0$ so that the output gap between the two regimes is zero when $\delta = \underline{\delta}$. When $\underline{\delta} \leq \delta \leq \delta_A$, the output gap equals the rent enjoyed by the elite, which is increasing in δ. ■

The total output under hierarchy is weakly higher for two reasons. (1) Under hierarchy (when $\underline{\delta} > \delta$), farmers cultivate only cereals. Thus they do not resort to self-protection through the cultivation of the less productive tubers, as they do (when $\delta < \delta_A$) under anarchy. (2) The state taxes less, since it sets the scale of tax collectors so that their marginal product is higher or equals their cost s, whereas under anarchy it is the average product of bandits that equal s. As a result, (weakly) fewer non-farmers are engaged in non-productive appropriation.

The main predictions of the analysis

1. Farmers may choose to grow tubers even when tubers are less productive as a measure of self-protection against appropriation by bandits or by tax collectors.

2. If tubers are sufficiently productive in comparison to cereals ($\delta < \underline{\delta}$), then a state cannot exist. This result illustrates our claim that it isn't low productivity that restrains the development

of hierarchy and related institutions, but rather high productivity of crops that are hard to expropriate. If, however, the reverse is true ($\delta > \underline{\delta}$) hierarchy could emerge and farmers would produce food surplus that would be taxed by the elite.

3. Whenever it exists, even a non-benevolent state that monopolizes coercive force dominates anarchy efficiency-wise (Propositions 3 and 4). This is a result of our assumption that the state can commit to a tax rate that maximizes its revenue net of collection costs, and that consequently farmers cultivate only the more efficient cereals.

We test predictions 1 and 2 in the empirical section below. Before turning to that section, we analyze a simple example that enables us to present the model's predictions diagrammatically and to examine also the case of risk aversion.

3.4 Example

Consider the following specification for the expropriation function:

$$\tau(\lambda) = \rho\sqrt{\lambda},$$

with $\rho \in (0,1)$.

In this case, $\delta_A = \rho^2/s$ and the equilibrium under anarchy is given by

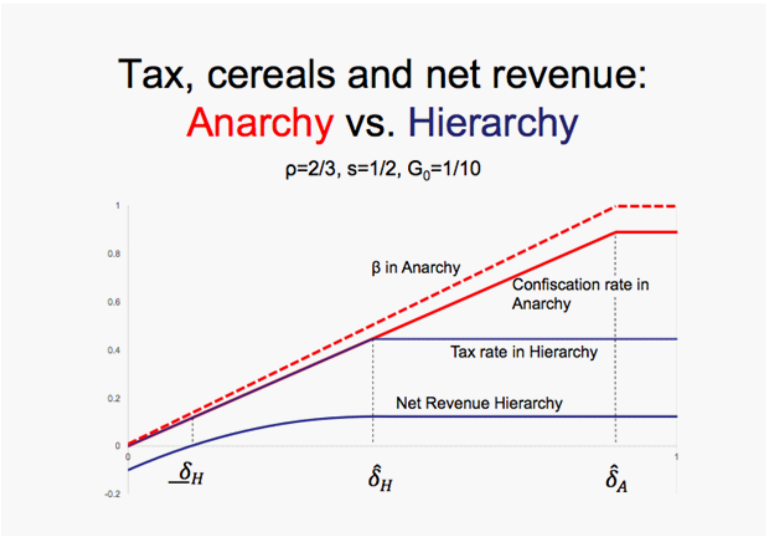
$$(\beta_A, \tau_A) = \begin{cases} \left(\frac{s\delta}{\rho^2}, \delta\right) & if \quad \delta < \delta_A \\ \\ \left(1, \frac{\rho^2}{s}\right) & if \quad \delta \geq \delta_A \end{cases} .$$

Under hierarchy, $\delta_H = \alpha\rho^2/s$ and the lower limit for state existence, $\underline{\delta} > 0$, is implicitly defined by the quadratic equation: $\underline{\delta} - s\left(\frac{\underline{\delta}}{\rho}\right)^2 = G_0$.[26]

For $\underline{\delta} \leq \delta \leq \delta_H$ a state sets a tax rate equal to δ and generates net tax revenue: $R(\delta) = \delta - s\left(\frac{\delta}{\rho}\right)^2$, which increases in δ up to the point where $\delta = \delta_H$ upon which $R(\delta) = R(\delta_H)$. Figure 1 presents the comparison between anarchy and hierarchy with respect to the tax rate and the production of cereals, as a function of δ. It also presents the net revenue of the elite in a regime of hierarchy.

[26] The existence of such a positive solution is conditioned on: $G_0 \leq \rho^2/4s$.

Figure 1: Tax, cereals and net revenue: Anarchy vs. Hierarchy



4 Evidence

In this section we provide supportive evidence for our main theoretical predictions. We employ two alternative datasets with information on social hierarchy: a cross section of societies and a panel of countries. Our main regressors are two measures of agricultural productivity: the productivity of the soil and the productivity advantage of cereals over roots and tubers – a measure corresponding to δ in our model. Consistently with the main prediction of our theory, our empirical investigation shows that it isn't low agricultural productivity that retards development of hierarchy, but rather high productivity of less appropriable crops. In combining agricultural productivity data with data from a cross section of societies and a panel of countries, we follow a similar strategy that is employed by a growing recent literature, including: Alesina et al. (2013), Fenske (2013), Galor and Ozak (2014), and Nunn and Qian (2011).

4.1 Data

4.1.1 Ethnographic data

Murdock's (1967) Ethnographic Atlas provides a database of 1,267 societies from around the world. The database contains information on several cultural, institutional and economic features for these societies at an idealized moment of first contact with Europeans. From this sample, we remove 2 duplicate observations, 7 societies observed before 1500, and 10 societies for which the year of observation is missing, so that we are left with a total of 1,248 societies. These are matched to ethnic maps using either the geo-coordinates of each ethnicity provided by the Ethnoatlas or the maps on the spatial location of ethnicities constructed by Fenske (2013).[27]

We measure pre-colonial hierarchical complexity using the variable "Jurisdictional Hierarchy beyond the Local Community."[28] This is an ordered variable with five possible levels: (i) no political authority beyond community, (ii) petty chiefdoms, (iii) larger chiefdoms, (iv) states, and (v) large states. We plot this measure of hierarchy in Figure 2 and present the summary statistics in the first row of Table E.1 in the appendix. The majority of our sample is composed of societies lacking any political integration above the local community, and groups where chiefs rule over very small districts. These societies prevail in North America, Australia and in Central Africa, but are rather rare in Northern Africa and in Asia, where large chiefdoms and states tend to prevail.

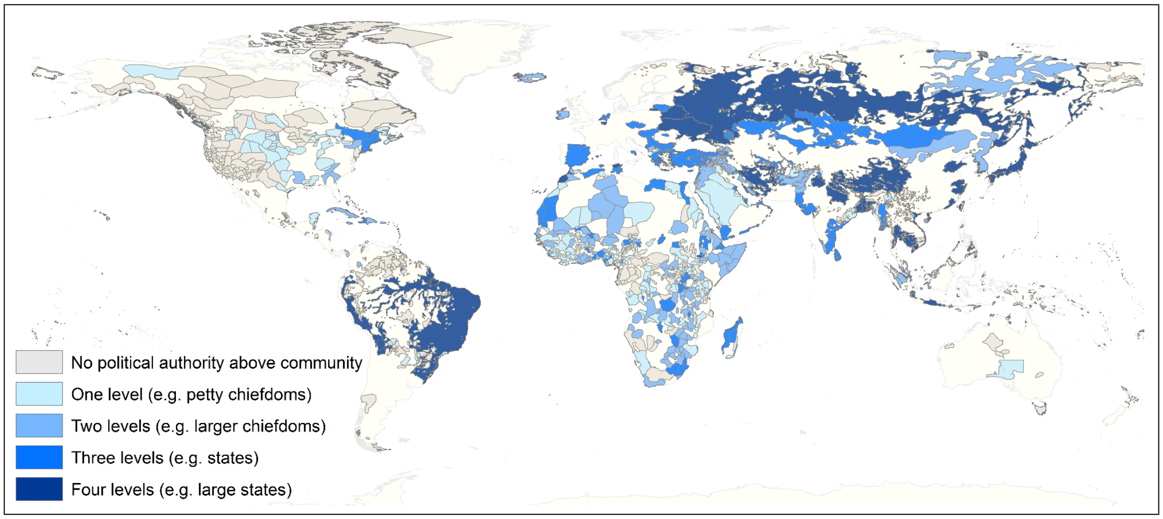
The Ethnoatlas also provides information on the reliance of these societies on agriculture for their diet, and on the major crop type of societies that practice agriculture. These two variables are plotted in Figure 3. with summary data in rows 2 and 3 of Table 1. As can be seen from Figure 5, approximately one fifth of the societies in the sample do not practice any form of agriculture. These societies are concentrated in North-West America, Central Asia, Australia and South-West Africa. The median society relies on agriculture for approximately 50% of its caloric needs. The great majority of the societies that practice some form of agriculture rely on either cereal grains (65.4 percent) or on roots and tubers (26.1 percent). The latter are concentrated in the tropics, while the former are scattered all over the world.[29] Using this information, we define a dummy

[27] The ethnic maps in Fenske (2013) are constructed by combining Murdock's (1959) ethno-linguistic map for Africa with three other sources for the rest of the world (Heizer and Sturtevant, 1978; Global Mapping International, and Weidmann et al., 2010).

[28] Gennaioli and Reiner (2007) and Michaelopoulos and Papaioannou (2013) make a similar use of this variable.

[29] Some societies in the temperate zones grow potatoes - a tuber crop that is in fact similar in its relevant properties

Figure 2: Jurisdictional hierarchy beyond the local community in pre-colonial societies



that identifies societies whose primary crop is cereals and present summary statistics on the second row of Table E.1.

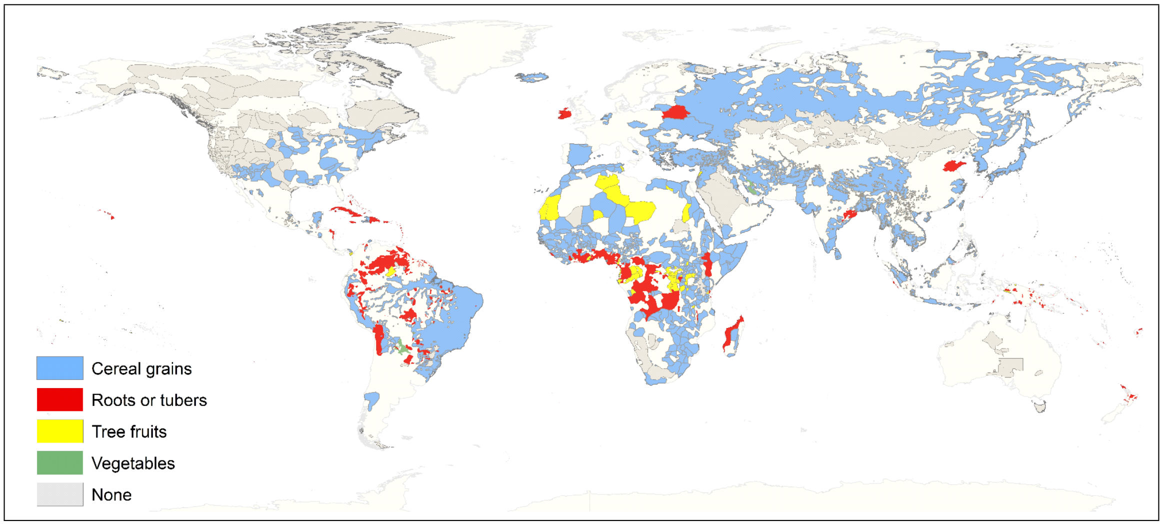
The second source of ethnographic information is provided by the Standard Cross-Cultural Sample (SCCS), which is a derivative of the Ethnographic Atlas. The data are based on a representative sample, defined by Murdock and White (1969), of 186 societies taken from the Ethnoatlas. A large number of publications by diverse authors coded the SCCS societies for many different types of societal characteristics. Cumulative ethnographic codes and codebooks are published in the World Cultures electronic journal.

We use two variables from the SCCS (rows 4 and 5 in Table E.1). The first one, coded by Tuden and Marshall (1972), lists the sources of political power to the local elite. We create a dummy on "the existence of a farming surplus" that is equal to zero if the most prestigious members of the society derive their livelihood from their own subsistence activities and one otherwise. This dummy is plotted in figure E.1 in the appendix. The second variable is a measure of population density coded by Pryor (1985). Societies are categorized into 6 bins (the first bin contains societies with 0-1 persons per square mile, while the last one societies with 500+ persons per square miles).

Table E.3 in the appendix of the paper reports pairwise correlations among the variables col-

to cereals in that it is seasonal and storable.

Figure 3: Major crop in pre-colonial societies



lected for the pre-colonial societies in the Ethnographic Atlas. As expected, societies characterized by more complex hierarchies do generally display a higher reliance on agriculture (and in particular on cereals), a higher probability of producing a farming surplus and more dense populations.

4.1.2 Country-level data

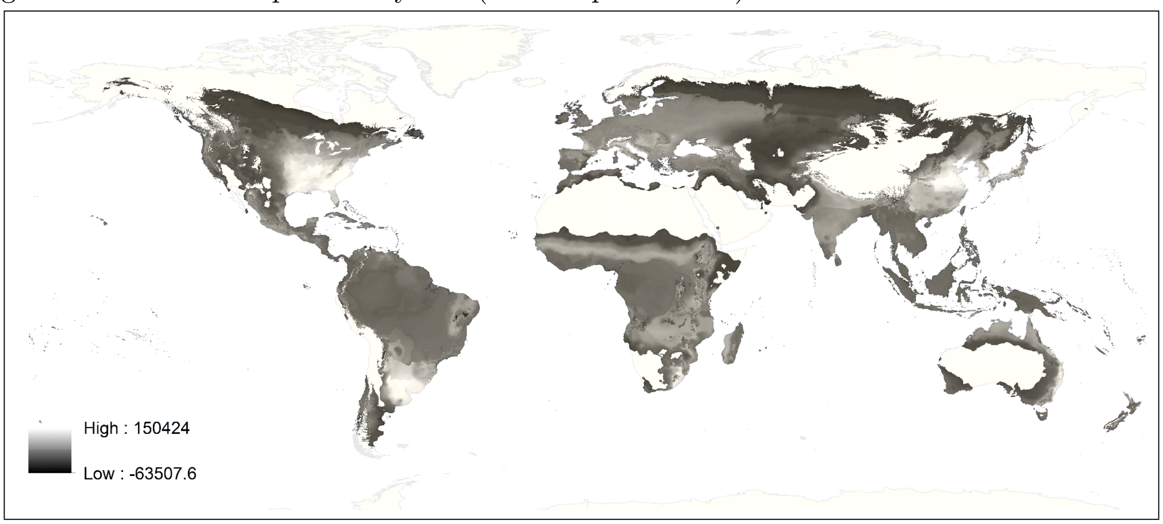
At the country level, we construct a hierarchy index using data from Borcan, Olsson and Putterman (2014). The data cover 159 modern-day countries for every half century from 50 CE to 2000 CE. The score is based on the following question: Is there a government above the tribal level? Borcan et al. (2014) assigned 1 point if the answer is yes, 0.75 points if the organization of the state can be at best described as a paramount chiefdom, and 0 points if the answer is no. The data are merged with data on: the legal origin of the country (from La Porta et al., 1999); population density in 1500 (Acemoglu, Johnson and Robinson, 2002); mortality of early settlers (Acemoglu, Johnson and Robinson, 2001); and the number of exported slaves (Nunn, 2008).

4.1.3 Soil suitability data

The nature of our study requires detailed spatial data on the suitability of soil for different crops. The Global Agro-Ecological Zones (GAEZ) project from the Food and Agriculture Organization

(FAO) provides global estimates of potential crop yields for different crops with cell size of 5'x5' (i.e. approximately 100 Km^2) based on two possible categories of water supply (rain-fed and irrigation) and three different levels of inputs (high, medium and low). In addition, it supplies two alternative projections of potential crop-yields: one is based on agro-ecological constraints, which could potentially reflect human intervention, and one based on agro-climatic conditions, which are arguably unaffected by human intervention. To capture the conditions that were prevalent before the first significant contact of the societies in the Ethnoatlas with Europeans, and to exclude problems of reverse causality, we consider potential yields based on agro-climatic conditions under rain-fed low-input agriculture.

Figure 4: Difference in potential yields (calories per hectare) of cereals versus roots and tubers.



GAEZ provides data on potential yields, in terms of tons per hectare per year, for 11 cereal grains and 4 roots and tubers. Following the same procedure as in Galor and Ozak (2015) for the crops relevant for our investigation, these yields are transformed from tons into calories using data on the caloric content of crops provided by the USDA National Nutrient Database for Standard Reference.[30] We then find the crop with the highest potential caloric yields for each raster point. The results are illustrated in figure E.4 in the Appendix. Cereal grains are the highest yielding

[30] See Table E.2 in the appendix for the complete list of cereal grains, roots and tuber used in the empirical section and the correspondent caloric content. The data source in table A1 is different, and therefore the caloric content reported there is slightly different.

crops in approximately 99 percent of the raster points in the sample, while roots and tubers are optimal in few very small areas in Siberia, Eastern Brazil and Central-East Africa.

On the basis of this data set we construct two measures: a measure of the productivity of land, measured as the maximum potential caloric yield per hectare; and a measure of the productivity advantage of cereals over roots and tubers, which equals the difference between the maximum caloric yield of cereals and the maximum caloric yield of roots or tubers. These measures are attributed to the different societies in the Ethnoatlas by taking an average of their values within a 20-miles radius around the geo-coordinates reported in the Ethnoatlas,[31] while they are attributed to the different countries by using the FAO country boundaries.

As robustness checks, we also exploit two alternative measures of the productivity of the land, which have been widely used in the literature. The first one is an index developed by Ramankutty et al. (2002), which measures the fraction of land that is suitable for agriculture. The second one is a caloric suitability index developed by Galor and Ozak (2015), which captures the highest attainable potential caloric yields from 48 crops (which includes not only cereals, roots and tubers but also sugar crops, pulses, oilcrops, vegetables, fruits, fiber crops and stimulant crops).

Table E.3 in the appendix illustrates that our measure of the productivity advantage of cereals is positively correlated with our benchmark measure of land productivity (the correlation is slightly below 0.8), with the Ramankutty et al. index of suitable land (0.4) and with the Galor and Ozak caloric suitability index (0.8).

Finally, we construct a measure of the productivity advantage that comes from using the plow in agriculture. This equals the difference between the maximum caloric yield among crops that Alesina, Giuliano and Nunn (2013) identify as "plow-positive" (wheat, barley and rye) and those that they identify as "plow-negative" (sorghum, foxtail millet and pearl millet).

4.1.4 Other demographic and geographic data

The History Database of the Global Environment (HYDE) supplies global estimates on population density at the raster level between 1500 and 2000 with cell size of 5'x5'. To each society in the Ethnoatlas, we assign a value that is equal to the average population density across the raster

[31] In the appendix we report the result of an alternative method, where we attribute these productivity measures to the different societies by using the maps on their spatial location constructed by Fenske (2013).

points within its territories for the year of observation recorded in the atlas. Data on population density for 1995 is provided by GAEZ and is similarly averaged within the territory of each society. Finally, we employ data on distance to major rivers or to the coast, precipitation, temperature, elevation, ruggedness, absolute latitude, incidence of malaria both at the society and the country level. Sources are detailed in Table E.1.

4.2 Empirical results

4.2.1 The choice of crop

We start our empirical analysis by studying the geographical factors that influence the choice of cultivating cereals rather than alternative crops or non-farming. Our theory suggests that farmers make this choice on the basis of comparing the net caloric yield of cereals to that of the alternatives crops (in which we focus on roots and tubers).

The first three columns of Table 1 presents the results of the following regression:

$$Cer_i = \alpha CalDiff_i + X_i'\beta + \varepsilon_i.$$

Cer_i is a dummy variable that identifies that society i cultivates a cereal grain as its main crop; $CalDiff_i$ is the caloric advantage of cereals in the land of society i (the difference between the maximum potential caloric yield of cereals and of roots or tubers); and X_i is a set of control variables. Column 1 reports the bivariate relationship without any controls. The association is positive and statistically significant. An increase in the productivity advantage of cereals over roots and tubers by one standard deviation is associated with an increase in the probability of planting cereals as main crop in the order of 20 percent. Moreover, variation in this regressor alone is able to explain 13 percent of the entire variation in the dependent variable. The first concern is that the productivity advantage of cereals might reflect the potential caloric yield of the soil, since cereals grains are the most productive crops in most of the world. Column 2 reports the results when adding as a control variable the productivity of the soil (the highest potential caloric yield across all 11 cereals and 4 roots/tubers). This variable does not produce any significant impact on the decision on whether to plant cereals or not, while the impact of the productivity advantage of cereals is unchanged. Adding this control leaves the R^2 of the regression practically unchanged, which suggests that soil productivity isn't relevant to explain the decision to cultivate cereals. Results are unchanged when exploiting within-continent variation (as in column 3) and when using a logistic model, which accounts for the binary nature of the dependent variable (see columns 4 and 5). Moreover, the results of the first five columns of Table 1 survive a battery or robustness checks that are detailed in the appendix of the paper. In table E.4, we control sequentially for precipitation, temperature, elevation, and ruggedness, which are the main factors affecting crop productivity in the GAEZ dataset. In table E.5, we control for geographical isolation (proxied as the distance to the nearest major river or coast), malaria endemicity, actual and historical population density and for the productivity advantage from using the plow. In all cases, the qualitative results on the effect of the productivity advantage of cereals over roots and tubers are almost unaffected (coefficients vary from 0.210 to 0.261 and are always statistically significant at the 1 percent confidence level).

Table 1: Potential Crop Yields, Choice of Crops and Reliance on Agriculture

	Dependent variable is:							
	Major crop is cereal grains (dummy)					Reliance on agriculture		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	OLS	Logit	Logit	OLS	OLS	OLS
CALORIC DIFF	0.205***	0.210***	0.253***	1.150***	1.617***	0.081***	-0.098***	-0.046**
(CER - TUB)	(0.029)	(0.063)	(0.059)	(0.339)	(0.380)	(0.022)	(0.029)	(0.022)
MAX CALORIES		-0.007	-0.137**	-0.119	-0.896**		0.230***	0.128***
(ALL CROPS)		(0.083)	(0.069)	(0.384)	(0.407)		(0.046)	(0.035)
CONTINENT FE	NO	NO	YES	NO	YES	NO	NO	YES
Ave marg. effect of				0.282***	0.385***			
CALORIC DIFF				(0.081)	(0.092)			
r2	0.132	0.132	0.359			0.0733	0.235	0.387
pseudo r2				0.109	0.258			
N	982	982	982	982	982	1063	1063	1063

The table reports cross-sectional OLS and Logit estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is either a dummy that identifies societies that cultivate cereal grains as main crop (columns 1-5) or the reliance of these societies on agriculture (columns 6-8). CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

In the last three columns of Table 1 the reliance of the society on agriculture is the dependent variable. As reasonably expected, land productivity increases the probability of reliance on farming. Interestingly, the productivity advantage of cereals has a negative effect on practicing agriculture, when controlling for soil productivity. That is, for the same level of land productivity (measured in calories per unit of land), cultivating roots and tubers is more rewarding than cultivating cereals. This is consistent with our theory as cereal farmers are more vulnerable to extraction.

Thus, in this subsection, we show that while the productivity advantage of cereals has a positive impact on the probability of cultivating cereals as the main crop, it has a negative impact on the reliance of societies in our sample on agriculture. Furthermore, the absolute productivity of land has a positive impact on reliance on agriculture, but no significant impact on the probability of cultivating cereals.

4.2.2 Cereals and hierarchy

According to our theory, societies that grow cereals rather than roots or tubers are characterized by a more complex hierarchy and by generating a higher farming surplus. To test these predictions, we estimate a regression of the form:

$$Y_i = \alpha Cer_i + X_i' \beta + u_i, \tag{2}$$

where Y_i is either a measure of hierarchy or an indicator for the presence of farming surplus in society i; Cer_i, is, as mentioned above, a dummy variable that identifies societies that rely mainly on cereals for their subsistence; and X_i' is a vector of control variables. This specification, however, encounters several problems.

First, the choice of the cultivated crop is influenced by the social institutions. In particular, according to our theory it is riskier to cultivate cereals in societies characterized by low state capacity, and thereby by low protection against bandits, since cereals render farmers more vulnerable to theft. To overcome this reverse causality concern, we exploit variations in potential, rather than actual, crop yields, which are derived from agro-climatic conditions that are presumably orthogonal to human intervention. Specifically, we run IV regressions, where we instrument for Cer_i by using the productivity advantage of cereals, $CalDiff_i$.

Second, there are several potential omitted variables that could be correlated with the main regressor and the measure of hierarchy. The disease environment, for instance, is correlated with both the cultivation of tubers (which is concentrated in the tropics) and is likely to be correlated with the quality of institutions (Acemoglu, Johnson and Robinson, 2001). A battery of robustness checks alleviates this concern. Moreover, we exploit the Columbian exchange and the effects it had on the productivity potential crops, to conduct panel regressions at the country-level that will rule out potential time-invariant omitted variables.

Table 2: Cereals, Surplus and Hierarchy - Reduced Form

	Dependent variable is:							
	Jurisdictional Hierarchy Beyond Local Community				Existence of Farming Surplus			
	(1) OLS	(2) OLS	(3) OLS	(4) Ord Logit	(5) OLS	(6) OLS	(7) OLS	(8) Logit
CALORIC DIFF	0.244***	0.179	0.274**	0.495***	0.141***	0.241***	0.202***	0.997***
(CER - TUB)	(0.069)	(0.120)	(0.107)	(0.149)	(0.0319)	(0.0681)	(0.0742)	(0.384)
MAX CALORIES		0.082	-0.188*	-0.224		-0.132	-0.0985	-0.479
(ALL CROPS)		(0.141)	(0.108)	(0.178)		(0.0870)	(0.0985)	(0.463)
CONTINENT FE	NO	NO	YES	YES	NO	NO	YES	YES
Ave marg. effect of								0.249***
CALORIC DIFF								(0.096)
r2	0.0416	0.0429	0.249		0.0757	0.0911	0.157	
pseudo r2				0.121				0.124
N	952	952	952	952	140	140	140	140

The table reports cross-sectional OLS (columns 1-3 and 5-7), Ordered Logit (column 4) and Logit (column 8) estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is either a dummy that identifies societies that produce a farming surplus or Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Columns 1-4 report in parentheses Conley standard errors adjusted for spatial correlation, while columns 5-8 report robust standard errors. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Before presenting the 2SLS regressions that estimate the effect of cereals on hierarchy and surplus, we report in Table 2 the reduced form of the analysis. Columns 1 illustrates that the higher the productivity advantage of cereals, the higher is the level of jurisdictional hierarchy that is reached by the societies in the Ethnoatlas. This result is unchanged when controlling for the productivity of the soil (column 2). More specifically, while one standard deviation increase in the productivity advantage of cereals increases the hierarchy index by 0.18 (0.27 in the specification with continent fixed effects), an increase of soil productivity does not produce any significant impact on the dependent variable. In column 3, we control for continent fixed effects. The impact of the relative productivity of cereals becomes larger, while the impact of the soil productivity becomes negative.

In column 4 we use an ordered logit model, which accounts for the ordinal nature of the dependent variable. A one standard deviation increase in the productivity advantage of cereals increases the log odds of being in a higher level of hierarchy by approximately 50 percent. In the appendix (see Table E.6), we relax the assumption of proportional odds, which is implicit in the standard ordered logit models, and estimate a generalized logit model.[32] As can be seen, the greatest impact of cereal advantage is to push societies from tribes and chiefdoms to states. More specifically, while an increase in one standard deviation in the productivity advantage of cereals increases the log odds of being in a level of hierarchy higher than a tribe by 32 percent, it increases the log odds of being in a level higher than a chiefdom by 65 percent and higher than a small state by 84 percent. In all cases, the impact of soil productivity is either very small and not statistically significant, or negative.

Columns 5 to 8 in Table 2 provide further support for the appropriability hypothesis versus the productivity-surplus hypothesis. In fact, the higher the productivity advantage of cereals, the higher is the probability of having an economy that produces a farming surplus – elite consumption isn't based on direct subsistence (column 5). When we run a horse race between the productivity advantage of cereals and the absolute productivity of the soil (columns 6 and 7), we find that only the former has a significant impact on surplus, independently on whether we control for continent fixed effects or not. Using a logistic regression rather than OLS regression does not alter this result (see column 8).

Table 3 reports the OLS and 2SLS estimates of equation 2, when the dependent variable is hierarchy. The OLS estimates in column 1 show that cultivating cereals is associated with an increase of 0.70 in the hierarchy measure. Clearly, this positive association cannot be interpreted

[32] The assumption of proportional odds means that each independent variable has an identical effect at each cumulative split of the ordinal dependent variable.

Table 3: Cereals and Hierarchy - OLS and 2SLS

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP:	0.707***	1.170***	0.863	1.040**	0.304**	0.892**	1.064**	0.993**
CEREALS	(0.131)	(0.359)	(0.596)	(0.414)	(0.120)	(0.420)	(0.538)	(0.463)
MAX CALORIES			0.081				-0.037	
(ALL CROPS)			(0.127)				(0.071)	
DEPENDENCE ON				0.334				-0.419
AGRICULTURE				(0.517)				(0.783)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	952	952	952	952	952	952	952	952
F excl instrum.		147.7	44.84	65.51		99.87	76.90	33.09

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

as causal. In order to overcome the reverse causality problem, we switch to the 2SLS estimates in the next three columns. Cultivating cereals as the main crop increases the hierarchy measure by more than one (column 2), which is equivalent, for instance, to a move from a tribe to a small chiefdom or from a large chiefdom to a state. In the following two columns, we run a horse race between our appropriability hypothesis and the land productivity-surplus hypothesis. In column 3, we add the productivity of land as a control variable. As can be seen, it does not have any significant effect on hierarchical complexity. In column 4, we add the dependence of the society on agriculture as a second endogenous variable. The instruments now are both the caloric advantage of cereals and absolute soil productivity; where the intuition is that the latter influences only the decision whether to become farmers, but not the choice of the crop. The results are once gain striking: societies that practice agriculture are not characterized by more complex hierarchies, unless they cultivate cereals. In columns 5-8, we repeat the analysis adding continent fixed effects in the regression. The

2SLS results are practically unchanged.

The results of Table 3 survive a battery or robustness checks that are detailed in the appendix of the paper. In Table E.7, we control sequentially for precipitation, temperature, elevation, and ruggedness, the main factors affecting crop productivities. In Table E.8, we control for geographical isolation, malaria endemicity and actual, historical population density and for the productivity advantage from using the plow. Results are robust throughout. In 9 out of 10 cases, cultivating cereals as main crop exerts a statistically significant impact on hierarchical complexity. Controlling for rainfall is the exception: the magnitude of the coefficient does not vary but the coefficient becomes statistically significant only at 15% level. The results are also practically unaffected when using ethnic boundaries as defined by Fenske (2013) to extract data on crop productivities (Table E.10), when the sample includes societies living in desertic soils (Table E.9), or when using either the Ramankutty et al. index of fertile land or the Galor and Ozak index of caloric suitability as alternative measures of land productivity (Table E.11). In all cases, qualitative results on the effect of cultivating cereals as main crops are almost unaffected (the coefficients vary from 0.750 to 1.471).

Table E.12, in the appendix, reports the OLS and 2SLS estimates of equation 2, when the dependent variable is the existence of a farming surplus in the society. The OLS estimates show that cultivating cereals is associated with an increase of 0.36 in the probability of producing a surplus (column 1). The coefficient more than doubles when turning to the 2SLS estimates (column 2). As in the previous table, also in this case absolute productivity of soil and reliance on agriculture do not affect the dependent variable (columns 3 and 4); and the results are robust when adding continent fixed effects in the specification (columns 5 to 8). Also in this case, the empirical results survive a long list of robustness checks reported in the appendix (Tables E.13-E.17).

These results provide evidence in support of our theory, as they indicate that the decision to cultivate cereals has a large and significant effect on the development of complex hierarchical institutions and a farming surplus. The analysis accounts for a large set of possible confounding geographical characteristics. But still, we cannot rule out that unobservable characteristics, systematically correlated with the productivity of different crops, might be driving our results. In order to overcome this potential concern, we exploit an exogenous variation in the available crops in different locations induced by the Columbian exchange.

In the New World, among the main four roots and tubers, three were available before 1500:

cassava, white potatoes and sweet potatoes, and among the eleven main cereals, only maize was available. In the Old World, the only available crop among roots and tubers was yam; while all cereal grains, excluding maize were available: barley, buckwheat, foxtail millet, indigo rice, oat, pearl millet, rye, sorghum, and wetland rice. Thus, for each raster point of the world we define the highest yielding crop among cereals and among roots and tubers both before and after the Columbian exchange. We then compute for each location the productivity advantage of cereals over roots and tubers and the absolute productivity of land before the Columbian exchange (prior to 1500) and after the Columbian exchange (in the years after 1600).[33]

Since the data in the Ethnographic Atlas pertains only to societies after the Columbian exchange, we exploit a different country-level panel dataset that reports on hierarchical complexity for the majority of the world over the last millennium. The unit of observation is the territory delimited by modern-day country borders for 159 countries every 50 years. Since we lack observations on the major crop cultivated in these territories for the period of analysis, we can only run the reduced form version of our empirical analysis where we regress the hierarchy index on the productivity advantage of cereals (and on the productivity of the soil):

$$Hier_{it} = \alpha CalDiff_{it} + X_{it}'\beta + \eta_i + \eta_t + u_{it}. \tag{3}$$

Here $Hier_{it}$ is the hierarchy index of country i in year t and $CalDiff_{it} = CalDiff_{i,BeforeExchange}$ (the caloric advantage of cereals over roots and tubers before the Columbian exchange) if $t \leq 1500$ and $CalDiff_{it} = CalDiff_{i,AfterExchange}$ (the caloric advantage of cereals over roots and tubers after the Columbian exchange) if $t \geq 1600$. X_i is a set of control variables, which includes the potential productivity of the soil calculated based on the relevant available crops. Country fixed effects control for all time invariant factors that differ between countries, while time period fixed effects control for any time patterns of hierarchical complexity that affects all countries. The identification assumption is that in the sixteenth century, there were no unobserved events, which are systematically correlated with the spatial variation in the change in the potential productivity

[33] We exclude the years from 1500 to 1600 as the historical evidence points out that the New World's crops were adopted in Europe and Africa in the seventeeth century. For instance, the adoption of the potato in the Old World began in the late seventeeth century by Irish peasants (Nunn and Qian, 2011), while the first accounts on the adoption of maize in Africa date back to the very end of the sixteenth century (Miracle, 1966). In the appendix, we show that our results are robuts when excluding the years between 1500 and 1750 (see Table E.21).

advantage of cereals, that had an effect on hierarchy.

The change in hierarchical complexity, induced by the change in appropriability (resulting from the change in the productivity advantage of cereals over roots and tubers), could be driven by either locals or colonizers. However, the colonization process does not seem to be driving our results: controlling for colonies doesn't have a quantitative effect on the estimates (see Table E.18 in the appendix). A related source of concern is that changes in hierarchy were a result of people moving from the Old to the New World, rather than a result of cereals making the same shift at the same time. This however, cannot explain the fact that our results (see Table 4) indicate a correlation between changes in the potential productivity advantage of cereals and changes in hierarchy and no correlation between changes in land productivity and hierarchy, controlling for changes in the potential productivity advantage of cereals. Note also that, as explained above, our measurement of the productivity advantage of cereals in different historical periods does not measure the actual productivity advantage, but rather the potential advantage, and is unaffected by the movement of people and the time of arrival of different crops in different locations.

The empirical results are illustrated in Table 4. Column 1 confirms that the higher the productivity advantage of cereals, the higher is the country's hierarchy index. This result is unchanged when controlling for soil productivity (column 2). More specifically, while a one standard deviation increase in the productivity advantage of cereals increases the hierarchy index by 0.19, soil productivity does not have any significant impact on the dependent variable. In the next five columns, we show that the results are robust when controlling for precipitation, temperature, elevation ruggedness and absolute latitude (interacted with the time-period fixed effects). In Table 5, we consider a host of additional factors (each interacted with time-period fixed effects) that might have affected hierarchical complexity. Our choice of controls is driven by the determinants of long-term economic development that have been emphasized in the literature. Sequentially, we control for: legal origin of the country; population density in 1500; settlers mortality; the number of exported slaves; distance to rivers and coast; endemicity of malaria; and the percentage of tropical land. Once again, our results are unaffected.

In Table E.18 in the appendix we exclude from the sample the cells in which the countries in our analysis were either colonies or protectorates. The estimated coefficients on the caloric advantage of cereals over roots and tubers become smaller by approximately a third. However, in

Table 4: Cereals and Hierarchy - Panel Regressions

	Dep. Variable: Hierarchy Index						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CALORIC DIFF	0.189***	0.272***	0.282***	0.240***	0.255***	0.261***	0.197**
(CER - TUB)	(0.0683)	(0.0834)	(0.0760)	(0.0857)	(0.0889)	(0.0839)	(0.0795)
MAX CALORIES		-0.163	-0.193	-0.152	-0.115	-0.148	-0.165
(ALL CROPS)		(0.141)	(0.131)	(0.139)	(0.142)	(0.138)	(0.123)
Controls (x Year FE):							
Precipitation	NO	NO	YES	NO	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO	NO
Elevation	NO	NO	NO	NO	YES	NO	NO
Ruggedness	NO	NO	NO	NO	NO	YES	NO
Abs Latitude	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES	YES	YES	YES
r2	0.680	0.682	0.716	0.684	0.681	0.686	0.705
N	2869	2869	2850	2812	2755	2869	2869

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The dependent variable is an hierarchy index: it equals 0 if there is not a government above tribal level, 0.75 if the political organization can be at best described as a paramount chiefdom and 1 otherwise. CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

all the specifications, they are all still positive and statistically significant, while the impact of land productivity on hierarchy is negative and not significant.

Table E.19 and E.20 in the appendix report further robustness checks. Specifically, in Table E.19, hierarchical complexity is proxied by a dummy that identifies those societies with a government above tribal level. In Table E.20, land productivity is proxied by the caloric suitability index developed by Galor and Ozak (2015), which also varies depending on whether it is measured before or after the Columbian exchange. Finally, in Table E.21, we exclude the years between 1500 and 1750, during which the Columbian exchange of crops was not completed. In all the three cases, our main results are unaffected.

Equation (3) examines the average effect on the hierarchy index following the change in the productivity advantage of cereals over roots and tubers due to the Columbian exchange. This estimation requires that we choose a date in which the Columbian exchange was completed. The

Table 5: Cereals and Hierarchy - Panel Regressions - Robustness Checks

	Dep. Variable: Hierarchy Index							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CALORIC DIFF	0.160*	0.127	0.206*	0.274***	0.245***	0.258***	0.273***	0.254***
(CER - TUB)	(0.0892)	(0.0843)	(0.116)	(0.0833)	(0.0928)	(0.0957)	(0.0840)	(0.0675)
MAX CALORIES	-0.0507	0.0471	-0.261	-0.176	-0.121	-0.133	-0.199	-0.211**
(ALL CROPS)	(0.133)	(0.132)	(0.192)	(0.143)	(0.151)	(0.151)	(0.145)	(0.102)
Controls (x Year FE):								
Legal Origin	YES	NO	NO	NO	NO	NO	NO	NO
Pop Density 1500	NO	YES	NO	NO	NO	NO	NO	NO
Settlers Mortality	NO	NO	YES	NO	NO	NO	NO	NO
Slave Exports	NO	NO	NO	YES	NO	NO	NO	NO
Distance River	NO	NO	NO	NO	YES	NO	NO	NO
Distance Coast	NO	NO	NO	NO	NO	YES	NO	NO
Pct Malaria	NO	NO	NO	NO	NO	NO	YES	NO
Tropical Land	NO	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES	YES	YES	YES	YES
r2	0.699	0.714	0.707	0.683	0.678	0.679	0.681	0.744
N	2869	2869	1501	2869	2755	2755	2793	2869

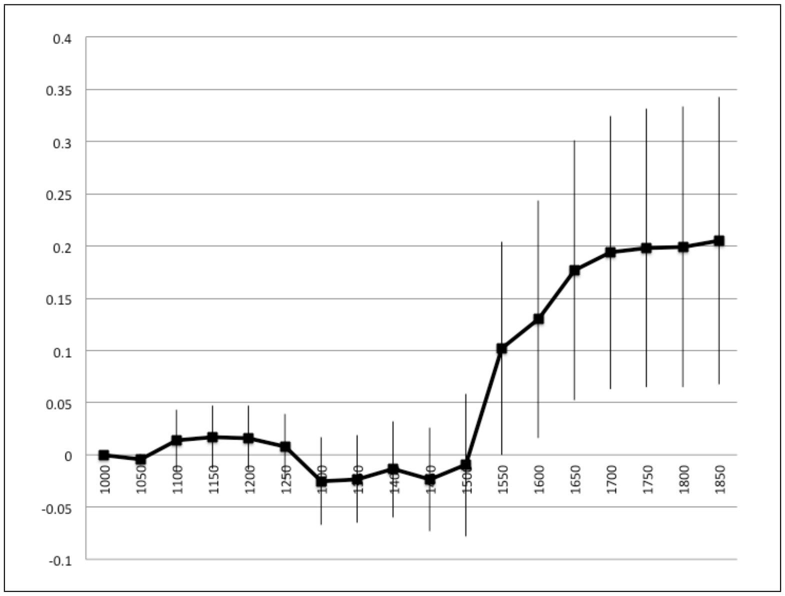
The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The dependent variable is an hierarchy index: it equals 0 if there is not a government above tribal level, 0.75 if the political organization can be at best described as a paramount chiefdom and 1 otherwise. CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

historical evidence suggests that it took at least a century for complete realization of the Columbian exchange, and therefore we took the entire sixteenth century as the relevant cutoff. In order to examine whether patterns of data are consistent with this assumption, we also estimate a more flexible equation that takes the following form:

$$Hier_{it} = \sum_{j=1050}^{1850} \alpha_j (CalDiff_{i,AfterExchange} - CalDiff_{i,BeforeExchange}) + X'_{it}\beta + \eta_i + \eta_t + u_{it}. \quad (4)$$

It is important to note that in this specification we are not particularly interested in the individual magnitudes of the point estimates but in their pattern over time. Because the main regressor is time invariant and equation (4) includes country- and time-period fixed effects, the estimated αs must be measured relative to a baseline time-period, which we take to be 1000. The estimated coefficients and their 10 percent confidence intervals are reported in Figure (5).[34]

Figure 5: Flexible estimates of the relationship between the change in the caloric advantage of cereals over roots and tubers due to the Columbian exchange and hierarchy.



The impact of the change in the productivity advantage of cereals over tubers due to the Columbian exchange is constant over time between 1000 and 1500; it increases steadily during the sixteenth century; it continues to increase but a lower rate until 1700; after which it stabilizes. This confirms the story that the Columbian exchange produced a differential increase in hierarchy in those countries for which it also caused a larger increase of the productivity advantage of cereals over roots and tubers and that the great majority of the full impact happened in the sixteenth century.

In conclusion, our empirical analysis strongly supports our appropriability theory, and does not support the alternative land productivity-surplus hypothesis. We show that the cultivation of cereals is crucial for the development of complex hierarchical institutions and for the existence of a farming surplus. On the other hand, both soil productivity and the reliance on non-cereal

[34]The 17 coefficients reported in Figure (5), can also be described as the estimated coefficients in 17 independent cross-country regressions, in which we regress the change in the hierarchy index between each of the 17 years in the sample (1050, 1100, .., 1850) and the year 1000 on the change in the caloric advantage of cereals over roots and tubers caused by the Columbian exchange.

agriculture do not exert any effect on hierarchy and surplus.

5 Concluding remarks

The prevailing scholarly view attributes the emergence of hierarchy to the increased productivity of agriculture. It is presumed that this productivity increase generated food abundance, which in turn led to population increase, specialization in crafts, exchange, and the rise of elite. We do not challenge the perception that the transition away from egalitarianism towards hierarchy was correlated with the shift to agriculture and to higher productivity, but we contend that the causal mechanism may have little to do with the increase in productivity. Noting that states failed to develop in regions that farm roots and tubers, and observing that hierarchies emerged also in some hunter-gathering societies, we propose that the key aspect of the Neolithic, that brought about the rise of a non-food producing elite, was reliance on seasonal stored food that rendered farmers vulnerable to appropriation. That is, we identify the shift towards appropriable food sources as the key causal element that explains the emergence of hierarchy and that accounts for cross regional differences in the complexity of hierarchy.

Our appropriability theory can be considered neo-Hobbesian, in the sense of emphasizing the role of government in protecting individuals from theft, banditry and expropriation. However it revises Hobbes ideas in identifying the need for protection as arising simultaneously with the increased ability of the would-be rulers to appropriate. Moreover, it identifies the emergence of hereditary hierarchy not with the need to protect life among 'savages' (hunter-foragers), but with the protection of food stockpiles, mostly in cereal farming societies. Furthermore, our approach avoids teleology: hierarchy does arise to serve a social purpose of protecting farmers; rather, in the spirit of Olson (1993), it arises because it becomes feasible to tax and it serves the elite's interest to protect farmers from expropriation by others.

Our theoretical claims are illustrated with a simple model of agricultural societies. The main testable prediction of the model is that the key variable that accounts for the emergence of hierarchy is sufficient productivity advantage of cereals over roots and tubers, and that given this advantage, absolute land productivity will have no effect on hierarchy. Thus, whereas conventional theories suggest that it is low agricultural productivity and disease which retard the development of tropical regions, our theory and our empirical results suggest that the hurdle that held back the development of hierarchical social institutions in the tropics was the relatively high productivity of crops that provide farmers with substantial immunity against appropriation.

We note that Acemoglu, Johnson and Robinson (2002) question the role of geography in accounting for current income disparities and argue that the underdevelopment of countries closer to the equator is an outcome of the extractive institutions that colonizers established there.[35] Acemoglu and Robinson (2012) also argue that inclusive institutions are the main source for economic prosperity, and that institutions are by and large determined by the vagaries of human history. Our own contribution identifies a particular channel by which environmental factors affect social institutions, and one that may be particularly important for understanding the underdevelopment of tropical countries. As Besley and Persson (2009, 2014) emphasize, underdevelopment is closely correlated with low fiscal capacity.[36] But, whereas they view this correlation as a vicious cycle that can be broken by investment in the ability to tax, our approach suggests that the low fiscal capacity may be a deep rooted problem in the tropics, and largely unrelated to the inheritance of colonialism.

[35] Easterly and Levine (2003) and Rodrik, Subramanian and Trebbi (2004) demonstrate empirically that the link between the tropics and underdevelopment is indirect, due to the growth-retarding social institutions in tropical countries.

[36] Gennaioli and Voth (2015) emphasize how investment in state capacity since the Middle-Ages responds to conflict. Dincecco and Prado (2012) and Dincecco and Katz (2014) show that state capacity is persistent, and has a positive effect on economic performance.

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Appendix A: Cereals vs. Roots and Tubers

In this appendix we seek to provide evidence in support of our various factual claims on the distinction between cereals and roots/tubers: (i) that reliance on roots and tubers is a major phenomenon in tropical regions; (ii) that roots and tubers are highly productive in the tropics; (iii) that their harvesting is in general non-seasonal; (iv) that after harvest they are significantly more perishable than cereals; and (v) that there exist significant climatic and soil variations in the productivity of cereals and of roots and tubers. (vi) that there moisture content is very high, making them bulky to transport.

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Table A.1: Major staple crops produced in the world and in Sub-Sahara Africa in 1961 and 2013

		World 1961		Sub-Sahara 1961		Nigeria 2013
	Energy Content (Kcal/100g)*	Average Caloric Yield (mil Kcal/ha)**	Total Energy Produced (10^{12} kcal)**	Average Caloric Yield (mil Kcal/ha)**	Total Energy Produced (10^{12} kcal)**	Total Energy Produced (10^{12} kcal)**
Rice	365	6.82	787	4.51	11	17
Maize	365	7.09	748	3.66	53	38
Wheat	327	3.56	727	2.25	6	
Barley	354	4.70	256	2.81	3	
Oats	389	5.04	193	4.52	1	
Rye	338	3.92	119	0.60	0	
Sorghum	329	2.93	135	2.46	28	22
Millet	378	2.24	97	2.17	24	19
Potatoes	77	9.41	208	5.14	1	1
Cassava	160	11.85	114	9.10	50	85
Sweet Potatoes	88	6.47	86	4.55	3	3
Yams	118	8.54	10	8.65	9	5
Total of above			3480		188	190
Population***			3083		223	174

* http://ndb.nal.usda.gov/ndb/, accessed Feb 2015. Rice: white, long-grain, regular, raw unenriched; maize: corn grain, yellow; wheat: hard red winter; Barley: hulled; oats; rye: grain; sorghum: grain; millet: raw; potatoes: flesh and skin, raw; cassava: raw; sweet potatoes: raw unprepared; Yams: raw; soybeans: green, raw; Bananas and plantain: raw. ** calculated on the basis of first column and FAO 1961 data on area and production in the world, in Africa and in northern Africa, and 2013 data for Nigeria. http://faostat3.fao.org/download/Q/*/E, accessed Feb 2015 *** http://faostat3.fao.org/download/O/*/E, accessed Feb 2015.

Table A1 presents summary data on the main staple crops in sub-Saharan Africa and in Eurasia in 1961 – the earliest year for which the Food and Agriculture Organization, FAO, provides that information.[37] Its last column presents comparable data for Nigeria in 2013. In relying on relatively

[37] Given a rough estimate of 1 million calories required per person per year (2740 kcal per day), the columns on

recent data, our presumption is that the soil and climatic conditions have not changed significantly since the Neolithic period. We recognize, of course, that the plants that provide most of the calories that humans consume have undergone major modifications since antiquity and that their availability was greatly impacted by the post-Columbian migration of species between the continents.[38]

(i) The data in Table A1 reveals that roots and tubers provided 33.5 percent of the total calories produced by the main staple crops in sub-Saharan Africa in 1961, and that cassava alone provided about 45 percent of the total calories produced by these crops in Nigeria in 2013.

(ii) The table reveals further that the average caloric yield of cassava and yam in sub-Saharan Africa (9.10 and 8.65 mil Kcal/Ha) exceeded the comparable world average yield of the three main cereals, rice, maize and wheat (equal to 6.82, 7.09 and 3.56 mil Kcal/Ha, respectively).

(iii) The seasonality of cereals is well known. They have to be sown and reaped in a relatively fixed time in the year, and usually once a year. On the other hand, roots and tubers are generally perennial and may be harvested at any time during the year. In fact, cassava can be left intact in the ground for two years. This provides farmers with much flexibility as to the timing of the harvest, and prevents the need for significant storage. Rees et al. (2012, p. 394) report: "Harvest time [of Cassava] ranges from six to 24 months, and roots can be left in the ground until needed, making cassava a very useful food security crop."[39]

(iv) Harvested grains are storable with relatively little loss from one harvest to the next, and even over several years. On the other hand, roots and tubers are in general perishable once out of the ground, though to different degrees. In particular, cassava starts to rot at ambient African temperature within 2-3 days of being harvested. The rotting of these roots and tubers is often hastened by abrasions cause by uprooting and transportation. Rees et al. (2012, p. 394) summarize the evidence: "Despite their agronomic advantages over grains, which are the other main staple food crops, root crops are far more perishable. Out of the ground, and at ambient temperatures these root crops have shelf lives that range from a couple of days for cassava . . . , two to four weeks for sweet potato, to between four and 18 weeks for the natural dormancy of yams . . . " Cassava's fast rotting upon harvest can be overcome only by freezing or by laborious processing that turns the moist root into dry flour.

total energy produced provide a crude estimate of the population (in millions) whose energy needs could be supported by each crop (ignoring the feeding of animals, seed requirements and wastage). It is evident that the total energy produced by the listed twelve major crops could roughly feed the entire population.

[38]While varieties of yam were known in the entire tropical zone, including Asia, Africa and South America, and are believed to have been cultivated in New Guinea as early as eight millennia ago, maize, potato, sweet potato and cassava were introduced to the Old World from America.

[39]See also Lebot (2009) and Bradshaw (2010).

(v) Lebot (2009) lists the optimal annual rainfall for cassava, yams and sweet potato as ranging from 750 to 1500 mm of rain, and the optimal temperature as 20-30 degrees centigrade. This reveals that while these crops are cultivable in the tropics, they cannot be cultivated in temperate climates.

(vi) According to Lebot (pp. vi, 78) the moisture content of cassava is 63% of the weight, and that of sweet potato and yam is 71% and 74% respectively.

By these considerations, even though the potato is biologically a tuber, for our concern here with the degree of appropriability, it may as well be considered a quasi-cereal, since it is cultivable in temperate climates, is seasonal, and is relatively non-perishable upon harvesting.

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Appendix B: The emergence of hierarchy: a literature survey and critique

Anthropologists and archaeologists have long concluded that hunter-gatherer societies were fairly egalitarian and ostensibly leaderless – in sharp distinction to the hierarchical nature of ape communities.[40] In this appendix we survey the extensive literature that links the transition to agriculture with the shift from egalitarianism toward hierarchy.[41]

The productivity-and-surplus theory for explaining the emergence of hierarchy

The idea that it is agriculture that generates surplus, and surplus that gives rise to hierarchy, is an old one. It can be traced to Adam Smith and to earlier seventeenth century social thinkers.[42] According to Smith, government and property protection first emerged with the transition to pastoralism and the need to protect herds from theft (Smith 1978, p. 16), but only the subsequent transition to agriculture generated surplus, division of labor, and exchange, and thus extended significantly the role of government (1978, p. 409).[43]

For Smith and his intellectual heirs surplus had to be available before the landlord, the capitalist or the ruler could seize it. Engels similarly stated that in pre-agricultural societies "Food had to be won anew day by day" and "Human labor power... yielded no noticeable surplus as yet over the cost of its maintenance" (1978, p. 65). It was the adoption of agriculture and the surplus that it generated that triggered the transition from classless society to a class society in which the usurpation of labor surplus was the essential source of class division. These ideas were highly influential in subsequent theories of social evolution. According to Childe (1936), the transition to agriculture resulted in food surplus that enabled individuals to specialize in non-farming activities. This surplus, and the concomitant resort to trade, helped create political integration and led eventually to the formation of city-states under a state bureaucracy. Agricultural surplus was thus a precondition for the emergence of artisans and elite in urban centers.

[40] See Boehm (1999) for a review of the literature about this early transition to egalitarianism.

[41] The timing and location of the initial transition to agriculture in the fertile crescent are commonly explained as due to climatic changes that led to evolutionary modifications in plant species (and in particular to grasses with larger seeds, to cope with the extended summer drought) which facilitated the adoption of these grasses by humans foragers (Bar-Yosef and Meadow, 1995; Diamond, 1997). An alternative explanation contends that it was food shortage due to population pressure that led hunter-gatherers to engage in agriculture. Richerson, Boyd and Bettinger (2001, pp. 388-389) debunk this theory by employing a similar Malthusian argument to the one we use against the idea that population pressure led to the rise of hierarchy.

[42] Meek (1976) and Aspromourgos (1996) review the surplus theories up to Adam Smith and Karl Marx.

[43] In emphasizing the role of appropriable property among pastoralists, Adam Smith can be considered to have anticipated our appropriability theory. However, in the case of pastoralists he adopted a functionalist approach and emphasized that government became "necessary," rather than that it became possible. Moreover, when he turned to agriculture, he reverted to emphasize the role of surplus as generating a demand for government.

In an influential similar theory of human development, Lenski (1966) views societies as advancing due to technological progress, and Integrates functionalist and conflict approaches. He contends that the egalitarian hunter-gatherers could not produce a surplus, but with progressively more advanced farming technologies generated surplus of goods and services. Social "power" then emerged to "determine the distribution of nearly all of the surplus possessed by a society" (p. 44). In a more recent survey of the anthropological and archaeological literature on the emergence of inequality in the Ancient Near East, Price and Bar-Yosef (2010) reach a similar conclusion: "The success of early cultivation and the advantages afforded by the genetic mutations among plants and animals, allows for rapid increase in human population ... Cultivation also supported a stable economy with surplus that resulted in the formation of elite groups as predicted by Lenski" (1966, p. 160).[44]

Diamond's (1997) theory conforms to this conventional view. He illustrates his environmental explanation for current income disparities by comparing two groups of seafaring migrants in the Pacific whose ancestors were farmers. One group settled on an island whose environment forced them to revert to hunting-gathering, and "Since as hunter-gatherers they did not produce crop surpluses available for redistribution or storage, they could not support and feed non-hunting craft specialists, armies, bureaucrats, and chiefs." The other group landed on an island that was suitable for agriculture, and "With the crop surpluses that they could grow and store, they fed craft specialists, chiefs, and part-time soldiers." Diamond summarizes his theory by stating (p. 92): "In short, plant and animal domestication meant much more food ... The resulting food surpluses ... were a prerequisite for the development of settled, politically centralized, socially stratified, economically complex, technologically innovative societies." He then applies this logic to attribute the economic advantage of Eurasia over Africa, America and the Pacific to Eurasia's east-west orientation which enabled the exploitation of a greater variety of domesticated plants and animals and thus led to more productive agriculture.

Other theories for explaining the emergence of hierarchy

We are not the first to find fault with the surplus theory for the emergence of hierarchy. Others have already pointed out that an increase in productivity may be dissipated in various ways, without leading to any surplus. Pearson (1957) contended that cultural needs would evolve to eliminate

[44] In a review of the literature on "transegalitarian" North American societies of hunter-gatherers, Hayden (2001, p. 242) reaches a similar assessment: "With food production, in some favorable (productive) locations in the world, even greater levels of surplus production became possible. In these situations, social inequality could develop into even more extreme forms resulting in chiefdoms, states and empires." Associating the emergence of elite with "aggrandizing" activities, and associating these activities with the use of surpluses (p. 247), Hayden concludes: "the surplus-based political models have proved to be far more insightful and rich with more interesting explanations [of complexity and inequality] than other approaches" (p. 265).

any surplus. Sahlins (1972) argued that hunter-gatherers could easily procure food beyond their immediate needs, but deliberately refrained from doing so by preferring leisure. He infers that the first farmers could have responded to increased productivity similarly by working less hard, without producing any surplus. Sahlins thus concludes (p. 140): "Leadership continually generates domestic surplus," claiming (like us) that it was hierarchy that generated surplus and not vice versa. Sahlins, though, doesn't answer the key questions: what accounts then for the rise of leadership and why did its emergence correlate with agriculture?

Another influential theory poses that the increased productivity of agriculture accounts for the emergence of hierarchy, not directly, via the availability of surplus, but indirectly, through the resulting swell in population. Increased population density is claimed to have led to deterioration of living conditions and to fiercer competition over resources, violence and warfare. These adverse social developments are claimed to have necessitated the reorganization of society into ever more complex social forms, leading ultimately to the formation of the central state – see Johnson and Earle (2000). Carneiro's (1970) influential "circumscription theory," offers a variant of this population pressure and conflict argument. Motivated by the contrasting political structures that evolved in the valleys of Peru and in Amazonia, he proposed that states arise as a result of conflict over farming land among autonomous farming villages, when the winner is able to subjugate the losers and to extract from them ongoing surplus, due to the losers' geographic entrapment. In applying this theory, Carneiro contends (p. 735) that states could not emerge in the Amazon basin, in spite of the "almost unlimited agricultural land", because "the vanquished could flee to a new locale, subsisting there about as well as they had subsisted before, and retaining their independence." In contrast, "in Peru ... this alternative was no longer open to the inhabitants of defeated villages. The mountains, the desert, and the sea ... blocked escape in every direction."

Carneiro's puzzlement over limited social complexity in Amazonia is analogous to Diamond's similar concern with respect to New Guinea and the Pacific Islands. Yet the environmental theories that each of them offers are inconsistent with the geographical evidence that motivates the other. Diamond's theory about the advantage of an east-west orientation of a land-mass can hardly resolve Carneiro's comparison between Peru and Amazonia. And Carneiro's circumscription theory fails to resolve Diamond's concern about limited social complexity in the Pacific tropical islands. Our appropriability theory resolves the puzzles that motivated both scholars: whereas agriculture in the tropical Amazon and the Pacific islands was based on tuber crops, farming in the western valleys of the Andes relied mostly on maize.[45]

[45] The formation of Mayan state societies in the tropical lowlands of Mexico, where maize was first domesticated

Dow and Reed (2013) associate hierarchy with conflict over land. They suggest that hierarchy emerged after those who gained control over the most fertile farming land organized themselves in order to exclude outsiders, and to employ these outsiders as workers. Boix (2015) offers another variant of a conflict theory in which technological shocks associated with the transition to agriculture caused inequality between insiders, who were able to benefit from the new technologies, and outsiders. This inequality broke down the social order of statelessness and cooperation of earlier non-farming societies, and led outsiders to raid the more productive insiders. This led to the emergence of two types of states to protect the insiders: dictatorships by outside bandits who turned stationary (as proposed by Olson, 1993); or republics managed by the insiders. Dal Bó, Hernández and Mazzuca (2015) focus on how farmers' higher insecurity discourages investment, and how this "paradox of civilization" was resolved by the development of defense capacity.

Other theories invoke alternative functional explanations for the coincidence between the emergence of hierarchy and farming. One theory associates the emergence of hierarchy with social storage as a buffer for shortages. Halstead (1989) suggests that early farmers generated "normal surplus" above their subsistence needs in average years, as a precaution against years of shortage. The elite emerged as a "social storage agent," effectively serving as a mutual insurance agency, to coordinate and redistribute between surplus and deficit households.[46] Leaving aside the plausibility of the benevolence that this theory attributes to the elite, we note that this interpretation misses the point that storage of cereals was primarily and necessarily intra-annual, due to the seasonality of cereals.[47] Storage of cereals as an inter-annual buffer is feasible and plausible, but it is unlikely that such longer-term storage played a significant role among the earliest farmers who continued to forage alongside farming, or that it had a major role in triggering the emergence of hierarchy.

Another influential functional theory was articulated by Wittfogel (1957). He relied on evidence from the major civilizations of antiquity, to contend that strong despotic hierarchies were required in riverine environments in order to realize their agricultural potential through the construction and management of large irrigation projects. Wittfogel's many critics pointed out that irrigation projects in the early civilizations were constructed by local communities, prior to the emergence of

and became the staple crop, provides additional support for our theory on the preponderant importance of cultivating cereals rather than tubers for the emergence of hierarchy. The migration of domesticated maize from the northern hemisphere to South America (Piperno and Pearsall, 1998) provides an important counter-example to Diamond's claim on the lack of mobility of plant species across the equator.

[46] See also Johnson and Earle (2000, pp. 251-256, 301-302).

[47] Hayden (2001) questions the validity of the presumption that the elite altruistically provided such insurance services, remarking (p. 247) that he "was completely astonished ... that local elites provided essentially no help to other members of the community in times of crisis."

a strong central state, and that even after the emergence of such central states, the management of these irrigation systems remained with the local elites. But this critique fails to explain the source of the correlation that Wittfogel identified between irrigation and strong states. Mayshar, Moav, and Neeman (2014) suggest that the direction of causality may have been a reverse one: it is not that a need for irrigation led to a despotic state, but rather that irrigation systems enabled control and expropriation by the central state – in analogy to the interpretation here that the need to store food facilitated confiscation.

A third functional theory focuses on the demand for law and order to facilitate trade. On the basis of evidence from Africa, Bates (1983) argues that ecologically diverse environments increase the returns from trade and thus increase the demand for hierarchy.[48] Fenske (2014) and Litina (2014) provide evidence for this theory. We interpret their findings as consistent with our general appropriability approach, since trade also facilitates taxation. Our focus here, though, is on societies in which farming was the predominant potential tax base.

Finally, there exist also a growing number of scholars who, in Weber's spirit, challenge the conventional materialistic socio-economic explanations for the emergence of hierarchy and reverse the causal direction between agriculture and hierarchy. These scholars maintain that hierarchy, possibly in association with centralized religion, preceded agriculture and, in fact, led to agriculture. Cauvin (2000) argues that the willingness of hunter gatherers to abandon their traditional ways of life and engage in farming was conditioned by a prior change in collective psychology and with the rise of religion ("the birth of the Gods"). Acemoglu and Robinson (2012, pp. 139-142) suggest in that spirit that an institutional innovation among the semi-sedentary Natufians in the ancient Near East enabled a political elite to gain power and to extract resources from the rest of society. It is to this political elite that they attribute "the transition first to sedentary life and then to farming" (p. 140).

In suggesting that hierarchy was the cause of surplus, rather than its consequence, this theory resembles ours. However, it is diametrically different in that we seek to explain the emergence of hierarchical institutions, taking the transition to farming as given. As we argue, this does not mean that hierarchy lagged behind agriculture, for even the earliest phases of the transition to reliance on cereals – which involved the collection and storage of natural grains, prior to cultivation and domestication – implied a fundamental shift in the vulnerability to appropriation. It is this shift, we argue, which increased the efficacy of thievery and led to a rise of hierarchy, in parallel to the gradual development of cultivation, domestication, and increased productivity and population. As

[48] Algaze (2008) applies an analogous theory to explain the emergence of ancient Sumer.

noted, our approach has also the merit of accounting also for the emergence of hierarchy among pre-agricultural complex foraging societies, as well as for explaining the social differences between farming societies that rely on non-appropriable crops, and those that rely on appropriable crops (mainly cereals).

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Appendix C: Surplus and appropriation – the role of population

We develop here a simple model to illustrate our Malthusian critique of the surplus theory for explaining the rise of hierarchy following the Neolithic Revolution. In this model, when population size is exogenous, both an increase in the degree of appropriability and a rise in productivity (generating surplus) lead to larger net tax revenue as a share of output. However, when the population is endogenous, according to the Malthusian framework, an increase in appropriability raises the share of net taxes, while a rise in productivity does not.

Denote the total size of the farming population by N. The production function is assumed to be Cobb-Douglas:

$$Y = (AX)^{\alpha} N^{1-\alpha} = A^{\alpha} N^{1-\alpha},$$

where A denotes the level of technology, X is the constant size of land which we normalize to one, and $0 < \alpha < 1$.

We assume that the cost of taxing a share τ of total income Y is given by:

$$\frac{Y \cdot C(\tau, m)}{z},$$

where m represents per-capita surplus income. The parameter $z > 0$ represents the degree of appropriability, so that a higher z implies a lower cost of taxation. The function $C(\tau, m)$ is continuous and differentiable, and increasing and convex in the tax rate τ. ($C_1 \geq 0, C_{11} > 0$). In adapting the standard surplus approach, we assume that resistance to tax payment is lower the higher is surplus income. As a result, the cost of taxation is assumed to decrease in surplus income, or $C_2 < 0$. Surplus income is:

$$m = (1 - \tau) \left(\frac{A}{N} \right)^{\alpha} - s,$$

where s is subsistence income. The share of total net taxes out of total income, denoted by π, is:

$$\pi(\tau, m, z) = \tau - \frac{C(\tau, m)}{z}.$$

The government chooses the tax rate τ to maximize its net revenue $\Pi = \pi Y$. We assume the existence of an interior solution for the tax rate, τ^*, where the first and second order conditions are satisfied. Our aim is to examine how π is affected by changes in productivity A and in the degree of appropriability z.

C1. The case of a fixed population

Given our assumptions, when the population is constant, Y is independent of τ. The optimal tax rate τ^* thus maximizes π and satisfies the first order condition:

$$\frac{1}{z}\frac{dC(\tau, y)}{d\tau}\bigg|_{\tau=\tau^*} = \frac{C_1(\tau^*, m) - C_2(\tau^*, m)\left(\frac{A}{N}\right)^{\alpha}}{z} = 1.$$

Consider the effect of an increase in the appropriability parameter z. By the envelope theorem:

$$\frac{d\pi(\tau^*, m, z)}{dz} = \frac{\partial\pi(\tau^*, m, z)}{\partial z} = \frac{C(\tau^*, m)}{z^2} > 0.$$

Consider next the effect of an increase in productivity A. By a similar argument:

$$\frac{d\pi(\tau^*, m, z)}{dA} = \frac{\partial\pi(\tau^*, m, z)}{\partial m} \cdot \frac{dm}{dA} = -\frac{C_2(\tau^*, m)}{z} \cdot \frac{\alpha(m+s)}{A} > 0.$$

Thus, we have:

Proposition C1. *With a fixed population, both an increase in appropriability z and an increase in productivity A raise the share of taxes out of income π.*

C2. The case of Malthusian population

In a Malthusian setting the population size adjusts to keep agents' per capita surplus income m at zero. Thus:

$$N = \frac{(1-\tau)Y}{s}.$$

This implies:

$$Y = A\left(\frac{1-\tau}{s}\right)^{\frac{1-\alpha}{\alpha}} \equiv Y(\tau, A);\ m \equiv 0.$$

Denote:

$$\pi^*(\tau, z) \equiv \pi(\tau, 0, z) = \tau - \frac{C(\tau, 0)}{z}.$$

In this case, the tax rate has a negative effect on output through its effect on the size of the farming population N.

The optimal tax rate $\tau^* = \tau^*(z, A)$ maximizes $\Pi = \pi^*(\tau, z)Y(\tau, A)$. Our assumptions imply that it is implicitly defined by the first order condition:

$$F(\tau, z, A) \equiv Y(\tau, A)\frac{\partial\pi^*(\tau, z)}{\partial\tau} + \pi^*(\tau, z)\frac{\partial Y(\tau, A)}{\partial\tau} = Y\left(1 - \frac{C_1(\tau, 0)}{z}\right) - \pi^*(\tau, z)\, Y \frac{1-\alpha}{\alpha(1-\tau)} = 0.$$

Thus, at the optimum τ^*:

$$\frac{\partial \pi^* (\tau, z)}{\partial \tau} = -\frac{\pi^* (\tau, z)}{Y (\tau, A)} \cdot \frac{\partial Y (\tau, A)}{\partial \tau} = \pi^* (\tau, z) \cdot \frac{1-\alpha}{\alpha (1-\tau)} > 0.$$

In addition,

$$\frac{d\pi^* (\tau^* (z, A), z)}{dz} = \frac{\partial \pi^* (\tau^* (z, A), z)}{\partial \tau} \frac{d\tau^* (z, A)}{dz} + \frac{\partial \pi^* (\tau^*, z)}{\partial z} = \frac{\partial \pi^* (\tau^*, z)}{\partial \tau} \frac{d\tau^*}{dz} + \frac{C(\tau^*, 0)}{z^2}.$$

To prove that this expression is positive, it is sufficient to prove that $\partial \tau^* / \partial z$ is positive. By the Implicit-Function Theorem, for $F (\tau, z, A)$ defined above:

$$\frac{\partial \tau^*}{\partial z} = - \left. \frac{\partial F / \partial z}{\partial F / \partial \tau} \right|,$$

and by the second-order conditions: $\partial F / \partial \tau < 0$. Thus,

$$sign \left[\frac{\partial \tau^*}{\partial z} \right] = sign \left[\left. \frac{\partial F}{\partial z} \right| \right].$$

Now,

$$\frac{\partial F}{\partial z} = Y \cdot \frac{C_1 (\tau, 0)}{z^2} + \frac{C (\tau, 0)}{z^2} \cdot Y \cdot \frac{1-\alpha}{\alpha (1-\tau)} > 0.$$

Similarly,

$$\frac{d\pi^* (\tau^* (z, A), z)}{dA} = \frac{\partial \pi^* (\tau^* (z, A), z)}{\partial \tau} \frac{d\tau^* (z, A)}{dA}.$$

Once again by the Implicit Function Theorem: $sign \left[\frac{\partial \tau^*}{\partial A} \right] = sign \left[\left. \frac{\partial F}{\partial A} \right| \right]$. But

$$\frac{\partial F (\tau, z, A)}{\partial A} = \frac{\partial \pi^* (\tau, z)}{\partial \tau} \cdot \frac{\partial Y (\tau, A)}{\partial A} + \pi^* (\tau, z) \cdot \frac{\partial^2 Y (\tau, A)}{\partial \tau \partial A}.$$

Since $\frac{\partial Y(\tau,A)}{\partial A} = \frac{Y(\tau,A)}{A}$ and $\frac{\partial^2 Y(\tau,A)}{\partial \tau \partial A} = \frac{\frac{\partial Y(\tau,A)}{\partial \tau}}{A}$, we have:

$$\frac{\partial F (\tau, z, A)}{\partial A} = \frac{F (\tau, z, A)}{A}.$$

Since the first order conditions require $F (\tau, z, A) = 0$, it follows that $\frac{\partial \tau^*}{\partial A} = 0$ so that

$$\frac{d\pi^* (\tau^* (z, A), z)}{dA} = 0.$$

Thus, we have:

Proposition C2. *With Malthusian population, an increase in appropriability z raises the share of taxes in the economy π, but an increase in productivity A leaves that share intact.*

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Appendix D: Risk-Averse Farmers

In this appendix we illustrate the robustness of the model's qualitative predictions when farmers are risk averse. The results are in a sense even stronger, given that risk-averse farmers under anarchy seek more protection by choosing a smaller share of cereals. Farmers' risk aversion does not affect the analysis of the model under a regime of hierarchy since in this case the tax rate that the state imposes is certain. We chose to illustrate the case of anarchy with risk-averse farmers by examining a case where a simple analytic solution can be obtained. For that purpose, we employ the specification of the expropriation function, $\tau(\lambda) = \rho\sqrt{\lambda}$, as in the model's example, and consider the case where farmers have a log-utility function: $u(I) = \log(I)$. Farmers under anarchy thus chose $\beta \geq 0$ to maximize the expected utility:

$$U(I) = (1-\tau)\log(\beta + (1-\delta)(1-\beta)) + \tau \log(1-\delta)(1-\beta).$$

The solution is

$$\beta_A = \max\left\{\frac{\delta - \tau}{\delta}, 0\right\}.$$

Non-farmers' freedom to enter banditry implies: $s = \tau\beta/\lambda(\tau)$. And thus:

$$\tau_A = \frac{\rho^2 \beta_A}{s}.$$

Solving for the equilibrium values of (β_A, τ_A) yields (when $\beta_A > 0$):

$$\beta_A = \frac{s\delta}{\rho^2 + s\delta};\ \tau_A = \frac{\rho^2\delta}{\rho^2 + s\delta}.$$

Inspection of the equilibrium values of (β_A, τ_A) reveals that as δ tends to zero, both β_A and τ_A tend to zero. As δ increases towards one, τ_A approaches $\rho^2/(\rho^2 + s)$ and β_A approaches $s/(\rho^2 + s)$. This implies that even in the limit, when the productivity of tubers approaches zero, they are still grown by farmers.

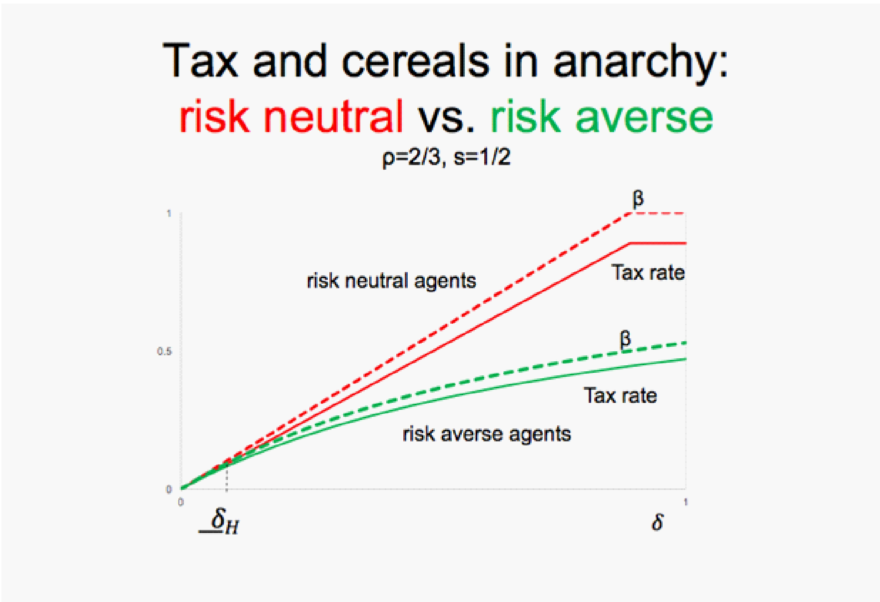
Compared to the model with risk neutrality (in the preceding sub-section), the introduction of risk aversion implies that farmers reduce the cultivation of cereals β_A, and increase the share of land devoted to tubers as a device for self-insurance. Consequently the confiscation rate τ_A is lower, and the measure of banditry λ_A is smaller as well.

While the former effect tends to increase overall inefficiency, the total efficiency effect of introducing risk aversion in a regime of anarchy is positive. To recall from corollary 1, under risk neutrality the overall inefficiency $(1-\beta_A)\,\delta + s\lambda_A$ is equal to δ. This is smaller than the inefficiency under risk aversion, which under our specification is equal to $(1-\beta_A)\,\delta + \lambda_A s = \delta - \beta_A\,(\delta - \tau_A) < \delta$. Correspondingly, the expected income of each farmer under anarchy is also higher under risk aversion, because

$(1-\tau_A)\,(\beta_A + (1-\delta)\,(1-\beta_A)) + \tau_A\,(1-\delta)\,(1-\beta_A) = 1-\delta+(\delta-\tau_A)\,\beta_A$ is equal to $1-\delta$ under risk neutrality, but is strictly larger under risk aversion because under risk aversion $\tau_A < \delta$. The reason for this is that under risk neutrality farmers in a mixed equilibrium are indifferent between growing cereals and tubers and so derive an identical income of $1-\delta$. In contrast, under risk aversion, farmers derive a strictly larger expected income from cereals to compensate for the risk associated with cereals, which pushes their expected income higher.[49] The figure illustrates the difference between the two types of equilibrium: the case of risk neutral farmers and risk averse farmers.

[49] This implies that risk neutral farmers would benefit if they could commit to grow less cereals in equilibrium, which we assume they cannot. The problem is that when a farmer decides how much cereal to grow, he ignores the negative externality this imposes on other farmers through contributing to the measure of bandits.

Figure E.1: Output: Anarchy vs. Hierarchy



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Appendix E: Additional Evidence

Table E.1: Descriptive Statistics

	SOURCE	Mean	p50	SDev	Min	Max	N
PANEL A: Societies in Ethnoatlas							
Hierarchy beyond Local Community	Ethnoatlas	1.89	2.00	1.04	1.00	5.00	1,059
Major Crop: Cereals	Ethnoatlas	0.54	1.00	0.50	0.00	1.00	1,092
Dependence on agriculture	Ethnoatlas	0.45	0.50	0.27	0.03	0.93	1,178
Farming surplus	Tuden and Marshall (1972)	0.49	0.00	0.50	0.00	1.00	162
Population density (categorical)	Pryor (1985)	3.83	4.00	1.57	2.00	7.00	168
Cal/ha Best Crop (std)	authors	0.00	0.23	1.00	-1.92	2.66	1,179
Cal/ha Cereals- Cal/ha Tubers (std)	authors	0.00	-0.13	1.00	-1.73	4.16	1,179
Precipitation (std)	FAO-GAEZ	0.00	-0.13	1.00	-1.39	10.65	1,179
Temperature (std)	FAO-GAEZ	0.00	0.37	1.00	-2.57	1.32	1,179
Elevation (std)	FAO-GAEZ	0.00	0.17	1.00	-9.24	3.58	1,179
Ruggedness (std)	FAO-GAEZ	0.00	-0.35	1.00	-0.90	6.41	1,179
Absolute Latitude (std)	Ethnoatlas	0.00	-0.43	1.00	-1.21	3.36	1,179
Distance to major river (std)	Fenske (2013)	0.00	-0.63	1.00	-0.63	1.58	1,179
Distance to coast (std)	Fenske (2013)	0.00	-0.30	1.00	-1.11	3.14	1,179
Pct Malaria	MAP	0.17	0.06	0.21	0.00	0.69	1,179
Population density 1995 (std)	FAO-GAEZ	0.00	-0.38	1.00	-0.62	7.23	1,161
Historical Population Density (std)	HYDE	0.00	-0.23	1.00	-0.30	25.85	1,179
plow Advantage (std)	FAO-GAEZ	-0.00	0.31	1.00	-2.83	2.61	1,179
% Fertile land	Ramankutty et al (2002)	-0.00	-0.03	1.00	-1.43	2.53	1,134
Caloric Suitability Index (std)	Galor and Ozak (2015)	0.00	0.28	1.00	-1.95	2.63	1,179
PANEL B: Countries X 50 years							
Hierarchy index	Borcan et al. (2014)	0.72	1.00	0.45	0.00	1.00	2,869
Cal/ha Best Crop (std)	authors	0.00	0.35	1.00	-1.64	2.69	2,959
Cal/ha Cereals- Cal/ha Tubers (std)	authors	0.00	-0.00	1.00	-1.49	3.12	2,959
Precipitation (std)	FAO-GAEZ	0.00	-0.29	1.00	-1.38	2.89	2,940
Temperature (std)	FAO-GAEZ	0.00	0.20	1.00	-2.68	1.52	2,884
Elevation (std)	FAO-GAEZ	0.00	-0.33	1.00	-1.10	4.65	2,845
Ruggedness (std)	Nunn and Puga (2012)	0.00	-0.31	1.00	-1.12	4.25	2,959
Absolute Latitude (std)	Nunn and Puga (2012)	0.00	-0.17	1.00	-1.51	2.18	2,959
Legal Origin: English common law	La Porta et al. (1999)	0.27	0.00	0.44	0.00	1.00	2,959
Legal Origin: French civil law	La Porta et al. (1999)	0.45	0.00	0.50	0.00	1.00	2,959
Legal Origin: Socialist law	La Porta et al. (1999)	0.22	0.00	0.41	0.00	1.00	2,959
Legal Origin: German civil law	La Porta et al. (1999)	0.03	0.00	0.18	0.00	1.00	2,959
Legal Origin: Scandinavian law	La Porta et al. (1999)	0.03	0.00	0.18	0.00	1.00	2,959
Population density 1500 (std)	Acemoglu et al. (2002)	0.00	-0.05	1.00	-2.96	2.78	2,959
Mortality of early settlers (std)	Acemoglu et al. (2002)	0.00	-0.11	1.00	-2.91	2.56	1,519
Slaves exported (std)	Nunn (2008)	0.00	-0.26	1.00	-0.26	9.01	2,959
Distance to major river (std)	www.pdx.edu/econ/	0.00	-0.29	1.00	-0.89	7.63	2,845
Distance to coast (std)	www.pdx.edu/econ/	0.00	-0.41	1.00	-0.75	4.48	2,845
Pct Malaria	MAP	0.65	0.94	0.41	0.00	1.00	2,883
% country with tropical climate (std)	Nunn and Puga (2012)	0.35	0.00	0.43	0.00	1.00	2,959
Caloric Suitability Index (std)	Galor and Ozak (2015)	0.00	0.29	1.00	-1.82	2.93	2,959

FAO GAEZ v3 database downloaded on 15/01/2016. std - a standardized variable that has been rescaled to have a mean of zero and a standard deviation of one.

Table E.2: Caloric content of cereals, roots and tubers

Crop	Energy	Crop	Energy
Barley	3.52	Sorghum	3.39
Buckwheat	3.43	Sweet Potato	0.86
Cassava	1.6	Wetland Rice	3.7
Foxtail Millet	3.78	Wheat	3.47
Indigo Rice	3.7	White Potato	0.77
Maize	3.65	Yams	1.18
Oat	2.46	Sorghum	3.39
Rye	3.38		

Values are in kilo calories per 100g. Source: Galor and Ozak (2015) and USDA Nutrient Database for Standard Reference (R25). The data source in table A1 is different, and therefore the caloric content reported there is slightly different as well.

Table E.3: Pairwise correlations of the main variables used in the empirical analysis on the societies in the Ethnoatlas

Variables	Hier.	Crop: cereals	Dep. agric.	Farm. surp.	Pop dens.	Cal/ha b. crop	Cer. -Tub.	% Fertile land	Caloric suit. ind.
Hierarchy	1.0								
Main crop: cereals	0.3	1.0							
Dependence agriculture	0.4	0.5	1.0						
Farming surplus	0.6	0.4	0.3	1.0					
Hist Pop density (Pryor)	0.6	0.5	0.7	0.4	1.0				
Cal/ha best crop	0.2	0.3	0.4	0.2	0.3	1.0			
Cereals-Tubers	0.2	0.4	0.3	0.3	0.2	0.8	1.0		
% Fertile land	0.2	0.2	0.3	0.2	0.3	0.4	0.5	1.0	
Caloric suitability index	0.2	0.3	0.5	0.2	0.3	1.0	0.8	0.5	1.0

Table E.4: Potential Crop Yields and Choice of Crops. Robustness checks: Controlling for Geography.

	Dep. Variable: Major crop is cereal grains (dummy)			
	(1)	(2)	(3)	(4)
CALORIC DIFF	0.214***	0.274***	0.248***	0.250***
(CER - TUB)	(0.057)	(0.054)	(0.059)	(0.059)
MAX CALORIES	-0.088	-0.174***	-0.132*	-0.133*
(ALL CROPS)	(0.067)	(0.064)	(0.069)	(0.070)
Precipitation	-0.058*			
	(0.031)			
Temperature		0.066**		
		(0.033)		
Elevation			0.030*	
			(0.017)	
Ruggedness				0.012
				(0.026)
CONTINENT FE	YES	YES	YES	YES
r2	0.367	0.364	0.362	0.359
N	982	982	982	982

The table reports cross-sectional OLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is a dummy that identifies societies that cultivate cereal grains as main crop. CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.5: Potential Crop Yields and Choice of Crops. Robustness checks: Controlling for Isolation, Population Density and the Plow.

	Dep. Variable: Major crop is cereal grains (dummy)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CALORIC DIFF	0.252***	0.250***	0.224***	0.254***	0.253***	0.261***	0.257***
(CER - TUB)	(0.058)	(0.060)	(0.061)	(0.059)	(0.059)	(0.071)	(0.049)
MAX CALORIES	-0.137**	-0.135*	-0.101	-0.139**	-0.136**	-0.222***	-0.205***
(ALL CROPS)	(0.067)	(0.069)	(0.071)	(0.069)	(0.069)	(0.086)	(0.061)
Major River	-0.028*						
	(0.017)						
Distance Coast		0.016					
		(0.035)					
Pct. Malaria			-0.348**				
			(0.167)				
Pop Dens 1995				-0.004			
				(0.025)			
Hist Pop Dens (HYDE)					-0.015		
					(0.016)		
Hist Pop Dens (PRYOR)						0.206***	
						(0.038)	
Plow Advantage							-0.148***
							(0.033)
CONTINENT FE	YES	YES	YES	YES	YES	YES	YES
r2	0.362	0.360	0.367	0.348	0.360	0.383	0.398
N	982	982	982	966	982	144	982

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.6: Cereals and Hierarchy - Reduced Form using generalized ordered logit

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community			
	Hierarchy<=1 vs Hierarchy>1	H<=2 vs H>2	H<=3 vs H>3	H<=4 vs H>4
CALORIC DIFF	0.327*	0.542***	0.674***	0.841**
(CER - TUB)	(0.173)	(0.172)	(0.230)	(0.407)
MAX CALORIES	0.0596	-0.392**	-0.485*	-0.597
(ALL CROPS)	(0.198)	(0.199)	(0.281)	(0.515)

The table reports the estimates from a generalized ordered logit. The unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.7: Cereals and Hierarchy - 2SLS. Robustness checks: Controlling for Geography.

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community			
	(1)	(2)	(3)	(4)
	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.911	0.750*	1.102**	1.071**
	(0.624)	(0.407)	(0.553)	(0.545)
MAX CALORIES	-0.008	0.051	-0.045	-0.039
(ALL CROPS)	(0.081)	(0.062)	(0.074)	(0.075)
Precipitation	-0.001			
	(0.001)			
Temperature		-0.248***		
		(0.072)		
Elevation			-0.069*	
			(0.039)	
Ruggedness				-0.008
				(0.050)
CONTINENT FE	YES	YES	YES	YES
N	952	952	952	952
F excl instrum.	49.13	83.83	74.16	74.51

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.8: Cereals and Hierarchy - 2SLS. Robustness checks: Controlling for Isolation, Population Density and the Plow.

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community					
	(1)	(2)	(3)	(4)	(5)	(6)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	1.073**	1.078**	1.021**	1.471*	0.992**	1.029**
	(0.519)	(0.545)	(0.504)	(0.811)	(0.472)	(0.453)
MAX CALORIES	-0.040	-0.038	-0.056	0.006	-0.085	0.080
(ALL CROPS)	(0.070)	(0.071)	(0.071)	(0.119)	(0.072)	(0.066)
Major River	0.122***					
	(0.038)					
Distance to Coast		-0.024				
		(0.058)				
Hist Pop Dens (HYDE)			0.211**			
			(0.102)			
Hist Pop Dens (PRYOR)				0.276		
				(0.192)		
Pop Dens 1995					0.290***	
					(0.048)	
Plow Advantage						0.259***
						(0.093)
CONTINENT FE	YES	YES	YES	YES	YES	YES
N	952	952	952	142	936	952
F excl instrum.	76.84	74.70	77.41	14.22	76.15	85

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.9: Cereals and Hierarchy - 2SLS. Robustness checks: Sample Including Societies Living in Desertic Soils.

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.712***	1.200***	0.831**	0.999***	0.313***	0.839***	1.180***	1.092***
	(0.0596)	(0.206)	(0.360)	(0.262)	(0.0703)	(0.273)	(0.322)	(0.284)
MAX CALORIES (ALL CROPS)			0.0667				-0.0489	
			(0.0520)				(0.0418)	
DEPENDENCE ON AGRICULTURE				0.327				-0.513
				(0.257)				(0.434)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	1059	1059	1059	1059	1059	1059	1059	1059
F excl instrum.		130.2	44.59	56.16		81.93	64.09	51.98
A-R Test (p-val)		0.000	0.0183	0.000		0.00163	0.000	0.000

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. All societies included in the Ethnoatlas, for which the relevant data are available, are included in the sample. "A-R Test" is the Anderson-Rubin test: the null hypothesis that the endogenous regressor is equal to zero. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.10: Cereals and Hierarchy - 2SLS. Robustness checks: Potential Calorie Yields Refer to Ethnic Boundaries in Fenske (2013)

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.707***	1.104***	0.752	0.872**	0.304**	0.839**	0.897**	0.898**
	(0.131)	(0.364)	(0.483)	(0.414)	(0.120)	(0.395)	(0.436)	(0.440)
MAX CALORIES			0.104				-0.015	
(ALL CROPS)			(0.099)				(0.060)	
DEPENDENCE ON				0.569				-0.225
AGRICULTURE				(0.520)				(0.892)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	952	942	942	952	952	942	942	942
F excl instrum.		156.3	55.98	52.60		120.1	88.82	20.90

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.11: Cereals and Hierarchy - 2SLS. Robustness checks: Controlling for Alternative Measures of Land Suitability for Agriculture

	Dependent variable:			
	Jurisdictional Hierarchy Beyond Local Community			
	(1)	(2)	(3)	(4)
	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	1.009***	0.723	0.867	1.121*
	(0.372)	(0.478)	(0.636)	(0.585)
% fertile land	0.073	0.057		
(Ramankutty et al. 2002)	(0.061)	(0.054)		
Caloric Suitability Index			0.081	-0.049
(Galor and Ozak, 2015)			(0.138)	(0.078)
CONTINENT FE	NO	YES	NO	YES
N	952	952	952	952
F excl instrum.	106.3	70.49	38.25	65.04

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. The excluded instrument is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. All societies included in the Ethnoatlas, for which the relevant data are available, are included in the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.12: Cereals and Surplus - OLS and 2SLS

	Dependent variable: Existence of a farming surplus							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP:	0.359***	0.940***	0.846***	0.846***	0.299***	1.005***	0.797**	0.799**
CEREALS	(0.0791)	(0.260)	(0.273)	(0.275)	(0.0901)	(0.316)	(0.314)	(0.317)
MAX CALORIES			0.0186				0.0361	
(ALL CROPS)			(0.0626)				(0.0611)	
DEPENDENCE ON				0.191				0.438
AGRICULTURE				(0.663)				(0.775)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	139	139	139	139	139	139	139	139
F excl instrum.		16.08	17.37	5.486		15.35	12.44	4.338

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.13: Cereals and Surplus - 2SLS. Robustness checks: Controlling for Geography.

	Dependent variable: Existence of a farming surplus			
	(1)	(2)	(3)	(4)
	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.686*	0.718**	0.855***	0.834**
	(0.385)	(0.284)	(0.329)	(0.327)
MAX CALORIES (ALL CROPS)	0.0567	0.0525	0.0211	0.00806
	(0.0722)	(0.0663)	(0.0639)	(0.0717)
Precipitation	-0.0546			
	(0.0727)			
Temperature		-0.0326		
		(0.0607)		
Elevation			-0.0934***	
			(0.0340)	
Ruggedness				-0.100
				(0.0637)
CONTINENT FE	YES	YES	YES	YES
N	139	139	139	139
F excl instrum.	9.260	17.77	12.12	12.20

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.14: Cereals and Surplus - 2SLS. Robustness checks: Controlling for Isolation, Population Density and the Plow.

	Dependent variable: Existence of a farming surplus					
	(1)	(2)	(3)	(4)	(5)	(6)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.736**	0.802**	0.732**	0.798**	0.825**	0.786***
	(0.318)	(0.319)	(0.324)	(0.312)	(0.327)	(0.283)
MAX CALORIES	0.0449	0.0358	0.0254	0.0333	0.0214	0.0395
(ALL CROPS)	(0.0594)	(0.0615)	(0.0584)	(0.0518)	(0.0603)	(0.0570)
Major River	0.0560					
	(0.0418)					
Distance to Coast		-0.00556				
		(0.0472)				
Hist Pop Dens (HYDE)			0.0689*			
			(0.0375)			
Hist Pop Dens (PRYOR)				0.0115		
				(0.0861)		
Pop Density 1995					0.0287	
					(0.0360)	
Plow Advantage						0.00735
						(0.0526)
N	139	139	139	139	137	139
CONTINENT FE	YES	YES	YES	YES	YES	YES
F excl instrum.	11.05	11.87	10.51	14.08	10.75	16.75

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.15: Cereals and Surplus - OLS and 2SLS. Robustness checks: Potential Calorie Yields Refer to Ethnic Boundaries in Fenske (2013).

	Dependent variable: Existence of a farming surplus							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.359***	0.909***	0.894***	0.846***	0.299***	0.953***	0.845**	0.864***
	(0.0791)	(0.274)	(0.297)	(0.275)	(0.0901)	(0.318)	(0.336)	(0.303)
MAX CALORIES			0.00286				0.0196	
(ALL CROPS)			(0.0657)				(0.0657)	
DEPENDENCE ON				0.191				0.210
AGRICULTURE				(0.663)				(0.723)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	139	138	138	138	139	138	138	138
F excl instrum.		15.52	17.23	5.486		16.90	13.56	4.786

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.16: Cereals and Surplus - OLS and 2SLS. Robustness checks: Sample Including Societies Living in Desertic Soils.

	Dependent variable: Existence of a farming surplus							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.368***	0.630***	0.871***	0.871***	0.294***	0.657**	0.814***	0.821***
	(0.0733)	(0.220)	(0.279)	(0.283)	(0.0849)	(0.260)	(0.300)	(0.316)
MAX CALORIES (ALL CROPS)			-0.0368				-0.0215	
			(0.0501)				(0.0473)	
DEPENDENCE ON AGRICULTURE				-0.362				-0.244
				(0.488)				(0.540)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	161	161	161	161	161	161	161	161
F excl instrum.		18.58	17.37	14.46		19.68	14.27	7.531
A-R Test (p-val)		0.00711	0.000	0.000		0.0109	0.00391	0.00191

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. All societies included in the Ethnoatlas, for which the relevant data are available, are included in the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.17: Cereals, Surplus and Hierarchy - 2SLS. Robustness Checks: Different Measures of Soil Suitability for Agriculture.

	Dependent variable: Existence of a farming surplus			
	(1)	(2)	(3)	(4)
	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	1.168***	1.270***	0.878***	0.843**
	(0.368)	(0.419)	(0.303)	(0.354)
% fertile land	-0.0819	-0.0844		
(Ramankutty et al. 2002)	(0.0574)	(0.0590)		
Caloric Suitability Index			0.0124	0.0285
(Galor and Ozak, 2015)			(0.0671)	(0.0652)
CONTINENT FE	NO	YES	NO	YES
N	139	139	139	139
F excl instrum.	8.528	10.39	14.30	10.30

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is either Murdock's (1967) index of jurisdictional hierarchy beyond the local community or a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. The excluded instrument is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. All societies included in the Ethnoatlas, for which the relevant data are available, are included in the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.18: Cereals and Hierarchy - Panel Regressions. Robustness checks: Excluding Colonies

	Dep. Variable: Hierarchy Index						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CALORIC DIFF	0.128*	0.186**	0.230***	0.162**	0.182**	0.178**	0.135*
(CER - TUB)	(0.0660)	(0.0786)	(0.0735)	(0.0816)	(0.0857)	(0.0788)	(0.0772)
MAX CALORIES		-0.111	-0.179	-0.0997	-0.0884	-0.0879	-0.115
(ALL CROPS)		(0.136)	(0.131)	(0.136)	(0.138)	(0.134)	(0.119)
Controls (x Year FE):							
Precipitation	NO	NO	YES	NO	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO	NO
Elevation	NO	NO	NO	NO	YES	NO	NO
Ruggedness	NO	NO	NO	NO	NO	YES	NO
Abs Latitude	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES	YES
r2	0.773	0.774	0.789	0.774	0.770	0.777	0.786
N	2414	2414	2398	2365	2329	2414	2414

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The dependent variable is a dummy that identifies those countries characterized by a supra-tribal government. CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. The sample excludes those cells 50yearsXcountry in which countries were either colonies or protectorates. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.19: Cereals and Hierarchy - Panel Regressions. Robustness checks: a Different Measure of Hierarchy

	Dep. Variable: Government above tribal level						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CALORIC DIFF	0.188***	0.270***	0.280***	0.235***	0.252***	0.259***	0.192**
(CER - TUB)	(0.0683)	(0.0835)	(0.0758)	(0.0855)	(0.0890)	(0.0840)	(0.0791)
MAX CALORIES		-0.159	-0.189	-0.150	-0.110	-0.145	-0.161
(ALL CROPS)		(0.140)	(0.131)	(0.138)	(0.142)	(0.138)	(0.122)
Controls (x Year FE):							
Precipitation	NO	NO	YES	NO	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO	NO
Elevation	NO	NO	NO	NO	YES	NO	NO
Ruggedness	NO	NO	NO	NO	NO	YES	NO
Abs Latitude	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES	YES
r2	0.672	0.674	0.707	0.677	0.673	0.677	0.699
N	2869	2869	2850	2812	2755	2869	2869

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The dependent variable is a dummy that identifies those countries characterized by a supra-tribal government. CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.20: Cereals and Hierarchy - Panel Regressions. Robustness checks: a Different Measure of Soil Suitability for Agriculture

	Dep. Variable: Hierarchy Index						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CALORIC DIFF	0.189***	0.272***	0.282***	0.240***	0.255***	0.261***	0.197**
(CER - TUB)	(0.0683)	(0.0834)	(0.0760)	(0.0857)	(0.0889)	(0.0839)	(0.0795)
Caloric Suitability Index		-0.163	-0.193	-0.152	-0.115	-0.148	-0.165
		(0.141)	(0.131)	(0.139)	(0.142)	(0.138)	(0.123)
Controls (x Year FE):							
Precipitation	NO	NO	YES	NO	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO	NO
Elevation	NO	NO	NO	NO	YES	NO	NO
Ruggedness	NO	NO	NO	NO	NO	YES	NO
Abs Latitude	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES	YES	YES	YES
r2	0.680	0.682	0.716	0.684	0.681	0.686	0.705
N	2869	2869	2850	2812	2755	2869	2869

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The dependent variable is an hierarchy index: it equals 0 if there is not a government above tribal level, 0.75 if the political organization can be at best described as a paramount chiefdom and 1 otherwise. CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. Caloric Suitability Index is a measure of potential caloric yields of the soil developed by Galor and Ozak (2015). Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table E.21: Cereals and Hierarchy - Panel Regressions. Robustness Checks: Excluding Years 1500-1750

	Dep. Variable: Hierarchy Index						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CALORIC DIFF	0.198***	0.272***	0.282***	0.235***	0.249***	0.260***	0.190**
(CER - TUB)	(0.0720)	(0.0889)	(0.0811)	(0.0912)	(0.0946)	(0.0892)	(0.0846)
MAX CALORIES		-0.145	-0.176	-0.140	-0.0889	-0.130	-0.148
(ALL CROPS)		(0.149)	(0.140)	(0.146)	(0.150)	(0.146)	(0.129)
Controls (x Year FE):							
Precipitation	NO	NO	YES	NO	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO	NO
Elevation	NO	NO	NO	NO	YES	NO	NO
Ruggedness	NO	NO	NO	NO	NO	YES	NO
Abs Latitude	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES	YES
r2	0.711	0.712	0.743	0.715	0.711	0.716	0.735
N	2416	2416	2400	2368	2320	2416	2416

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The dependent variable is an hierarchy index: it equals 0 if there is not a government above tribal level, 0.75 if the political organization can be at best described as a paramount chiefdom and 1 otherwise. CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Figure E.1: Farming surplus in pre-colonial societies

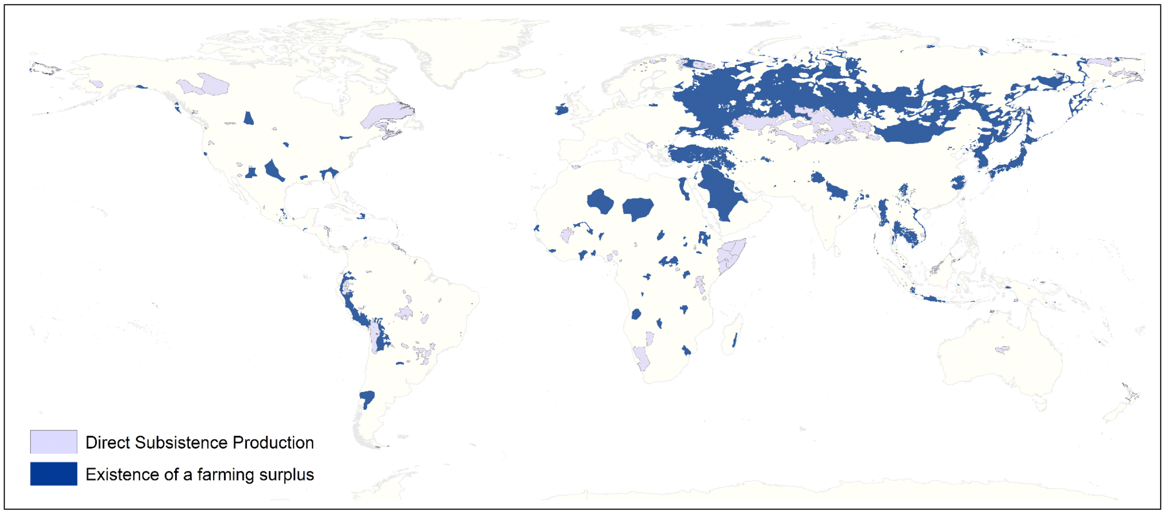

Figure E.2: Potential yields (calories per hectare) from cereal grains.

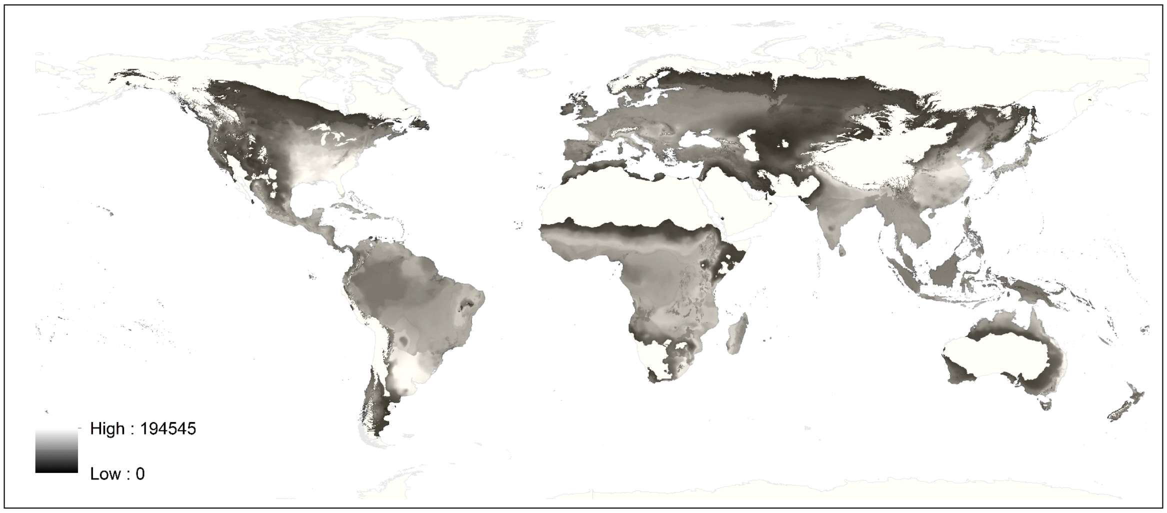

Figure E.3: Potential yields (calories per hectare) from roots and tubers

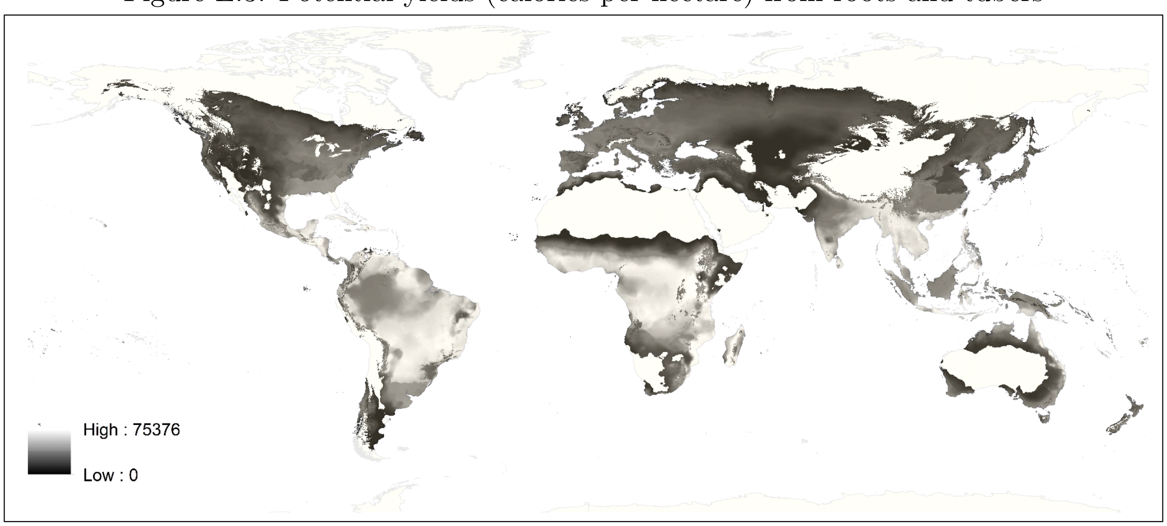

Figure E.4: Optimal crop in terms of caloric yields among cereals, roots and tubers