The Origin of the State: Land Productivity or Appropriability?

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The conventional theory about the origin of the state is that the adoption of farming increased land productivity, which led to the production of food surplus. This surplus was a prerequisite for the emergence of tax-levying elites and, eventually, states. We challenge this theory and propose that hierarchy arose as a result of the shift to dependence on appropriable cereal grains. Our empirical investigation, utilizing multiple data sets spanning several millennia, demonstrates a causal effect of the cultivation of cereals on hierarchy, without finding a similar effect for land productivity. We further support our claims with several case studies.

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I. Introduction

Following the Neolithic Revolution—our ancestors' transition from hunting-gathering to sedentary farming—complex hierarchical societies emerged, leading eventually to the rise of tax-levying states. The Neolithic transition raises intriguing, fundamental questions: What are the mechanisms by which the adoption of agriculture led to complex hierarchies and states? Why did states emerge in some regions but not in others, despite the adoption of agriculture? And why have some states failed to develop significant state capacity?

The prevailing theory traces back to Adam Smith and earlier scholars. It holds that following the adoption of farming, complex social hierarchies emerged as a result of increased food output. Specifically, high output generated a surplus (food in excess of farmers' subsistence needs), which was a prerequisite for the rise of an elite that taxed farmers and supported bureaucrats, troops, and other specialists who did not engage in food production. According to this conventional productivity theory, regional differences in land productivity explain regional disparities in the development of hierarchies and states.

However, there are regions in the world where complex hierarchies did not emerge, even after the adoption of productive agriculture that increased food output. The common feature of many of these regions is that the staple crops that were cultivated were not cereals but mainly roots and tubers. As Scott (2017, 21) puts it, "It is surely striking that virtually all classical states were based on grain. . . . History records no cassava states, no sago, yam, taro, plantain, breadfruit, or sweet potato states."[1]

Cereal grains can be stored and, because they are harvested seasonally, have to be stored so that they can be drawn on for year-round subsistence. The relative ease of confiscating stored cereals, their high energy density, and their durability enhance their appropriability, thereby facilitating the emergence of tax-levying elites. Roots and tubers, in contrast, are typically perennial and do not have to be reaped in a particular period, and once harvested they are rather perishable.[2]

We challenge the conventional productivity theory, contending that it was not an increase in food production that led to complex hierarchies

[1] In distinguishing between cereals and other crops that are not storable, without questioning the conventional productivity-and-surplus theory, as we do, Scott (2009, 2017) follows Taylor (1973) and Testart (1982a, 1982b, 1982c). Taylor, in fact, proposed that the Neolithic Revolution ought to be called the "storage revolution."

[2] Moreover, roots' and tubers' high water content hampers the efficient transportation of their nutritional content. In app. A (apps. A–F are available online), we describe the characteristics of roots and tubers. We show that their portability is hindered by both their vulnerability to spoilage and their bulkiness (due to ca. 70% moisture content). We also support the claims that (1) reliance on roots and tubers is a major phenomenon in many regions, (2) roots and tubers are highly productive in these regions, (3) their harvest is in general nonseasonal, and (4) after harvest they are significantly more perishable than cereals.

and states but rather the transition to reliance on appropriable cereal grains that facilitated taxation by the emerging elite. It follows from our critique that it is primarily differences in land suitability for different crops that account for regional disparities in the developmental trajectory of hierarchies and states, rather than differences in land productivity per se.

In challenging the claim that the emergence of hierarchy was a result of high farming productivity, we also contest that surplus is the mechanism that links productivity to taxes. We illustrate our argument with the following scenario. Consider a farming society that subsists on a cereal grain that has to be harvested within a short period and then stored for year-round consumption. A tax collector could confiscate part of the stored grain and transport it for consumption by distant elite and other non–food producers, even if there is no food surplus. One might worry that ongoing confiscation would lead to a shrinking population and eventually eliminate the source of income for the elite. However, because of diminishing average product of labor, the smaller population would produce higher output per farmer. This would result in an equilibrium with a stable population in which total output exceeds the farming population's subsistence needs, with the surplus confiscated by the nonfarming elite.[3]

We concur with the conventional productivity theory to the extent that in hierarchical societies farmers produce a surplus. Our contention is that surplus is not a prerequisite for the emergence of a tax-levying elite; it is rather that once the opportunity to appropriate arises, the elite generates the food surplus on which it can flourish. This simple hypothetical scenario demonstrates that the availability of surplus is not a precondition for taxation and hierarchy, as argued by the conventional productivity theory.

To further illustrate our critique, consider now an early society that cultivates cassava. Cassava is a perennial root that can be harvested year-round but rots shortly after harvest. This makes it difficult to confiscate and practically impossible to transport for use by a distant elite. It is thus unlikely that a complex hierarchy could emerge in this society, even if a food surplus is available. This scenario suggests that had the Neolithic Revolution amounted solely to a transition to the cultivation of perishable food sources, the increase in productivity would not have led to the emergence of complex hierarchy.

Moreover, we propose that increased output is unlikely to generate a surplus, as conventional theory asserts.[4] This is simply inconsistent with

[3] If the tax-levying elite provides farmers with protection from bandits, the emerging state is not expected to negatively affect the size of the farming population.

[4] Other scholars have already pointed out that an increase in productivity may be dissipated in various ways without creating surplus. Pearson (1957) contends that cultural needs would evolve to eliminate any surplus. Sahlins (1972) argues that hunter-gatherers, too, could have procured food beyond their subsistence needs but deliberately refrained from doing so by preferring leisure. He infers that the first farmers could have similarly responded to increased

the Malthusian mechanism.[5] Improved hunting techniques and the accumulation of knowledge led to increased productivity over time among hunter-gatherers, too. That increase was apparently converted to larger population size rather than to sustainable surplus, leaving hunter-gatherers in small, egalitarian societies without complex hierarchies. Since the Neolithic Revolution spanned several millennia (Purugganan and Fuller 2011), one could expect that this gradual increase in productivity would also have been absorbed by increased population.

The conventional theory fails to explain why the adoption of agriculture is different from productivity growth among hunter-gatherers, but this disparity is easily explained by the appropriability theory. Hunter-gatherers relied on hand-to-mouth food sources, which are not easily appropriable, and therefore did not develop hierarchies even when their productivity increased.

We propose that when it became possible to appropriate crops, a taxing elite emerged and that this led to the state. We note that stored cereals are appropriable not just by a would-be elite but also by bandits—therefore, their cultivation generated a demand for protection and at the same time facilitated taxation to finance the supply of such protection by the elite.[6] Accordingly, we propose that the protection of food stockpiles and hierarchy emerged in parallel to the gradual transition to reliance on appropriable food sources. However, even though the elite provided protection, it does not follow that they were benign; our theory requires neither benign nor self-serving motivations on their part. As Olson (1993) observed, deterring bandits served both the farmers and the elite.[7]

In appendix D, we present a formal model that focuses on the possibility of a state emerging and deterring bandits (which provides one specific interpretation of our general thesis). In our model, farmers allocate their land between tubers, which cannot be looted or taxed, and cereals, which can be taxed by the elite at a cost of employing tax collectors or looted by unorganized bandits. The productivity of the two crops differs across geographic locations. Farmers choose to cultivate cereals only in locations where their productivity advantage over tubers is sufficiently high to compensate for the loss due to taxation or looting. We distinguish between

productivity by working less hard. But he does not explain why they failed to do so or what accounts for the rise of hierarchy following the adoption of agriculture.

5 Ashraf and Galor (2011) provide empirical support for the applicability of Malthus's theory in the preindustrial era.

6 If the elite/state deters bandits, then the population is likely to be larger with a state than without one (see the model in app. B), unlike our simple scenario described above, in which we abstract from bandits.

7 The role of banditry as posing a significant threat to farmers and as provoking a basic need for protection is often raised (e.g., Mann 1986, 48 and McNeill 1992, 85). We do not provide any evidence in our empirical analysis for the role of bandits, but we note that for our main thesis the question of the existence of bandits is irrelevant.

two regimes. In "anarchy," there is no protection against looting. The number of bandits is determined endogenously, so that their average revenue from theft is equal to the alternative productivity in foraging. Under "hierarchy," there is a net revenue–maximizing elite that commits to its selected rate of taxation of cereals and provides farmers with full protection from bandits. A state can exist only if its tax revenue covers the fixed cost of deterring bandits.

The main prediction of this model is that a state can exist only if cereals are sufficiently more productive than tubers. This result illustrates our main claim that it is the magnitude of the productivity advantage of cereals over tubers, rather than high agricultural productivity per se, that determines whether hierarchy emerges. The model also suggests that even though the elite is self-serving, whenever hierarchy exists it dominates anarchy in terms of farmers' welfare. Anarchy is more distortionary than hierarchy for two reasons.[8] First, the state's ability to commit to a lower tax rate encourages the cultivation of cereals when these are sufficiently more productive than tubers. Second, the net revenue–maximizing state employs tax collectors only up to the point where their marginal tax revenue equals their wage (which we assume to equal the alternative income from foraging) and thus employs (weakly) fewer tax collectors than the equilibrium number of bandits under anarchy.

In our empirical section (sec. II), we test for the root cause of the emergence of hierarchy: Is it land productivity or appropriability?[9] Our research question does not allow for one perfect randomized controlled trial that could prove or disprove our thesis. We therefore perform multiple imperfect tests based on different data sets. We present our empirical analysis in four subsections, each using a different data set that measures hierarchical complexity.

Section II.B is based on Murdock's (1967) *Ethnographic Atlas*, which covers cultural, institutional, and economic features of more than 1,200 precolonial societies from around the world. Our main outcome variable is the level of hierarchical complexity, which we regress on a dummy that identifies societies that rely on cereal grains for their subsistence. Since the choice of the main crop might depend on hierarchy, we instrument for the cultivation of cereals by the potential productivity advantage of cereals over roots and tubers in a rain-fed subsistence economy, calculated from the land-suitability data provided by the Food and Agriculture Organization

[8] We ignore here the possibility that the nonbenevolent state may contribute further to farmers' welfare if it contributes directly to agricultural productivity, e.g., through publicly provided irrigation infrastructure.

[9] We cannot test empirically for the direction of a causal effect between hierarchy and surplus, which are correlated according to both the productivity and appropriability theories. But we do provide some evidence, when data permit, that it is appropriability, and not productivity, that causes surplus.

(FAO). Consistent with the appropriability theory, the two-stage least squares (2SLS) estimates show that cultivating cereals has a considerable positive effect on hierarchical complexity. Moreover, and consistent with our criticism of the conventional theory, our analysis fails to show any positive effect of land productivity on hierarchy, while it shows that societies based on roots or tubers display levels of hierarchy similar to those of nonfarming societies. Finally, for a subset of the sample for which data are available, we also find that societies growing cereals are characterized by more burdensome taxation. These results hold when we control for land productivity.

The results based on the *Ethnographic Atlas* are not conclusive. First, because of the cross-sectional nature of the data, we cannot exclude potential omitted geographic factors that might be driving the 2SLS results (though we do control for a large set of potential confounders). Second, the *Ethnographic Atlas* is not a random sample of societies, and it is biased toward relatively isolated societies with relatively low levels of hierarchy. Third, the data pertain mainly to the eighteenth and nineteenth centuries, a long time after the early transition to farming.

To overcome these limitations, in section II.C we employ a data set on hierarchy compiled by Borcan, Olsson, and Putterman (2018). This data set is based on the present-day boundaries of 159 countries, with institutional information every half-century. We can run only reduced-form regressions with this data set, because of the lack of information about the prevalent crop over the same time span in these regions. We first look at the classical age—the earliest period in human history for which detailed data on the location of large states are available. For the year 450 CE (just before the collapse of the Roman Empire), qualitative results are consistent with those obtained using the data from the *Ethnographic Atlas* described above: we document a significant positive correlation between the productivity advantage of cereals (proxied with the FAO data) and state presence. Moreover, once the productivity advantage of cereals is controlled for, the correlation between land productivity and hierarchy disappears.

The FAO data are based on modern yield predictions. To overcome any concerns about relevance to earlier periods, in collaboration with the Global Crop Diversity Trust we have developed a data set on the distribution of wild relatives (WRs) of domesticated crops (i.e., wild plants that are genetically related to cultivated crops). The number of WRs of a certain domesticated crop in a region proxies for the potential for the domestication of that crop in that region. Therefore, as Diamond (1997) argued, the presence of more WRs is an indication of higher land productivity. Our cross-sectional regressions using the WR data suggest that the key for hierarchy is the combination of availability of cereal grains and no availability of an alternative root or tuber. Thus, in contrast to the conventional productivity theory, we show that where less appropriable productive crops are available, hierarchy does not emerge. The analysis accounts for a large set of possible confounding factors, but we cannot rule out that unobservable characteristics that are systematically correlated with the availability of different crops might be driving our results.

To alleviate this concern, we focus on the past millennium and exploit the "Columbian Exchange" of crops between the New World and the Old World as a natural experiment. The exchange introduced new crops that, as predicted by FAO data, changed both land productivity and the productivity advantage of cereals over roots and tubers in most countries in the sample. Consistent with the appropriability theory and with our critique of the productivity theory, the panel regressions confirm that the productivity advantage of cereals over roots and tubers had a positive impact on hierarchical complexity, while land productivity did not.

Section II.D gets us closer to the Neolithic transition and is based on cross-section data from various sources on the location of ancient cities and archeological sites (e.g., pyramids, ancient temples, palaces, and mines), which presumably indicate social hierarchy. With these data, we employ three different cross-sectional approaches to test the appropriability and productivity theories. First, using the WR data and following the same approach described above for classical states, we obtain the same qualitative results: the availability of WRs of domesticated cereal grains and lack of availability of WRs of domesticated roots or tubers explain a significant part of the variation in the different indications of hierarchy in all the archeological data sets, for data spanning various periods of antiquity.

As an alternative to the WR proxy for crop availability, we utilize data on the location of centers of origin of agriculture. We show that distance from these centers has a negative impact on the development of early civilization only if the center domesticated cereals. Finally, using the FAO-based data, we find that the cultivation of cereals, unlike land productivity, can explain the distribution of ancient cities and other indications of hierarchy. Although results are robust to a large number of confounders, a limit of this data set is that it is cross sectional.

We overcome this limitation in section II.E, in which we use data from the *Archaeological Atlas of the World* (Whitehouse and Whitehouse 1975). Although this source was published more than 40 years ago, it has the advantage of providing radiocarbon estimates dating various archaeological sites, enabling us to count the number of pre-Neolithic and post-Neolithic sites in each area. The difference-in-differences estimates support the appropriability theory. Specifically, we find that the Neolithic transition led to more traces of indications for complex hierarchical societies only in areas where agriculture was more likely to start with cereals, on the basis of our three proxies explained above (WRs of domesticated crops, proximity to areas of domestication, and FAO productivity data). We find no evidence for the conventional productivity theory using these data.

In summary, our empirical analysis provides repeated evidence that the cultivation of cereals had a significant causal effect on the development of complex hierarchies and states, consistent with the appropriability theory. It also shows that the correlation between land productivity and hierarchy disappears when the cultivation of cereals is controlled for, consistent with our critique of the conventional productivity theory. Moreover, the finding that it is unlikely that complex hierarchies would emerge when productive roots and tubers are available supports both the appropriability theory and the critique of the productivity theory. It is consistent with the prediction that farmers would prefer, when practically possible, to cultivate less appropriable crops that protect from bandits and tax collectors. Complex hierarchies, the data suggest, emerged when farmers were constrained to cultivating cereals.

In section II, we discuss other potential concerns regarding the data and the identification. As mentioned above, we acknowledge that none of our empirical investigations provides full proof for our thesis. However, we contend that the robustness of our results is sufficient to cast doubt on the prevailing productivity-and-surplus explanation for the emergence of hierarchy and, pending further studies, to favor the appropriability explanation.

Our empirical analysis, presented in section II, does not identify the mechanism that links cereal cultivation and complex hierarchy. In section III, we present five case studies that are consistent with the appropriability theory. Nonetheless, the properties of cereals that render them appropriable could give rise to other mechanisms that are also consistent with the evidence. For example, increasing returns to scale in the construction of storage facilities, which are required where cereals are the staple food source, may have contributed to early communal storage under leaders. Moreover, communal storage and redistribution across both time and individuals provide better food security and might require leadership to organize. In addition, the durability and transportability of cereals may have had a role in promoting trade, which increases the return to public goods such as law and order and requires leadership for their provision.

Finally, our model in which cereals attract bandits is related to various conflict theories, which are also consistent with our main finding: storage of appropriable cereals increases the return to attacks and makes it easier for the winners of a conflict to extract ongoing surplus from the losers. The review of the extensive literature on the rise of hierarchy and states is in section IV, so that we can discuss it in the context of our empirical findings and case studies. We offer a few concluding remarks in section V.

II. Evidence I: Empirical Investigation

In this section, we report the results of our empirical tests. We describe the data in section II.A and present our various empirical exercises and findings, using four different data sets on hierarchy and statehood, in sections II.B–II.E.

A. Data

1. Ethnographic Data

Murdock's (1967) *Ethnographic Atlas* (or *Ethnoatlas*) presents a database of 1,267 societies from around the world. The database contains information on cultural, institutional, and economic features of these societies, before they experienced any significant industrialization.[10] The sample is global, with an emphasis on North American and African societies. We removed from the sample two duplicate observations, seven societies observed before 1500 CE, and 10 societies for which the year of observation is missing, leaving 1,248 societies. These are matched to ethnic maps using either the geocoordinates of each ethnicity provided by the *Ethnoatlas* or maps of the spatial location of ethnicities constructed by Fenske (2013).[11]

We use the variable Hierarchy (i.e., "jurisdictional hierarchy beyond the local community") as a measure of hierarchical complexity.[12] This is an ordered variable with five possible levels: (1) no political authority beyond community, (2) petty chiefdoms, (3) larger chiefdoms, (4) states, and (5) large states. We plot this measure of hierarchy in figure 1 and present the summary statistics in the first row of table F.1 (tables A.1 and F.1–F.44 are available online). Most of our sample is composed of societies that lack any political integration above the local community or of small districts ruled by chiefs. These societies prevail in North America, Australia, and Central Africa but are rare in northern Africa and in Asia, where large chiefdoms and states are more common.

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 2, with summary data in rows 2 and 3 of table F.1. Figure 2 shows that approximately one-fifth of the societies in the sample do not practice any form of agriculture. These societies are concentrated in western North America, central Asia,

[10] The focal year of the data is pre-1800 for 3% of the societies, the nineteenth century for 25%, the first half of the twentieth century for 69%, and the second half of the twentieth century for just 2.5%. The remaining societies are missing a focal year. Figure F.1 (figs. D.1, D.2, and F.1–F.12 are available online) reports the density plot of the year that the data refer to for the different societies.

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

[12] Gennaioli and Rainer (2007) and Michaelopoulos and Papaioannou (2013) make similar use of this variable.

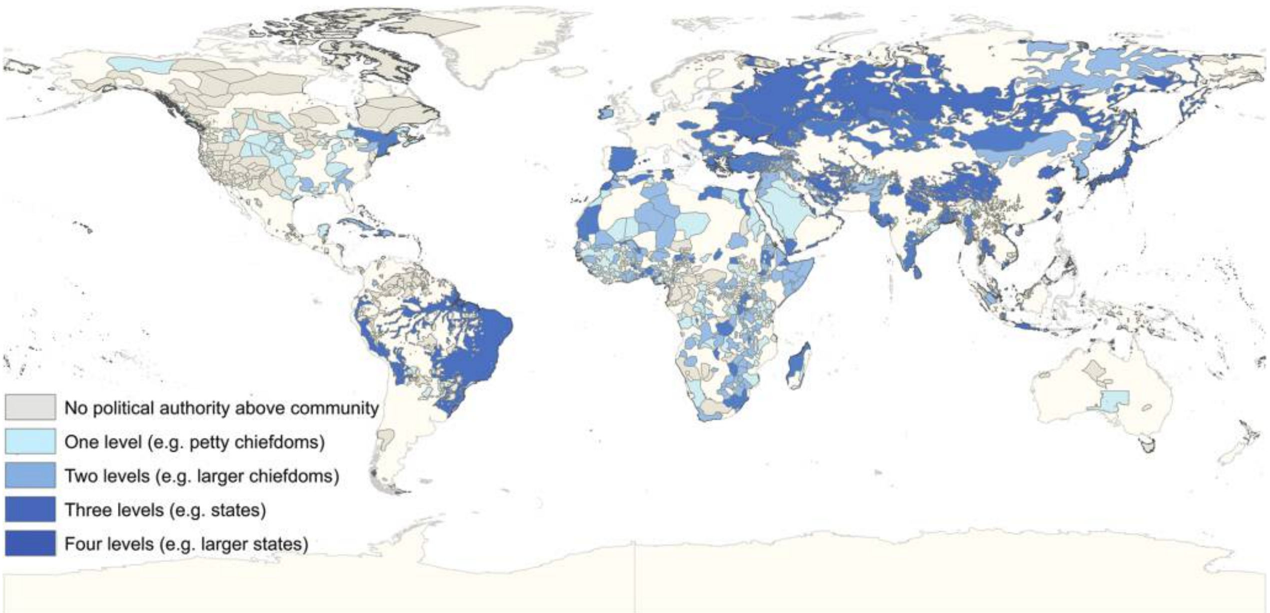

FIG. 1.—Jurisdictional hierarchy beyond the local community in preindustrial societies.

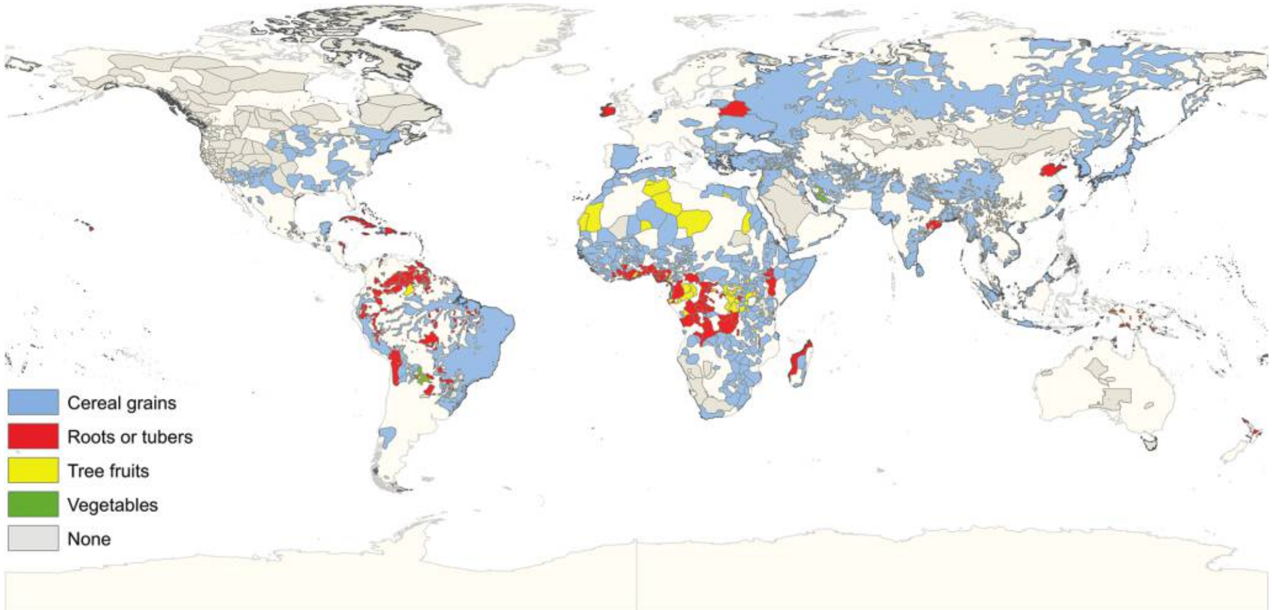

FIG. 2.—Major crops in preindustrial societies.

Australia, and southwestern 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%) or roots and tubers (26.1%). Using this information, we define a dummy that identifies societies whose primary crop is cereals and present summary statistics in the second row of table F.1. The *Ethnoatlas* also provides data on the use of domestic animals. On the basis of this information, we create three dummy variables (rows 4–6 in table F.1). The first dummy identifies societies that rely on some form of animal husbandry; the second dummy identifies societies in which domesticated ruminants are the most relevant animal husbandry, and the third dummy identifies societies that use animals for cultivation.

The second source of data we use is a derivative of the *Ethnographic Atlas*, provided by the Standard Cross-Cultural Sample (SCCS). The data are based on a representative sample, defined by Murdock and White (1969), of 186 societies from the *Ethnoatlas*. Different authors coded the SCCS societies for many different characteristics. Cumulative ethnographic codes and codebooks are published in the electronic journal *World Cultures*. We use three variables from the SCCS (rows 7–9 in table F.1). The first variable, coded by Tuden and Marshall (1972), lists the local elite's sources of political power. We create a dummy for "the existence of a farming surplus" that is 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 F.2. The second variable refers to the "extent of burden caused by tribute payments or taxation," coded by Lang (1998). On the basis of his work, we create a variable that captures the tax burden on members of these societies. We code this variable as 0 if there is no evidence of tribute or taxation, 1 if there is evidence of sporadic taxation or the taxes are reported not to be burdensome, and 2 if there is evidence of regular or burdensome taxation. The third variable is a measure of population density coded by Pryor (1985). Societies are categorized into six bins (the first bin contains societies with 0–1 persons per square mile, and the last contains societies with 500 or more persons per square mile).

Table F.5 reports pairwise correlations between the variables of the 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, higher tax burden, and more dense populations.

2. Country-Level Data

We constructed a hierarchy index using data from Borcan, Olsson, and Putterman (2018). The data cover the area of 159 modern-day countries for every half-century 50 to 2000 CE. A score of 1 is assigned if there is a government above the tribal level in that area, 0.75 if there is a chiefdom, and 0 if there is no authority above the tribe. We merge these data with information on the legal origin of the country (from La Porta et al. 1998), population density in 1500 (Acemoglu, Johnson, and Robinson 2002), mortality of early settlers (Acemoglu, Johnson, and Robinson 2001), the number of exported slaves (Nunn 2008), climate and latitude (Nunn and Puga 2012), genetic diversity (Ashraf and Galor 2013), the density of locally available wild animals suitable for domestication (Hibbs and Olsson 2004; Ashraf and Galor 2011),[13] the potential for irrigation (Bentzen, Kaarsen, and Wingender 2017), and the colonial history of each country (Pascali 2017). Figure F.3 shows the colonial history of each country, and table F.2 provides summary statistics for these variables.

3. Location of Ancient Cities and Archaeological Sites

To capture differences in hierarchical complexity farther back in time, we collected data on the location of ancient cities. We use two different sources of information. The first is Reba, Reitsma, and Seto (2016), which provides data on the location of urban settlements from 3700 BCE to 2000 CE. The data set is based on historical, archaeological, and census-based urban population data previously published in tabular form by Chandler (1987) and Modelski (2003). Figure F.4 shows ancient settlements (founded before 500 BCE), while figure F.5 shows classical settlements (founded before 450 CE). The second source is the website developed by Daniel DeGroff,[14] which provides the list of cities and towns that were founded before 400 CE. We also use archaeological evidence indicating ancient complex civilizations, collected from miscellaneous sources. These references are included in the appendix.[15]

[13] This variable is computed by dividing the number of wild terrestrial mammals, which are believed to have been domesticated prehistorically for herding, by the area of the country. These are the ancient ancestors of sheep, goats, cattle, horses, pigs, Bactrian camels, Arabian camels, llamas, yaks, Bali cattle, reindeer, water buffaloes, donkeys, and mithuns. Both Hibbs and Olsson (2004) and Ashraf and Galor (2011) exclude neo-European countries from the data set. We have therefore complemented their data set with new data we collected on Australia, Canada, New Zealand, and the United States, using Nowak (2011) as our primary source.

[14] https://sites.google.com/site/ancientcitiesdb.

[15] Data on archaeological sites from the ancient world come mainly from Ancient locations.net. Sites are included if they existed before 476 CE (end of the Western Roman Empire) in the Old World and before 1492 in the New World. The data are complemented with archaeological data from the Megalithic Portal (https://www.megalithic.co.uk/), a web community with input from thousands of photographers and archaeologists. Ruins are classified according to 57 categories, which allows us to distinguish the effect of cereals and land productivity on different archaeological evidence of complex societies, such as pyramids, mines, temples, and palaces, from their effect on other types of evidence (e.g.,

We aggregate data on the location of cities and archaeological ruins at the 1×1–decimal degree raster level. The first 10 rows of panel A in table F.3 present descriptive statistics on the number of cities and relevant archaeological ruins in each terrestrial raster point.

4. Radiocarbon-Dated Prehistoric Archaeological Sites

Whitehouse and Whitehouse's (1975) *Archaeological Atlas of the World* provides a database of the most relevant global prehistoric and protohistoric archaeological sites known at that time. This atlas includes 4,215 sites that are radiocarbon dated.[16]

We georeference these sites and, using the information in the map titles and accompanying text, classify them according to whether or not they predate the Neolithic transition in that location. The result is a list of 825 sites that belong to pretransition years and 3,309 sites that belong to the posttransition years. (We exclude eight sites for which either georeferencing was not possible or dates were uncertain and 73 sites for which we were uncertain about whether they belong to the pre- or posttransition years.)

We compute the number of pre-Neolithic sites and post-Neolithic sites at the 1×1–decimal degree raster level.[17] In the empirical analysis, we either use all sites or, alternatively, only sites of prehistoric settlements. Panel B of table F.3 presents the descriptive statistics for these variables.

5. Soil-Suitability Data

For data on land productivity and the farming of cereals, we use detailed spatial data on the suitability of soil for different crops from the Global Agro-Ecological Zones (GAEZ) project of the FAO. The data provide global estimates of potential crop yields for different crops with a cell size of $5' \times 5'$ (i.e., approximately 100 km^2) based on two possible categories

standing stones) that are perhaps less indicative of complex hierarchies. The portal initially categorized archaeological ruins in Great Britain and only recently extended to cover the entire world. As a result, it oversamples Europe. We therefore exclude types of ruins that are found only in Europe and its surroundings and always show the robustness of our regressions when excluding Europe.

[16] Although this database is approximately 40 years old, Bakker et al. (2018, 43) conclude that "although there has been much additional excavation in the intervening period, there is little reason to believe that it is unrepresentative for the broad coverage of sites and locations."

[17] The atlas classifies these sites according to 10 different categories: (1) undifferentiated sites and find-spots, (2) settlements, (3) funerary monuments, (4) religious monuments, (5) caves and rock shelters, (6) cave art and rock reliefs, (7) hoards and votive deposits, (8) mineral sources, (9) mineral workings, and (10) sites that combine several of the above 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 agroecological constraints, which could potentially reflect human intervention, and one is based on agroclimatic conditions, which are arguably unaffected by human intervention. To preempt concerns of reverse causality, we consider potential yields based on agroclimatic conditions under rain-fed low-input agriculture.

The GAEZ project provides data on potential yields, in terms of tons per hectare per year, for 11 cereal grains and four roots and tubers. Following the same procedure as in Galor and Özak (2016), we transformed tons to calories, using data provided by the US Department of Agriculture's National Nutrient Database for Standard Reference,[18] and find the crop with the highest potential caloric yields for each raster point (we report the results in fig. F.9). Cereal grains are the highest-yielding crops in approximately 99% of the raster points in the sample, while roots and tubers are optimal in a few very small areas in Siberia, eastern Brazil, and Central–East Africa.[19] From these data we construct two measures: the productivity of land, measured as the maximum potential caloric yield per hectare, and the productivity advantage of cereals over roots and tubers, measured as the difference between the maximum caloric yield of cereals and the maximum caloric yield of roots or tubers. The latter measure is captured in figure 3.

As robustness checks, we exploit two alternative measures of the productivity of the land, which have been widely used in the literature. The first is an index developed by Ramankutty et al. (2002), which measures the fraction of land that is suitable for agriculture. The second is a caloric suitability index developed by Galor and Özak (2016), which captures the highest attainable potential caloric yields from 48 crops (including sugar crops, pulses, oil crops, vegetables, fruits, fiber crops, and stimulant crops, in addition to cereals, roots, and tubers). Table F.5 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 Galor and Özak's caloric suitability index (0.8). We also 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

[18] See table F.4 for the complete list of cereal grains, roots, and tubers used in sec. II and the corresponding caloric content.

[19] Calculating the "net" potential caloric yield of each crop would require additional data on the caloric cost of cultivating it and procuring eventual complementary inputs. To the best of our knowledge, these data are not available. Although, ideally, we would have preferred to work with net yields, we show in the next subsection that gross yields are still a good predictor of the crop choice.

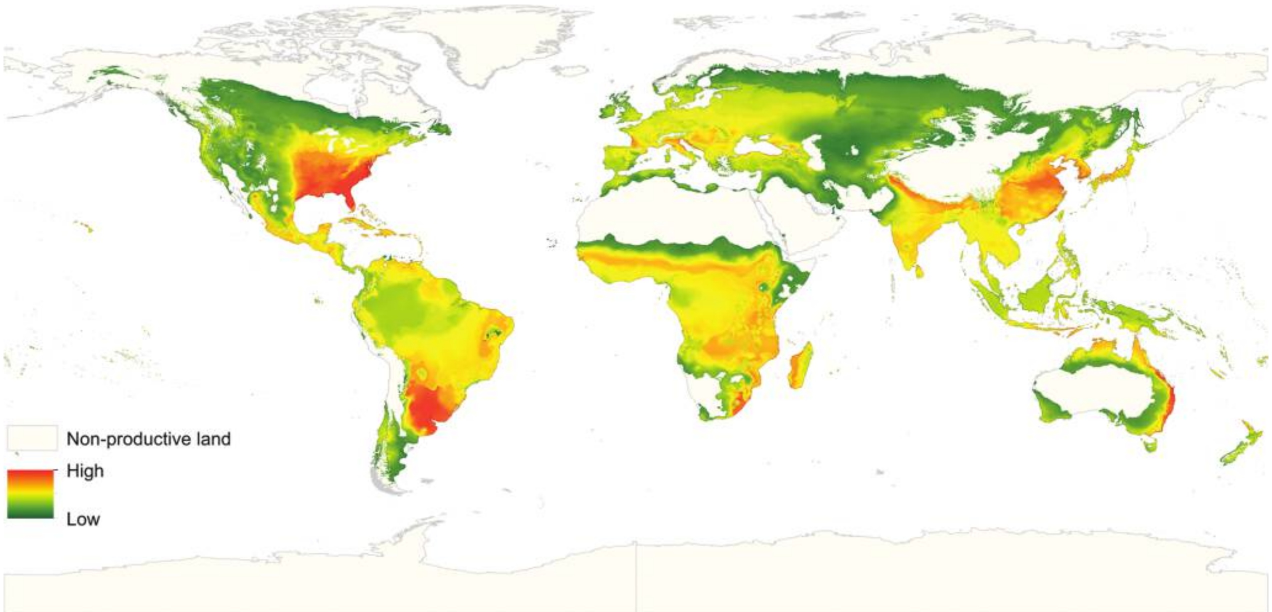

FIG. 3.—Difference in potential yields (calories per hectare) of cereals versus roots and tubers.

(2013) identify as “plow-positive” (wheat, barley, and rye) and that of crops that they identify as “plow-negative” (sorghum, foxtail millet, and pearl millet).

These productivity variables are attributed to the different societies in the *Ethnoatlas* by taking an average of their values within a 20-mile radius around the geocoordinates reported in the *Ethnoatlas*.[20] They are attributed to countries and the 1×1–decimal degrees raster squares by averaging them within these boundaries.

6. WRs of Domesticated Crops

We use resources from the Global Crop Diversity Trust for the potential distribution of WRs of domesticated crops.[21] Crop WRs are the wild plants that are genetically related to cultivated crops (i.e., in the same way that the wolf is related to the dog). Consider, for example, *Oryza rufipogon*, a wild species that grows in Southeast Asia. Rice originated from this plant, which was probably domesticated in China and India around 8,000–9,000 years ago (Callaway 2014). We concentrate on wild plants in the primary gene pool of a domesticated crop: the wild plants that can be directly mated with the relevant domestic crop. We assembled a data set of their potential geographical distributions.[22] For our empirical analysis, we assume that the number of primary WRs of a domestic crop in a certain region proxies for the potential for domestication of that crop in that region. From the data on the potential geographic distribution of these primary WRs, we computed the number of primary WRs of cereals and the number of WRs of roots and tubers in each raster point in our data. Appendix E lists all the domesticated crops in the data set and their WRs. As detailed in that appendix, data on the potential distribution of a limited number of WRs are missing. We constructed a map of the world, dividing areas in which only WRs of cereals are available, areas in which only WRs of roots and tubers are available, and areas in which WRs of both cereals and roots and tubers are available. The results are presented in figure 4, which

[20] In the app. F.4, 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).

[21] We thank Nora Castañeda-Álvarez for sharing the data with us and for her invaluable help.

[22] The maps of the potential distribution of WRs are provided by the Global Crop Diversity Trust and are available to download at https://www.cwrdiversity.org/distribution-map/. They are constructed with Maxent—a machine-learning algorithm for modeling the distribution of species—using a database of georeferenced occurrence records (Castañeda-Álvarez et al. 2016) and a grid database of 27 edaphic, geophysical, and climatic variables (Vincent et al. 2019). The MaxEnt algorithm is used to compute a probability distribution, determining for each grid cell a predicted suitability for each of the WR species. Under particular assumptions about the biological sampling efforts that led to the occurrence records, a predicted probability of presence is obtained for each cell.

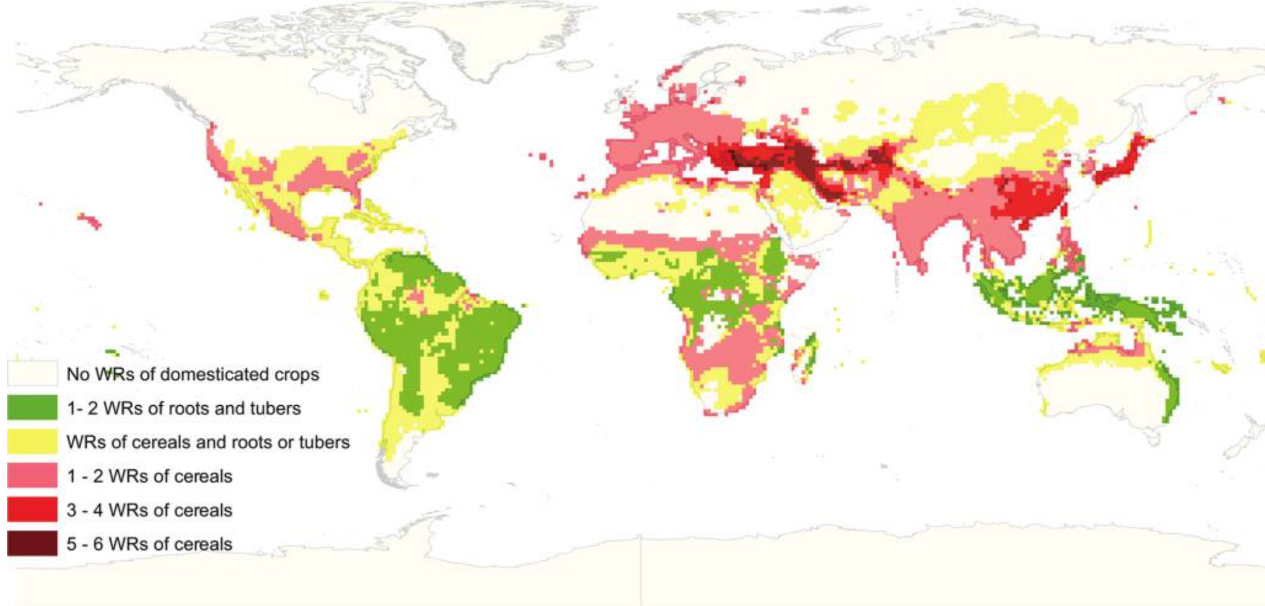

FIG. 4.—Distribution of wild relatives (WRs) of domesticated cereals, roots, and tubers.

shows that the number of WRs can easily predict patterns of early domestication. For instance, the largest number of WRs of cereals are found in the Fertile Crescent, the first region in the world to adopt agriculture and the cradle of the first civilizations.

7. Other Historical, Demographic, and Geographic Data

Larson et al. (2014) provide data on the 20 centers in which domestication of at least one plant or animal most likely took place and the list of domesticates in each of these areas (see fig. F.6). We use these data to compute the distance of each raster point in the archeological data set to the closest region of independent adoption of agriculture and to the closest region of independent domestication of cereal grains. Descriptive statistics on these two variables are reported in rows 16 and 17 in table F.3.

In addition, data on population density in 1995, precipitation, and temperature come from GAEZ, the Global Digital Elevation Map (GDEM) provides raster data on elevation and ruggedness, and the History Database of the Global Environment (HYDE) provides raster data on global estimates of population density between 1500 and 2000. These data are averaged within societies in the *Ethnoatlas*, countries, and 1×1–decimal degree raster points.

B. Preindustrial Societies: 2SLS Estimates

The appropriability theory posits that the cultivation of cereals had a causal effect on the emergence of hierarchies. In this subsection, we test this prediction with the preindustrial societies data, surveyed in Murdock's (1967) *Ethnographic Atlas*. In appendix F.2, we report the determinants of the crop choice in these societies. As expected, cereal grains are cultivated in areas where they are naturally more productive than roots and tubers. Below, we report the findings from 2SLS regressions that study the impact of cultivating cereals and land productivity on hierarchical complexity. We use the productivity advantage of cereals over roots and tubers as an instrument for the cultivation of cereals. We find that the cultivation of cereals leads to more complex hierarchies, while land productivity does not. We further document that cereal cultivation leads to a more burdensome tax system and to the formation of an elite that does not derive its livelihood from subsistence activities.

1. Cereals and Hierarchy

According to the appropriability theory, cereal-based agriculture led to more complex hierarchies. To test this prediction with the *Ethnographic Atlas* data, we estimate a regression of the form

$$Y_i = \alpha_1 \text{CerMain}_i + \alpha_2 \text{LandProd}_i + X_i'\beta + u_i, \quad (1)$$

where Y_i is a measure of hierarchy in society i, CerMain_i is a dummy variable that identifies societies that rely mainly on cereals for their subsistence; LandProd_i is a measure of land productivity, and X_i' is a vector of control variables.[23]

This specification, however, raises two concerns. First, the choice of crop might be influenced by social institutions. To overcome this reverse-causality concern, we exploit variations in potential, rather than actual, crop yields, which are derived from agroclimatic conditions that are presumably orthogonal to human intervention. Specifically, we run 2SLS regressions, where we instrument for CerMain_i by using the productivity advantage of cereals, CerAdv_i (i.e., the difference between the maximum potential caloric yield of cereals and that of roots or tubers under a rain-fed subsistence agriculture). The first stage is then

$$\text{CerMain}_i = \beta_1 \text{CerAdv}_i + \beta_2 \text{LandProd}_i + X_i'\beta + \varepsilon_i. \quad (2)$$

We construct the caloric-advantage-of-cereals measure using the procedure detailed in section II.A.5, under the assumption that the Columbian Exchange of crops between the Old World and the New World was completed and all continents had access to all major crops in our data.[24] The variables LandProd_i and CerAdv_i are based on productivity estimates for different crops, which are constructed from agroclimatic conditions that are unaffected by human intervention. These estimates capture potential productivity under rain-fed subsistence agriculture and not actual productivity. This is an important distinction, as actual productivity is likely to depend on factors that are endogenous to local hierarchy.

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 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 mitigates this concern. In two of the following subsections, we utilize an alternative data set to conduct panel regressions that alleviate concerns regarding potential time-invariant omitted variables.

In the appendix, we report the reduced-form relationship. First, figure F.10 presents the box plot of the productivity advantage of cereals

[23] To correct for spatial autocorrelation of the error term, we estimate the standard errors in three different ways: we allow either for clustering at the country level or for spatial autocorrelation with a distance cutoff of 5 or 10 decimal degrees. Results are consistent across the three choices. In the appendix, we report only the most restrictive choice (autocorrelation with 10–decimal degree cutoff).

[24] This is a reasonable assumption, as the great majority of the societies in the *Ethnoatlas* are captured between the end of the nineteenth century and the beginning of the twentieth century.

corresponding to each level of hierarchy: the productivity advantage of cereals is generally larger in societies organized as states than in societies organized as either chiefdoms or tribes. Table F.9 reports the reduced-form estimates. Column 1 shows a significant correlation between (potential) land productivity and the level of jurisdictional hierarchy in the societies in the *Ethnoatlas*, as predicted by the conventional productivity-and-surplus theory. Column 2 illustrates a significant correlation between the productivity advantage of cereals and hierarchy, as predicted by the appropriability theory. Once both regressors are included (col. 3), the effect of the productivity advantage of cereals remains positive and significant and the effect of land productivity disappears. Specifically, an increase of 1 standard deviation in the productivity advantage of cereals increases the hierarchy index by 0.27. The qualitative nature of this result is unchanged when using a logit or a generalized logit rather than OLS to estimate the reduced form.[25]

Table 1 reports the OLS and 2SLS estimates of equation (1), 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. The 2SLS estimates are presented in the next five columns. Panel A reports the second-stage estimates, while panel B reports the first-stage estimates. In the latter, an increase in the productivity advantage of cereals over roots and tubers by 1 standard deviation is associated with an increase in the probability of growing cereals as the main crop by about 20%. Reassuringly, the *F*-statistic on the excluded instrument is between 49.3 and 75.9 (depending on the methodology to estimate the standard errors), and the instrument alone is able to explain 13% of the variation in CerMain_i. Appendix F2 provides a detailed discussion of the first-stage relationship with a long list of robustness checks and additional results on the effect of geography on the decision to farm.

Turning to the second stage, the baseline 2SLS estimates predict that cultivating cereals as the main crop increases the hierarchy measure by more than 1 (col. 2), which is equivalent, for instance, to a move from a

[25] Table F.10 reports the estimates from an ordered logit model (col. 1) and a generalized ordered logit model (cols. 2–5) to account for the ordinal nature of the dependent variable. The estimates reported in col. 1 show that a 1–standard deviation increase in the productivity advantage of cereals increases the log odds of being in a higher level of hierarchy by approximately 50%. This estimate is based on the assumption of proportional odds (i.e., each independent variable has an identical effect at each cumulative split of the ordinal dependent variable). Columns 2–5 present the estimates of a generalized logit model, which relaxes the assumption of proportional odds. 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 of 1 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%, it increases the log odds of being in a level higher than a chiefdom by 65% and those of being in a level higher than a small state by 84%. In all cases, the impact of land productivity is either very small and not statistically significant or negative.

TABLE 1
Cereals and Hierarchy: OLS and 2SLS

	Dependent Variable: Jurisdictional Hierarchy beyond Local Community					
	OLS (1)	2SLS (2)	2SLS (3)	2SLS (4)	2SLS (5)	2SLS PDS (6)
	A. Second Stage					
CerMain	.707	1.170	.892	1.064	.830	.797
	{.114}***	{.352}***	{.447}**	{.556}*	{.554}	{.378}**
	[.097]***	[.292]***	[.352]**	[.459]**	[.426]*	. . .
	(.131)***	(.359)***	(.420)**	(.538)**	(.511)	
LandProd				−.037		. . .
				{.086}		
				[.067]		
				(.071)		
Dependence on agriculture					.259	. . .
					{.544}	
					[.398]	
					(.478)	
Continent fixed effects	No	No	Yes	Yes	Yes	. . .
Observations	952	952	952	952	952	877
F-statistic[a]		{52.15}	{33.13}	{13.06}	{20.38}	{16.11}
		[74.90]	[52.50]	[29.20]	[37.83]	
		(49.34)	(34.76)	(19.70)	(23.18)	
R^2	.113					
	B. First Stage					
CerAdv		.209	.155	.258	130	.256
		{.029}***	{.027}***	{.071}***	{.068}***	{.063}***
		[.024]***	[.021]***	[.047]***	[.021]***	
		(.029)***	(.026)***	(.059)***	(.027)***	

Note.—The table reports cross-sectional OLS, 2SLS, and 2SLS PDS estimates, and the unit of observation is the society in Murdock's (1967) *Ethnoatlas*. Panel A reports the main estimates, while panel B reports the first-stage estimates (only the estimated coefficient of the excluded instrument). Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors in curly brackets are clustered at the country levels; standard errors in square brackets and parentheses are adjusted for spatial correlation using the methodology in Conley (1999), with a distance cutoff of 5 and 10 decimal degrees, respectively.

[a] *F*-statistic on the excluded instrument.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the <1% level.

tribe to a small chiefdom or from a large chiefdom to a state. We note that the 2SLS coefficient on cereals is larger than the OLS one.[26] In column 3, we show that results are qualitatively unchanged when adding

[26] There could be two explanations. First, the measurement error in the cereal variable is likely to downwardly bias the OLS estimates. Second, and more important, while OLS estimates describe the average difference in hierarchy between societies cultivating cereals

continent fixed effects. Column 4 adds land productivity as a control variable. Consistent with the reduced-form regressions, land productivity does not have any significant effect on hierarchical complexity. Column 5 includes a control for the dependence of the society on agriculture. Results indicate that societies that practice agriculture are not characterized by more complex hierarchies unless they cultivate cereals.

The 2SLS results in table F.11 survive a battery of robustness checks, which we discuss in detail in appendix F.4. We provide here a brief summary. In table F.11, we control sequentially for precipitation, temperature, elevation, ruggedness, and latitude/longitude—the main geographical factors affecting crop productivity. In table F.12, we control sequentially for geographical isolation, historical population density, potential for intensive irrigation, and the productivity advantage of the plow—the main factors that political scientists and economists have associated with the rise of complex hierarchies. Finally, table F.16 adds sequentially controls for animal husbandry and animal use in agriculture to confirm that our results are not just capturing the role of animal domestication in the development of the state.

Column 6 in table 1 reports the estimation results when adding all the controls mentioned above—including the continent fixed effects—at the same time, in a post-double-selection (PDS) 2SLS methodology.[27] The estimated coefficient for $\mathrm{CerMain}_i$ is still positive and statistically significant, although somewhat smaller compared to the coefficient estimated without this long list of controls.[28]

and the rest, the instrumental variable (IV) estimates measure the effect of growing cereals only for societies whose choice of crop is affected by the instrument—the potential caloric advantage of cereals over roots and tubers (this is the local average treatment effect). This is relevant, as there are several societies, especially on islands and in the most remote areas of the world, for which the choice of the crop is dictated by their availability and not by their potential caloric advantage over other crops. To understand whether this might be responsible for the lower OLS coefficients, compared to the IV coefficients, we reestimate the first two columns of table 3 only for societies living in areas in which WRs of both cereals and roots/tubers are present. The result is that the OLS estimates are now larger than the IV estimates. Specifically, in the regression without controls, the OLS coefficient on cereal cultivation is 1.23, while the IV coefficient is 1.11.

[27] This methodology is used for estimating structural parameters in linear models with many controls. A square-root lasso (least absolute shrinkage and selection operator) is used to identify the relevant controls in predicting the dependent variable, the main regressor, and the instrument. The union of the variables selected from these reduced forms is then included in the 2SLS estimates. See Belloni, Chernozhukov, and Hansen (2014) for details. We use for estimation the Stata package pdslasso (Ahrens, Hansen, and Schaffer 2019). As far as we know, there is no previous study in which the PDS methodology has been used in conjunction with Conley's standard errors (and no available routine in any statistical software to do so). We therefore provide only standard errors clustered at the country level when using PDS.

[28] The PDS procedure produces a consistent estimate only for the main variable of interest and not for the controls. Therefore, we do not report in col. 6 the coefficient on land productivity, though it is included in the controls.

Finally, the qualitative results are maintained (the coefficient varies between 0.750 and 1.471) when using ethnic boundaries, as defined by Fenske (2013), to extract data on crop productivity (table F.14), when the sample includes societies living in desertic soils (table F.13), or when using either the Ramankutty et al. (2002) index of fertile land or the Galor and Özak (2016) index of caloric suitability as alternative measures of land productivity (table F.15).

2. The Appropriability Mechanism: Evidence on Taxation and Farming Surplus

In this subsection, we show that the cultivation of cereals is correlated with the existence of a farming surplus and with a tax burden (both variables are described above), as consistent with the appropriation mechanism. Reduced-form estimates are reported in table F.17. In columns 1–4, the correlation between the productivity advantage of cereals over roots and tubers (indicating that cereals are the staple crop) and the presence of a farming surplus is positive and statistically significant. This is true in both OLS and logistic regressions, and the result is robust to the inclusion of continent dummies. Land productivity is not statistically correlated with the presence of a farming surplus (cols. 2–4). In columns 5–8, we show that the productivity advantage of cereals is also positively correlated with the burden of local taxes. This correlation is generally statistically significant at a conventional level. A notable exception is in column 7, in which we control for continent fixed effects and the estimated coefficient on the cereal advantage loses statistical significance. This is not surprising, as tax regressions are based on only 56 observations and the number of observations from each continent is limited. Finally, land productivity in all specifications is not significantly correlated with the tax burden.

In table F.18, we report the OLS and 2SLS estimates. In columns 1–4, we look at the impact of cultivating cereals on the existence of a farming surplus. The OLS estimates show that cultivating cereals is associated with an increase of 0.36 in the probability of producing a surplus. The coefficient more than doubles when we turn to the 2SLS estimates; in this case, too, land productivity (and reliance on agriculture) does not affect the dependent variable. Finally, results are robust to adding continent fixed effects.

In columns 5–8, we address the impact of cultivating cereals on the tax burden. In the 2SLS estimates, cultivating cereals is associated with an increase in the tax burden variable in the order of 1. This is a large number, compared to the mean of the dependent variable (1.09), which suggests that taxation was not possible in practice in nonagricultural societies or in societies cultivating roots or tubers. Again, land productivity does not seem to have any effect on the dependent variable. This result is robust to adding continent fixed effects, and it survives the same robustness checks that we run for table 1 (see tables F.19–F.21).

The cross-sectional nature of the regressions and the limited number of observations, however, imply that these results should be taken with a grain of salt and might be compatible with other mechanisms, discussed in section IV, through which cereal cultivation might be fostering the development of complex hierarchies.

C. Country-Level Data: Cross-Section and Panel Estimates

In this subsection, we use data on hierarchical complexity from Borcan, Olsson, and Putterman (2018). The unit of observation is the territory delimited by modern-day country borders for 159 countries every 50 years. The data allow for panel estimates, so it is not limited to the cross-sectional nature of the *Ethnographic Atlas* data employed in the previous subsections.

We first look at the classical age—the earliest period in human history for which detailed and complete data on the location of large states are available. We show, using cross-sectional variation, that regions that were organized as states in 450 CE are characterized by the presence of several WRs (wild relatives) of cereals, while WRs of roots and tubers are absent. Alternatively, using FAO data, we show that regions in which cereals are substantially more productive than roots and tubers are the regions that are organized as states. Both the presence of WRs of roots and tubers and land productivity are uncorrelated with the presence of states. These results persist when a large number of potential confounders are controlled for and suggest that adopting cereals is fundamental for the emergence of states. However, the cross-sectional nature of the analysis does not allow ruling out that omitted variables might be driving the results.

We therefore turn to a natural experiment of history—the Columbian Exchange—and exploit the panel nature of the data set. The Columbian Exchange of crops between the Old World and the New World permanently changed the productivity advantage of cereals over roots and tubers and land productivity in virtually every region of the world. We show that only the former change can explain subsequent changes in hierarchical complexity across different regions, which is consistent with both the appropriability theory and our critique of the conventional productivity theory. The analysis is robust to controlling for a large number of potential confounders, and the main results are not explained by colonization patterns or pretrends.

1. Explaining Differences in Hierarchy during the Classical Age

Figure 5 identifies the areas corresponding to modern-day countries that were organized (for the majority of their current territory) as states at the peak of the classical age, just before the collapse of the Roman Empire (450 CE). We focus on this period because the exact location of

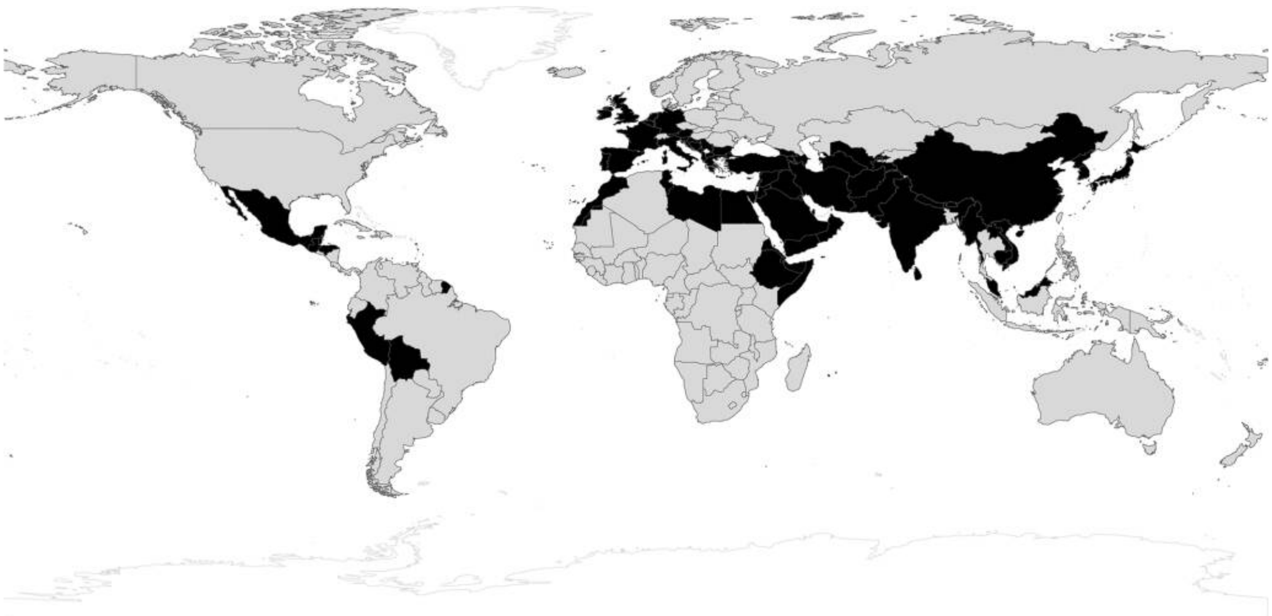

Fig. 5.—Modern countries' areas that were mainly organized as states in 450 CE.

state borders is less certain for the preclassical period. We use a measure of the potential availability of each domesticated crop, based on the information on the distribution of its WRs in the world, which is presumably unaffected by the development of hierarchy and therefore alleviates reverse causality concerns.

According to our thesis, states develop where cereals are farmed, and cereals are farmed where cereals are available and roots and tubers are not. This prediction is consistent with the data. By comparing figure 5 to figure 4, which shows the distribution of WRs of different domesticated crops, it is apparent that civilization started exactly in those places characterized by a large number of WRs of cereals but with no WRs of roots and tubers. The Fertile Crescent is the most prominent example. Table 2 reports the estimated coefficients from the following regression:

$$\begin{aligned}\text{Hierarchy}_i^{450} = {} & \alpha_1 I(\text{WR\_Cer})_i + \alpha_2 I(\text{WR\_RT})_i \\ & + \alpha_3 I(\text{WR\_Cer\&RT})_i + X_i'\beta + u_i.\end{aligned} \tag{3}$$

The hierarchy index in 450 CE (Hierarchy_i^{450}) is regressed on a dummy that identifies areas with only WRs of cereals available ($I(\text{WR\_Cer})_i$), a dummy that identifies areas with only WRs of roots and tubers ($I(\text{WR\_RT})_i$), a dummy that identifies areas in which WRs of both cereals and of roots and tubers are available ($I(\text{WR\_Cer\&RT})_i$), and a vector of control variables (X_i'). The control group is composed of areas in which no WR of domesticated crops is available. The presence of only WRs of roots and tubers and the presence of WRs both of roots and tubers and of cereals are not correlated with the hierarchy index. In contrast, regions in which only WRs of cereals are available are characterized by an increase in the hierarchy index of 0.50. This is a large effect: the average of the dependent variable is 0.38. Moreover, the R^2 of this regression is 0.3, showing that the availability of WRs of cereals and the lack of WRs of roots or tubers could explain almost a third of cross-regional differences in hierarchy in 450 CE. Results are robust to adding continent dummies (col. 3). Figures 4 and 5 suggest that latitude is correlated with both Hierarchy_i^{450} and $I(\text{WR\_Cer})_i$. However, controlling for differences in latitude leaves the estimated coefficient on $I(\text{WR\_Cer})_i$ practically unaffected (col. 4). Results are practically unaffected when adding a long list of controls sequentially. In columns 4–8 in table 2, we control for precipitation, temperature, elevation, ruggedness, and latitude. In tables F.23 and F.24, we consider a host of additional factors 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: legal origin of the country, population density in 1500, settlers' mortality, the number of exported slaves, genetic diversity, distance to rivers and coast, endemicity of malaria, the percentage of tropical land, the density of wild

TABLE 2

Cereals and Hierarchy in Classical Antiquity: Cross-Sectional Regressions

	Dependent Variable: Hierarchy Index in 450 CE								
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	OLS (5)	OLS (6)	OLS (7)	OLS (8)	PDS (9)
WR_Cer	.535***	.526***	.465***	.505***	.433***	.462***	.423***	.487***	.356**
	(.0655)	(.0989)	(.124)	(.118)	(.129)	(.121)	(.136)	(.117)	(.165)
WR_RT		.125	.182	.196	.168	.204	.123	.222	. . .
		(.174)	(.173)	(.170)	(.172)	(.174)	(.170)	(.172)	
WR_Cer&RT		−.0319	.0623	.0568	.0709	.0304	.0447	.123	. . .
		(.0918)	(.114)	(.114)	(.112)	(.112)	(.126)	(.114)	
Controls:									
Absolute latitude	No	No	No	Yes	No	No	No	No	. . .
Precipitation	No	No	No	No	Yes	No	No	No	. . .
Temperature	No	No	No	No	No	Yes	No	No	. . .
Elevation	No	No	No	No	No	No	Yes	No	. . .
Ruggedness	No	No	No	Yes	No	No	No	Yes	. . .
Continent FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	. . .
R^2	.305	.310	.408	.418	.408	.428	.402	.435	
Observations	151	151	151	151	151	150	148	145	73

Note.—The table reports cross-sectional OLS and PDS estimates, and the unit of observation is the territory delimited by modern country borders. Robust standard errors are in parentheses. FE = fixed effects.

** Significant at the 5%. level

*** Significant at the <1% level.

animals and ruminants suitable for domestication, and the potential for irrigation. Column 9 in table 2 reports the results of adding this long list of controls at the same time in a PDS methodology. As can be seen, the estimated coefficient for $I(\text{WR\_Cer})_i$ is smaller but still positive and statistically significant. We do not report in the table the coefficients on WR_RT and WR_Cer&RT, as the PDS procedure produces a consistent estimate only for the main variable of interest and not for the controls. Finally, in table F.25, we show that results are robust to excluding each continent one by one, confirming that our key results are not driven by a specific region of the world.

We further illustrate how cereals can explain the distribution of states in classical antiquity in a box plot (fig. F.11). The plot shows that states emerged in areas in which the difference between the number of WRs of cereals and the number of WRs of roots and tubers is large: the median is 3, and 75% of states are in the range of 2–4. The median difference in areas defined as tribes is zero with 75% of tribes in the range of 0–1.

In table F.26, we turn to the potential productivity of crops (GAEZ data set) and estimate an equivalent of equation (2) at the country level for the year 450 CE. Here we confirm the results of table 2: there is a significant positive correlation between the productivity advantage of cereals and hierarchy, as predicted by the appropriability theory, while land productivity is negatively correlated with hierarchy, in contrast to the conventional productivity theory.[29]

2. Panel Data Based on the Columbian Exchange

The analysis based on the cross section of states in 450 CE accounts for a large set of possible confounding factors, but we cannot rule out that unobservable characteristics that are systematically correlated with the productivity or availability of different crops might be driving our results. To alleviate this concern, we exploit the exogenous change in the set of available crops in different locations of the world that was induced by the Columbian Exchange.

Among the four main roots and tubers that we consider, three were available in the New World before 1500: cassava, white potatoes, and sweet potatoes. Among the 11 main cereals, only maize was available in the New World. In the Old World, yam was the only available crop from the four main roots and tubers, while all cereals but maize were available. Accordingly, we compute for each location the productivity advantage of cereals over roots and tubers and the land productivity before the Columbian

[29] In this table, the productivity advantage of cereals and land productivity are calculated using only the subsets of cereals and roots/tubers that were available in the Old World and the New World before the Columbian Exchange.

Exchange (before 1500), based on the relevant subset of crops, and after the Exchange (after 1550), based on the full set of crops.[30]

The benchmark sample used in this subsection comprises 151 countries for which the hierarchy data constructed by Borcan, Olsson, and Putterman (2018) and the crop productivity data are available. We use the years 1000–1950, with observations available every half century, but we exclude the half century 1500–1550. This leaves us with a total of 2,869 observations. We regress the hierarchy index on the productivity advantage of cereals and on land productivity:

$$\text{Hierarchy}_{it} = \alpha_1 \text{CerAdv}_{it} + \alpha_2 \text{LandProd}_{it} + X'_{it}\beta + \eta_i + \eta_t + u_{it}. \quad (4)$$

The dependent variable is the hierarchy index of country i in year t, while $\text{CerAdv}_{it} = \text{CerAdv}_{i,\text{BeforeExchange}}$ (the caloric advantage of cereals over roots and tubers before the Columbian Exchange) if $t \leq 1500$ and $\text{CerAdv}_{it} = \text{CerAdv}_{i,\text{AfterExchange}}$ (the caloric advantage after the Columbian Exchange) if $t > 1550$. Similarly, potential land productivity (LandProd_{it}) is calculated on the basis of the relevant crops available before and after the Columbian Exchange. The vector X'_{it} is a set of control variables. Country fixed effects control for all time-invariant factors that differ between countries, and time-period fixed effects control for any time pattern of hierarchical complexity that affects all countries simultaneously. The critical identification assumption is that there were no unobserved events in the sixteenth century that are systematically correlated with the spatial variation in the change in the potential productivity advantage of cereals and that had an independent effect on hierarchy.

We are aware that the change in crop availability induced by the Columbian Exchange coincided with colonization. However, colonization does not seem to be driving our results: excluding colonies from the estimation sample does not have a quantitative effect on the estimates (discussed below). Moreover, the concern that changes in hierarchy were a result of colonization, rather than changes in the availability of crops, cannot explain the different impact of the changes in cereal advantage and the changes in land productivity that we observe in table 3.

Column 1 in table 3 shows a positive but insignificant effect of land productivity on hierarchy, when cereal advantage is not controlled for. The sign of this coefficient turns negative but the coefficient remains insignificant once the cereal advantage is included in the regression.

[30] The historical evidence shows that the New World's crops were adopted in Europe and Africa only in the seventeenth century. For instance, potato cultivation in the Old World was commenced in the late seventeenth 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 benchmark analysis, we exclude the years from 1500 to 1550. In app. F.6, we show that our results are robust when excluding the years between 1500 and 1750 (table F.32).

TABLE 3

Cereals and Hierarchy: Panel Regressions

	Dependent Variable: Hierarchy Index								
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	OLS (5)	OLS (6)	OLS (7)	OLS (8)	PDS (9)
CerAdv		.189***	.272***	.282***	.240***	.255***	.261***	.197**	.202**
		(.0683)	(.0834)	(.0760)	(.0857)	(.0889)	(.0839)	(.0795)	(.0850)
LandProd	.141		−.163	−.193	−.152	−.115	−.148	−.165	. . .
	(.0971)		(.141)	(.131)	(.139)	(.142)	(.138)	(.123)	
Controls × 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	. . .
Absolute latitude		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	. . .
R^2	.669	.680	.682	.716	.684	.681	.686	.705	
Observations	2,869	2,869	2,869	2,850	2,812	2,755	2,869	2,869	1,387

Note.—The table reports panel OLS and PDS estimates, and the unit of observation is the territory delimited by modern country borders every 50 years. Robust standard errors, clustered at the country level, are in parentheses. FE = fixed effects.

** Significant at the 5% level.

*** Significant at the <1% level.

Column 2 confirms that the higher is the cereal advantage, the higher is the country's hierarchy index. A 1–standard deviation increase in the productivity advantage of cereals increases the hierarchy index by 0.19. In the next six columns, we show that the results are robust when land productivity and, in addition, precipitation, temperature, elevation, ruggedness, and absolute latitude (all interacted with the time-period fixed effects), are controlled for. In tables F.27 and F.28, we consider a host of additional factors (interacted with time-period fixed effects) that might have affected hierarchical complexity. In particular, as in the previous subsection, we control sequentially for legal origin, population density in 1500, settlers' mortality, exported slaves, genetic diversity, distance to rivers and coast, endemicity of malaria, the percentage of tropical land, the density of wild animals and ruminants suitable for domestication, and the potential for irrigation. The key results are essentially unaffected. Column 9 in table 3 reports the results of adding all these controls at the same time in a PDS methodology: once again, results are practically unaffected, compared to the specification without any control. (In this column, we report only the coefficient on our main regressor. Land productivity enters as one of the controls in the PDS.)

In table F.29, we exclude the cells in which the countries in our analysis were either colonies or protectorates. The estimated coefficient on the caloric advantage of cereals over roots and tubers becomes smaller by approximately a third but remains positive and statistically significant, while the impact of land productivity on hierarchy is still not significant. Tables F.30 and F.31 report further robustness checks. Specifically, in table F.30, hierarchical complexity is proxied by a dummy that identifies societies with a government above tribal level. In table F.31, land productivity is proxied by the caloric suitability index developed by Galor and Özak (2016), which also varies depending on whether it is measured before or after the Columbian Exchange. Finally, in table F.32, we exclude the years between 1500 and 1750, when the Columbian Exchange of crops was not complete. In all three cases, our main results are unaffected.

Testing for pretrends.—The identification assumption of equation (4) requires that, until 1500, Hierarchy_{it} did not exhibit systematically different trends across the set of countries that experienced different shocks in the productivity advantage of cereals after 1500. Here, we show the existence of parallel linear and nonlinear pre-1500 trends.

We first use data on the years before the Columbian Exchange and regress Hierarchy_{it} on the change in the caloric advantage generated by the Columbian Exchange (Change_CerAdv_j) interacted with a linear trend and a set of country and year dummies (table F.33). The coefficient on the interaction term indicates whether hierarchy in countries that experienced a larger cereal advantage shock were on a different linear trend before the Columbian Exchange. The estimated coefficient is always small and not statistically significant. Similar results are obtained if we control for the interaction between the potential changes in land productivity due to the Columbian Exchange with a linear trend and if we control for the usual geographic characteristics interacted with year fixed effects.

Second, we regress Hierarchy_{it} on year fixed effects interacted with the change in the caloric advantage generated by the Columbian Exchange, year fixed effects, and country fixed effects:

$$\text{Hierarchy}_{it} = \sum_{j=1050}^{1850} \alpha_j \times (\text{Change\_CerAdv})_i \times j + X_{it}'\beta + \eta_i + \eta_t + u_{it}. \quad (5)$$

This specification does not require any assumption about the timing of the Columbian Exchange and takes the year 1000 as the baseline year. Results are presented in table F.34. In the first column, there are no further control variables. The estimated α_j and their 10% confidence intervals are reported in figure 6.[31]

The impact of the change in the productivity advantage of cereals over roots and tubers enabled by the Columbian Exchange is constant over time between 1000 and 1500; it increases steadily during the sixteenth century and continues to increase, but at a lower rate, until 1700, after which it stabilizes. Results are practically unchanged when we control for the potential changes in land productivity and the usual geographic characteristics, both interacted with year fixed effects.

This analysis confirms that the Columbian Exchange produced a differential increase in hierarchy in the countries for which it caused a larger increase in the productivity advantage of cereals over roots and tubers and that most of the impact was in the sixteenth century. It also rules out the possibility that nonlinear pretrends might be driving our results.

D. Early Traces of Civilization: Cross Section of Archaeological Sites

The results presented in the two previous subsections support our thesis based on data from 450 CE and more recent centuries. We now turn to data that cover the period from pre-Neolithic sites to classical cities. With these data, we connect indications of early civilization with the domestication of cereals and roots or tubers. In this subsection, we present cross-section results based on the location of classical and preclassical

[31] The 17 coefficients reported in fig. 6 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.

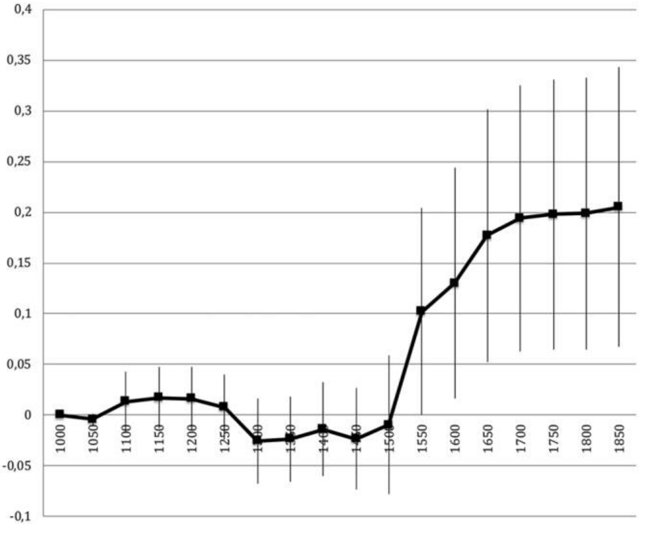

Fig. 6.—Flexible estimates of the relationship between the change in the caloric advantage of cereals over roots and tubers due to the Columbian Exchange and hierarchy.

large settlements or archaeological ruins, with the presumption that the existence of a city or a large settlement is an indicator of hierarchy. We show that these archeological findings are concentrated in areas in which agriculture was likely to start with only cereal crops. In particular, these are areas that are characterized by a large number of WRs of domesticated cereal crops but where WRs of roots and tubers are not available.

In table 4, we use two different data sets for our dependent variable. The first is the data set provided by Daniel DeGroff on the location of cities founded before 400 CE in the Old World (cols. 1–5). The second data set comes from Reba, Reitsma, and Seto (2016) and refers to the location of large settlements from classical antiquity (450 CE) and preclassical antiquity up to 500 BCE (cols. 6–9). We use a grid of the world land surface, in which the unit of observation is the 1 × 1–decimal degree raster, to test our thesis. We run regressions of the form

$$\begin{aligned}\text{Settlement}_i = {} & \alpha_1 I(\text{WR\_Cer})_i + \alpha_2 I(\text{WR\_RT})_i \\ & + \alpha_3 I(\text{WR\_Cer\&RT})_i + X_i'\beta + u_i.\end{aligned} \tag{6}$$

Column 1 shows that the availability of only WRs of domesticated cereals is associated with an absolute increase in the probability of having a city in a cell in classical antiquity of 19.7 percentage points. The magnitude of this coefficient is exceptional, compared to the mean of the dependent

TABLE 4

Wild Relatives of Domesticated Crops and the Location of Ancient Cities

	Dependent Variable: Presence of Cities/Large Settlements Founded by:								
	400 CE					450 CE		500 BCE	
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	PDS (5)	OLS (6)	PDS (7)	OLS (8)	PDS (9)
WR_Cer	.197***	.195***	.195***	.0965***	.145***	.0232***	.0136***	.00941***	.00358
	(.0325)	(.0326)	(.0377)	(.0280)	(.0268)	(.00500)	(.00434)	(.00264)	(.00310)
WR_RT		−.00809	.00478	−.0277	. . .	−.00243	. . .	−.00179	. . .
		(.00700)	(.0145)	(.0232)		(.00157)		(.00133)	
WR_Cer&RT		−.00901	.0245	−.00191	. . .	−.00307**	. . .	−.00244**	. . .
		(.00694)	(.0201)	(.0221)		(.00142)		(.00115)	
Continent FE	No	No	Yes	No	. . .	No	. . .	No	. . .
Country FE	No	No	No	Yes	. . .	No	. . .	No	. . .
R^2	.124	.124	.144	.407		.0125		.00398	
Observations	17,076	17,076	17,076	17,076	8,568	17,076	8,568	17,076	8,568

Note.—The table reports cross-sectional OLS and PDS estimates, and the unit of observation is the 1 × 1–decimal degree square. Robust standard errors, clustered at the country level, are in parentheses. FE = fixed effects.

** Significant at the 5% level.

*** Significant at the <1% level.

variable (0.049), and is explained by the fact that almost all cities in the sample are located in areas in which WRs of cereals are present and WRs of roots and tubers are absent.[32] In column 2, the presence of an ancient city is regressed on all the three main regressors in equation (6). The estimated coefficient on $I(\mathrm{WR\_Cer})_i$ does not change. Moreover, consistent with our critique, we find that the presence of ancient cities is not different between areas in which WRs of roots and tubers are present (regardless of the presence of WRs of cereals) and areas with no WRs of any domesticated crops. This result is practically unchanged when either continent or country fixed effects are controlled for (cols. 3 and 4). In table F.37, we report results when controlling sequentially for precipitation, temperature, elevation, ruggedness, absolute latitude, irrigation potential, and plow advantage. Our estimates for the coefficient on $I(\mathrm{WR\_Cer})_i$ are substantially unchanged, although in some specifications the coefficient on $I(\mathrm{WR\_Cer\&RT})_i$ becomes positive and statistically significant. Column 5 of table 4 reports the PDS regression adding all these controls at the same time: the estimates on $I(\mathrm{WR\_Cer})_i$ are similar to those for the specification without controls. In the second part of the table, we use data on the presence of large ancient settlements from Reba, Reitsma, and Seto (2016). In columns 6 and 7, we look at settlements that were established before 450 CE. The qualitative results are the same as in columns 1–5. In the last two columns, we move back in time to preclassical antiquity and find the same qualitative results. The estimated coefficients on $I(\mathrm{WR\_Cer})_i$ are approximately half those in the previous columns, consistent with the substantially smaller mean of the dependent variable. Our results are robust to using a logit model to account for the binary nature of the dependent variable (table F.36).

We turn to data on centers of domestication during the Neolithic as an alternative proxy for the cultivation of roots, tubers, or cereals. The underlying assumption is that the probability that a crop would reach a certain area would be negatively associated with the geographic distance to the nearest center of domestication of that crop. Therefore, communities living in raster points that are geographically close to centers where cereals were first domesticated, relative to the distance to areas of tuber domestication, would be more likely to adopt cereal farming and thus, as the appropriability theory predicts, more likely to develop hierarchies.

Global data on the diffusion of crops during the Neolithic transition are not available, but archaeologists and botanists have identified some 20 centers where there was independent domestication and from which

[32] The probability of observing an ancient city in the cells located in areas in which either WRs of cereals are not available or both WRs of cereals and WRs of roots and tubers are available is 0.013. If instead we look at cells in which only WRs of cereals are available, the probability of observing an ancient city is 0.210.

domesticated crops spread to the rest of the world (see fig. F.6 and Larson et al. 2014). We use these data to compute the distance to the nearest center of independent domestication of roots or tubers and of cereals. A box plot (fig. F.12) shows that the vast majority of the raster points that have a large settlement are within 2,000 km of a center of cereal domestication, with the median less than 1,000 km. Their distance from a center of root or tuber domestication is much larger and comparable to the distance of a raster point without settlements from areas of any domestication (cereals or roots/tubers).

Table 5 reports OLS estimates from the following regression equation:

$$\text{Settlement}_i = \alpha_1 \text{DistanceCer}_i + \alpha_2 \text{DistanceAgr}_i + X'_{it}\beta + u_{it}, \quad (7)$$

where DistanceAgr_i is the distance to the nearest center of independent domestication of agriculture and DistanceCer_i is the distance to the nearest center of independent domestication of cereal grains.

The estimates illustrated in table 5 show that distance from the nearest area of independent domestication of a cereal grain, DistanceCer_i, is negatively correlated with urbanization. Moreover, when DistanceCer_i is controlled for, the distance from the nearest area of independent adoption of agriculture is not correlated with urbanization, thus suggesting that farming noncereal crops might be irrelevant to the development of complex hierarchies. This result is robust to a long list of checks and alternative archaeological data to measure hierarchical complexity (e.g., pyramids, temples, and palaces), which we discuss in detail in appendix F.9.

E. Difference-In-Differences Using Radiocarbon-Dated Prehistoric Archaeological Sites

The results in the previous subsection are based on a cross-section analysis, and even though we control for a large set of confounders, we cannot exclude that our proxies for cereals and other crops could be correlated with unobservable geographic characteristics affecting the location of ancient cities and archaeological sites. To alleviate this concern, we use the radiocarbon-dated prehistoric and protohistoric data on archaeological sites listed in Whitehouse and Whitehouse's (1975) *Archaeological Atlas of the World*. We assign each of these sites to a 1 × 1–decimal degree raster point of the world land surface and count the number of pre-Neolithic sites and post-Neolithic sites in each of these points. We then run the following difference-in-differences regressions:

$$\begin{aligned} \text{Settlement}_{i,t} = {} & \alpha_1 I(\text{WR\_Cer})_i \times P_t + \alpha_2 I(\text{WR\_RT})_i \\ & \times P_t + \alpha_3 I(\text{WR\_Cer\&RT})_i \times P_t \\ & + X'_{it}\beta + \eta_i + \eta_t + u_{it} \end{aligned} \quad (8)$$

TABLE 5

ORIGIN OF THE NEOLITHIC TRANSITION AND LOCATION OF ANCIENT CITIES

	DEPENDENT VARIABLE: PRESENCE OF CITIES/LARGE SETTLEMENTS FOUNDED BY:								
	400 CE					450 CE		500 BCE	
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	PDS (5)	OLS (6)	PDS (7)	OLS (8)	PDS (9)
DistCer	−.0160***	−.0214***	−.0143**	−.00269	−.0335***	−.00303***	−.00456***	−.00168***	−.0026***
	(.00342)	(.00597)	(.00604)	(.00198)	(.00673)	(.000943)	(.00120)	(.000585)	(.000808)
DistAgr		.00909	.00253	.0000138	. . .	.0000595	. . .	−.000319	. . .
		(.00676)	(.00566)	(.00102)		(.000743)		(.000423)	
Continent FE	No	No	Yes	No	. . .	No	. . .	No	. . .
Country FE	No	No	No	Yes	. . .	No	. . .	No	. . .
R^2	.0284	.0307	.0495	.446		.00674		.00460	
Observations	15,927	15,927	15,927	15,927	8,169	15,927	8,169	15,927	8,169

NOTE.—The table reports cross-sectional OLS and PDS estimates and the unit of observation is the 1 × 1–decimal degree square. Robust standard errors, clustered at the country level, are in parentheses. FE = fixed effects.

** Significant at the 5% level.

*** Significant at the <1% level.

and

$$\text{Settlement}_{i,t} = \alpha_1 \text{DistanceCer}_i \times P_t + \alpha_2 \text{DistanceAgr}_i \times P_t + X'_{it}\beta + \eta_i + \eta_t + u_{it}, \tag{9}$$

where the subscript i indicates the raster point of the world, the subscript t indicates whether the site predates the Neolithic transition, η_i and η_t are cell and period fixed effects, respectively, and P_t is a dummy variable that identifies archaeological sites dating to after the Neolithic transition.

Column 1 of table 6 shows that the presence of WRs of domesticated cereals in areas in which WRs of domesticated roots and tubers are not available is associated with an increase in the probability of finding a post-Neolithic site, in comparison to finding a pre-Neolithic site, confirming that the Neolithic transition led to more visible traces of human societies only in areas where agriculture started with cereals. In addition, it illustrates that in areas in which WRs of roots and tubers exist, with or without WRs of cereals, there is no increase in post-Neolithic sites relative to pre-Neolithic sites. Column 2 shows that the distance from the nearest area of cereal domestication is associated with a decrease in the probability of finding a post-Neolithic site rather than a pre-Neolithic site. Again, once distance from cereal domestication is included in the regression, distance from the nearest area of independent domestication does not produce any significant effects. The results reported in the rest of table 6 confirm the results in columns 1 and 2, with different dependent variables: the number of archaeological sites (cols. 3, 4), the presence of a prehistoric settlement (cols. 5, 6), or the number of prehistorical settlements in the area (cols. 7, 8).

The same qualitative results are obtained when we use the GAEZ data for our regressors. Higher productivity advantage of cereals over roots and tubers is associated with a relative increase in the probability of finding a post-Neolithic site/ancient settlement rather than a pre-Neolithic site/ancient settlement, confirming that the Neolithic transition led to more visible traces of human societies, but only in areas where agriculture started with cereals. In addition, it illustrates that if we control for cereal advantage, land productivity does not produce any significant positive effect. Results are reported in table F.44.

III. Evidence II: Case Studies

The most direct evidence that cereals played a crucial role in state formation is the observation that in farming societies that rely on roots and tubers, hierarchical complexity never exceeded the level that anthropologists define as "chiefdoms," while all agriculture-based large states that

TABLE 6

Potential Crop Yields and the Location of Ancient Cities

	Dependent Variable							
	Archaeological Site (Dummy)		Log(1 + No. Archaeological Sites)		Ancient Settlement (Dummy)		Log(1 + No. Ancient Settlements)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$P \times$ WR_Cer	.142***		.189***		.149***		.179***	
	(.0245)		(.0366)		(.0235)		(.0324)	
$P \times$ WR_RT	−.00775		−.0102		.00543		.00217	
	(.0183)		(.0154)		(.0159)		(.0137)	
$P \times$ WR_Cer&RT	−.00554		−.00347		.00693		.00740	
	(.0178)		(.0179)		(.0147)		(.0157)	
$P \times$ DistCer		−.015**		−.019***		−.014**		−.016***
		(.0060)		(.0071)		(.0055)		(.0063)
$P \times$ DistAgr		.0038		.0090		.0001		.0043
		(.0064)		(.0085)		(.0057)		(.0071)
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	.0903	.0253	.0983	.0265	.0958	.0316	.0976	.0294
Observations	34,152	31,854	34,152	31,854	34,152	31,854	34,152	31,854

Note.—The table reports difference-in-differences OLS regressions. The unit of observation is the 1 × 1–decimal degree square either before or after the Neolithic transition. Robust standard errors, clustered at the country level, are in parentheses. FE = fixed effects.

** Significant at the 5% level.

*** Significant at the <1% level.

we know of relied on cereals.[33] In this section, we examine several societies at different stages of the emergence of hierarchies and states, which we interpret as supporting our appropriability critique of the prevailing productivity theory.[34]

A. *Complex Hunter-Gatherers in North America*

Summarizing extensive anthropological evidence on hunting-gathering societies, Testart (1982a, 1982b) identified a positive association between social inequality and the prevalence of storage of seasonal food sources. Testart may have been the first to distinguish between agricultural societies based on cereals and those based on tubers, and to attribute inegalitarian, complex social structures to reliance on sedentism and storage (1982a, 195–204).

Tushingham and Bettinger (2013) study the transition of some hunting-foraging aboriginal Californians to intensified reliance on salt-drying and storing seasonal salmon, a transition that coincided with the concentration of the population in permanent villages and increased social complexity.[35] They theorize that reliance on salmon was avoided for many centuries, despite its many advantages, because it is a "front-loaded" food source that takes much effort to procure and store but relatively little effort to prepare for consumption. They state that such a food source increases "the possibility that others will rob caches, which mobile foragers are not positioned to protect," and also increases the vulnerability of loss to "freeloaders" from the inside (533–34). Tushingham and Bettinger propose that the transition to reliance on such a front-loaded food source had to coincide with increased social complexity. Their analysis of the consequences of reliance

[33] In app. C, we defend the statement above by examining three purported counterexamples in Murdock's (1967) *Ethnographic Atlas*, where societies that depended on the cultivation of roots or tubers are coded as large states. We are aware that our binary measure of appropriability is imperfect, that classifying only cereals as "appropriable" is too simplistic, and that we ignore altogether important food sources such as pulses, fruit, vegetables, fish, and animals. To the extent that these are not easily appropriable, we would classify them with roots and tubers. Some of these can be stored but did not give rise to states, possibly because they are not seasonal and thus do not require lengthy storage. It is known, e.g., that potatoes have been freeze-dried in the mountains of ancient Peru by the Incas (who also grew a cereal, maize) and are somewhat storable. And, as Mokyr (1985) argues, potato-eating pigs, which can be appropriated (but whose maintenance is costly), helped the Irish hierarchy to survive. Livestock is also appropriable but requires costly maintenance. In the empirical analysis, we control for animal husbandry when possible and find that this leaves our main results on the effect of cereals and land productivity on hierarchy unchanged. By focusing on agriculture-based societies, we exclude from our discussion states like the Nabateans, the Venetians, and several African kingdoms, which relied primarily on taxing trade.

[34] Buonanno et al. (2015) and Sánchez de la Sierra (2020) present additional evidence on the effect of appropriability on the emergence of elites.

[35] Cook's (1784) account of his voyages to the eastern shores of the Pacific Ocean (vol. II, book IV) offers a vivid eyewitness depiction of these villages.

on food storage in a preagricultural society is highly consistent with the idea that increased vulnerability to appropriation contributes to expanded hierarchy.[36]

B. The Neolithic in the Ancient Near East

Archaeological findings show that the earliest phases of the transition to cereal farming are correlated with communal storage and with the emergence of inequality and hierarchy. Semisedentary forms of living, dwellings, sickles, mortars and pestles, grinding stones, and storage facilities appear in the ancient Near East as early as the pre-Neolithic Natufian period, when cereals were collected but not yet sown or domesticated. Active cereal cultivation emerged only later, during the Pre-Pottery Neolithic A (PPNA, ca. 9500–8500 BCE), when, still before domestication, farmer-foragers collected wild grain on a large scale and sowed the grain.[37] Differentiated dwelling sizes and funerary assemblages suggest that systematic inheritable inequality was already observable at that stage. Kuijt and Finlayson (2009) report the discovery of an elaborate circular communal storage pit in the Jordan Valley from about 9000 BCE. This shows that sizeable communal storage was an integral part of the earliest phase of the transition to cereal farming. Communal storage probably reflected a need to protect stored grains from the elements (moisture, insects, and rodents) as well as the existence of volume-related increasing returns to scale in storage. Such communal storage also attests to the emergence of leadership alongside the gradual intensification of cereal farming and sedentism. Constructing and overseeing the storage pit (which protected the prime source of the community's nonhuman wealth) and distributing the stored foodstuffs required leadership, even if initially banditry may not have been a major issue.[38] The need to protect stockpiles is manifest also by the

[36] Chiwona-Karltun et al. (2002) illustrate how reliance on a back-loaded food source provides protection. They report that women in modern Malawi, particularly single women, prefer to grow bitter and toxic cassava variants, even though these require significantly more postharvest processing. This pattern is explained as being due to the protection that this extra postharvest drudgery provides these women against thievery, as thieves prefer the nonbitter variant.

[37] For surveys, see Barker (2006) and Simmons (2007). Increased climatic seasonality at the end of the Ice Age that generated evolutionary modifications in grasses—larger seeds to adapt to summer drought—is commonly presumed to explain the timing of the transition to agriculture in Eurasia (Diamond 1997; Matranga 2017). Richerson, Boyd, and Bettinger (2001, 388–89) debunk the theory that this transition was caused by food shortage due to population growth. Bowles and Choi (2019) argue that the strategic complementarity between farming and private property impeded the transition to agriculture, since it required the parallel adoption of the social institution of private property.

[38] Large round pits from that period were found elsewhere in the Jordan Valley and in several sites near the Euphrates (Mithen et al. 2011; Willcox and Stordeur 2012). These pits are identified as having served as communal storage and also as communal meeting

subsequent agglomeration of people in early walled villages and urban centers, long before the formation of city-states.

C. The Post-Columbian Introduction of Sweet Potatoes to New Guinea

New Guinea adopted agriculture at about the same time as Egypt (ca. 5000–4500 BCE), cultivating bananas, taro, and yam. But unlike Egypt, the increase in food production did not lead to the development of a complex hierarchy.[39] In the seventeenth century, the sweet potato, which originated in America, reached New Guinea and rapidly displaced older crops to become the staple. Wiessner and Tumu (1998) record how the new crop resulted in a substantial increase in productivity, population, and the production of prestige goods, such as the aggrandizing slaughter of pigs in communal festivals. But this considerable increase in land productivity left the highland population of New Guinea fragmented, subject to endemic tribal warfare, and without any consolidation of power or a significant increase in social complexity.

Thus, increased productivity of a less appropriable crop that generates only a temporary surplus (until the crop rots) did not prompt significant hierarchy. This observation stands in contrast to the conventional productivity theory yet is consistent with the appropriability theory.

D. State Avoidance in Southeast Asia

With the idea of explaining how some societies managed to avoid subjugation to state authority, Scott (2009) posits that in Southeast Asia, states emerged only in the river valleys, where they relied on intensively cultivated appropriable rice. He argues that tribal hill people resisted the valley states and retained freedom by adopting foraging and shifting agriculture, based on the cultivation of less appropriable roots and tubers. While he refers to the distinction between crop types, Scott's key distinctions relate to geographic differences between valley and hill people and between sedentary and shifting farming.[40]

places, possibly for ritual ceremonies. Some archaeologists identify storage as an indication of surplus, but cereal-based farming requires intra-annual storage even if living at subsistence, with no long-term surplus. The salience of communal storage in some PPNA (ca. 10,000–8800 BCE) sites is explained as being mostly due to increasing returns to scale. But this advantage is rather limited. In the dense Neolithic village of Çatalhöyük (PPNB, ca. 7500–6000 BCE), the storage of grains was already entirely private within the homes.

[39] One could argue, as Diamond (1997) seems to, that farmers in these areas did not produce any surplus because of low land productivity. However, the claim of low productivity is inconsistent with the evidence (see app. A). Amazonia provides another example of a region with productive farming and no complex hierarchies (Neves and Heckenberger 2019).

[40] Yet the role of elevation is reversed in South America, where the Incas had a powerful state in the mountains and no major state emerged in the Amazon valley.

E. *The Maize-Growing Bushong in Congo*

We conclude this brief survey with an example that Acemoglu and Robinson (2012) discuss to support their claim for the precedence of political innovations to the adoption of agriculture. They describe how, in the seventeenth century and after maize reached the West African coast, a leader of the Bushong people in the Congo heartland promoted the adoption of maize farming and transformed what had been a tribal society into a kingdom. The Bushong's neighbors across the river, the Lele people, share the same environment but avoided the cultivation of cereals and resisted subjugation to hierarchy. Once again, this example demonstrates the critical role of the crop type for the emergence of complex hierarchy and for its avoidance.

IV. Alternative Theories for the Emergence of Hierarchy and States

Our extensive empirical analysis reveals that cereal cultivation had a causal effect on various indicators of hierarchy in farming-based societies.[41] It fails to reveal any evidence that land productivity had such an impact, once cereal cultivation is controlled for. In this section, we review the literature on the emergence of hierarchy and states in light of these findings.

Adam Smith invoked the appropriability argument when arguing that governments and property protection first emerged with the transition to pastoralism and the need to protect livestock from theft (Smith 1978, 16). But once he addressed agriculture, Smith leaned on the role of productivity as generating a surplus, division of labor, and trade and, as a result, also a demand for an extended role for government (Smith 1978, 409).[42] For Smith and his intellectual heirs, the surplus had to be available before the landlord, the capitalist, or the ruler could seize it.

Friedrich Engels argued similarly that the surplus generated by the adoption of agriculture was a prerequisite for the transition to class society ([1884] 1972, 65–66). Childe (1936), too, posits that the transition to agriculture resulted in food surplus and prosperity that enabled farmers to demand specialty items—leading artisans to specialize in nonfarming activities and to trade. This division of labor led over time to political integration and eventually to urban centers and the formation of city-states.

[41] The empirical approach adopted here is similar to that of Alesina, Giuliano, and Nunn (2013), who offer a geographical explanation for a facet of hierarchy we ignore—hierarchy between men and women.

[42] The idea that agriculture generated surplus and that surplus led to the government had already been expressed earlier in the seventeenth century—see Meek (1976) and Aspromourgos (1996).

Lenski (1966) emphasizes the surplus generated by farming, which intensified with the transition from horticulture to intensive agriculture, as the source of social power.[43]

Many scholars have sought to explain what lies behind the relative underdevelopment of tropical countries.[44] Diamond (1997, 92) employs the conventional productivity theory when he summarizes the source of the advantages of temperate regions: "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." Price and Bar-Yosef (2010, 160) reach a similar conclusion: "Cultivation also supported a stable economy with surplus that resulted in the formation of elite groups as predicted by Lenski (1966)." Indeed, the productivity-and-surplus theory is the default explanation for state formation in both popular and scientific writing; Diamond (1997) and Price and Bar-Yosef (2010) are but two salient examples.

Our opening arguments, our case studies, and our extensive empirical evidence cast doubt on this conventional and still predominant productivity theory. Indeed, our empirical evidence and case studies suggest that increased land productivity in itself (without increased appropriability) had a limited causal effect on hierarchy, if any.

We now turn to alternative theories that still invoke increased productivity but suggest factors other than the availability of surplus as the mechanism leading to the emergence of hierarchy. Some of these theories are consistent with our findings. Johnson and Earle (2000) claim that increased land productivity led to population growth and increased density, fostering conflict and necessitating increasingly complex social forms to contain violence. North, Wallis, and Weingast (2009) adopt this functionalist theory, explaining the evolution of human history from the Neolithic age to modern times in terms of the institutions formed to contain humans' natural

[43] Lenski is preoccupied with a presumed technological shift from horticulture to agriculture that increased land productivity further and enabled the transition from chiefdoms to states. However, the horticulture witnessed by ethnographers is almost invariably based on roots and tubers. This observation and our analysis make it apparent that horticulture is simply a less intensive form of agriculture and that horticulture and chiefdoms may represent a long-term geography-conditioned equilibrium rather than a stage in the transition to intensive (cereal-based) agriculture and statehood.

[44] Sachs, Mellinger, and Gallup (2001), Olsson and Hibbs (2005), Ashraf and Galor (2013), and Spolaore and Wacziarg (2013) provide empirical attempts to link 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 relatively small and cannot explain the extent of the gap between tropical and nontropical countries, but his findings are controversial. Here, we question the productivity explanation and provide an alternative geographical/institutional explanation.

proclivity to violence. When permitted by the data, we control for population size in our regressions. Consistent with this theory, the coefficient of hierarchy on population is positive and significant but leaves the coefficient on our proxy for cultivating cereals practically unchanged.

Motivated by the contrasting political structures in the valleys of Peru and in Amazonia, Carneiro's (1970) "circumscription theory" offers another variant of a conflict theory. He postulates that an elite can extract ongoing surplus only when those subjected to taxation are geographically entrapped and contends that states could not emerge in the Amazon Basin because "the vanquished could flee to a new locale, subsisting there about as well as they had subsisted before, and retaining their independence," whereas "[i]n 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" (735).

Carneiro's puzzlement over limited social complexity in Amazonia is reminiscent of Diamond's concern about the underdevelopment of New Guinea. But the environmental theory of one contrasts with that of the other. Diamond's theory about the advantage of an east-west orientation of landmass cannot resolve Carneiro's comparison between Peru and Amazonia. And Carneiro's circumscription theory fails to resolve Diamond's puzzle of limited social complexity in the Pacific tropical islands. Our appropriability theory offers an explanation: 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]

Other scholars provide variants of conflict theory. Dow and Reed (2013) suggest that warfare between different groups leaves the victor as the owner of land and the vanquished employed as workers. Boix (2015) argues that the introduction of agriculture caused bandits to raid farmers. This conflict ended either in dictatorships by bandits who turned stationary (as in Olson 1993) or in republics managed by the farmers. Finally, Dal Bó, Hernández-Lagos, and Mazzuca (2022) theorize that farmers' increased insecurity due to pillage discouraged investment. State defense capacity evolved to resolve this inefficiency.

Our finding of a positive effect of cereal cultivation on hierarchy is consistent with these various conflict theories, since stored cereals attract predation by outsiders, generating a need for organized protection. Our thesis is arguably a variant of a conflict theory with an important addition. We distinguish between appropriable cereals and other less appropriable crops, and we identify that reliance on appropriable crops

[45] Allen (1997) applies Carneiro's theory to explain the emergence of the ancient Egyptian state in the circumscribed Nile Valley. He mentions how the appropriability of cereals contributed to hierarchy, maintaining, however, that surplus was a precondition for the emergence of the Egyptian state.

increases the tax capacity of the elite, independently of predation by outsiders and the functional demand for security.

Another functional theory focuses on the demand for law and order to facilitate trade. On the basis of African evidence, Bates (1983) argues that ecologically diverse environments increase the returns from commercial trade and generate demand for hierarchy. Fenske (2014) and Litina (2014) provide empirical support for this theory.[46] Trade also increases the return to the construction and maintenance of roads, ports, and marketplaces. Thus, similar to our claim that the cultivation of appropriable cereals generates demand for protection and facilitates the taxation to provide such protection, we note that trade, too, creates demand for a state and simultaneously enhances the state's opportunity to tax economic activity.

Cereals can be stored and transported, so their cultivation facilitates trade, and our empirical findings that link cereals with hierarchy are consistent with this theory. When possible, we control for proxies for trade (geographical isolation, measured by distance from a major river and distance from the coast) in our empirical analysis. We find some evidence that supports the trade channel, with the effect of cereals on hierarchy practically unaffected. This suggests that cereal cultivation affects hierarchy beyond its impact on trade.

Long-term storage plays an important role in another functional theory for the emergence of complex societies (Halstead 1989; Johnson and Earle 2000, 51–256, 301–2). Under Polanyi's ([1944] 1957) influence, it is argued that early agricultural societies were "redistributive," where surplus output was voluntarily transferred to a central authority, then redistributed and, in part, also stored on a long-term basis as a buffer against future shortfalls. This theory thus views the central authority as an insurance agency. Our emphasis here is on intra-annual storage and its potential for appropriation by the elite, rather than on central storage as a means of redistribution for the benefit of cultivators. We conjecture that overcoming idiosyncratic shortfalls to individuals did not require protostate centralized institutions and was managed by sharing within kin groups (as among hunter-gatherers). However, since this theory, too, emphasizes the role of storage, we find it consistent with our empirical findings.

Wittfogel (1957) proposed another functionalist theory. He contends that strong despotic hierarchies were required to realize the agricultural potential of riverine environments, through the public construction and management of large irrigation projects. Indeed, Bentzen, Kaarsen, and Wingender (2017) show that environments with the potential for irrigation

[46] Algaze (2008) offers a similar theory regarding ancient Mesopotamia. We note that these scholars typically have in mind long-distance trade in luxury items rather than in staple food.

systems have had greater inequality in the past and more authoritarian states in the present. In our empirical analysis, we control for evidence of agriculture based on intensive irrigation. Our estimates confirm that societies that practice intensive irrigation are characterized by relatively more complex hierarchies. Our results on the impact of cereals are unchanged when we control for irrigation.[47]

Several scholars reverse the standard causal direction from farming to hierarchy and maintain that the rise of religion and institutional innovations enabled a political elite to gain power and may have been the driving force behind the transition to agriculture (Cauvin 2000; Acemoglu and Robinson 2012). These theories are consistent with our empirical findings to the extent that these social and institutional changes were correlated with land suitability for cereals.

Nunn and Qian (2011) show how the adoption of the potato in Europe in the mid–sixteenth century led to population growth and to substantial social changes. They argue that these changes were due to the higher caloric yield of the potato in regions that are particularly suitable for its cultivation. We suggest a complementary mechanism, whereby European farmers adopted the potato because it provided them with greater immunity from taxation/theft, thus enabling the growth of the farming population. Consistent with this mechanism, McNeill (1999, 71) reports that European farmers initially resisted adopting the potato and did so only during the Dutch Wars in 1557–1609, when "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."

V. Concluding Remarks

We conclude by commenting on the pertinence of our research for understanding current issues. Besley and Persson (2009, 2014) argue that underdevelopment is closely related to low state capacity. While we address agriculture-based economies in earlier periods, we contend that the appropriability mechanism and our critique of the conventional

[47] However, Wittfogel's critics point out that irrigation projects in early civilizations were constructed by local communities, before the emergence of a powerful central state, and were also typically managed locally rather than centrally. Mayshar, Moav, and Neeman (2017) contend that, in contrast to Wittfogel's causal theory, it is not a need for irrigation that led to a despotic state but rather that (local) irrigation systems enabled control and expropriation by the central state—in analogy to the interpretation here that food storage facilitated confiscation. The findings by Bentzen et al. are consistent with the appropriability approach, since they do not address the direction of causality, i.e., whether hierarchy preceded or followed irrigation.

productivity theory shed important light on the sources of current underdevelopment. Since the modern transition away from agriculture to manufacturing and services is protracted and, in many countries, extended well into the twentieth century, and since social institutions exhibit inertia, we contend that our theory applies to the modern age.[48]

In particular, the appropriability theory provides new insights about the root cause of the underdevelopment in the tropics. We contend that the high productivity of less appropriable food sources provided the population with substantial immunity against taxation, which inhibited the emergence of stable state institutions and the development of high state capacity.[49] To the extent that hierarchy and state capacity are crucial for economic development, the environment in tropical regions might be a curse of plenty.

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[48] Bockstette, Chanda, and Putterman (2002), Gennaioli and Rainer (2007), Michalopoulos and Papaioannou (2013, 2014), and Spolaore and Wacziarg (2013) demonstrate that deep-rooted, precolonial institutions affect current institutions and economic outcomes. Dincecco and Prado (2012) and Dincecco and Katz (2016) show that state capacity is persistent and positively affects economic performance.

[49] Besley and Persson (2009, 2014) propose that low state capacity can be overcome by investment in fiscal administration. But our theory leads us to be less sanguine about tropical states' ability to raise revenue from the countryside, where the bulk of the population still resides. Gennaioli and Voth (2015) emphasize how investment in state capacity since the Middle Ages responded to conflict in the spirit of Tilly's (1975) theory. Becker et al. (2018) provide further empirical support for that theory.

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