The Origin of the State: Land Productivity or Appropriability?*

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Abstract

The conventional theory about the origin of the state is that the adoption of farming led to an increase in productivity, which led to food surplus. Food surplus is held to be a prerequisite for the emergence of hierarchical societies and eventually states. We challenge this theory and propose that hierarchy arose due to 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 present several case studies that further support our claims.

Geography, Hierarchy, Institutions, State Capacity

JEL Classification Numbers: *D02, D82, H10, O43*

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1 Introduction

Following the Neolithic Revolution – the transition of our ancestors from hunting-gathering to sedentary farming – complex hierarchical societies emerged, leading to the rise of tax levying states. These developments raise two related questions, which are among the most intriguing of the social sciences: What are the mechanisms that led to the development of complex hierarchies and states? And why didn't complex hierarchies emerge in some regions long into recent centuries, despite the adoption of farming?

The prevailing theory goes 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. In particular, high output generated surplus (food beyond 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 theory, regional differences in land productivity explain regional disparities in the development of hierarchies and states.

We challenge this theory, contending that it was not an increase in food production that led to complex hierarchies and states, but rather the transition to reliance on appropriable cereal grains that facilitate taxation by the emerging elite. We note that in some regions of the world complex hierarchies did not emerge, despite the adoption of productive agriculture and the resulting increase in 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) 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 in order to provide year-round subsistence. The relative ease of confiscating stored cereals, their high energy density and their durability enhances 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, but once harvested are rather perishable. Moreover, their high water

[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."

content hampers the efficient transportation of their nutritional content.[2] Thus, we argue 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 conventional theory, we argue that food surplus is neither necessary nor sufficient to give rise to hierarchy, and that in any case increased output is unlikely to generate surplus.[3] To illustrate our contention, consider the following two scenarios. First, an early society that cultivates cassava with output above long-term subsistence (that is, with 'surplus'). Cassava is a perennial root that can be harvested year-round, yet 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, despite the availability of food surplus. This scenario suggests that surplus isn't a sufficient condition for the emergence of a taxing elite, and 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 advanced hierarchy beyond local chiefdoms.

Second, consider a farming society that subsists on a cereal grain with no surplus. Since the crop has to be harvested within a short period and then stored, a tax collector could confiscate part of the stored grain and transport it for consumption by distant elite and other non-food producers. Ongoing confiscation of food can be expected to impact adversely the size of the farming population, and due to diminishing average product of labor, this would result in an equilibrium in which total output exceeds the farming population's subsistence needs, with the surplus confiscated by the non-farming elite. Thus, we concur with conventional productivity theory that farmers in hierarchical societies produce surplus, but our contention is that rather than surplus generating the elite, the

[2] In Appendix A we describe the characteristics roots and tubers. Their portability is hindered both by their vulnerability to spoilage and their bulkiness (due to ca. 70% moisture content). In this appendix we support also additional claims: (i) that reliance on roots and tubers is a major phenomenon in many regions; (ii) that roots and tubers are highly productive in these regions; (iii) that their harvest is in general non-seasonal; (iv) that after harvest they are significantly more perishable than cereals.

[3] 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 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.

elite generate the food surplus on which it can flourish, once the opportunity to appropriate rises. This scenario demonstrates that the availability of surplus is not a necessary precondition for taxation and hierarchy.

Finally, conventional theory asserts that increased farming productivity leads to surplus but this is inconsistent with the Malthusian mechanism.[4] Improved hunting techniques and the accumulation of knowledge led to increasing productivity over time among hunter-gatherers too. That increase was apparently translated to larger population size rather than to sustainable surplus, leaving hunter-gatherers in small egalitarian societies. Since the Neolithic Revolution spanned several millennia (Purugganan and Fuller, 2010), 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 food sources a taxing elite emerged, and 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.[5] Accordingly, we propose that protection of food stockpiles and hierarchy emerged in parallel to the gradual transition to reliance on appropriable food sources. We do not suggest, however, that elites were benign; rather, as Olson (1993) observed, deterring bandits served both the farmers and the elite.[6]

We develop a model that provides a specific interpretation of our thesis, focusing on the possibility of a state emerging and deterring bandits. Because it provides a specific interpretation, we present it in Appendix D, and briefly summarize its main insights here. In our model farmers allocate their land between tubers that cannot be looted or taxed, and cereals that can be taxed by the elite at a cost of employing tax collectors, or looted by unorganized bandits. The productivity

[4] Ashraf and Galor (2011) support the applicability of Malthus's theory in the pre-industrial era.

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

[6] The role of banditry as posing a significant threat to farmers and as provoking a basic need for protection is often raised (e.g., McNeill 1992: 85, and Mann 1986: 48). 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.

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 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 only exist if its tax revenue covers the fixed cost of deterring bandits.

The main prediction of this model is that a state can only exist 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.[7] First, the state's ability to commit to a lower tax rate encourages the cultivation of cereals when these are sufficiently more productive. Second, the net tax 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) less tax collectors than the equilibrium number of bandits under anarchy.

Our research question doesn't 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 dataset that measures hierarchical complexity.

The first subsection is based on Murdock's (1967) Ethnographic Atlas, which covers cultural, institutional and economic features of more than 1,200 pre-industrial 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

[7] We ignore here the possibility that the non-benevolent state may contribute further to farmers' welfare, if it contributes directly to agricultural productivity, for example through publicly provided irrigation infrastructure.

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 (FAO). Consistent with the appropriability theory, the 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 similar levels of hierarchy to non-farming 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 controlling for land productivity.

The results based on the Ethnographic Atlas are not conclusive. First, due to the cross-sectional nature of the data we cannot exclude potential omitted geographic factors which 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 towards relatively isolated societies with relatively low levels of hierarchy. Third, the data pertains mainly to the 19th and 20th century, which is a long time after the early transition to farming.

To overcome these limitations, in the second subsection we employ a dataset on hierarchy compiled by Borcan, Olsson and Putterman (2018). This dataset is based on present-day boundaries of 159 countries, with institutional information every half-century. We can only run reduced form regressions with this dataset, due to 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 AD 450 (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 effect of the productivity advantage of cereals (proxied with the FAO data) on states while we do not find any evidence of an impact of land productivity on hierarchy.

FAO data is 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 dataset 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 domestication of that crop in that region. Our cross-sectional regressions using the WRs 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 the availability of less appropriable productive crops prevents the emergence of hierarchy. 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 last millennium and exploit the "Columbian Exchange" of crops between the New and the Old World as a natural experiment. The exchange introduced new crops which, 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.

The third subsection 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 WRs 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 WRs proxy for crop availability, we utilize data on the location of centers of origin of agriculture. We show that distance from these centers only has a negative impact on the development of early civilization 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 our fourth empirical subsection, 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-difference estimates support the appropriability theory. Specifically, we find that the Neolithic transition only led to more traces of indications for complex hierarchical societies in areas where agriculture was more likely to start with cereals, based on 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 illustrates that the correlation between land productivity and hierarchy disappears after controlling for the cultivation of cereals, consistent with our critique of the conventional productivity-and-surplus 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, ceteris paribus, prefer to cultivate less appropriable crops that provide protection from bandits and tax collectors. Complex hierarchies, the data suggest, emerged when farmers were constrained to cultivating cereals.

In the empirical section 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 proposed appropriability explanation.

Our empirical analysis, presented in section 2, does not identify the mechanism that links cereal cultivation and complex hierarchy. In section 3 we present six 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 provides 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 the provision of public goods that facilitate trade and require leadership, such as law and order. 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 detailed review of the extensive literature on the rise of hierarchy and states is presented in section 4, so that we can discuss it in light of our empirical findings and case studies. We offer a few concluding remarks in Section 5.

2 Evidence I - Empirical Investigation

In this section we report the results of our empirical tests. We describe the data in subsection 2.1 and present our various empirical exercises and findings, using four different datasets on hierarchy and statehood, in subsections 2.2 to 2.5.

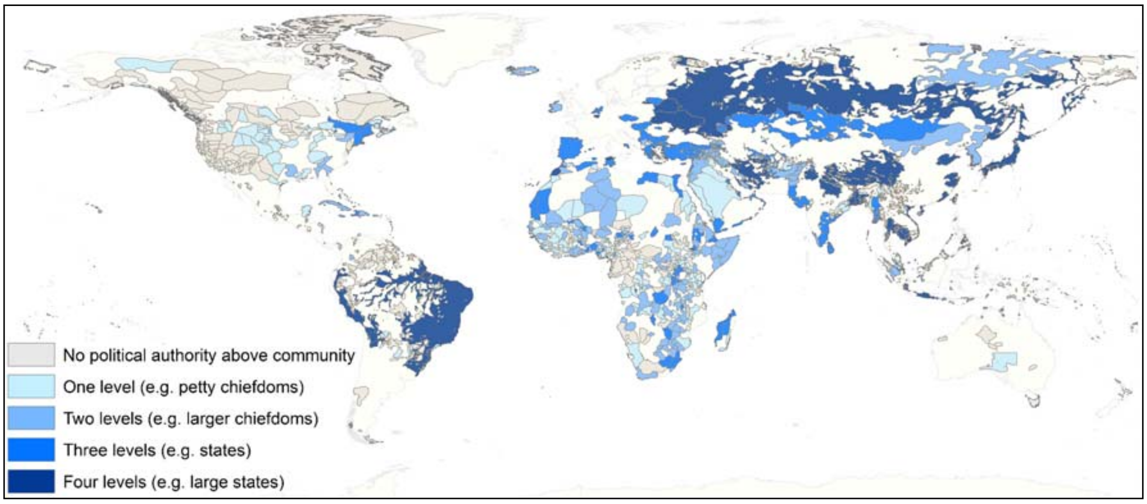
2.1 Data

2.1.1 Ethnographic data

Murdock's (1967) Ethnographic Atlas provides a database of 1,267 societies from around the world. The database contains information on several cultural, institutional, and economic features of these societies. These societies are described as they were before experiencing any significant industrialization. The focal year that data refer to is pre-1800 for 3% of the societies, the 19th century for 25%, the first half of the 20th century for 69%, and the second half of the 20th century for just 2.5%. The remaining societies are missing a focal year. Figure F.1 in the online Appendix F reports the density plot of the year that the data refers to for the different societies. While the sample is global, there is an emphasis on North American and African societies. From this sample, we remove 2 duplicate observations, 7 societies observed before AD 1500, and 10 societies for which the year of observation is missing, leaving 1,248 societies. These are matched to ethnic maps using either the geo-coordinates of each ethnicity provided by the Ethnoatlas or the maps on the spatial location of ethnicities constructed by Fenske (2013).[8]

We measure hierarchical complexity using the variable "Jurisdictional Hierarchy beyond the Local Community."[9] This is an ordered variable with five possible levels: (i) no political authority beyond community, (ii) petty chiefdoms, (iii) larger chiefdoms, (iv) states, and (v) large states. We plot this measure of hierarchy in Figure 1 and present the summary statistics in the first row of Table F.1 in the online appendix. 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 in Central Africa, but are rather rare in Northern Africa and in Asia, where large chiefdoms and states are more common.

Figure 1: Jurisdictional hierarchy beyond the local community in pre-industrial societies



The Ethnoatlas also provides information on the reliance of these societies on agriculture for their diet, and on the major crop type of societies that practice agriculture. These two variables are plotted in Figure 3, with summary data in rows 2 and 3 of Table F.1 in the online appendix. As can be seen from Figure 5, approximately one fifth of the societies in the sample do not practice any form of agriculture. These societies are concentrated in North-West America, Central Asia, Australia

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

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

and South-West Africa. The median society relies on agriculture for approximately 50 percent of its caloric needs. The great majority of the societies that practice some form of agriculture rely on either cereal grains (65.4 percent) or on roots and tubers (26.1 percent). 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 information on whether agriculture in farming societies relied on intensive irrigation (row 4 in Table F.1). Finally, the Ethnoatlas contains data on the use of domestic animals. Based on this information, we create three types of variables (see rows 5-14 of Table F.1). First, we construct 4 dummies that identify societies relying on animal husbandry for less than 25%, between 26% and 50%, between 51% and 75% and above 75% for their diet. Second, we construct five dummies that define the dominant type of animal husbandry (pigs, sheep, equine animals, camelids, bovine animals). Finally, we create a dummy that identifies societies that use animals for cultivation.

Figure 2: Major crop in pre-industrial societies

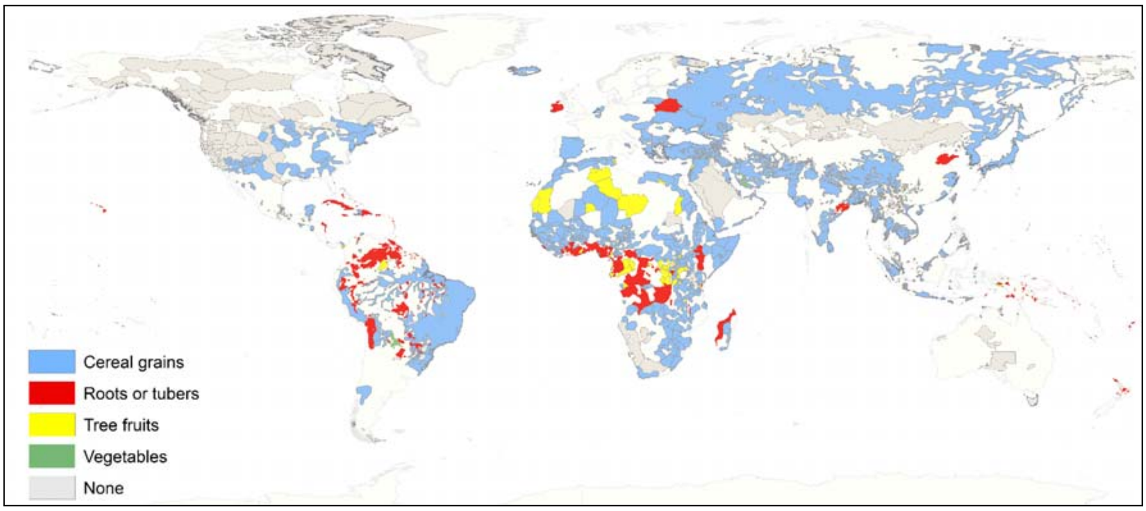


Figure 3

The second source of ethnographic information 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. A large number of publications by diverse authors coded the SCCS societies for many different characteristics. Cumulative ethnographic codes and codebooks are published in the World Cultures electronic journal. We use three variables from the SCCS (rows 15-17 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 in the online appendix. The second variable refers to the "Extent of burden caused by tribute payments or taxation," coded by Lang (1998). Based on 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 either there is evidence of regular taxation or the exactions are reported to be burdensome. The third variable is a measure of population density coded by Pryor (1985). Societies are categorized into 6 bins (the first bin contains societies with 0-1 persons per square mile, and the last contains societies with 500+ persons per square miles).

Table F.5 in the online appendix reports pairwise correlations between the variables of the pre-industrial 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.

2.1.2 Country-level data

We construct 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 from AD 50 to 2000. The score is based on the following question: Is there a government above the tribal level in that area? If yes, a score of 1 is assigned, 0.75 if it is a chiefdom, and 0 if the answer is no. 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); and the density of locally available wild animals suitable for domestication (Hibbs and Olsson 2004 and Ashraf and Galor 2011).[10] Finally, Pascali (2017) provides information on the colonial history (Figure F.3 in the online appendix shows the colonial history of each country). Table F.2 in the online appendix provides summary statistics for these variables.

2.1.3 Location of ancient cities and archaeological sites

To capture differences in social and hierarchical complexity further back in time, we collected data on the location of ancient cities. We use two different sources of information. The first source is Reba, Reitsma and Seto (2016), which provides data on the location of urban settlements from 3700 BC to AD 2000. The dataset is based on historical, archaeological, and census-based urban population data previously published in tabular form by Chandler and Modelski. Figure F.5 shows ancient settlements (founded before 500BC), while Figure F.6 shows classical settlements (founded before AD 450). The second source is the website developed by Daniel DeGroff,[11] which provides the list of cities and towns that were founded before AD 400. We also use archaeological evidence indicating ancient complex civilizations, collected from miscellaneous sources, presented in the online appendix.[12]

We aggregate data on the location of cities and archaeological ruins at the 1x1 decimal degree raster area. The first 10 rows of Panel A in Table F.5, in the online appendix, present descriptive statistics on the number of cities and relevant archaeological ruins in each terrestrial raster point.

[10] This variable is computed 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, Bakhtrian camels, Arabian camels, llamas, yaks, Bali cattle, reindeers, water buffalos, donkeys and mithans. Both Hibbs and Olsson (2004) and Ashraf and Galor (2011) exclude neo-Europes from the dataset. We have therefore complemented their dataset with new data we collected on Australia, Canada, New Zealand, and United States using Nowak (2011) as primary source.

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

[12] Data on archaeological sites from the ancient world come mainly from Ancientlocations.net. Sites are included if they existed prior to AD 476 (end of the West Roman Empire) in the Old World and prior to 1492 in the New World. The data are complemented with archaeological data from the Megalith Portal, 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 cereals and land productivity on different archaeological evidence of complex societies, such as pyramids, mines, temples and palaces, from the effect on other types of evidence (e.g. standing stones) that are perhaps less indicative of complex hierarchies. The portal initialy 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 only found in Europe and its surroundings, and always show the robustness of our regressions when excluding Europe.

2.1.4 Radiocarbon-dated prehistoric archaeological sites

David and Ruth Whitehouse's (1975) *Archaeological Atlas of the World* provides a database of the most relevant global prehistoric and proto-historic archaeological sites, which were known at that time. The atlas includes 4,215 sites that are radiocarbon dated.[13]

We geo-reference these sites and, using the information in the map titles and accompanying text, classify them depending on whether they pre-date the Neolithic transition in the relevant location or not. The result is a list of 825 sites that belong to pre-transition years and 3,309 sites that belong to the post-transition years. (We exclude 8 sites for which either geo-referencing was not possible or dates were uncertain and 73 sites for which we were uncertain about whether they belong to the pre- or post- transition years).

We compute the number of pre-Neolithic sites and post-Neolithic sites at the 1x1 decimal degree raster. The Atlas also classifies these sites according to eight different categories.[14] In the empirical analysis we either use all sites, or alternatively, only sites of prehistoric settlements. Panel B of Table F.3, in the online appendix, presents the descriptive statistics for these variables.

2.1.5 Soil suitability data

To obtain 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 Food and Agriculture Organization (FAO). The data provides global estimates of potential crop yields for different crops with cell size of 5'x5' (i.e. approximately 100 km^2) based on two possible categories of water supply (rain-fed and irrigation) and three different levels of inputs (high, medium and low). In addition, it supplies two alternative projections of potential crop-yields: one is based on agro-ecological constraints, which could potentially reflect human intervention, and one based on agro-climatic conditions, which are arguably unaffected by human intervention. To prevent concerns of reverse causality, we consider potential yields based on agro-climatic conditions under rain-fed low-input agriculture.

[13] Although this database is approximately 40 years old, Maurer, Pischke and Rauch (2016) conclude that: "While there has been much additional excavation in the intervening period, there is little reason to believe that it is unrepresentative for the coverage of sites and locations."

[14] These categories are: 1. Undifferentiated sites and find-spots 2. Settlements 3. Funerary monuments 4. Religious monuments 5. Caves and rock shelters 5. Cave art and rock reliefs 6. Hoards and votive deposits 7. Mineral sources 8. Mineral workings 9. Sites which combine several of the above categories.

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

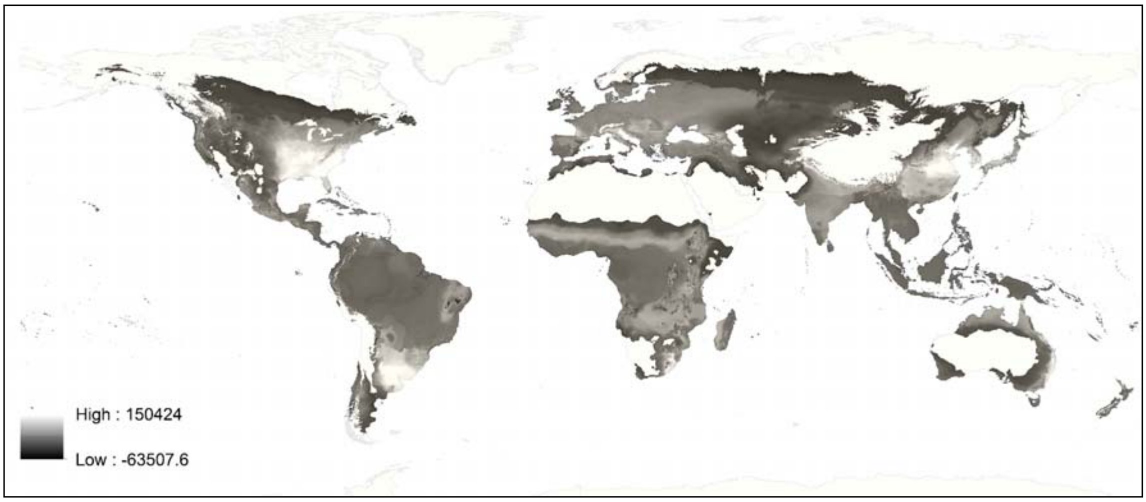


Figure 5

GAEZ provides data on potential yields, in terms of tons per hectare per year, for 11 cereal grains and 4 roots and tubers. Following the same procedure as in Galor and Ozak (2016) for the crops relevant for our investigation, these yields are transformed from tons into calories using data on the caloric content of crops provided by the USDA National Nutrient Database for Standard Reference.[15] We then find the crop with the highest potential caloric yields for each raster point. The results are illustrated in figure F.10 in the online appendix. Cereal grains are the highest yielding crops in approximately 99 percent 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.[16] 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 described in Figure 5.

[15] See Table F.4 in the appendix for the complete list of cereal grains, roots and tubers used in the empirical section and the corresponding caloric content.

[16] 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 will show in the next subsection that gross yields are still a good predictor of the crop choice.

As robustness checks, we exploit two alternative measures of the productivity of the land, which have been widely used in the literature. The first one is an index developed by Ramankutty et al. (2002), which measures the fraction of land that is suitable for agriculture. The second one is a caloric suitability index developed by Galor and Ozak (2016), which captures the highest attainable potential caloric yields from 48 crops (which includes not only cereals, roots and tubers but also sugar crops, pulses, oil crops, vegetables, fruits, fiber crops and stimulant crops). Table F.5 in the online appendix illustrates that our measure of the productivity advantage of cereals is positively correlated with our benchmark measure of land productivity (the correlation is slightly below 0.8), with the Ramankutty et al. index of suitable land (0.4) and with the Galor and Ozak caloric suitability index (0.8). 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 (2013) identify as "plow-positive" (wheat, barley and rye) and those 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-miles radius around the geo-coordinates reported in the Ethnoatlas.[17] They are attributed to countries and the 1x1 decimal degrees raster squares by averaging them within these boundaries.

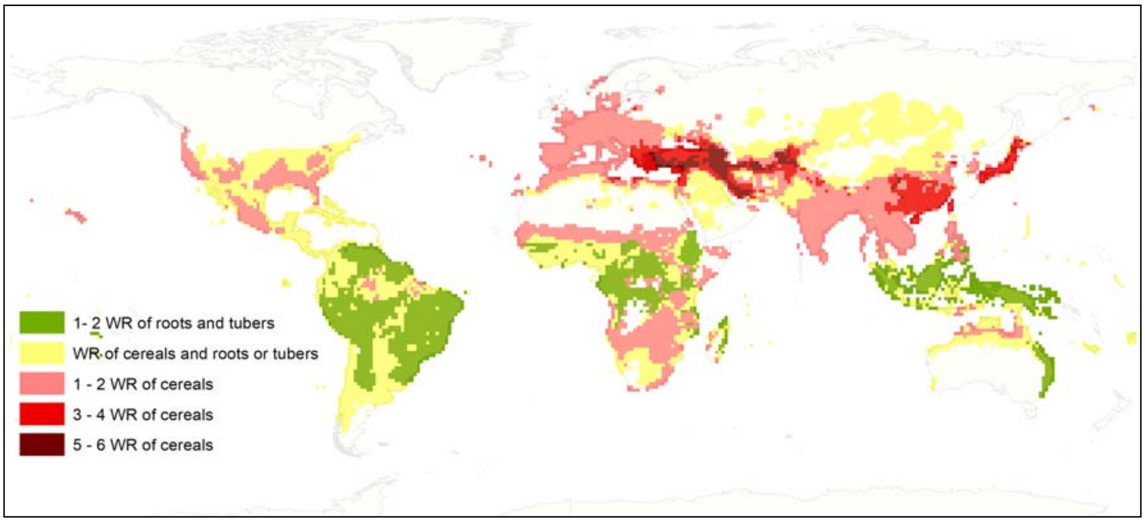
2.1.6 Wild relatives of domesticated crops

We use resources from the Global Crop Diversity Trust that show the potential distribution of wild relatives of domesticated crops (see Castaneda-Alvarez et al. 2016).[18] Crop wild relatives (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 the Oryza rufipogon, a wild species that grows in South-East Asia. Rice originates from this wild crop, which was probably domesticated in China and India around 8,000 to 9,000 years ago (Callaway, 2014). We concentrate on wild crops in the primary gene pool of a domesticated crop - the wild crop that can be directly mated with the domesticated crop, and assemble a dataset of their geographical distributions. In the empirical analysis, we assume that the number of primary WRs of a certain domesticated crop in a certain

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

[18] We thank Nora Castaneda-Alvarez for sharing the data with us. Her help was invaluable.

Figure 6: Distribution of wild relatives of domesticated cereals, roots and tubers



region proxies for the potential for domestication of that crop in the region. Based on the data on the potential distribution map of these primary WRs of domestic crops we computed the number of primary WRs of cereals and the number of WRs of roots and tubers in each raster point of the globe. Online appendix E lists all the domesticated crops available in the dataset and their respective WRs. We then construct 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 illustrated in Figure 6. As can be seen, the number of WRs can easily predict patterns of early domestication. For instance, the areas with the largest number of WRs of cereals correspond to the Fertile Crescent, the first region in the world that adopted agriculture, and the cradle of the first civilizations.

2.1.7 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 Figure (F.14)). We use these data to compute the distance of each raster point in the archeological data set from the closest region of independent adoption of agriculture and from the closest region of independent domestication of cereal grains. Descriptive statistics on these two variables are reported in columns

11 and 12 in Table F.3.

Finally, GAEZ provides raster data on population density in 1995, precipitation and temperature; the Global Digital Elevation Map (GDEM) provides raster data on elevation and ruggedness; 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 1x1 decimal degree raster points.

2.2 Pre-industrial societies: 2SLS estimates

According to the appropriability theory, the cultivation of cereals had a causal effect on the emergence of hierarchies. In this subsection we test this prediction on the pre-industrial societies surveyed in Murdock's Ethnographic Atlas. We first study (subsubsection 2.2.1) the determinants of the crop choice in these societies. As expected, cereal grains are cultivated in areas in which they are naturally more productive compared to roots and tubers. In the second subsubsection (2.2.2), we use 2SLS regressions to study the impact of cultivating cereal grains on hierarchical complexity. Using the productivity advantage of cereals over roots and tubers as an instrument, we document that the cultivation of cereals leads to more complex hierarchies (while land productivity does not). In the last subsubsection (2.2.3), we 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. The main limitation of this exercise comes from the cross-sectional nature of the database; we overcome this limitation in the next subsections by moving to a panel dataset.

2.2.1 The choice of crop

We formally analyze farmers' choice in the model presented in Appendix D. Farmers decide whether to cultivate cereals rather than roots or tubers based on two features of the environment: the productivity advantage of cereals over roots and tubers, which is exogenous, and the greater vulnerability of cereals to appropriation by bandits or the state, which is determined endogenously. To capture the response of the crop choice to geography, we run the following regression:

$$Y_i = \alpha CerAdv_i + X_i'\beta + \varepsilon_i, \tag{1}$$

where the dependent variable Y_i is either a dummy variable that identifies societies choosing cereals as the main crop ($CerMain_i$) or a measure of the reliance of these societies on agriculture for their diet ($AgrRely_i$); $CerAdv_i$ is the caloric advantage of cereals in the land of society i (the difference between the maximum potential caloric yield of cereals and of roots or tubers), and X_i' is a vector of control variables. The caloric advantage of cereals is constructed using the procedure detailed in section 2.1.5, under the assumption that the Columbian exchange was completed and every continent had potential access to every crop.[19]

Results are reported in Table 1. Column 1 reports the bivariate relationship between cereal advantage and the decision to cultivate cereals as the main crop, without any controls. The association is positive and statistically significant. An increase in the productivity advantage of cereals over roots and tubers by one standard deviation is associated with an increase in the probability of growing cereals as the main crop by about 20 percent. Moreover, variation in this regressor alone is able to explain 13 percent of the variation in the dependent variable. Column 2 reports the results when adding as a control variable land productivity (the highest potential caloric yield across all 11 cereals and 4 roots/tubers), to address the concern that the productivity advantage of cereals might reflect land productivity. The impact of the productivity advantage of cereals is unchanged, land productivity doesn't have any significant impact on crop choice and the R^2 of the regression is practically unchanged. Results hold with continental fixed effects (in column 3), and when resorting to logistic estimation to account for the binary nature of the dependent variable (columns 4 and 5).

In the online Appendix F we show that these results survive a battery or robustness checks, when controlling sequentially for: precipitation, temperature, elevation, and ruggedness, which are the main factors affecting crop productivity in the GAEZ dataset (Table F.6). We also control for: geographical isolation (proxied by the distance to the nearest major river or coast), historical and current population density, evidence of intensive irrigation, and the productivity advantage from using the plow (Table F.7). In all cases, the qualitative results on the effect of cereal productivity advantage over roots and tubers are almost unaffected: the coefficients vary from 0.250 to 0.261 and are always statistically significant at the 1 percent confidence level.

[19] This is a reasonable assumption as the great majority of the societies in the Ethnoatlas are captured between the end of the 19th century and the beginning of the 20th century.

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

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

The table reports cross-sectional OLS and Logit estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

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

2.2.2 Cereals and hierarchy: 2SLS estimates

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:

$$Y_i = \alpha_1 CerMain_i + \alpha_2 LandProd_i + X_i'\beta + u_i, \tag{2}$$

where Y_i is a measure of hierarchy in society i; $CerMain_i$, as mentioned above, 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. This specification, however, raises two concerns.

First, the choice of crop is influenced by social institutions, as explained above. To overcome this reverse causality concern, we exploit variations in potential, rather than actual, crop yields, which are derived from agro-climatic conditions that are presumably orthogonal to human intervention. Specifically, we run IV regressions, where we instrument for $CerMain_i$ by using the productivity advantage of cereals, $CerAdv_i$.

Second, there are several potential omitted variables that could be correlated with the main regressor and the measure of hierarchy. The disease environment, for instance, is correlated with both the cultivation of tubers (which is concentrated in the tropics) and is likely to be correlated with the quality of institutions (Acemoglu, Johnson and Robinson, 2001). A battery of robustness checks mitigates this concern. In two of the following sections, we utilize alternative datasets to conduct panel regressions that alleviate concerns regarding potential time-invariant omitted variables.

Table 2: Cereals and Hierarchy - Reduced Form

	Dependent variable is: Jurisdictional Hierarchy Beyond Local Community				
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	Ord Logit
$CerAdv$		0.244***	0.179	0.274**	0.495***
		(0.069)	(0.120)	(0.107)	(0.149)
$LandProd$	0.239***		0.082	-0.188*	-0.224
	(0.075)		(0.141)	(0.108)	(0.178)
CONTINENT FE	NO	NO	NO	YES	YES
r2	0.0361	0.0416	0.0429	0.249	
pseudo r2					0.121
N	952	952	952	952	952

The table reports cross-sectional OLS (columns 1-4), Ordered Logit (column 5) estimates. The unit of observation is the society in Murdock's Ethnoatlas. Columns 1-4 report in parentheses Conley standard errors adjusted for spatial correlation. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Before presenting the 2SLS regressions we present the box plot of the productivity advantage of cereals for each level of hierarchy and the reduced form estimates. The box plot reported in the online appendix Figure F.11 reveals that the productivity advantage of cereals is generally larger in societies organized as states compared to societies organized as either chiefdoms or tribes. Table 2 reports the reduced form analysis. 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 (columns 3-5) the effect of the productivity advantage of cereals remains positive and significant (excluding in column 3) and the effect of land productivity disappears. An increase of one standard deviation in the productivity advantage of cereals increases the hierarchy index by 0.27 in the specification with continent fixed effects (column 4). In column 5, we use an ordered logit model to account for the ordinal nature of the dependent variable. A one standard deviation increase in the productivity advantage of cereals increases the log odds of being in a higher level of hierarchy by approximately 50 percent. In the appendix (Table F.8), we relax the assumption of proportional odds, which is implicit in the standard ordered logit models, and estimate a generalized logit model.[20] As can be seen, the greatest impact of cereal advantage is to push societies from tribes and chiefdoms to states. More specifically, while an increase in one standard deviation in the productivity advantage of cereals increases the log odds of being in a level of hierarchy higher than a tribe by 32 percent, it increases the log odds of being in a level higher than a chiefdom by 65 percent and higher than a small state by 84 percent. In all cases, the impact of land productivity is either very small and not statistically significant, or negative.

Table 3 reports the OLS and 2SLS estimates of equation 2, when the dependent variable is hierarchy. The OLS estimates in column 1 show that cultivating cereals is associated with an increase of 0.70 in the hierarchy measure. The 2SLS estimates are presented in the next three columns. Cultivating cereals as the main crop increases the hierarchy measure by more than one (column 2), which is equivalent, for instance, to a move from a tribe to a small chiefdom or from a large chiefdom to a state. We note that the 2SLS coefficient on cereals is *larger* than the OLS one.[21]

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

[21] There could be two explanations. First, the measurement error in the cereal variable is likely to downward bias the OLS estimates. Second, and more important, while OLS estimates describe the average difference in hierarchy between societies cultivating cereals and the rest, the 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, or LATE). This is relevant, as there are several societies, especially in 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 on other crops. To understand whether this might be responsible for the lower OLS coefficients compared to the IV coefficients, we re-estimate the first two columns of Table 3 only

Table 3: Cereals and Hierarchy - OLS and 2SLS

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

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

In column 3, we add land productivity as a control variable. As consistent with the reduced form regressions, land productivity does not have any significant effect on hierarchical complexity. In this specification, the effect of cereals is no longer insignificant. The effect of cereals is significant in all other specifications. Column 4 includes the dependence of the society on agriculture instrumented with caloric advantage of cereals and land productivity. Results indicate that societies that practice agriculture are not characterized by more complex hierarchies unless they cultivate cereals. In columns 5-8, we repeat the analysis adding continent fixed effects to the regression. The 2SLS results are practically unchanged, with the exception of column 6 in which cultivating cereals has a significant effect on hierarchy despite controlling for land productivity.

The results of Table 3 survive a battery of robustness checks presented in the online appendix. In Table F.9, we control sequentially for precipitation, temperature, elevation, and ruggedness – the main factors affecting crop productivity. Table F.10 addresses other potential channels, through which the cultivation of cereals might affect economic development and hierarchical complexity.

As mentioned in the introduction, since cereals can be stored and transported, their cultivation

for societies living in areas in which wild relatives 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.

facilitates trade, which could give rise to leadership and taxation. In an attempt to mitigate the possibility that the effect of cereals on hierarchy is only a result of trade, we control for geographical isolation (proxied by distance from a major river and distance from the coast). There is some evidence that close proximity to a river is associated with more complex hierarchies, but the impact of cereals on hierarchy is unaffected. We control also for historical and current population density,[22] which is associated in several theories with increased hierarchy (and with economic and technological development). Cereals still have a large impact on hierarchy when adding these controls. The data, as one would expect, reveal a positive correlation between population density and hierarchical complexity. We control for evidence of agriculture based on intensive irrigation. This could be an important potential confounder as Bentzen et al. (2016) provide evidence of a causal impact of irrigation potential on autocracy. Our estimates confirm the validity of their results: societies that practice intensive irrigation are characterized by relatively more complex hierarchies. Our results on the impact of cereals are unchanged. Finally, results are robust to the inclusion of the productivity advantage of the plow, a variable that Alesina, Giuliano and Nunn (2013) have identified as an important determinant of gender roles.

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 crops productivity (Table F.12), when the sample includes societies living in desertic soils (Table F.11), or when using either the Ramankutty et al. index of fertile land or the Galor and Ozak index of caloric suitability as alternative measures of land productivity (Table F.13).

In Table F.14, we control for animal husbandry and animal use in agriculture. Throughout the table, the estimates on the cereal coefficient are practically unaffected by the addition of these controls, reassuring that cereal advantage is not picking up an effect coming from an unobservable variable correlated with animal domestication. We start in column 1 by adding a dummy for each disconnected continent. In columns 2 and 3, we add 3 dummies that identify societies relying on herding for 26% to 50%, for 51% to 75% and for above 75% of their diet. The higher the reliance

[22] We use two different proxies for historical population density. The first one, HYDE, is based on historical recostruction at the raster level and is available for the entire sample of societies in the Ethnoatlas. Because historical population reconstruction is unavoidably inexact, we also show the robustness of our results when using data from Pryor (1985), which are available for a much smaller sample (only 144 societies) and are based on completely different sources.

of a society on herding, the higher is the level of hierarchy. This association is in line with our thesis as domesticated animals, one can reasonably argue, are appropriable. In columns 3 and 4, we control for the predominant type of animal husbandry: herding based on sheep, camelids and bovine animals are associated with higher hierarchical complexity. Finally, in columns 5 and 6, we control for the use of draft animals. In line with Diamond's (1997) geographical hypothesis, in particular the role of draft animals in the emergence of complex hierarchy, societies that use draft animals in farming are on average one step higher in the hierarchy ladder.

2.2.3 The appropriability mechanism: evidence on the rise of taxation and farming surplus

In this subsection, we show that the cultivation of cereals is correlated with the existence of 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.15, in the online appendix. 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 both in 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 (columns 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 should not come as a surprise 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 isn't significantly correlated with the tax burden.

In Table F.16 in the online appendix 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 turning 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 turn to 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) and suggests that taxation was not possible in non-agricultural societies nor 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. Finally, it survives the same robustness checks that we run for Table 3 (see Tables F.17-F.19 in the online appendix).

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 4, through which cereal cultivation might be fostering the development of complex hierarchies.

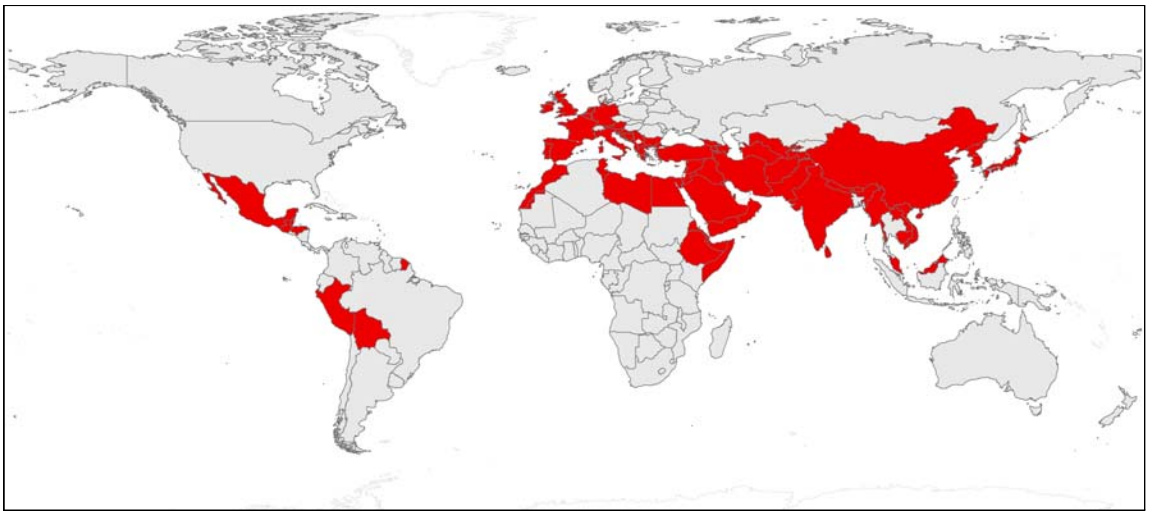
2.3 Country-level data: cross-section and panel estimates

In this subsection we use data on hierarchical complexity from Borcan et al. (2018). The unit of observation is the territory delimited by modern-day country borders for 159 countries every 50 years.

In the first subsubsection (2.3.1), we 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 AD 450 are characterized by the presence of several wild relatives (WRs) 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 controlling for a large number of potential confounders and they suggest that adopting cereals might be 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.

In the second subsubsection (2.3.2), we turn to a natural experiment of history – the Columbian Exchange – and exploit the panel nature of the dataset. The Columbian Exchange led to an exchange of crops between the Old World and the New World that permanently changed the

Figure 7: Modern countries that were mainly organized as states in 450 AD



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. The analysis is robust to controlling for a large number of potential confounders, and the main results are not explained by colonization patterns or pre-trends.

2.3.1 Explaining differences in hierarchy during the Classical Age

Figure 7 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 (AD 450), just before the collapse of the Roman Empire. We focus on this period because for the pre-classical period the exact location of state borders is less certain. According to our thesis, regions in which agriculture started with cereals and not with roots or tubers for exogenous reasons, would develop complex hierarchies. Although data on the exact crops that were cultivated in each region of the world at that period are not available, we use information on the distribution of WRs of domesticated crops, which also alleviates reverse causality concerns. Specifically, we use a measure of the potential availability of each domesticated crop in different areas of the world, which is presumably unaffected by the development of hierarchy.

According to our thesis, states develop where cereals are farmed, and cereals are farmed where they are available and roots and tubers are not. This prediction is consistent with the data. By comparing Figure 7 to Figure 6, 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 being the most prominent example. Table 4 reports the estimated coefficients from the following regression:

$$Hierarchy_i^{450} = \alpha_1 I(WR\_Cer)_i + \alpha_2 I(WR\_RT)_i + \alpha_3 I(WR\_Cer + WR\_RT)_i + X_i'\beta + u_i. \quad (3)$$

The hierarchy index in AD 450 ($Hierarchy_i^{450}$) is regressed on a dummy that identifies areas with only WRs of cereals available ($I(WR\_Cer)_i$), a dummy that identifies areas with only WRs of roots and tubers available ($I(WR\_RT)_i$), a dummy that identifies areas in which both WRs of cereals and of roots and tubers are available ($I(WR\_Cer + WR\_RT)_i$), 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 both WRs 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 AD 450. A close look at Figures 7 and 6 suggests that latitude is correlated with both $Hierarchy_i^{450}$ and $I(WR\_Cer)_i$. However, controlling for differences in latitude, leaves the estimated coefficient on $I(WR\_Cer)_i$ practically unaffected (column 2). Results are robust to adding continent dummies (column 3). In Table F.21 in the online appendix we show that results are robust to excluding each continent one-by-one. Finally, results are practically unaffected when we control sequentially for precipitation, temperature, elevation and ruggedness (columns 4-8 in Table 4).

In Table F.22, in the online appendix, we consider a host of additional factors that might have impacted 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,

Table 4: Cereals and Hierarchy in Classical Antiquity - Cross-sectional regressions

	Dep. Variable: Hierarchy Index in AD 450							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
WR Cer	0.535***	0.526***	0.465***	0.505***	0.433***	0.462***	0.423***	0.487***
	(0.0655)	(0.0989)	(0.124)	(0.118)	(0.129)	(0.121)	(0.136)	(0.117)
WR RT		0.125	0.182	0.196	0.168	0.204	0.123	0.222
		(0.174)	(0.173)	(0.170)	(0.172)	(0.174)	(0.170)	(0.172)
WR Cer and RT		-0.0319	0.0623	0.0568	0.0709	0.0304	0.0447	0.123
		(0.0918)	(0.114)	(0.114)	(0.112)	(0.112)	(0.126)	(0.114)
Controls:								
Abs 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	NO	NO	NO	NO	YES
CONTINENT FE	NO	NO	YES	YES	YES	YES	YES	YES
r2	0.305	0.310	0.408	0.418	0.408	0.428	0.402	0.435
N	151	151	151	151	150	148	145	151

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The years 1500-1750 are excluded from the regression. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

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, and the density of wild animals suitable to domestication. The key results are essentially unaffected.

We further illustrate how cereals can explain the distribution of states in classical antiquity in a box plot (plot F.12 in the appendix). 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.23, in the online appendix, 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 AD 450. 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. Controlling sequentially for a large number of geographical confounders, including latitude, does not affect the estimates of the main coefficients. In this table, the productivity advantage of cereals and land productivity are calculated using only the subset of cereals and roots/tubers that were available in the Old World and in the New World before the Columbian Exchange.

2.3.2 Panel data based on the Columbian Exchange

The latest results indicate that the cultivation of cereals is correlated in a positive and significant way with the presence of states at the peak of the classical era. Land productivity does not seem to play any role in the development of early states. 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 productivity or availability of different crops might be driving our results. To alleviate this concern, we exploit in this sub-section the exogenous change in the set of available crops in different locations of the world that was induced by the Columbian Exchange.

Among the main four roots and tubers that we considered thus far, only three were available in the New World before 1500: cassava, white potatoes and sweet potatoes. Among the eleven main cereals, only maize was available in the New World. In the Old World, yam was the only available crop from among 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 land productivity before the Columbian Exchange (prior to 1500), based on the relevant subset of crops, and after the exchange (after 1550), based on the full set of crops.[23]

The benchmark sample used in this subsection comprises 151 countries, for which the hierarchy data constructed by Borcan et al. (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:

$$Hierarchy_{it} = \alpha_1 CerAdv_{it} + \alpha_2 LandProd_{it} + X'_{it}\beta + \eta_i + \eta_t + u_{it}. \tag{4}$$

Here, the dependent variable is the hierarchy index of country i in year t, while $CerAdv_{it} =$

[23] The historical evidence points out 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 began 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 appendix F we show that our results are robust when excluding the years between 1500 and 1750 (Table F.28).

$CerAdv_{i,BeforeExchange}$ (the caloric advantage of cereals over roots and tubers before the Columbian Exchange) if $t \leq 1500$ and $CerAdv_{it} = CerAdv_{i,AfterExchange}$ (the caloric advantage after the Columbian Exchange) if $t > 1550$. Similarly, potential land productivity ($LandProd_{it}$), is calculated based on the pertinent crops available before and after the Columbian Exchange. 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, we contend that the colonization process does not seem to be driving our results: excluding colonies from the estimation sample doesn't 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 observation on the differential impact of the changes in cereal advantage and in changes in land productivity that we observe in Table 5.

Column 1 in table 5 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 not significant in all other specifications, when the cereal advantage is included in the regression. Column 2 confirms that the higher is cereal advantage, the higher is the country's hierarchy index. A one 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 controlling for land productivity, and in addition also for precipitation, temperature, elevation, ruggedness and absolute latitude (interacted with the time-period fixed effects). In Table F.24, in the online appendix, we consider a host of additional factors (each interacted with time-period fixed effects) that might have impacted hierarchical complexity. In particular, as in the previous subsection we control 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, and the density of wild animals suitable for domestication. The key results are essentially unaffected.

Table 5: Cereals and Hierarchy - Panel Regressions

	Dep. Variable: Hierarchy Index							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CerAdv		0.189***	0.272***	0.282***	0.240***	0.255***	0.261***	0.197**
		(0.0683)	(0.0834)	(0.0760)	(0.0857)	(0.0889)	(0.0839)	(0.0795)
LandProd	0.141		-0.163	-0.193	-0.152	-0.115	-0.148	-0.165
	(0.0971)		(0.141)	(0.131)	(0.139)	(0.142)	(0.138)	(0.123)
Controls (x Year FE):								
Precipitation		NO	NO	YES	NO	NO	NO	NO
Temperature		NO	NO	NO	YES	NO	NO	NO
Elevation		NO	NO	NO	NO	YES	NO	NO
Ruggedness		NO	NO	NO	NO	NO	YES	NO
Abs Latitude		NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES	YES	YES	YES	YES
r2	0.669	0.680	0.682	0.716	0.684	0.681	0.686	0.705
N	2869	2869	2869	2850	2812	2755	2869	2869

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. Robust standard errors, clustered at the country-level, in parentheses. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

In Table F.25 in the online appendix 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 become smaller by approximately a third, but remains positive and statistically significant, while the impact of land productivity on hierarchy is still not significant. Table F.26 and F.27 in the appendix report further robustness checks. Specifically, in Table F.26, hierarchical complexity is proxied by a dummy that identifies societies with a government above tribal level. In Table F.27, land productivity is proxied by the caloric suitability index developed by Galor and Ozak (2016), which also varies depending on whether it is measured before or after the Columbian Exchange. Finally, in Table F.28, 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 pre-trends The identification assumption of equation (4) requires that, until 1500, $Hierarchy_{it}$ did not follow systematically different trends across the set of countries that experienced different shocks in the productivity advantage of cereals after 1500. In this section, we show the existence of parallel linear and non-linear 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.29 in the online appendix). 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 change 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:

$$Hier_{it} = \sum_{j=1050}^{1850} \alpha_j * (Change\ CerAdv)_i * j + X_{it}'\beta + \eta_i + \eta_t + u_{it}. \quad (5)$$

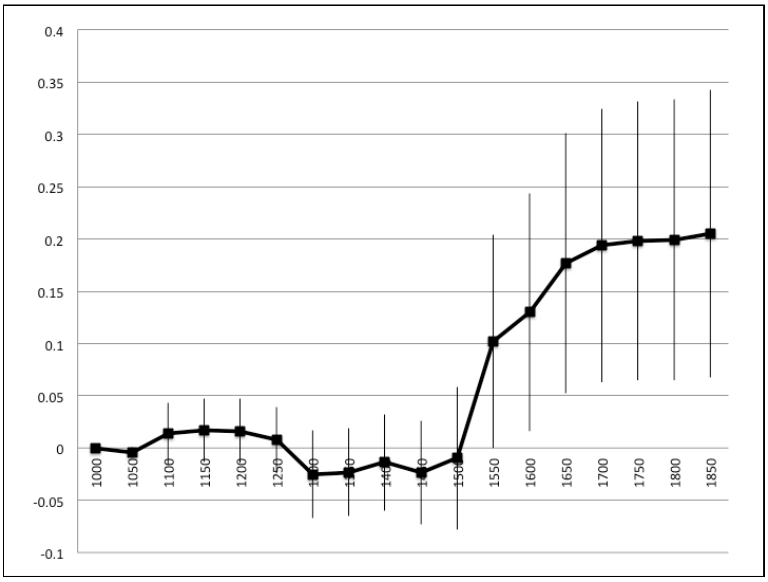
This specification does not require any assumption about the timing of the Columbian Exchange and considers the year 1000 as the baseline year. Results are presented in Table F.30. In the first column, there are no further control variables. The estimated α_js and their 10 percent confidence intervals are reported in Figure (8).[24]

The impact of the change in the productivity advantage of cereals over 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 controlling for the interaction between the potential change in land productivity with year fixed effects and the usual geographic characteristics 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

[24] The 17 coefficients reported in Figure (8), 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.

Figure 8: Flexible estimates of the relationship between the change in the caloric advantage of cereals over roots and tubers due to the Columbian exchange and hierarchy.



the possibility that non-linear pre-trends might be driving our results.

2.4 Early traces of civilization: cross section of archaeological sites

The results presented in the two previous subsections support our thesis based on data from AD 450 and more recent centuries. We now turn to data that covers the era 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 pre-classical large settlements or archaeological ruins. We show that these cities are concentrated in areas in which agriculture was likely to start only with cereal crops. In particular, these are areas that are characterized by a large number of wild relatives (WRs) of domesticated cereal crops, but where WRs of roots and tubers are not available. Alternatively, these are areas close to centers of independent domestication of cereals.

Table (6) employs two different datasets. The first is the dataset provided by Daniel DeGroff on the location of cities founded before AD 400 in the Old World (columns 1-4). The second dataset comes from Reitsma and Seto (2016) and refers to the location of large settlements present in classical antiquity (AD 450) and pre-classical antiquity up to 500 BC (columns 5-8). Under the presumption that the existence of a city or large settlement is an indicator of hierarchy, we use a grid of the world land surface, in which the unit of observation is the 1x1 decimal degree raster, to test our thesis. We run regressions of the form:

$$Settlement_i = \alpha_1 I(WR\_Cer)_i + \alpha_2 I(WR\_RT)_i + \alpha_3 I(WR\_Cer + WR\_RT)_i + X_i'\beta + u_i. \quad (6)$$

Table 6: Wild Relatives of Domesticated Crops and the Location of Ancient Cities.

	Dependent variable is the presence of cities/large settlements founded by:							
	AD 400				AD 450		500 BC	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
WR Cer	0.197***	0.195***	0.195***	0.0965***	0.0191***	0.0101***	0.00587**	0.00233
	(0.0325)	(0.0326)	(0.0377)	(0.0280)	(0.00529)	(0.00380)	(0.00277)	(0.00271)
WR RT		-0.00809	0.00478	-0.0277	-0.00353	-0.00322	-0.00304	-0.00155
		(0.00700)	(0.0145)	(0.0232)	(0.00299)	(0.00352)	(0.00215)	(0.00184)
WR Cer and RT		-0.00901	0.0245	-0.00191	-0.00162	-0.00108	-0.00304	-0.00107
		(0.00694)	(0.0201)	(0.0221)	(0.00358)	(0.00308)	(0.00258)	(0.00167)
CONTINENT FE	NO	NO	YES	NO	NO	YES	NO	YES
COUNTRY FE	NO	NO	NO	YES	NO	NO	NO	NO
r^2	0.124	0.124	0.144	0.407	0.0180	0.119	0.00944	0.125
N	17076	17076	17076	17076	17076	17076	17076	17076

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. Robust standard errors, clustered at the country-level, in parentheses. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

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 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.[25] In column 2, the presence of an ancient city is regressed on all the three main regressors in equation (6). The estimated coefficient on $I(WR\_Cer)_i$ does not change. Moreover, consistent with our claims, areas in which WRs of roots and tubers are present are not different from areas with no WRs of

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

any domesticated crops, in the presence of ancient cities. This is true regardless of the existence of WRs of cereals in addition to the WRs of roots/tubers. This result is practically unchanged when controlling for continent fixed effects (columns 3) and when using a logit model to account for the binary nature of the dependent variable (see appendix table F.32).

A potential concern with these estimates is that data on the location of ancient cities might have different levels of accuracy in different (modern) countries. In column 4 we exploit only within country variation. The qualitative results do not change substantially, but the estimated coefficient on $I(WR\_Cer)_i$ drops by a factor of 2.

In the second part of the table we use data on the presence of large ancient settlements coming from Reitsma and Seto (2016). In columns 5 and 6, we look at settlements that were established before AD 450. The qualitative results are the same as in columns 1-4. In the last two columns, we move back in time to pre-classical antiquity. From a qualitative point of view, results are practically unchanged. The estimated coefficients on $I(WR\_Cer)_i$ are approximately half compared to the previous columns but this is due to the fact that the mean of the dependent variable is substantially smaller.

In Table (F.33) in the appendix we report results when controlling sequentially for precipitation, temperature, elevation, ruggedness and absolute latitude. Our results are substantially unchanged when controlling for irrigation potential, plow advantage, current population density and are robust to excluding Europe or deserts from the sample (see appendix Table F.34), though in some specifications the coefficient on $I(WR\_Cer+WR\_RT)_i$ becomes positive and statistically significant.

In an attempt to connect our analysis to evidence on domestication of plants during the Neolithic, rather than the potential for domestication that is based on the presence of WRs of domestic crops, we turn to data on centers of domestication. The underlying assumption is that the probability that a crop would reach a certain area would be negatively associated with the geographic distance between that area and the nearest area in which that crop was domesticated. Therefore, 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, are 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 in which independent domestication took place and from which domesticated crops spread to the rest of the world (see map E.5 and Larson et al., 2014). We use these data to compute the distance to the nearest center of independent domestication of cereals grains and roots/tubers. A box plot (plot F.13 in the appendix) 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 1000 km. Their distance from a center of root/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).

More formally, Table (7) report OLS estimates from the following regression equation:

$$Settlement_i = \alpha_1 DistanceCer_i + \alpha_2 DistanceAgr_i + X'_{it}\beta + u_{it}, \quad (7)$$

where $DistanceCer_i$ 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.

Table 7: The Origin of the Neolithic Transition and the Location of Ancient Cities.

	Dependent variable is the presence of cities/large settlements founded by:					
	AD 400				AD 450	500 BC
	(1) OLS	(2) OLS	(3) OLS	(4) Logit	(5) OLS	(6) OLS
DistanceCer	-0.00160***	-0.00214***	-0.00143**	-0.187***	-0.000320**	-0.000199**
	(0.000342)	(0.000597)	(0.000604)	(0.0333)	(0.000136)	(0.0000861)
DistanceAgr		0.000909	0.000253	0.112***	0.000117	0.0000733
		(0.000676)	(0.000566)	(0.0379)	(0.000123)	(0.0000754)
CONTINENT FE	NO	NO	YES	YES	YES	YES
Ave marg. effect of *DistanceCer*						
r2	0.0284	0.0307	0.0495		0.0132	0.00962
N	15927	15927	15927	15927	15927	15927

The table reports cross-sectional OLS and Logit estimates and the unit of observation is the 1x1 decimal degree square. Robust standard errors, clustered at the country-level, in parentheses. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

The estimates illustrated in the first column of Table (7) show that distance from the nearest area of independent domestication of a cereal grain is negatively correlated with urbanization. This result still holds (column 2) when controlling for distance from the nearest area of independent adoption of agriculture (any crop). This result is robust when considering within-continent variation (column 3), using logit rather than OLS (column 4), or when looking at the data from Reitsma and Seto (2016) for AD 450 and 500 BC see column 5 and 6).

In the appendix table F.35, we show that results are robust to controlling sequentially for precipitation, temperature, elevation, and ruggedness. In Table F.36, we extend the analysis of Table 7 by controlling for: absolute latitude, irrigation potential, productivity advantage from the plow, and population density in 1995. In the last two columns of the table, we limit the analysis to Asia and Africa and exclude deserts. The results are robust with one exception. When controlling for absolute latitude the coefficient on distance to the areas of cereal domestication drops by half and is no longer statistically significant (column 1). The great majority of the centers of cereal domestication are concentrated in a very limited latitude band (between 10 and 40 degrees N), in which there are almost no centers of domestication of roots and tubers. Thus, the data limit our ability to disentangle the impact of distance to the closest cereal domestication center and absolute latitude. There are, however, a couple of exceptions to this rule: in Lingnan (South China, lat: approx. 25 N) yams and taro were domesticated but not cereals, and in the Sudanese savannah (lat: approx. 5 N) sorghum was domesticated. When limiting the analysis to Africa and Asia, distance to the closest centers of early domestication of cereals matters, while distance to the closest centers of early domestication of roots and tubers does not, even after controlling for absolute latitude (column 2).

In Table (F.37) in the online appendix, we replace the left hand side variable of ancient cities with alternative archaeological sites (which predate the 476 CE fall of the Roman Empire in the Old World, or the 1492 discovery of the Americas in the New World), that are reasonable proxies for hierarchy/civilization. Column 1 documents a negative and statistically significant correlation between the presence of ancient archaeological sites and the distance from the nearest area of domestication of cereals. As before, distance to the nearest center of domestication of other crops does not seem to matter when controlling for distance to centers of cereal adoption. This result is confirmed when archaeological sites are pyramids, ancient temples, ancient mines, ancient palaces and ancient sculptured stones, but not when the archaeological sites are ancient standing stones. The results reported in this table are also valid when examining the extensive margin and focusing on the number of archaeological sites in each cell (Table (F.38) in the appendix) and when excluding

Europe (Table (F.39) in the appendix).

As another robustness check, in Table (F.40) in the online appendix, we repeat the analysis presented in Table (6), but using GAEZ data. The presence of an ancient city is regressed on land productivity and the productivity advantage of cereals over roots and tubers. Column 2 illustrates that a higher productivity advantage of cereals over roots and tubers is associated with an increase in the probability of finding an ancient city in that area. In addition, it shows that if we control for cereal advantage, land productivity is uncorrelated with the location of ancient cities. Results are robust to adding continent fixed effects (column 3), for country fixed effects (column 4) and when using the Reitsma and Seto (2016) data on the location of large settlements founded before either 450 AD or 500 BC (columns 5-8).

2.5 Difference-in-difference using radiocarbon-dated prehistoric archaeological sites

The results in the previous section are based on a cross-section analysis, and even though we control for a large set of confounders, we cannot exclude that the presence of WRs of domesticated cereals and the proximity to centres of domestication could be correlated with unobservable geographic characteristics affecting the location of ancient cities and archaeological sites. In this last subsection, we move to the radiocarbon-dated prehistoric and proto-historic archaeological sites listed in David and Ruth Whitehouse's (1975) *Archaeological Atlas of the World*. We assign each of these sites to a 1x1 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-difference regressions:

$$\begin{aligned} Settlement_{i,t} &= \alpha_1 I(WR\_Cer)_i * P_t + \alpha_2 I(WR\_RT)_i * P_t + \alpha_3 I(WR\_Cer + WR\_RT)_i * P_t \\ &\quad + X_{it}'\beta + \eta_i + \eta_t + u_{it}, \end{aligned} \tag{8}$$

and:

$$Settlement_{i,t} = \alpha_1 DistanceCer_i * P_t + \alpha_2 DistanceAgr_i * P_t + X_{it}'\beta + \eta_i + \eta_t + u_{it}, \tag{9}$$

where the subscript i indicates the raster point of the world; the subscript t indicates whether the site pre-dates or not the Neolithic transition; η_i and η_t are cell and period fixed effects, and P_t is a dummy variable that identifies archaeological sites dating after the Neolithic transition.

Column 1 of Table (8) 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 a relative increase in the probability of finding a post-Neolithic site rather than 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 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 (8) confirm the results in columns 1 and 2, with different dependent variables: the number of archaeological sites (columns 3 and 4), the presence of a prehistoric settlement (columns 5 and 6), or the number of prehistorical settlements in the area (columns 7 and 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.41) in the appendix.

3 Evidence II – Case studies

The most straightforward evidence to support the claim that cereals played a crucial role in state formation is 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

Table 8: Potential Crop Yields and the Location of Ancient Cities.

	Dependent variable is:							
	archaeol. site (dummy)		Log(1+ # archaeol. site)		anc. settlem. (dummy)		Log(1+ # anc. settlem.)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
P X WR Cer	0.142***		0.189***		0.149***		0.179***	
	(0.0245)		(0.0366)		(0.0235)		(0.0324)	
P X WR RT	-0.00775		-0.0102		0.00543		0.00217	
	(0.0183)		(0.0154)		(0.0159)		(0.0137)	
P X WR Cer+RT	-0.00554		-0.00347		0.00693		0.00740	
	(0.0178)		(0.0179)		(0.0147)		(0.0157)	
P X DistanceCer		-0.0015**		-0.0019***		-0.0014**		-0.0016***
		(0.00060)		(0.00071)		(0.00055)		(0.00063)
P X DistanceAgr		0.00038		0.00090		0.00001		0.00043
		(0.00064)		(0.00085)		(0.00057)		(0.00071)
CELL FE	YES	YES	YES	YES	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES	YES	YES	YES	YES
r2	0.0903	0.0253	0.0983	0.0265	0.0958	0.0316	0.0976	0.0294
N	34152	31854	34152	31854	34152	31854	34152	31854

The table reports difference-in-difference OLS regressions. The unit of observation is the 1x1 decimal degree square either before or after the Neolithic transition. Robust standard errors, clustered at the country-level, in parentheses. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

that we know of relied on cereals.[26] In this section we examine several examples, related to different stages in the emergence of hierarchies and states, which we interpret as supporting our appropriability critique of the prevailing productivity-and-surplus theory.

[26]In Appendix C we defend the statement above by examining three purported counter-examples 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 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, though, can be stored, but did not give rise to states, possibly because they are not seasonal, and thus do not required lengthy storage. It is known, for example, that potatoes have been freeze dried in the mountains of ancient Peru by the Incas (who also grew maize), and are altogether somewhat storable. Sauer (1993) reports that "Spanish colonists soon began exacting tribute from the Indians of part of their potato crop. The forced labor in the high elevation Andean mines such as Potosí, which the Spaniards developed in the 1540s, subsisted mainly on S. tuberosum." Moreover, 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, and several African Kingdoms, which relied primarily on taxing trade.

3.1 Complex hunter gatherers in North America

Anthropologists have long pondered the mechanisms that mediated the transition to agriculture and the emergence of advanced hierarchy. 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, but he did not emphasize that storage facilitates appropriation. When considering agricultural societies he may have been the first to distinguish between societies based on cereals and those based on tubers, and to attribute inegalitarian, complex social structures mostly to reliance on sedentism and storage (1982a, pp. 195-204).

Tushingham and Bettinger (2013) study the transition of some hunting-foraging aboriginal Californians to intensified reliance on drying and storing salmon, a transition that coincided with the concentration of population in permanent villages and in increased social complexity.[27] They theorize that reliance on salmon was avoided for many centuries, in spite of its many advantages, because it is a "front loaded" food source that takes a lot of effort to procure 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 (pp. 533-534). Tushingham and Bettinger's analysis of increased social complexity as coinciding with storage of a "front loaded" food source, prior to the adoption of agriculture, is perfectly consistent with the idea that increased vulnerability to appropriation contributes to increased hierarchy.[28]

3.2 The Neolithic in the Ancient Near East

Archaeological findings show that the earliest phases of the transition to cereal farming correlated with communal storage and with the emergence of inequality and hierarchy. Semi-sedentary forms

[27] Cook's account of his voyages to the eastern shores of the Pacific Ocean (1784, volume II, book IV) provides a vivid eye-witness depiction of these villages.

[28] Chiwona-Karltun et al. (2002) provide an anecdotal illustration of the theory in a farming setting. They report that women in modern Malawi, and particularly single women, prefer to grow bitter and toxic cassava variants, even though these require significantly more post-harvest processing. This pattern is explained as due mostly to the advantages of this extra post-harvest drudgery, which protects these women against thievery since thieves prefer the non-bitter variant. A Malawian woman is quoted: "We grow bitter, toxic cassava because it gives a certain level of food security. If we are to grow sweet cassava, look at our neighbors! Their whole field was harvested by thieves while they slept and now they have no food."

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 period known as Pre-Pottery Neolithic A (ca. 9500-8500 BCE), when farmer-foragers collected wild grains on a large scale and sowed grain, yet still prior to domestication.[29] Differentiated dwelling sizes and funerary assemblages suggest that systematic inheritable inequality was already present. Kuijt and Finlayson (2009) report the discovery of an elaborate circular communal storage pit in the Jordan Valley from about 9000 BCE. This finding reveals 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, and the advantages of social cooperation. Such storage attests also to the emergence of leadership alongside the gradual intensification of cereal farming and sedentism. Constructing and overseeing the storage pit (the prime source of the community's non-human wealth) and distributing the stored foodstuffs required leadership, even if initially banditry may not have been a major issue.[30] The need to protect stockpiles is manifest also by the subsequent agglomeration of people in early walled villages and urban centers, long before the formation of city-states.[31]

[29] For a survey see Simmons (2007). Barker (2006) surveys the onset of the Neolithics across the globe. The general timing of the earliest transition to agriculture in Eurasia is commonly explained as increased climatic seasonality at the end of the ice age generating evolutionary modifications in grasses that developed larger seeds to adapt to extended summer drought (Diamond, 1997; Matranga, 2017). However, the more specific onset of the Neolithic period in the Near East is attributed to adverse climatic change (Bar-Yosef and Meadow, 1995). Richerson, Boyd and Bettinger (2001, pp. 388-389) debunk another common theory that this transition was caused by food shortage that resulted from population growth. Cauvin (2000) argues that the adoption of farming was preconditioned by a change in collective psychology and by the rise of centralized religion. Bowls and Choi (2019) argue that due to strategic complementarity between farming and private property, the transition to agriculture was impeded in that it required the parallel adoption of the social institution of private property.

[30] Similar 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 Strodeur 2012). These pits are identified as having served as communal storage and communal meeting places, possibly for ritual ceremonies. Some archaeologists identify storage as an indication of surplus, but a cereal-based farming society may be living at subsistence while engaging in intra-annual and even inter-annual storage.

[31] The massive stone tower and wall of ancient Jericho, whose function is debated, attest to the existence of communal organization and leadership, and a possible perceived need for defense (see Simmons, 2007, p. 99).

3.3 Ancient Egypt

Ancient Egypt is the paradigmatic example for a super-hierarchical state organization. It grew from the Nile Valley in Upper Egypt ca. 3000 BCE, after a few centuries of wars between city-states in that area (Kemp 2006). Wars are also characteristic of rival chieftainships, but unlike chiefdoms, the early Egyptian city-states before the emergence of the unified super-hierarchical state, were fortified, suggesting that they were protecting something more than people. Perhaps this would have been the annual stockpile of grain, which was necessary for survival. Given the arid climate and total reliance on the annual flooding of the Nile, the cereal crop reaped in the spring was the paramount source of nutrition for the entire year. As the Egyptian state grew, the Nile River was a conduit to transport the cereal collected as taxes at harvest time to the capital city in the north, where there were large storage facilities. We contend that in a region were agriculture was based on perishable and non-appropriable roots and tubers, there would be no opportunity to develop efficient state machinery like that of ancient Egypt. The strength of the state that could be developed by taxing appropriable crops was reflected, for example, by the construction of the pyramids.

3.4 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 didn't lead to the development of complex hierarchy.[32] In the 17th century the sweet potato that 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. This increase in productivity left the highland population of New Guinea fragmented, subject to endemic tribal warfare, and without any consolidation of power or significant increase in social complexity.

Increased productivity of a less appropriable crop, which presumably generated a temporary

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

surplus, didn't engender significant hierarchy, in contrast to the prediction of the conventional productivity theory, and consistent with the appropriability theory.

3.5 State avoidance in South East Asia

With the idea of explaining how some societies managed to avoid subjugation to state authority, Scott (2009) posits that in South East Asia states only emerged 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, his key distinctions relate to geographic elevation between valley vs. hill people, and to sedentary vs. shifting farming.[33]

3.6 The maize growing Bushong in Congo

We conclude this brief survey of case studies with an example that Acemoglu and Robinson (2012) discuss in support of their claim for the precedence of political innovations to the adoption of agriculture. They describe how the Bushong people in the Congo heartland became the subjects of a kingdom in the seventeenth century. Their leader advanced the adoption of maize farming, after it reached the African coast from America. The Lele people, the Bushong's neighbors across the river, share the same environment and yet avoided the cultivation of cereals, and were able to resist subjugation to hierarchy, either by the Bushong, or by a copycat leader of their own. Once again, this example demonstrates the critical role played by the choice of crop type for the emergence of complex hierarchy, and for its avoidance.

4 Alternative theories on the origin of the state: a discussion in light of the evidence

There are many theories that try to explain how the transition to agriculture led to increased hierarchy and to the emergence of states. Most of these theories, particularly in political science and economics, generalize from the experience of cereal-based societies. Anthropologists, who rely

[33] 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.

on ethnographic evidence, usually generalize from the experience of chiefdoms that are typically based on non-cereal farming. Some anthropologists have realized, however, that there was no unique path from farming to political hierarchy, and thus call for a comparative study of complex premodern societies (see Smith, 2012). The distinction between crop type, which is the focus of our contribution, does not play a major role in any of these theories.

Our extensive empirical analysis reveals that the cultivation of cereals has a causal effect on various indications of hierarchy in farming-based societies. It fails to find any evidence that land productivity has such an effect, 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.

First we survey the theories that explain the emergence of complex hierarchy as resulting from an increase in productivity and the resulting surplus – the theories that we critique. Then we discuss the theories that are supported by our findings, and finally we address briefly other theories for which our evidence has limited relevance.

The productivity explanation for the emergence of hierarchy can be traced to Adam Smith, who also invoked the appropriability explanation. According to Smith, governments and property protection first emerged with the transition to pastoralism and the need to protect livestock from theft (Smith 1978, p. 16). But, when he turned to agriculture, Smith reverted to emphasize the role of productivity as generating surplus, division of labor and trade, and, as a result, a demand for an extended role of government (1978, p. 409).[34] For Smith and his intellectual heirs, surplus had to be available before the landlord, the capitalist or the ruler could seize it.

Friedrich Engels similarly stated that in pre-agricultural societies, "Human labor power... yielded no noticeable surplus as yet over the cost of its maintenance," and that it was only the surplus generated by the adoption of agriculture that triggered the transition to a class society (1978, p. 65). According to Childe (1936) the transition to agriculture resulted in food surplus and prosperity, which enabled farmers to demand specialty items – leading to specialization in non-farming activities and to trade. This division of labor led over time to political integration, and eventually to urban centers and to the formation of city-states under a state bureaucracy. Lenski (1966), too, contends that farming technologies generated a surplus that hunter-gatherers could not

[34] The idea that agriculture generated surplus and that surplus led to government was expressed already by earlier seventeenth century social thinkers. See Meek (1976) and Aspromourgos (1996).

produce and that this surplus, which intensified with the transition from horticulture to intensive agriculture, led to the emergence of social power.[35]

Many scholars have sought to explain what lies behind the relative underdevelopment of tropical countries.[36] Diamond (1997) uses the productivity and surplus approach when he summarizes the source of the advantages of temperate regions (p. 92): "In short, plant and animal domestication meant much more food ... The resulting food surpluses ... were a prerequisite for the development of settled, politically centralized, socially stratified, economically complex, technologically innovative societies." Price and Bar-Yosef (2010; p. 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)." The productivity and surplus explanations seem to be the default in popular and scientific writing; Diamond (1997) and Price and Bar-Yosef (2010) are but two salient examples.

One of our important contributions in this paper is in casting doubt on this conventional and still predominant theory. In addition to our conceptual claims, that surplus isn't a prerequisite for taxation and that a gradual increase in productivity is unlikely to generate surplus, our empirical evidence and case studies suggest that land productivity had limited, if any, causal effect on hierarchy.[37] We note, however, that differences in productivity between regions could, in addition to

[35] Lenski's emphasis on the distinction between horticulture and agriculture, and his underlying presumption that the former is but a less developed form of the latter, reflects a misperception. Once one realizes that the forms of horticulture that ethnographers witness are highly biased towards farming of roots and tubers, it becomes clear that horticulture and chiefdoms may represent a long-term geographic-conditioned state of affairs, rather than a stage in the transition to (cereal based) agriculture and to state institutions. We argue that the proposed distinction between crop types also provides a better interpretation of the results reported in Smith et al. (2010) about inequality in premodern societies: they conclude (p. 92): "the overall intergenerational transmission of wealth is no greater in horticultural than in hunter-gatherer populations. ... contrary to the many models of the emergence of institutionalized inequality, the domestication of plants and animals per se may not have been sufficient [to cause a significant increase in institutional inequality]." Their focus on institutional inequality and our focus on hierarchy is highly related. However, they relate these differences in inequality to the distinction between horticulture and agriculture, rather than to crop appropriability, and they identify the pertinent characteristic of horticulture as "abundance of land relative to labor and, hence, low payoffs to defending property rights at the household level."

[36] Sachs, Mellinger and Gallup, (2001), Olsson and Hibbs (2005) 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 rather small and cannot explain the extent of the gap between tropical and non-tropical countries, but his findings are controversial. Here, we question the productivity explanation and provide an alternative geographical/institutional explanation.

[37] Other scholars who find fault with the surplus theory point 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 could also have easily procured food beyond their immediate needs, but deliberately refrained from doing so by preferring leisure. He infers that the first farmers could have similarly responded to increased productivity by working less hard. Sahlins concludes (p. 140): "Leadership con-

differences in land productivity, be an outcome of other factors, such as farmers' effort, specialization, and available technologies. For our theoretical critique – that surplus isn't a prerequisite for hierarchy and that productivity isn't expected to create surplus – the sources of productivity do not matter. In our empirical exercise, however, we focus only on land productivity (which in some specifications considers the availability of domesticable plants). This limitation is dictated by the lack of an exogenous source of variation for productivity differences other than land productivity. Despite this limitation, our empirical exercise casts serious doubts on the productivity-and-surplus theory for the emergence of hierarchy, because it implies that any source of productivity should impact hierarchical complexity, in particular land productivity, which is its central mechanism.

We now turn to theories for the emergence of hierarchy that are consistent with our findings. Most of these theories invoke conflict and/or functional explanations – that an elite emerged to perform a function, in response to a growing public need.

One such influential theory posits that increased productivity of agriculture accounts for the emergence of hierarchy through the growth of population and the resultant population pressure, rather than through generating surplus. Johnson and Earle (2000) claim that the higher agglomeration of population led to increased conflict, necessitating increasingly complex social forms to contain violence. This functionalist theory was adopted by North, Wallis and Weingast (2009), who explain the evolution of human history from the Neolithic age to modern times in terms of the institutions that are formed to contain humans' natural 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, leaving the coefficient on our proxy for the cultivation of cereals practically unchanged.

Motivated by the contrasting political structures in the valleys of Peru and in Amazonia, Carneiro's (1970) 'circumscription theory' offers an earlier variant of a conflict argument. Postulating that an elite can extract ongoing surplus only when the subjects of taxation are geographically entrapped, Carneiro contends (p. 735) 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

tinually generates domestic surplus," claiming (like us, though offering a different mechanism) that it was hierarchy that generated surplus and not vice versa. Sahlins, however, did not resolve the key questions: what accounts for the rise of hierarchy and why did its emergence correlate with agriculture, and more particularly, with the cultivation of grains?

before, and retaining their independence." Whereas "in Peru ... this alternative was no longer open to the inhabitants of defeated villages. The mountains, the desert, and the sea ... blocked escape in every direction."

Carneiro's puzzlement over limited social complexity in Amazonia is reminiscent of Diamond's concern about the underdevelopment of New Guinea, but we note that the environmental theory of one is inconsistent with the geographical evidence of the other. Diamond's theory about the advantage of an east-west orientation of land mass can hardly resolve Carneiro's comparison between Peru and Amazonia, and Carneiro's theory fails to resolve Diamond's observation about limited social complexity in the Pacific tropical islands. Our theory and empirical findings offer 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. The formation of the Mayan state societies in the non-circumscribed tropical lowlands of Mexico, where maize was first domesticated and became the staple crop, provides additional support for the theory about the role of cereal cultivation in the emergence of hierarchy.[38]

Dow and Reed (2013) provide another variant of conflict theory, suggesting that warfare between different groups leaves the victor as the owner of land and the vanquished employed as workers. Boix (2015), too, suggests that the introduction of agriculture caused inequality between inside farmers, who were able to benefit from the new productive technology, and outsiders. He posits that this led the latter to raid the former and that this conflict ended either in dictatorships by the outside bandits who turned stationary (as in Olson, 1993), or in republics managed by the insiders themselves. Finally, Dal Bó, Hernández and Mazzuca (2015) theorize that farmers' increased insecurity due to pillage by outsiders discouraged investment, and that state defense capacity was developed to resolve this inefficiency.

Our finding of a positive effect of cereal cultivation on hierarchy is consistent with the 'conflict' theories, as storage of cereals that are appropriable attracts attacks from outsiders and increases the need for organized protection. Our thesis is arguably a variant of a conflict theory with an important addition: the distinction between appropriable cereals and other less appropriable crops.

[38] Allen (1997) applies Carneiro's theory to explain the emergence of the Ancient Egyptian state in the circumscribed Nile Valley. But he mentions also how the appropriability of cereals contributes to hierarchy, and notes that the perishability of the food sources collected by foragers renders them non-exploitable. Allen, however, still claims that surplus created by the farming of cereals was a precondition for the emergence of the Egyptian state.

Another functional theory focuses on the demand for law and order to facilitate trade. Based on African evidence, Bates (1983) argues that ecologically diverse environments increase the returns from trade and generate a demand for hierarchy. Fenske (2014) and Litina (2014) provide empirical support for this theory.[39] Trade also increases the return to the construction and maintenance of roads, ports, and marketplaces. Thus, similar to our claim that the cultivation of cereals generates a demand for protection and facilitates taxation to provide for such protection, we note that trade too generates 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. In our empirical analysis, when possible we control for proxies for trade (geographical isolation, proxied by distance from a major river and distance from the coast). We find some evidence that supports the trade channel. The data do not reveal the mechanism explaining the remaining positive and significant effect of cereals on hierarchy: it could be trade, taxation, or other. But since the effect of cereals on hierarchy is practically unaffected by the control for proxies for trade, it reasonably implies that cereals have an effect on hierarchy beyond their effect on trade.

Long-term storage plays an important role in another functional theory that maintains that the demand for central storage had a causal effect on the emergence of complex society (see Johnson and Earle 2000:251-256, 301-302, and Halstead 1989). Under the influence of Polanyi (1944), 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 posits that the key role of the central authority is insurance. Our emphasis is on intra-annual storage that the seasonality of cereals imposes and on the potential that it creates for expropriation, rather than as a source for redistribution for the benefit of cultivators. We conjecture that overcoming idiosyncratic shortfalls to individuals did not require proto-state centralized institutions and was managed by sharing within kin groups (as was the case among hunter-gatherers).[40]

[39] 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.

[40] The salience of communal storage in some PPNA sites, as noted above, is explained mostly as due to increasing returns to scale. But this advantage is rather limited. It is thus noteworthy that in the Neolithic dense village-town of

However, since cereals are storable this theory predicts an effect of cereal farming on hierarchy, which is consistent with our empirical findings.

Another functionalist theory is proposed by Wittfogel (1957), who 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. In our empirical analysis we control for evidence of agriculture based on intensive irrigation. Irrigation could be an important potential confounder, as Bentzen, Kaarsen and Wingendr (2017) show that environments with potential for irrigation systems have had greater inequality in the past and more authoritarian states in the present. Our estimates confirm their results: societies that practice intensive irrigation are characterized by relatively more complex hierarchies. Our results on the impact of cereals are unchanged when controlling for irrigation.[41]

A number of scholars reverse the standard causal direction and maintain that hierarchy preceded farming, and may have been a prerequisite to agriculture. Cauvin (2000) argues that the willingness of hunter gatherers to abandon their traditional ways of life and to engage in farming was conditioned by a prior change in collective consciousness and the rise of religion. Acemoglu and Robinson (2012, pp. 139-142) suggest that an institutional innovation among the semi-sedentary Natufians in the ancient Near East enabled a political elite to gain power, and then, in effect, to cause "the transition first to sedentary life and then to farming" (p. 140). In suggesting that hierarchy was the cause of surplus, rather than its consequence, this theory resembles ours. However, it is diametrically different in that we seek to explain the emergence of hierarchical institutions while taking the transition to farming as given. Our empirical findings of a causal effect of cereals on hierarchy seem consistent with the theory of Acemoglu and Robinson (2012), assuming that the emergent political elite among foragers would facilitate the transition to farming only if the cultivation of appropriable cereals was possible.

Çatalhöyük (PPNB, ca. 7500-6000 BCE), storage of grains was already entirely private, within the homes of nuclear families; but the (private) sharing of meat was apparently widespread, as "storage in the form of social sharing" (Bogaard et al. 2009, p. 650).

[41] Wittfogel's critics point out that irrigation projects in early civilizations were constructed by local communities, prior to the emergence of a strong 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 that a need for irrigation led to a despotic state, but rather that (local) irrigation systems enabled control and expropriation by the central state – analogous 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 on whether hierarchy preceded or followed irrigation.

We conclude this literature survey with some theories that relate between alternative forms of farming and social institutions. 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 highly 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, leading to growth of the farming population. Consistent with this mechanism, Mcneill (1999, pp. 71-72) reports that European farmers first resisted adopting the potato, and that only during the Dutch Wars in 1557-1609, "villagers along the route [of the Spanish army] swiftly discovered that by leaving the tubers in the ground and digging them only as needed for their own consumption, they could safely survive even the most ruthless military requisitioning. Foraging parties were unwilling to dig for their food when stores of grain were available in barns."

Mayshar, Moav and Neeman (2017) study another aspect of appropriability, arguing that geographical attributes that contribute to the transparency of farming may alleviate principal-agent problems and facilitate more onerous taxation and increased state capacity.[42] Finally we note that 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. They demonstrate how early farming techniques, and in particular the use of the plow, impact current perceptions of gender roles.

5 Concluding remarks

The prevailing scholarly view attributes the emergence of complex hierarchies and states to the increased productivity of agriculture. It is commonly presumed that this increase in productivity generated food surplus, which led to population increase, to specialization, to trade, and to the rise of elite. According to this conventional theory, different societies that made the transition to farming

[42] Mayshar, Moav and Neeman (2017) purport to explain key institutional differences between the cereal-dependent states in Egypt, Southern Mesopotamia, and Northern Mesopotamia. De la Sierra (2019) presents alternative evidence on the significance of transparency for appropriability. Studying the mining regions in the modern Democratic Republic of Congo, he shows that a rise in the price of coltan, which is produced from bulky and transparent ores, led to the monopolization of power and to the cessation of conflict between rival armed groups in the coltan-rich regions, whereas an increase in the price of gold, which is easier to conceal and hence less transparent, did not. Similarly, Buonanno et al. (2015) show the effect of a rise in the price of sulphur on the emergence of the Sicilian Mafia.

followed very different paths because of differences in land productivity. We do not challenge the perception that the transition away from egalitarianism towards hierarchy was affected by the shift to agriculture. But we contend that the causal mechanism that relates agriculture to hierarchy may have had less to do with the increase in productivity, and more to do with the transition to appropriable food sources.

Noting that states failed to develop in regions that cultivate highly productive roots and tubers, we examine the alternative appropriability theory. According to that theory, the key feature by which the Neolithic triggered a path to the emergence of complex hierarchies and states was farmers' increased vulnerability to appropriation, as a result of reliance on seasonal cereals that require storage.[43] This theory also accounts for cross regional differences in the extent of hierarchical institutions between temperate regions, whose geographical conditions are particularly suited to growing appropriable cereals, and other regions - particularly in the tropics - where roots and tubers are highly productive.

The main testable prediction of our theoretical claims is that the principal variable that accounts for the emergence and persistence of hierarchy in farming societies is not absolute land productivity, but sufficient productivity advantage of cereals over roots and tubers. The nature of the question and the available data do not provide an empirically fool-proof test for the correctness of the appropriability theory and for our critique of the conventional productivity theory. Nevertheless, in addition to the multiple supporting facts and arguments we present here, the findings of our many empirical investigations clearly support the appropriability theory and provide no support for the productivity theory.

We readily acknowledge that our empirical analysis doesn't test for the specific appropriability mechanism to link cereals to states. Thus, we do not rule out that some alternative mechanisms, such as trade or communal storage, could also have played a significant role.

To conclude we comment on the pertinence of our research to more recent issues. We propose that the appropriability mechanism and our critique of the conventional productivity theory apply

[43] Our approach can be considered to be neo-Hobbesian, in the sense of combining the functional role of government in protecting individuals from theft and banditry, with the recognition that this need for protection arose simultaneously with the non-functional increased ability of the would-be rulers to appropriate. Thus, it avoids teleology. In the spirit of Olson (1993), hierarchy and protection arise because it becomes feasible to tax, and because it serves the elite's interest to protect farmers from expropriation by bandits.

beyond antiquity. Since the modern transition away from agriculture to manufacturing and services is protracted, and since social institutions exhibit inertia, our theory and findings may contribute to explaining current institutional differences, specifically in hierarchical complexity and in states' capacity to tax and provide public goods.[44]

As Besley and Persson (2009, 2014) contend that underdevelopment is closely related to low state capacity,[45] our conclusions have significant implications for the understanding of income differences between nations, particularly as pertaining to the underdevelopment of tropical regions. According to the appropriability theory, supported by the evidence we provide, the root cause for the underdevelopment in the tropics is the relatively high productivity of less appropriable crops and other food sources that provided the population with substantial immunity against taxation. This inhibited the formation of stable hierarchical states and contributed to low state capacity. To the extent that hierarchy and state capacity are indeed crucial for economic development, the geography in tropical regions is thus a curse of plenty.

[44] Bockstette, Chanda and Putterman (2002), Gennaioli and Rainer (2007), Spolaore and Wacziarg (2013), and Michalopoulos and Papaioannou (2013, 2014) demonstrate that deep rooted pre-colonial institutions affect current institutions and economic outcomes. Dincecco and Prado (2012) and Dincecco and Katz (2014) show that state capacity is persistent and has a positive effect on economic performance.

[45] Besley and Persson (2009, 2014) propose that low state capacity might be overcome by investment in fiscal administration, ignoring geographical differences between regions. Gennaioli and Voth (2015) emphasize how investment in state capacity since the Middle Ages responded to conflict, in the spirit of the theory by Tilly (1975). Becker et al (2018) provide further empirical support for that theory.

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Appendix A: Cereals vs. Roots and Tubers

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

.

Table A.1: Major staple crops produced in regions of the world in 1961

	World 1961		Sub-Sahara 1961		Papua New-Guinea 1961	
	Average Cal Yield (mil Kcal/ha)*	Total Energy Produced (10^{12} kcal)**	Average Cal Yield (mil Kcal/ha)*	Total Energy Produced (10^{12} kcal)**	Average Cal Yield (mil Kcal/ha)*	Total Energy Produced (10^{9} kcal)**
Rice	6.92	798	4.57	12	13.16	6
Wheat	3.78	772	2.39	6		
Maize	7.09	748	3.66	53	3.34	0
Barley	4.68	255	2.79	3		
Oats	3.19	122	2.86	0		
Sorghum	3.02	139	2.53	29	5.62	0
Rye	3.92	119	0.60	0		
Millet	2.24	97	2.17	24		
Soybean	1.66	40	0.55	0		
Potato	9.41	208	5.14	1	5.21	0
Cassava	11.85	114	9.10	50	15.94	84
Sweet Potato	6.32	84	4.44	3	3.44	254
Yam	8.54	10	8.65	9	19.56	142
Taro	6.63	5	0.54	0	7.51	136
Banana	9.47	19	5.21	3	11.17	276
Plantain	6.37	16	5.65	11		
Total of above		3,545		203		898
Population (mil)		3,083		223		2

The average caloric content of each crop is based on the figures in table E.4. For Soybeans, Taro, Bananas and Plantains the respective figures are 1.47, 1.12, 0.89, and 1.22, based on http://ndb.nal.usda.gov/ndb/, accessed Feb 2017. * Calculated on the basis of the caloric content of each crop multiplied by the average land yield, as reported by the FAO (http://faostat3.fao.org/download/Q/*/E accessed Feb 2017). ** Calculated on the basis of the average caloric yield multiplied by the crop area, as reported by the FAO (http://faostat3.fao.org/download/Q/*/E accessed Feb 2015).

Table A1 presents summary data on the main staple crops in sub-Saharan Africa, in Papua New Guinea (PNG) and the world in 1961 – the earliest year for which the Food and Agriculture Organization (FAO) provides the information.[46] In relying on relatively recent data, our presumption is that the soil and climatic conditions have not changed significantly since the Neolithic period. Of course, we recognize that the plants that provide most of the calories that humans consume have undergone major modifications since antiquity, and that their availability was greatly impacted by the post-Columbian migration of species between the continents.

(i) The data in Table A1 reveals that roots and tubers provided 37.9 percent of the total calories produced by the main staple crops in sub-Saharan Africa in 1961. We note that cassava alone provided about 45 percent of the total calories produced by these crops in Nigeria in 2013.

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

(iii) The table reveals that the yield of non-cereals in PNG is generally high.

(iv) The seasonality of cereals is well known. They have to be sown and reaped in a relatively fixed period in the year, and usually once a year. On the other hand, roots and tubers are generally perennial and may be harvested at any time during the year. In fact, cassava can be left intact in the ground for two years. This gives farmers great flexibility around the timing of the harvest, and prevents the need for significant storage. Rees et al. (2012, p. 394) report: "Harvest time [of cassava] ranges from six to 24 months, and roots can be left in the ground until needed, making cassava a very useful food security crop."[47]

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

[46] Given a rough estimate of 1 million calories required per person per year (2740 kcal per day), the columns on total energy produced provide a crude estimate of the population (in millions) whose energy needs could be supported by each crop (ignoring the feeding of animals, seed requirements and wastage). It is evident that (other than in PNG) the total energy produced by the listed major crops could roughly feed the entire population – but in PNG it could feed less than half the population.

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

moist root into dry flour.

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

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

By these considerations, even though the potato is biologically a tuber, when it comes to the degree of appropriability, it could be considered a quasi-cereal, since it is cultivable in temperate climates, is seasonal, and is relatively non-perishable upon harvesting.

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Appendix B: Surplus and appropriation – the role of population

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

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

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

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

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

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

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

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

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

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

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

B1. The case of a fixed population

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

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

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

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

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

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

Thus, we have:

Proposition B1. *With a fixed population, both an increase in appropriability z and an increase in productivity A raise the share of taxes out of income π.*

B2. The case of Malthusian population

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

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

This implies:

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

Denote:

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

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

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

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

Thus, at the optimum τ^*:

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

In addition,

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

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

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

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

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

Now,

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

Similarly,

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

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

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

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

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

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

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

Thus, we have:

Proposition B2. *With Malthusian population, an increase in appropriability z raises the share of taxes in the economy π, but an increase in productivity A leaves that share intact.*

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Appendix C: Counter-examples in the Ethnographic Atlas

We checked the Ethnographic Atlas database for possible outliers. Out of the total Atlas sample of 1412 societies, only 1259 had data on hierarchy above the local level (variable 33). Out of these 1259 societies, only 959 are coded as reliant on specified food sources (variable 29): 634 relied mostly on cereal grains, 259 on roots and tubers, 82 on fruit trees and 4 on vegetables. The Atlas defines a "large state" as possessing at least four levels of hierarchy above the local community, and defines those with three levels as "states" (Gray, 1998). The following table provides the distribution of these societies by the major crop type.[48]

	Total	% Cereal	% Roots & tubers	% Fruit trees	% Other
All societies	979	64.8	26.5	8.4	0.4
Above hierarchy = 4	32	90.6	9.4	0	0
Above hierarchy = 3	82	79.3	13.4	7.3	0

It is evident that societies that rely on grain crops form a significantly larger share of those with higher levels of hierarchy than in the total sample. Still, we were intrigued by the three societies (9.4%) that are coded as "large states" that are reliant on roots and tubers. In this appendix we examine the three apparent exceptions to our statement that all pre-modern large states relied on cereals. Our conclusion is that our statement stands.

1. The first case is identified by Murdock (1981, p. 39) as "Shantung Chinese." The anthropological data were based on Yang's (1945) detailed report about the small village of Taitou, apparently pertaining to the 1930s. The province where this village (which no longer exists) was located is now known as Shandong. Shandong, on the eastern edge of China (in between Beijing and Shanghai) is now one of the more prosperous provinces. There is little doubt that the village of Taitou was at the time part of a major state: China. We take issue, however, with the presumption that this state, or even that province, should be classified as based on roots and tubers, as the Ethnographic Atlas has it.

To begin with, Yang reports (1945 p. 16) that the main crops cultivated in the village of Taitou were "wheat, millet, barley, soybean, corn, sweet potatoes, and peanuts." Thus it is not clear why the village was coded as reliant on the intensive cultivation of roots, even though this may not be entirely wrong. According to Yang, the land of the village was multi-cropped, and sweet potatoes

[48] All of the societies with maximal hierarchies had a specified major crop type, and two societies with above hierarchy coded as 3 had unspecified crop type (thus making the total 84, instead of 82).

were the principal crop during the summer months. More precise information can be obtained from the data collected by Buck (1937). Buck provides detailed statistics from another village, Tsimio, located about forty kilometers from Taitou. According to these data (pp. 73, 75), sweet potatoes supplied 43.3 percent of the total calories consumed in Tsimio, and seeds supplied 54.4 percent of the calories. But Tisimio (and presumably also Taitou) was unrepresentative of Shandong as a whole. In the other eleven villages that entered Buck's sample from the province, one listed the percentage of calories supplied by seeds as 76.0 (with sweet potatoes supplying 20.8 percent), and all of the other ten villages listed seeds as supplying at least 91 percent of the calories consumed. We conclude that the coding of the "shantung Chinese" society as reliant on the intensive cultivation of roots is wrong.

But the problem at hand goes beyond coding. The Ethnographic Atlas focuses mostly on cultural issues such as kin relations, with the underlying presumption that the data from one location pertains for the society as a whole. Yet the number of levels of hierarchy presiding over any location depends mostly on the region that encompasses that specific location. Even if Shandong's farming were based solely on roots, it could easily belong to a complex polity whose hierarchy relies on taxing cereals. This is evidently the case for China, whose state relied from the very start on the cultivation of cereals: mostly on wheat in the north (where Shandong is located), and mostly on rice in the south. Furthermore, sweet potatoes reached China only after the Columbian Exchange, while Shandong was already an integral part of the Chinese hierarchical state almost two millennia earlier.

2. The data source for "Byelorussians (White Russian)" society (latitude: 55N, longitude 28E) is identified in Ethnology, (vol. 4, April 1965) as "Unpublished ethnographic notes" by Melvin Ember (1954), pertaining to 1910. We were unable to obtain this source, but employed alternative sources about the Belarus.[49]

Vakar (1956, p. 30) describes the territory as a "low marshy plane, sloping slightly to the south and east. Only in the north and northeast are there elevation of the soil," with the highest point at 345 meters above sea level. "In general ... the soil ... is not very favorable for cultivation. Forest and shallow lakes cover more than one half the whole land. ... Crops are liable to be damaged by humidity rather than droughts. ... fish and potatoes being the staff of life for most Belarusian peasants." This characterization is confirmed by the soil-suitability data according to which the soil suitability for agriculture in Belarus is in the 25th percentile below the average, and

[49] The following summary is based mostly on Vakar (1956), and The Great Soviet Encyclopedia (GSE), vol. 3, 1973.

the productivity of cereals is below average. The fact that potatoes became the main cultivated crop from the 16th century is thus not surprising. In 1913 the land yielded 4.0 million tons of potatoes and only 2.6 million tons of all cereal grains; at the same time, "livestock raising is the leading branch of agriculture in Byelorussia" (GSE, p. 627). Thus, we do not question the Atlas's coding of Belarus as based on roots and tubers (at least since Columbus).

The multiple rivers that cross Belarus provided the main waterway for early trade between the Black Sea in the south and the Baltic Sea in the north. The area was settled between the 6th and the 8th centuries by East Slav tribes, whose economy was apparently based on trade in forest products like furs, game, honey, beeswax and amber and on primitive (cereal) agriculture. As it turns out, almost throughout its history, the territory of Belarus was ruled from outside by its neighboring states, rather than from within. In the 10-12 centuries it was controlled from Kiev (now in the Ukraine) in the south, under the Grand Duke of the Kieven Rus' – but several local feudal vassal principalities existed (all centered in the relatively elevated north).[50] From the 13th until the 18th centuries, the territory was ruled from the north and the west: first by the Grand Duchy of Lithuania, then by the Polish-Lithuanian Commonwealth, and effectively by Poland. Finally, from 1795 until 1990 Byelorussia was ruled from the east, as part of the Russian Empire and later as a Republic within the USSR. Thus we don't question the coding of Belarus society as subjected to full state hierarchy, however, we note that as a dependent territory almost throughout its history, its form of agriculture can hardly be considered to have shaped the degree of complexity of the states that controlled it. Indeed, Borcan et al. (2018) assign Belarus a statehood score of 0.5 from 850 until 1950 – where, in their scoring system "Band/tribe is marked by a rule score of 0, paramount chiefdom is assigned 0.75 and fully-fledged state receives the value 1."

3. The third case concerns the Bubi society on the tropical island of Fernando Po (now called Bioko, and part of the state of Equatorial Guinea). This volcanic island, whose area is about 2,000 square kilometers, is located in the Atlantic Ocean, about 30 kilometers off the coast of present Cameroon. The Bubis' staples were yams and cocoyams (=taro), in addition to fish and game. Thus, also in this case we do not contest the Atlas identification of this society as reliant on roots and tubers. However, we find problematic the characterization of this society (presumably in 1920) as a large state society.[51] Indeed, according to the Atlas, the form of agriculture is not extensive,

[50] Some historians identify the second half of the 11th century as the "first Independent Belorussian State," under the prince ruling in Polock (=Polacak= Polatsk) – see Vakar (1956) and Plokhy (2006 pp. 12, 46-54). If so, Belarus regained independence only with the breakup of the USSR in 1991.

[51] One indication for the problematic identification of the Bubi society as a "large state" is its lack of urban centers. Of the 32 Atlas societies coded as "large states," 27 had cities with population exceeding 50,000 people, 3 more had towns with 5,000 or more people, and one (the Siamese) had towns in the range of 1,000-5,000 people. The Bubi

but rather "extensive or shifting agriculture." Written sources about the island by missionaries and travelers since the 19th century are surprisingly abundant. The Atlas was coded on the basis of several such sources (Ethnology vol. 5, Jan 1966 pp. 132-133). For our purposes of examining mostly the Bubis' political institutions, we find it expedient to rely mostly on Sundiata (1994, 1996, 2011).

The island of Fernando Po was a Spanish colony, but the British set a station in its northern coast from 1827 until 1943. The colonists (including freed slaves that they brought to the island) settled in the coast, while the native Bubis concentrated in the interior hilly slopes of the island where they managed their own affairs. According to Sundiata (1996 p. 7), in 1912 the island's Bubi population numbered only 6,800.[52] The coastal settlers traded with the Bubis by purchasing from them palm oil for export, in exchange for various imported wares (like knifes).

The Bubis were divided in the 19th century into 28 districts, with several villages in each district. The districts often fought with one another over women and over imported objects (Sundiata, 1996 pp. 75-79). According to Sundiata (1996 p. 75), "in spite of their fairly simple material culture, the nineteenth-century Bubi had an elaborate system of socioeconomic stratification." Within chiefdoms, individuals were distinguished as nobles or as commoners, as well as by age groups. The chiefs' role was mostly in settling disputes, imposing and collecting fines, and leading fights.

The long-standing political fragmentation of the Bubis underwent substantial change in the 1840s. Sundiata (1996, p. 80-82) attributes this development to recurring incidents after the British left the island, whereby foreign interlopers from the coasts raided the Bubis inland. As a result, Moka, the chief of one of the southern districts, was able to form a loose confederacy of the various chiefs and was recognized as "Great Chief," (or king) with the task of mediating intra-ethnic strife and containing the incursions.[53] The island under Moka might be considered a hierarchical kingdom.[54] We doubt that this should be considered a case of a stable state society based on the

society is coded as "missing data," but in fact had not had villages exceeding 1,000 people.

[52] An 1837 report by British adventurers states "The native population of Fernando Po may be about five thousand, divided into tribes, that were formerly constantly at war with each other" (Laird and Oldfield, p. 301). That report also notes the Bubis' "free and independent bearing" and adds that "they still go perfectly naked" (p. 302). The missionary Clarke (1848, p. v) estimates the island's total population (including the non-Bubis) at "20,000 souls."

[53] According to Sundiata (1996 p.80-81), Moka "had seventy wives and concubines" and reinforced his position by exercising magical powers. He refused to be seen by any Europeans and "limited his use of European wares to guns and machetes," scorning "the use of European cloth, rum, salt and tobacco."

[54] Baumann (1888), a German traveler, provides a firsthand report of Moka's "kingdom" in 1886. He describes Moka's capital village as consisting of scattered hut complexes, surrounded by fields of yam (p. 103). He also narrates how, on the way there, a Bubi chief asked if he would become their king and resist Moka, telling him how much they resented being subjected to Moka (p. 33).

cultivation of tubers, but rather than an ad hoc confederacy of chiefdoms, motivated primarily by external issues related to warfare and trade (as was the case with several earlier African kingdoms). The fragility of the Bubis' presumed state is evident in that little of it survived into the twentieth century, after cocoa plantations (manned by imported laborers) started to dominate the Island's economy and the Spanish colonial power asserted its rule on the Island.

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Appendix D: A Model of Cereals and Hierarchy

The basic premise of the model is that regions of the world differ in their productivity of tubers relative to that of cereals. For simplicity we postulate that tubers, unlike cereals, cannot be expropriated by bandits or by tax collectors. We model farmers' choice of what crop to grow in two different regimes: anarchy and hierarchy, and derive conclusions on the circumstances that are conducive for the emergence of hierarchy.

The economy is populated by a measure one of farmers and a measure N of non-farmers. Our main exogenous variable, $\delta > 0$, measures the productivity advantage of cereals over tubers.[55] The productivity of cereals is normalized to unity. Thus, farmers can grow one unit of cereals, or $1-\delta$ units of tubers, or any linear combination thereof. Hence, a farmer's output is $\beta + (1-\beta)(1-\delta) = (1-\delta) + \beta\delta$, where $\beta \in [0,1]$ is the fraction of land allocated to cereals. Output is measured in nutritional units independently of their source.

The income of non-farmers who engage in foraging is assumed to be constant and denoted: $s > 0$. In a state of anarchy, non-farmers can chose to be either foragers or bandits who expropriate crops from farmers. In a state of hierarchy, we assume that some non-farmers are hired by the state to serve as tax collectors, and are paid the wage s. We denote by λ the measure of bandits or tax collectors. N is assumed to be larger than the equilibrium level of λ. We also assume that in order to be viable and to deter bandits, the state has to possess monopoly over the use of force which entails a cost.

Anarchy

Under anarchy, farmers might be raided by bandits. A raided farmer loses his entire cereal crop, but none of his crop of tubers. Farmers are assumed to be risk neutral.[56] A farmer who faces a raid with probability τ, chooses the fraction of land allocated to cereal β to maximize his expected income I, weighing the productivity advantages of cereals over tubers, δ, against the disadvantage, as measured by the expropriation rate τ:

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

We assume that the rate of expropriation, τ, is a function of the measure of bandits λ: $\tau = \tau(\lambda)$. The function, $\tau(\lambda)$ is strictly increasing and strictly concave, and satisfies: $\tau(0) = 0$, $\lim_{\lambda \searrow 0} \tau'(\lambda) =$

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

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

∞, $\lim_{\lambda \nearrow \infty} \tau'(\lambda) = 0$ with $\lim_{\lambda \nearrow \infty} \tau(\lambda) = \overline{\tau} \leq 1$, with corresponding properties for the inverse function $\lambda(\tau)$. Bandits are uncoordinated (if they coordinate they become the ruling elite and the equilibrium becomes identical to that under hierarchy). Thus each bandit's expected income π is given by the total amount of confiscated cereals divided by the measure of bandits: $\pi = \tau(\lambda)\beta/\lambda$.

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

1. *β maximizes farmers' income I, given the confiscation rate τ;*
2. *given β, non-farmers are indifferent between being foragers or bandits, so that $\pi = s$.*[57]

Using the inverse relation $\lambda(\tau)$, the last condition can be restated as requiring: $\tau\beta/\lambda(\tau) = s$. Define now a threshold rate δ_A by the implicit relationship:[58]

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

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

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

That is, the equilibrium confiscation rate τ_A equal δ if tubers are grown, and tubers are not grown if $\delta > \delta_A$.

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

If $\delta \geq \delta_A$, farmers cultivate only cereals ($\beta_A = 1$), even though this entails a maximal confiscation rate $\tau_A = \delta_A$ and a corresponding maximal number of bandits, $\lambda(\delta_A)$.

Our assumptions on $\tau(\cdot)$ imply that the confiscation rate, $\tau(\lambda)/\lambda$, is monotonically decreasing in τ, from infinity towards zero. Thus, when $\delta < \delta_A$, both cereals and tubers are cultivated and we have: $\delta/\lambda(\delta) > \delta_A/\lambda(\delta_A) = s$. Hence, there exists a unique $\beta_A \in (0, 1]$ such that $\pi_A \equiv \delta\beta_A/\lambda(\delta) =$

[57] Micro-foundation for the shape of $\tau(\lambda)$ can be obtained by assuming that banditry is time consuming and that bandits are not coordinated, so that when their number increase, the probability of raiding the same farmers increases, and the marginal total loot declines.

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

s. The last condition, in conjunction with the condition $\tau_A = \delta$, defines the equilibrium combination (β_A, τ_A). ■

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

The effect of the reservation income s. The smaller is s, the larger the incentive for foragers to engage in banditry. This implies a higher threshold δ_A, meaning that farmers will raise tubers in a wider range of δ. Thus, for values of $\delta > \delta_A$, a lower s reduces farmers' income. However, for $\delta < \delta_A$, a smaller s has no effect on farmers income, or on τ and therefore on λ; it will reduce however the equilibrium value of β.

Two sources of inefficiency. Denote by Y_0 the maximal possible level of output in the economy, when all farmers cultivate only the more productive cereals (assuming $\delta > 0$) and all non-farmers engage in foraging. This maximal output level is: $Y_0 = 1 + Ns$. We can observe that the equilibrium (β_A, τ_A) introduces two deviations from this maximal output level: the first is due to farmers growing tubers (if $\delta < \delta_A$); and the other is due to the forgone output by banditry. Thus, equilibrium output is:

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

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

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

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

Hierarchy

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

A key advantage that a state has is that it is farsighted and organized, and can thus commit not to expropriate farmers beyond a certain tax rate.[59] That is, the state selects a tax rate τ, and hires $\lambda(\tau)$ tax-collectors at cost $s\lambda(\tau)$, to maximize its net revenue, subject to the constraint that farmers respond to the tax rate:

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

subject to

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

It is evident that $\beta=0$ if $\tau>\delta$. This implies that in the optimum $\tau\leq\delta$. In addition $\beta=1$ if $\tau<\delta$. Assuming that $\beta=1$ when $\tau=\delta$, the state's problem becomes:

$$\max_{\tau}[\tau-s\lambda(\tau)], \text{ subject to } \tau\leq\delta.$$

The optimal tax rate under hierarchy is therefore: $\tau_H(\delta)=\min\{\delta,\delta_H\}$, where δ_H is the parameter that solves $s\lambda'(\delta_H)=1$. Thus, at the high range of tubers' productivity, where $\delta<\delta_H$, $\tau_H=\delta$, the net revenue is $R(\tau_H(\delta))=\delta-s\lambda(\delta)$, which is increasing in δ. Our assumption that the state has to sustain deterrence against bandits at a fixed cost $G_0>0$ sets a lower limit on the

[59] Another difference between bandits and the state is that bandits confiscate a farmer's entire cereal crop with probability τ, while an organized hierarchy taxes farmers at the rate τ with certainty. If farmers are risk neutral, as assumed here, this difference is unimportant.

net revenue for the state to be viable. Clearly if G_0 exceeds the maximal revenue $R(\delta_H)$, the state is not viable. We thus assume that $R(\delta_H) > G_0$. Under this assumption we can define a viability threshold $\underline{\delta} < \delta_H$, such that: $R(\underline{\delta}) = G_0$, so that he state is viable when $\delta > \underline{\delta}$.

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

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

Output Loss. Analogously to the case of anarchy, we obtain here:

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

Corollary 2. The output loss due to hierarchy is:

$$Y_0 - Y = \begin{cases} s\lambda(\delta) + G_0 & if \quad \delta < \delta_H \\ \\ s\lambda(\delta_H) + G_0 & if \quad \delta \geq \delta_H \end{cases}.$$

.

Anarchy vs. Hierarchy

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

These threshold levels satisfy: $\delta_A > \delta_H > \underline{\delta}$. Since δ_H is defined by $\tau'(\lambda(\delta_H)) = s$, and δ_A is defined by $\delta_A/\lambda(\delta_A) = s$, $\delta_A > \delta_H$ follows from the strict concavity of $\tau(\lambda)$.

Proposition 3. *For $\delta > \underline{\delta}$ the state is viable and:*

(i) Hierarchy weakly Pareto dominates anarchy. (ii) The economy is more productive under hierarchy than under anarchy.

Proof. (i) Because the function $\tau(\cdot)$ is strictly concave, the marginal productivity of tax collectors (or bandits) is lower than the average productivity: $\tau'(\lambda) < \tau(\lambda)/\lambda$ and $\tau'(\lambda(\tau)) < \tau/\lambda(\tau)$.

Recall that, $\lambda(\delta_H)$ is defined by $\tau'(\lambda(\delta_H)) = s$ and $\lambda(\delta_A)$ is defined by $\delta_A/\lambda(\delta_A) = s$. It therefore follows from the concavity of $\tau(\cdot)$ that $\delta_H < \delta_A$ and $\lambda(\delta_H) < \lambda(\delta_A)$.
Non-farmers earn the same income s irrespective of the regime. Suppose that $\delta > \underline{\delta}$. On the other hand, the implied tax rate on farmers under anarchy is larger than or equal than the tax rate under hierarchy. In the range where $\underline{\delta} \leq \delta \leq \delta_H$, the tax rate under both anarchy and hierarchy is δ; in the range $\delta_H \leq \delta < \delta_A$ the tax rate under anarchy δ is higher than the tax rate under hierarchy δ_H and in the range $\delta_A \leq \delta$ the tax rate under anarchy is δ_A, whereas under hierarchy it is lower δ_H. Hence, farmers are weakly better off in all cases under hierarchy than under anarchy. Finally, when $\delta > \underline{\delta}$, a hierarchy generates an additional surplus to the elite, since by construction: $\tau - s\lambda(\tau) - G_0 > 0$. ∎
(ii) From corollaries 1 and 2 we obtain that the difference between total output under hierarchy to that under anarchy is equal to:

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

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

The total output under hierarchy is weakly higher for two reasons. (1) Under hierarchy farmers cultivate only cereals. Thus they do not resort to self-protection through the cultivation of the less productive tubers, as they do (when $\delta < \delta_A$) under anarchy. (2) The state employs (weakly) fewer tax collectors than the scale of foragers who engage in banditry under anarchy, since with the state their marginal product is higher or equals their cost s, whereas under anarchy it is their average product that equal s.

The main predictions of the analysis

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

2. If the productivity advantage of cereals over tubers is sufficiently small, $\delta < \underline{\delta}$, a state cannot exist. This result illustrates our claim that it isn't low productivity that hinders the development of hierarchy and related institutions, but rather relatively high productivity of

crops that are hard to expropriate. A hierarchy could emerge if the productivity advantage of cereals is sufficiently high: $\delta > \underline{\delta}$.

3. Whenever it exists, even a non-benevolent state hierarchy that monopolizes coercive force dominates anarchy from an efficiency point of view. This follows from our assumption that the state can commit to a tax rate that maximizes its net revenue, and that consequently farmers cultivate only the more efficient cereals.

4. If cereals are sufficiently more productive than tubers, a state of hierarchy is a possible outcome but anarchy can persist. A reasonable interpretation for a transition from anarchy to hierarchy, is that coordination is required, either within the emerging state, by the farmers who seek protection, or by the outsider bandits under the leadership of the would be elite. The coordination problem could explain the lag of several millennia between the adoption of cereal cultivation, for instance in the fertile crescent, and the emergence of early states (Scott, 2017).

Example

A simple example helps to illustrate our results diagrammatically. Consider the following specification for the expropriation function: $\tau(\lambda) = \rho\sqrt{\lambda}$, with $\rho \in (0, 1)$.

In this case, $\delta_A = \rho^2/s$ and $\delta_H = \alpha^2/2s$.[60] The equilibrium under anarchy is given by

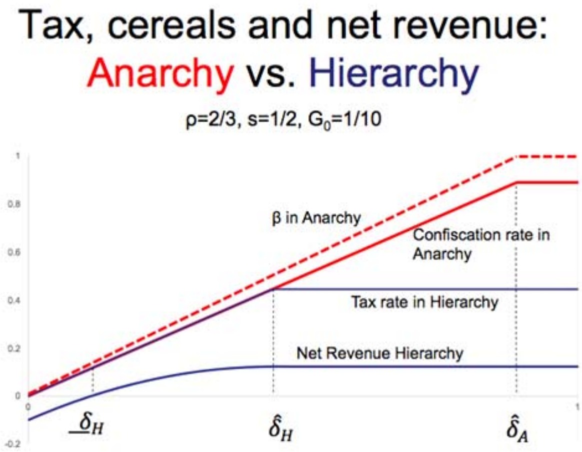
$$(\beta_A, \tau_A) = \begin{cases} \left(\frac{s\delta}{\rho^2}, \delta\right) & if \quad \delta < \delta_A \\ \\ \left(1, \frac{\rho^2}{s}\right) & if \quad \delta \geq \delta_A \end{cases} .$$

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

Risk averse farmers. We illustrate here the robustness of the model's qualitative predictions when farmers are risk averse. The results are in a sense even stronger, given that risk-averse farmers under anarchy seek more protection by choosing a smaller share of cereals. Farmers' risk aversion

[60] The lower limit for state existence, $\underline{\delta} > 0$, is implicitly defined by the quadratic equation: $\underline{\delta} - s\left(\frac{\delta}{\rho}\right)^2 = G_0$, where to have any solution we require that : $G_0 \leq \rho^2/4s$.

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



does not affect the analysis of the model under a regime of hierarchy since in this case the tax rate that the state imposes is certain. We chose to illustrate the case of anarchy with risk-averse farmers by examining a case where a simple analytic solution can be obtained. For that purpose, we employ the specification of the expropriation function, $\tau(\lambda) = \rho\sqrt{\lambda}$, as in the model's example, and consider the case where farmers have a log-utility function: $u(I) = \log(I)$. Farmers under anarchy thus chose $\beta \geq 0$ to maximize the expected utility:

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

The solution is

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

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

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

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

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

Inspection of the equilibrium values of (β_A, τ_A) reveals that as δ tends to zero, both β_A and τ_A

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

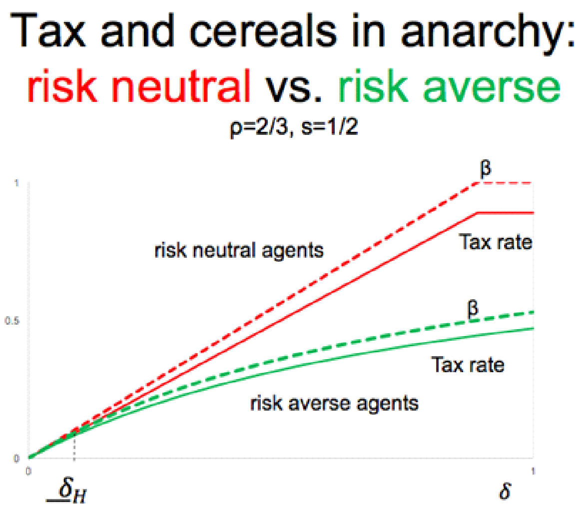
Compared to the model with risk neutrality (in the preceding sub-section), the introduction of risk aversion implies that farmers reduce the cultivation of cereals β_A, and increase the share of land devoted to tubers as a device for self-insurance. Consequently the confiscation rate τ_A is lower, and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

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

$(1-\tau_A)\,(\beta_A+(1-\delta)\,(1-\beta_A))+\tau_A\,(1-\delta)\,(1-\beta_A) = 1-\delta+(\delta-\tau_A)\,\beta_A$ is equal to $1-\delta$ under risk neutrality, but is strictly larger under risk aversion because under risk aversion $\tau_A<\delta$. The reason for this is that under risk neutrality farmers in a mixed equilibrium are indifferent between growing cereals and tubers and so derive an identical income of $1-\delta$. In contrast, under risk aversion, farmers derive a strictly larger expected income from cereals to compensate for the risk associated with cereals, which pushes their expected income higher.[61] The figure illustrates the difference between the two types of equilibrium: the case of risk neutral farmers and risk averse farmers.

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

Figure E.2: Output: Anarchy vs. Hierarchy



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Appendix E: Wild relatives of domesticated crops

In this appendix, we report the list of the wild relatives of domesticated crops. In parenthesis we indicate whether the wild crop is a primary, secondary or tertiary relative.

Barley

Hordeum brevisubulatum (3), Hordeum bulbosum (3), Hordeum chilense (3), Hordeum vulgare spontaneum (1)

Cassava

Manihot esculenta (1), Manihot pruinosa (1), Manihot aesculifolia (2), Manihot anomala (2), Manihot brachyloba (2), Manihot chlorosticta (2), Manihot dichotoma (2), Manihot espruinosa (2), Manihot garcilis (2), Manihot leptophylla (2), Manihot pilosa (2), Manihot tripartita (2), Manihot esculenta subsp. peruviana (2), Manihot cartaghinensis subsp. glaziovii (2), Manihot angustiloba (2), Manihot caerulescens (2), Manihot cartaghinensis (2), Manihot davisiae (2), Manihot oligantha (2), Manihot rubricaulis (2), Manihot anomala subsp. glabrata (2), Manihot baccata (2), Manihot caerulescens subsp. caerulescens (2), Manihot cecropifoliia (2), Manihot compositifolia (2), Manihot diamantinensis (2), Manihot fruticulosa (2), Manihot gabrielensis (2), Manihot garcilis subsp. garcilis (2), Manihot grahamii (2), Manihot guaranitica (2), Manihot heptaphylla (2), Manihot hunzikeriana (2), Manihot irwinii (2), Manihot jacobinensis (2), Manihot janiphoides (2), Manihot pauciflora (2),] Manihot peltata (2), Manihot pentaphylla (2), Manihot pentaphylla subsp. pentaphylla (2), Manihot pentaphylla subsp. tenuifolia (2), Manihot pringlei (2), Manihot purpureocostata (2), Manihot quinquepartita (2), Manihot rhomboidea subsp. microcarpa (2), Manihot rhomboidea subsp. rhomboidea (2), Manihot salicifolia (2), Manihot sparsifolia (2), Manihot stricta (2), Manihot tomentosa (2), Manihot violacea (2), Manihot xavantinensis (2)

Maize

Zea diploperennis (2), Zea luxurians (2), Zea mays subsp. mexicana (1), Tripsacum dactyloides (3), Tripsacum dactyloides var. dactyloides (3), Tripsacum dactyloides var. hispidum (3),

Millet, Broom

Millet Panicum Miliaceum (1), Millet Panicum Bergii (2), Millet Panicum Fauriei (2), Millet Panicum Nephelophilum (2)

Millet, Foxtail

Millet Setaria italica (1), Millet Setaria viridis (1), Millet Setaria adhaerans/verticillata (2), Millet Setaria faberi (2)

Oat

Avena abyssinica (3), Avena byzantina (1), Avena fatua (1), Avena hybrida (1), Avena insularis (2), Avena maroccana (Avena magna) (2), Avena murphyi (2), Avena sterilis (1), Avena strigosa (3)

Potato

Solanum clarum (2), Solanum multiinterruptum (2), Solanum colombianum (2), Solanum oxycarpum (2), Solanum microdontum (2), Solanum candolleanum (1), Solanum longiconicum (2), Solanum chomatophilum (2), Solanum sogarandinum (2), Solanum flahaultii (2), Solanum laxissimum (2), Solanum coelestipetalum (1), Solanum bombycinum (2), Solanum piurae (2), Solanum iopetalum (2), Solanum cajamarquense (2), Solanum chiquidenum (2), Solanum burkartii (2), Solanum hjertingii (2), Solanum contumazaense (2), Solanum bulbocastanum (3), Solanum venturii (2), Solanum gracilifrons (2), Solanum demissum (2), Solanum hintonii (2), Solanum infundibuliforme (1), Solanum hastiforme (2), Solanum albicans (2), Solanum tarnii (3), Solanum okadae (1), Solanum schenckii (2), Solanum palustre (3) , Solanum brevicaule (1), Solanum polyadenium (2), Solanum medians (2), Solanum chacoense (2), Solanum neovavilovii (2), Solanum violaceimarmoratum (2), Solanum kurtzianum (2), Solanum verrucosum (2), Solanum neorossii (2), Solanum gandarillasii (2), Solanum rhomboideilanceolatum (2), Solanum berthaultii (1), Solanum andreanum (2), Solanum garcia-barrigae (2), Solanum stoloniferum (2), Solanum agrimonifolium (2), Solanum acroscopicum (2), Solanum marinasense (1), Solanum cantense (2), Solanum raphanifolium (2), Solanum acaule (1), Solanum hougasii (2), Solanum pillahuatense (2), Solanum buesii (2), Solanum maglia (2), Solanum boliviense (2), Solanum neocardenasii (2), Solanum commersonii (2), Solanum morelliforme (2), Solanum vernei (1)

Rice

Oryza alta (2), Oryza australiensis (2), Oryza barthii (1), Oryza glaberrima (1), Oryza glumipatula (1), Oryza grandiglumis (2), Oryza latifolia (2), Oryza longistaminata (1), Oryza meridionalis (1), Oryza minuta (2),Oryza nivara (1), Oryza officinalis (2), Oryza punctata (2), Oryza rhizomatis (2), Oryza ridleyi (3), Oryza rufipogon (1)

Rice bean

Vigna acontifolia (3), Vigna angularis (2), Vigna dalzelliana (2), Vigna khandalensis (3), Vigna minima (2), Vigna mungo (3), Vigna radiata (3), Vigna subramaniana (3), Vigna triloba (3), Vigna umbellata (1)

Rye

Secale cereale ancestrale (1), Secale cereale segetale (1)

Sorghum

Sorghum angustum (3), Sorghum bicolor drummondii (1), Sorghum bicolor verticilliflorum (1), Sorghum ecarinatum (3),Sorghum exstans (3), Sorghum halepense (2), Sorghum interjectum (3), Sorghum intrans (3), Sorghum laxiflorum (3), Sorghum matarankense (3), Sorghum nitidum (3), Sorghum propinquum (3), Sorghum stipoideum (3), Sorghum timorense (3), Sorghum versicolor (3)

Sweet Potato

Ipomoea cordatotriloba (3), Ipomoea cynanchifolia (3), Ipomoea grandifolia (3), Ipomoea lacunosa (3), Ipomoea leucantha (3), Ipomoea littoralis (2), Ipomoea ramosissima (3), Ipomoea splendor-sylvae (3), Ipomoea tabascana (2), Ipomoea tenuissima (3), Ipomoea tiliacea (3), Ipomoea trifida (2), Ipomoea triloba (3)

Wheat

Aegilops bicornis (2), Aegilops biunicalis (2), Aegilops columnaris (2), Aegilops comosa subventricosa (2), Aegilops crassa (2), Aegilops cylindrica (2), Aegilops geniculata (2), Aegilops juvenalis (2), Aegilops kotschyi (2), Aegilops longissima (2), Aegilops markgrafii (2), Aegilops neglecta (2), Aegilops peregrina (2), Aegilops searsii (2), Aegilops speltoides ligustica (2), Aegilops speltoides speltoides (2), Aegilops speltoides (2), Aegilops tauschii (2), Aegilops triuncialis (2), Aegilops umbellulata (2), Aegilops vavilovii (2), Aegilops ventricosa (2), Amblyopyrum muticum muticum (2), Triticum monococcum aegilopoides (1), Triticum monococcum (1), Triticum timopheevii armeniacum (1), Triticum timopheevii (1), Triticum turgidum dicoccoides (1), Triticum urartu (1)

Yam, Water

Dioscorea brevipetiolata (2), Dioscorea hamiltonii (2), Dioscorea nummularia (1), Dioscorea transversa (1), Dioscorea abyssinica (3), Dioscorea cayenensis subsp. rotundata (2)

Yam, Lagos

Dioscorea burkilliana (1), Dioscorea minutiflora (1), Dioscorea smilacifolia (1), Dioscorea abyssinica (3), Dioscorea cayenensis subsp. rotundata (1), Dioscorea praehensilis (1)

Yam, White Guinea

Dioscorea abyssinica (3), Dioscorea cayenensis subsp. rotundata (1), Dioscorea praehensilis (1)

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Appendix F: Additional data tables and figures

Table F.1: Descriptive Statistics: societies in Ethnoatlas

	SOURCE	**Mean**	**p50**	**SDev**	**Min**	**Max**	**N**
Hierarchy	Ethnoatlas	1.89	2.00	1.04	1.00	5.00	1,059
CerMain	Ethnoatlas	0.54	1.00	0.50	0.00	1.00	1,092
Dependence on agriculture	Ethnoatlas	0.45	0.50	0.27	0.03	0.93	1,178
Intensive irrigation	Ethnoatlas	0.14	0.00	0.35	0.00	1.00	862
Dependence on herding $\leq 25\%$	Ethnoatlas	0.77	1.00	0.42	0.00	1.00	1,178
Dependence on herding $> 26\%$ and $\leq 50\%$	Ethnoatlas	0.18	0.00	0.39	0.00	1.00	1,178
Dependence on herding $> 26\%$ and $\leq 50\%$	Ethnoatlas	0.02	0.00	0.14	0.00	1.00	1,178
Dependence on herding $> 76\%$	Ethnoatlas	0.02	0.00	0.15	0.00	1.00	1,178
Herding main animals: pigs	Ethnoatlas	0.07	0.00	0.26	0.00	1.00	1,086
Herding main animals: sheep	Ethnoatlas	0.16	0.00	0.37	0.00	1.00	1,086
Herding main animals: equine anim.	Ethnoatlas	0.06	0.00	0.24	0.00	1.00	1,086
Herding main animals: camels, llama	Ethnoatlas	0.02	0.00	0.15	0.00	1.00	1,086
Herding main animals: bovine	Ethnoatlas	0.40	0.00	0.49	0.00	1.00	1,086
Animals in cultivation	Ethnoatlas	0.14	0.00	0.35	0.00	1.00	1,086
Farming surplus	Tuden and Marshall (1972)	0.49	0.00	0.50	0.00	1.00	162
Tax burden	Ross (1983)	1.11	1.00	0.90	0.00	2.00	66
Population density (categorical)	Pryor (1985)	3.83	4.00	1.57	2.00	7.00	168
LandProd (std)	authors	0.00	0.23	1.00	-1.92	2.66	1,179
CerAdv (std)	authors	0.00	-0.13	1.00	-1.73	4.16	1,179
Precipitation (std)	FAO-GAEZ	0.00	-0.13	1.00	-1.39	10.65	1,179
Temperature (std)	FAO-GAEZ	0.00	0.37	1.00	-2.57	1.32	1,179
Elevation (std)	GDEM	0.00	0.17	1.00	-9.24	3.58	1,179
Ruggedness (std)	GDEMs	0.00	-0.35	1.00	-0.90	6.41	1,179
Absolute Latitude (std)	Ethnoatlas	0.00	-0.43	1.00	-1.21	3.36	1,179
Distance to major river (std)	Fenske (2013)	0.00	-0.63	1.00	-0.63	1.58	1,179
Distance to coast (std)	Fenske (2013)	0.00	-0.30	1.00	-1.11	3.14	1,179
Pct malaria	MAP	0.17	0.06	0.21	0.00	0.69	1,179
Population density 1995 (std)	FAO-GAEZ	0.00	-0.38	1.00	-0.62	7.23	1,161
Historical population density (std)	HYDE	0.00	-0.23	1.00	-0.30	25.85	1,179
Plow Advantage (std)	FAO-GAEZ	-0.00	0.31	1.00	-2.83	2.61	1,179
% Fertile land	Ramankutty et al (2002)	-0.00	-0.03	1.00	-1.43	2.53	1,134
Caloric Suitability Index (std)	Galor and Ozak (2015)	0.00	0.28	1.00	-1.95	2.63	1,179

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

Table F.2: Descriptive Statistics: Countries X 50 years

	SOURCE	**Mean**	**p50**	**SDev**	**Min**	**Max**	**N**
Hierarchy	Borcan et al. (2018)	0.72	1.00	0.45	0.00	1.00	2,869
LandProd (std)	authors	0.00	0.35	1.00	-1.64	2.69	2,959
CerAdv (std)	authors	0.00	-0.00	1.00	-1.49	3.12	2,959
WR of cereals	authors	0.49	0.00	0.50	0.00	1.00	2,959.00
WR of roots and tubers	authors	0.05	0.00	0.22	0.00	1.00	2,959.00
WR of cereals, roots and tubers	authors	0.34	0.00	0.47	0.00	1.00	2,959.00
Precipitation (std)	FAO-GAEZ	0.00	-0.29	1.00	-1.38	2.89	2,940
Temperature (std)	FAO-GAEZ	0.00	0.20	1.00	-2.68	1.52	2,884
Elevation (std)	GDEM	0.00	-0.33	1.00	-1.10	4.65	2,845
Ruggedness (std)	GDEM	0.00	-0.31	1.00	-1.12	4.25	2,959
Absolute latitude (std)	Nunn and Puga (2012)	0.00	-0.17	1.00	-1.51	2.18	2,959
Legal origin: English common law	La Porta et al. (1999)	0.27	0.00	0.44	0.00	1.00	2,959
Legal origin: French civil law	La Porta et al. (1999)	0.45	0.00	0.50	0.00	1.00	2,959
Legal origin: Socialist law	La Porta et al. (1999)	0.22	0.00	0.41	0.00	1.00	2,959
Legal origin: German civil law	La Porta et al. (1999)	0.03	0.00	0.18	0.00	1.00	2,959
Legal origin: Scandinavian law	La Porta et al. (1999)	0.03	0.00	0.18	0.00	1.00	2,959
Population density 1500 (std)	Acemoglu et al. (2002)	0.00	-0.05	1.00	-2.96	2.78	2,959
Mortality of early settlers (std)	Acemoglu et al. (2002)	0.00	-0.11	1.00	-2.91	2.56	1,519
Slaves exported (std)	Nunn (2008)	0.00	-0.26	1.00	-0.26	9.01	2,959
Genetic diversity (std)	Ashraf and Galor (2013)	0.00	0.24	1.00	-3.66	1.74	2,675
Hist. domesticable animals/area	Ashraf and Galor (2011)	2.58	0.01	17.72	0.00	168.00	2,032
Distance to major river (std)	www.pdx.edu/econ/	0.00	-0.29	1.00	-0.89	7.63	2,845
Distance to coast (std)	www.pdx.edu/econ/	0.00	-0.41	1.00	-0.75	4.48	2,845
Pct malaria	MAP	0.65	0.94	0.41	0.00	1.00	2,883
% country with tropical climate (std)	Nunn and Puga (2012)	0.35	0.00	0.43	0.00	1.00	2,959
Caloric suitability index (std)	Galor and Ozak (2015)	0.00	0.29	1.00	-1.82	2.93	2,959

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

Table F.3: Descriptive Statistics: 1x1 decimal degree pixel

	SOURCE	Mean	p50	SDev	Min	Max	N
Panel A: *cross-sectional data-15,927 raster points*							
City founded <AD 450 (dummy)	Reba et al. (2016)	0.01	0.00	0.08	0.00	1.00	15,927
City founded <500 BC (dummy)	Reba et al. (2016)	0.00	0.00	0.06	0.00	1.00	15,927
City founded <AD 400 (dummy)	DeGroff (2009)	0.05	0.00	0.22	0.00	1.00	15,927
Archaeological sites	ANCIENTLOCATIONS.NET	0.24	0.00	2.58	0.00	138.00	15,927
Pyramids or Mastaba	MEGALITHIC.CO.UK	0.01	0.00	0.75	0.00	87.00	15,927
Temples	MEGALITHIC.CO.UK	0.04	0.00	0.64	0.00	46.00	15,927
Mines	MEGALITHIC.CO.UK	0.01	0.00	0.21	0.00	22.00	15,927
Palaces	MEGALITHIC.CO.UK	0.00	0.00	0.06	0.00	5.00	15,927
Sculptured Stones	MEGALITHIC.CO.UK	0.02	0.00	0.83	0.00	101.00	15,927
Standing Stones	MEGALITHIC.CO.UK	0.04	0.00	0.71	0.00	45.00	15,927
LandProd (std)	authors	-0.70	-1.28	1.26	-1.78	3.76	15,927
CerAdv (std)	authors	-0.93	-1.40	1.03	-2.67	2.96	15,927
WR of cereals	authors	0.19	0.00	0.39	0.00	1.00	15,927
WR of roots and tubers	authors	0.08	0.00	0.27	0.00	1.00	15,927
WR of cereals, roots and tubers	authors	0.05	0.00	0.23	0.00	1.00	15,927
DistanceCer	authors	28.71	24.72	22.78	0.00	270.26	15,927
DistanceAgr	authors	19.02	15.51	17.57	0.00	234.51	15,927
Precipitation (std)	FAO-GAEZ	0.00	-0.32	1.00	-1.06	9.24	15,862
Temperature (std)	FAO-GAEZ	0.00	-0.32	1.00	-1.33	1.81	15,833
Elevation (std)	GDEM	-0.00	-0.34	1.00	-0.87	6.01	15,927
Ruggedness (std)	GDEM	-0.00	0.35	1.00	-3.38	1.10	15,927
Absolute Latitude	authors	40.52	41.50	22.20	0.50	83.50	15,927
Irrigation Potential (std)	authors	0.00	0.67	1.00	0.67	1.74	8,214
Plow Advantage (std)	authors	0.00	0.05	1.00	-3.00	3.44	15,927
Population density 1995 (std)	FAO-GAEZ	0.00	-0.59	1.00	-0.76	3.58	15,861
Panel B: *panel data-15,927 raster points with observations either before or after Neolithic transition*							
Prehistoric archaelogical sites	D. and R. Whitehouse (1975)	0.11	0.00	0.71	0.00	23.00	31,854
Prehistoric settlements	D. and R. Whitehouse (1975)	0.08	0.00	0.59	0.00	21.00	31,854

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

Table F.4: Caloric content of cereals, roots and tubers

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

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

Table F.5: Pairwise correlations of the main variables used in the empirical analysis on the societies in the Ethnoatlas

Variables	*Hier.*	*CerMain*	Dep. agric.	Farm. surp.	H. Pop dens.	*LandProd*	*CerAdv*	% Fertile land	Caloric suit. ind.
Hierarchy	1.0								
CerMain	0.3	1.0							
Dependence agriculture	0.4	0.5	1.0						
Farming surplus	0.6	0.4	0.3	1.0					
Hist Pop density (Pryor)	0.6	0.5	0.7	0.4	1.0				
LandProd	0.2	0.3	0.4	0.2	0.3	1.0			
CerAdv	0.2	0.4	0.3	0.3	0.2	0.8	1.0		
% Fertile land	0.2	0.2	0.3	0.2	0.3	0.4	0.5	1.0	
Caloric suitability index	0.2	0.3	0.5	0.2	0.3	1.0	0.8	0.5	1.0

Table F.6: Potential Crop Yields and Choice of Crops. Robustness checks: Controlling for Geography.

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

The table reports cross-sectional OLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.7: Potential Crop Yields and Choice of Crops. Robustness checks: Controlling for Isolation, Population Density and the Plow.

	Dep. Variable: Major crop is a cereal grain (dummy)						
	(1)	(2)	(5)	(6)		(7)	(8))
CerAdv	0.252***	0.250***	0.253***	0.261***	0.254***	0.253***	0.257***
	(0.058)	(0.060)	(0.059)	(0.071)	(0.059)	(0.058)	(0.049)
LandProd	-0.137**	-0.135*	-0.136**	-0.222***	-0.139**	-0.204***	-0.205***
	(0.067)	(0.069)	(0.069)	(0.086)	(0.069)	(0.060)	(0.061)
Major River	-0.028*						
	(0.017)						
Distance Coast		0.016					
		(0.035)					
Hist Pop Dens (HYDE)			-0.015				
			(0.016)				
Hist Pop Dens (PRYOR)				0.206***			
				(0.038)			
Pop Dens 1995					-0.004		
					(0.025)		
Irrigation						0.191***	
						(0.049)	
Plow Advantage							-0.148***
							(0.033)
CONTINENT FE	YES	YES	YES	YES	YES	YES	YES
r2	0.362	0.360	0.360	0.383	0.348	0.396	0.398
N	982	982	982	144	966	800	982

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.8: Cereals and Hierarchy - Reduced Form using generalized ordered logit

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community			
	Hierarchy<=1 vs Hierarchy>1	H<=2 vs H>2	H<=3 vs H>3	H<=4 vs H>4
CerAdv	0.327*	0.542***	0.674***	0.841**
	(0.173)	(0.172)	(0.230)	(0.407)
LandProd	0.0596	-0.392**	-0.485*	-0.597
	(0.198)	(0.199)	(0.281)	(0.515)

The table reports the estimates from a generalized ordered logit. The unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.9: Cereals and Hierarchy - 2SLS. Robustness checks: Controlling for Geography.

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

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.10: Cereals and Hierarchy - 2SLS. Robustness checks: Controlling for Isolation, Population Density and the Plow.

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
CerMain	1.073**	1.078**	1.021**	1.471*	0.992**	0.933*	1.029**
	(0.519)	(0.545)	(0.504)	(0.811)	(0.472)	(0.555)	(0.453)
LandProd	-0.040	-0.038	-0.056	0.006	-0.085	0.012	0.080
	(0.070)	(0.071)	(0.071)	(0.119)	(0.072)	(0.078)	(0.066)
Major River	0.122***						
	(0.038)						
Distance to Coast		-0.024					
		(0.058)					
Hist Pop Dens (HYDE)			0.211**				
			(0.102)				
Hist Pop Dens (PRYOR)				0.276			
				(0.192)			
Pop Dens 1995					0.290***		
					(0.048)		
Irrigation						0.445*	
						(0.242)	
Plow Advantage							0.259***
							(0.093)
CONTINENT FE	YES	YES	YES	YES	YES	YES	YES
N	952	952	952	142	936	770	952
F excl instrum.	76.84	74.70	77.41	14.22	76.15	84.42	85

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.11: Cereals and Hierarchy - 2SLS. Robustness checks: Sample Including Societies Living in Desertic Soils.

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

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. All societies included in the Ethnoatlas, for which the relevant data are available, are included in the sample. "A-R Test" is the Anderson-Rubin test: the null hypothesis that the endogenous regressor is equal to zero. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.12: Cereals and Hierarchy - 2SLS. Robustness checks: Potential Calorie Yields Refer to Ethnic Boundaries in Fenske (2013)

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

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.13: Cereals and Hierarchy - 2SLS. Robustness checks: Controlling for Alternative Measures of Land Suitability for Agriculture

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community			
	(1)	(2)	(3)	(4)
	2SLS	2SLS	2SLS	2SLS
CerMain	1.009***	0.723	0.867	1.121*
	(0.372)	(0.478)	(0.636)	(0.585)
% fertile land	0.073	0.057		
(Ramankutty et al. 2002)	(0.061)	(0.054)		
Caloric Suitability Index			0.081	-0.049
(Galor and Ozak, 2016)			(0.138)	(0.078)
CONTINENT FE	NO	YES	NO	YES
N	952	952	952	952
F excl instrum.	106.3	70.49	38.25	65.04

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. All societies included in the Ethnoatlas, for which the relevant data are available, are included in the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.14: Cereals and Hierarchy - 2SLS. Robustness checks: the role of domesticated animals

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
CerMain	0.820*	1.092***	0.921**	0.782	0.839*	1.037***	0.774**
	(0.440)	(0.383)	(0.447)	(0.511)	(0.472)	(0.313)	(0.390)
America	-0.200						
	(0.194)						
Eurasia and Africa	0.367						
	(0.325)						
Hearding 25-50%		0.363*	0.187				
		(0.199)	(0.168)				
Hearding 51-75%		0.411	0.277				
		(0.349)	(0.325)				
Hearding 76-100%		0.851***	0.679*				
		(0.254)	(0.271)				
Pigs				0.112	-0.143		
				(0.107)	(0.175)		
Sheeps				0.470**	0.414		
				(0.229)	(0.253)		
Equine animals				0.207	0.253		
				(0.191)	(0.159)		
Camels, Llamas				1.526***	1.437***		
				(0.467)	(0.479)		
Bovine animals				0.696**	0.520*		
				(0.319)	(0.311)		
Animals Cultivation						1.001***	1.043***
						(0.207)	(0.215)
CONTINENT FE	NO	NO	YES	NO	YES	NO	YES
N	952	952	952	949	949	949	949
F excl instrum.	89.85	124.2	93.21	75.62	88.77	145.8	98.57

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Standard errors (in parentheses) are adjusted for spatial correlation using Conley's (1999) method. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.15: Cereals, Surplus, and Taxation -Reduced Form

	Dependent variable is:							
	Existence of a farming surplus				Tax burden			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	OLS	Logit	OLS	OLS	OLS	Ord Logit
CerAdv	0.141***	0.241***	0.202***	1.128***	0.223*	0.433**	0.257	1.038**
	(0.0319)	(0.0681)	(0.0742)	(0.363)	(0.116)	(0.183)	(0.175)	(0.494)
LandProd		-0.132	-0.0985	-0.601		-0.293	-0.206	-0.654
		(0.0870)	(0.0985)	(0.392)		(0.238)	(0.231)	(0.536)
CONTINENT FE	NO	NO	YES	NO	NO	NO	YES	NO
N	140	140	140	140	56	56	56	56
r2		0.0757	0.0911	0.157		0.0533	0.0781	0.341

The table reports cross-sectional OLS (columns 1-3 and 5-7), Logit (column 4) and ordered logit (column 8) estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.16: Cereals, Surplus, and Taxation - OLS and 2SLS

	Dependent variable is:							
	Existence of a farming surplus				Tax burden			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
CerMain	0.359***	0.940***	0.846***	0.846***	0.853***	0.846**	1.018**	1.173
	(0.0791)	(0.260)	(0.273)	(0.275)	(0.209)	(0.406)	(0.471)	(0.850)
LandProd			0.0186				-0.0634	
			(0.0626)				(0.158)	
DEPENDENCE ON AGRICULTURE				0.191				-0.584
				(0.663)				(1.574)
CONTINENT FE	NO	NO	YES	NO	NO	NO	YES	NO
N	139	139	139	139	56	56	56	56
F excl instrum.		16.08	17.37	5.486		22.58	15.11	3.184
r2	0.128				0.233			

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.17: Cereals and Surplus - 2SLS. Robustness checks: Controlling for Geography.

	Dependent variable: Existence of a farming surplus				
	(1)	(2)	(3)	(4)	(5)
	2SLS	2SLS	2SLS	2SLS	2SLS
$CerMain$	0.774**	0.764***	0.921***	0.930***	0.681**
	(0.375)	(0.261)	(0.301)	(0.315)	(0.267)
$LandProd$	0.0334	0.0387	0.00222	-0.0215	0.0534
	(0.0793)	(0.0686)	(0.0677)	(0.0811)	(0.0637)
Precipitation	-0.0334				
	(0.0762)				
Temperature		-0.0283			
		(0.0479)			
Elevation			-0.106***		
			(0.0372)		
Ruggedness				-0.111	
				(0.0723)	
Abs Latitude					0.0516
					(0.0472)
N	139	139	139	139	139
F excl instrum.	10.41	19.42	15.50	14.83	15.68

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.18: Cereals and Surplus - 2SLS. Robustness checks: Controlling for Isolation, Population Density, Potential for Irrigation, and the Plow.

	Dependent variable: Existence of a farming surplus						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
CerMain	0.823***	0.851***	0.820***	0.848***	0.916***	0.646***	0.822***
	(0.277)	(0.275)	(0.300)	(0.288)	(0.314)	(0.245)	(0.237)
LandProd	0.0215	0.0191	0.0132	0.0208	0.0117	0.101*	0.0265
	(0.0625)	(0.0626)	(0.0589)	(0.0530)	(0.0616)	(0.0540)	(0.0574)
Major River	0.0368						
	(0.0414)						
Distance to Coast		-0.0149					
		(0.0447)					
Hist Pop Dens (HYDE)			0.0291				
			(0.0379)				
Hist Pop Dens (PRYOR)				-0.00808			
				(0.0840)			
Pop Density 1995					0.00145		
					(0.0357)		
Irrigation						0.0291	
						(0.128)	
Plow Advantage							0.0129
							(0.0489)
N	139	139	139	139	137	111	139
F excl instrum.	15.86	17.09	13.35	17.91	12.99	23.25	22.07

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.19: Cereals and Taxation- 2SLS. Robustness checks: Controlling for Geography.

	Dependent variable: Tax Burden				
	(1)	(2)	(3)	(4)	(5)
	2SLS	2SLS	2SLS	2SLS	2SLS
CerMain	0.808	1.056**	1.019**	1.014**	1.132**
	(0.577)	(0.495)	(0.473)	(0.501)	(0.571)
LandProd	0.0487	-0.0814	-0.0667	-0.0603	-0.112
	(0.214)	(0.190)	(0.164)	(0.178)	(0.205)
Precipitation	-0.180				
	(0.167)				
Temperature		0.0232			
		(0.128)			
Elevation			-0.0488		
			(0.250)		
Ruggedness				0.00906	
				(0.116)	
Abs Latitude					-0.0593
					(0.150)
N	56	56	56	56	56
F excl instrum.	10.10	14.75	15.43	13.08	8.491

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.20: Cereals and Taxation - 2SLS. Robustness checks: Controlling for Isolation, Population Density, Potential for Irrigation, and the Plow.

	Dependent variable: Tax Burden						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
CerMain	0.999**	0.993**	0.380	0.00327	0.627	0.689	1.102**
	(0.470)	(0.438)	(0.591)	(0.536)	(0.492)	(0.659)	(0.483)
LandProd	-0.0530	-0.0573	-0.0998	-0.174	-0.158	-0.0175	-0.108
	(0.158)	(0.152)	(0.154)	(0.138)	(0.151)	(0.163)	(0.160)
Major River	0.101						
	(0.122)						
Distance to Coast		-0.0310					
		(0.0998)					
Hist Pop Dens (HYDE)			0.291**				
			(0.119)				
Hist Pop Dens (PRYOR)				0.641***			
				(0.166)			
Pop Density 1995					0.227***		
					(0.0852)		
Irrigation						0.329	
						(0.328)	
Plow Advantage							-0.0601
							(0.0974)
N	56	56	56	56	56	42	56
F excl instrum.	13.15	18.51	9.980	4.693	11.48	8.747	14.18

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.21: Cereals and Hierarchy in Classical Antiquity - Cross-sectional regressions. Robustness Checks: Excluding Continents one-by-one

	Dep. Variable: Hierarchy Index in AD 450				
	(1)	(2)	(3)	(4)	(5)
WR Cer	0.481***	0.398***	0.493***	0.510***	0.465***
	(0.143)	(0.133)	(0.140)	(0.168)	(0.124)
WR RT	0.179	0.170	0.174	0	0.182
	(0.175)	(0.172)	(0.174)	(.)	(0.173)
WR Cer and RT	0.0429	0.0573	0.0164	0.141	0.0623
	(0.133)	(0.104)	(0.120)	(0.180)	(0.114)
CONTINENT FE	YES	YES	YES	YES	YES
Sample excludes	Africa	Asia	Europe	America	Oceania
r2	0.371	0.206	0.538	0.410	0.401
N	103	113	116	124	148

The table reports cross-sectional OLS estimates and the unit of observation is the territory delimited by modern-country borders. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.22: Cereals and Hierarchy in Classical Antiquity - Cross-sectional regressions. Further robustness checks

	Dep. Variable: Hierarchy Index in AD 450									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
WR Cer	0.460***	0.414***	0.500**	0.467***	0.417***	0.449***	0.457***	0.412***	0.499***	0.500***
	(0.104)	(0.104)	(0.195)	(0.124)	(0.135)	(0.117)	(0.132)	(0.130)	(0.125)	(0.163)
WR RT	0.0887	0.197	0.152	0.181	0.148	0.172	0.204	0.117	0.123	0.153
	(0.175)	(0.164)	(0.186)	(0.173)	(0.176)	(0.180)	(0.177)	(0.188)	(0.174)	(0.194)
WR Cer and RT	0.0586	0.0569	-0.0283	0.0573	0.0265	0.0534	0.0440	0.0787	0.0806	0.170
	(0.101)	(0.0983)	(0.152)	(0.113)	(0.124)	(0.112)	(0.127)	(0.114)	(0.118)	(0.159)
Controls:										
Legal Origin	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO
Pop. Dens. 1500	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO
Settlers Mortality	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO
Slave Exports	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO
Genetic Diversity	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
Distance River	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
Distance Coast	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO
Pct Malaria	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
Tropical Land	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO
Dom. Animals	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
CONTINENT FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
N	151	151	79	151	145	145	147	151	137	106
r2	0.509	0.467	0.568	0.409	0.396	0.429	0.412	0.417	0.418	0.380

The table reports cross-sectional OLS estimates and the unit of observation is the territory delimited by modern-country borders. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.23: Cereals and Hierarchy in Classical Antiquity - Cross-sectional regressions

	Dep. Variable: Hierarchy Index in AD 450					
	(1)	(2)	(3)	(4)	(5)	(6)
CerAdv	0.245**	0.355***	0.160	0.278**	0.198*	0.187*
	(0.0993)	(0.118)	(0.102)	(0.108)	(0.111)	(0.101)
LandProd	-0.262***	-0.400***	-0.154	-0.312***	-0.214*	-0.210**
	(0.0986)	(0.123)	(0.104)	(0.107)	(0.112)	(0.0984)
Controls:						
Abs Latitude	NO	YES	NO	NO	NO	NO
Precipitation	NO	NO	YES	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO
Elevation	NO	NO	NO	NO	YES	NO
Ruggedness	NO	NO	NO	NO	NO	YES
CONTINENT FE	YES	YES	YES	YES	YES	YES
r2	0.328	0.343	0.336	0.350	0.326	0.353
N	151	151	150	148	145	151

The table reports cross-sectional OLS estimates and the unit of observation is the territory delimited by modern-country borders. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.24: Cereals and Hierarchy - Panel Regressions - Robustness Checks

	Dep. Variable: Hierarchy Index									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
CerAdv	0.160*	0.127	0.206*	0.274***	0.162*	0.245***	0.258***	0.273***	0.254***	0.252**
	(0.0892)	(0.0843)	(0.116)	(0.0833)	(0.0831)	(0.0928)	(0.0957)	(0.0840)	(0.0675)	(0.101)
LandProd	-0.0507	0.0471	-0.261	-0.176	-0.00456	-0.121	-0.133	-0.199	-0.211**	-0.186
	(0.133)	(0.132)	(0.192)	(0.143)	(0.148)	(0.151)	(0.151)	(0.145)	(0.102)	(0.159)
Controls (xYear):										
Legal Origin	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO
Pop. Dens. 1500	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO
Settlers Mortality	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO
Slave Exports	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO
Genetic Diversity	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
Distance River	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
Distance Coast	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO
Pct Malaria	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
Tropical Land	NO	YES	NO	NO	NO	NO	NO	NO	YES	NO
Dom. Animals	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
r2	0.699	0.714	0.707	0.683	0.682	0.678	0.679	0.681	0.744	0.696
N	2869	2869	1501	2869	2603	2755	2755	2793	2869	2014

The table reports panel OLS 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, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.25: Cereals and Hierarchy - Panel Regressions. Robustness checks: Excluding Colonies

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

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The sample excludes those cells 50yearsXcountry in which countries were either colonies or protectorates. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.26: Cereals and Hierarchy - Panel Regressions. Robustness checks: a Different Measure of Hierarchy

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

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The dependent variable is a dummy that identifies those territories characterized by a supra-tribal government. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.27: Cereals and Hierarchy - Panel Regressions. Robustness checks: a Different Measure of Soil Suitability for Agriculture

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

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.28: Cereals and Hierarchy - Panel Regressions. Robustness Checks: Excluding Years 1500-1750

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

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The years 1500-1750 are excluded from the regression. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.29: Cereals and Hierarchy - Panel Regressions. Robustness Checks: Excluding Years 1500-1750

	Dep. Variable: Hierarchy Index						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$Change\ CerAdv * LinearTrend$	-0.0000601	-0.000138	-0.000145	-0.000153	-0.000169	-0.000138	-0.000138
	(0.0000691)	(0.000135)	(0.000137)	(0.000138)	(0.000134)	(0.000135)	(0.000135)
$Change\ LandProd * LinearTrend$		0.000142	0.000152	0.000164	0.000196	0.000142	0.000142
		(0.000191)	(0.000193)	(0.000194)	(0.000187)	(0.000191)	(0.000191)
Controls (x Year FE):							
Precipitation	NO	NO	YES	NO	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO	NO
Elevation	NO	NO	NO	NO	YES	NO	NO
Ruggedness	NO	NO	NO	NO	NO	YES	NO
Abs Latitude	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES
YEAR FE	YES	YES	YES	YES	YES	YES	YES
r2	0.887	0.887	0.887	0.885	0.888	0.887	0.887
N	1661	1661	1650	1628	1595	1661	1661

The table reports panel OLS estimates and the unit of observation is the territory delimited by modern-country borders every 50 years. The years 1500-1750 are excluded from the regression. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.30: Cereals and Hierarchy - Panel Regressions 2

	Dep. Variable: Hierarchy Index						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Change CerAdv∗ 1050	-0.00422	-0.00799	-0.00811	-0.00825	-0.00810	-0.00799	-0.00799
	(0.00332)	(0.00573)	(0.00581)	(0.00592)	(0.00581)	(0.00573)	(0.00573)
Change CerAdv∗ 1100	0.0135	0.0119	0.0118	0.0117	0.0131	0.0119	0.0119
	(0.0180)	(0.0205)	(0.0205)	(0.0206)	(0.0218)	(0.0205)	(0.0205)
Change CerAdv∗ 1150	0.0172	0.0305	0.0303	0.0302	0.0334	0.0305	0.0305
	(0.0185)	(0.0278)	(0.0278)	(0.0279)	(0.0300)	(0.0278)	(0.0278)
Change CerAdv∗ 1200	0.0164	0.0298	0.0294	0.0292	0.0334	0.0298	0.0298
	(0.0186)	(0.0281)	(0.0281)	(0.0281)	(0.0303)	(0.0281)	(0.0281)
Change CerAdv∗ 1250	0.00759	0.0200	0.0191	0.0182	0.0252	0.0200	0.0200
	(0.0194)	(0.0299)	(0.0299)	(0.0300)	(0.0323)	(0.0299)	(0.0299)
Change CerAdv∗ 1300	-0.0253	-0.0404	-0.0425	-0.0448	-0.0350	-0.0404	-0.0404
	(0.0254)	(0.0440)	(0.0443)	(0.0448)	(0.0462)	(0.0440)	(0.0440)
Change CerAdv∗ 1350	-0.0234	-0.0388	-0.0409	-0.0431	-0.0333	-0.0388	-0.0388
	(0.0254)	(0.0440)	(0.0443)	(0.0448)	(0.0462)	(0.0440)	(0.0440)
Change CerAdv∗ 1400	-0.0139	-0.0460	-0.0485	-0.0511	-0.0598	-0.0460	-0.0460
	(0.0280)	(0.0509)	(0.0513)	(0.0518)	(0.0496)	(0.0509)	(0.0509)
Change CerAdv∗ 1450	-0.0235	-0.0451	-0.0479	-0.0509	-0.0573	-0.0451	-0.0451
	(0.0303)	(0.0619)	(0.0624)	(0.0628)	(0.0622)	(0.0619)	(0.0619)
Change CerAdv∗ 1500	-0.00977	-0.0452	-0.0488	-0.0524	-0.0629	-0.0452	-0.0452
	(0.0414)	(0.0688)	(0.0692)	(0.0698)	(0.0686)	(0.0688)	(0.0688)
Change CerAdv∗ 1550	0.102*	0.221**	0.128	0.193*	0.225**	0.207*	0.128
	(0.0618)	(0.108)	(0.111)	(0.110)	(0.112)	(0.110)	(0.107)
Change CerAdv∗ 1600	0.130*	0.379***	0.286**	0.350***	0.397***	0.364***	0.286**
	(0.0690)	(0.125)	(0.124)	(0.128)	(0.130)	(0.127)	(0.121)
Change CerAdv∗ 1650	0.177**	0.505***	0.412***	0.477***	0.514***	0.491***	0.412***
	(0.0756)	(0.123)	(0.122)	(0.124)	(0.128)	(0.124)	(0.121)
Change CerAdv∗ 1700	0.194**	0.511***	0.418***	0.482***	0.459***	0.497***	0.418***
	(0.0794)	(0.129)	(0.126)	(0.131)	(0.134)	(0.131)	(0.125)
Change CerAdv∗ 1750	0.198**	0.578***	0.485***	0.549***	0.532***	0.563***	0.485***
	(0.0807)	(0.109)	(0.109)	(0.111)	(0.114)	(0.110)	(0.108)
Change CerAdv∗ 1800	0.199**	0.544***	0.450***	0.516***	0.496***	0.529***	0.450***
	(0.0813)	(0.110)	(0.110)	(0.112)	(0.115)	(0.111)	(0.109)
Change CerAdv∗ 1850	0.205**	0.504***	0.409***	0.476***	0.455***	0.490***	0.411***
	(0.0834)	(0.112)	(0.111)	(0.114)	(0.118)	(0.114)	(0.110)
Controls (x Year FE):							
Change LandProd	NO	YES	YES	YES	YES	YES	YES
Precipitation	NO	NO	YES	NO	NO	NO	NO
Temperature	NO	NO	NO	YES	NO	NO	NO
Elevation	NO	NO	NO	NO	YES	NO	NO
Ruggedness	NO	NO	NO	NO	NO	YES	NO
Abs Latitude	NO	NO	NO	NO	NO	NO	YES
COUNTRY FE	YES	YES	YES	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES	YES	YES	YES
r2	0.717	0.733	0.750	0.732	0.730	0.736	0.745
N	2718	2718	2700	2664	2610	2718	2718

The table reports panel OLS 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, in parentheses. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.31: Wild Relatives of Domesticated Crops and the Location of Ancient Cities. Robustness Checks: Excluding Continents one-by-one

Dep. variable: presence of cities/large settlements founded by AD 400					
	(1)	(2)	(3)	(4)	(5)
WR Cer	0.239***	0.220***	0.102***	0.224***	0.199***
	(0.0495)	(0.0503)	(0.0292)	(0.0392)	(0.0385)
WR RT	0.00373	0.0160	-0.0224	0.0100	0.00537
	(0.0138)	(0.0173)	(0.0142)	(0.0197)	(0.0157)
WR Cer and RT	-0.00320	0.0386	-0.0117	0.0392*	0.0267
	(0.0178)	(0.0256)	(0.0141)	(0.0236)	(0.0217)
CONTINENT FE	YES	YES	YES	YES	YES
Sample excludes	Africa	Asia	Europe	America	Oceania
r2	0.176	0.182	0.0953	0.144	0.144
N	14487	13902	13201	11598	16265

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.32: Wild Relatives of Domesticated Crops and the Location of Ancient Cities. Robustness Checks: Logit regressions

Dep. variable: presence of cities/large settlements founded by AD 400				
	(1)	(2)	(3)	(4)
WR Cer	2.963***	2.852***	2.877***	1.698***
	(0.391)	(0.438)	(0.616)	(0.324)
WR RT		-0.771	-0.0138	-1.331***
		(0.650)	(0.686)	(0.429)
WR Cer and RT		-0.912	-0.191	-0.759
		(0.676)	(0.868)	(0.823)
CONTINENT FE	YES	YES	YES	YES
N	17076	17076	17076	17076

The table reports cross-sectional Logistic estimates and the unit of observation is the 1x1 decimal degree square. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.33: Wild Relatives of Domesticated Crops and the Location of Ancient Cities. Robustness Checks: Controlling for Geography.

Dependent variable is the presence of cities/large settlements founded by AD 400					
	(1)	(2)	(3)	(4)	(5)
WR Cer	0.210***	0.189***	0.195***	0.196***	0.198***
	(0.0388)	(0.0397)	(0.0380)	(0.0376)	(0.0371)
WR RT	0.0423***	0.00105	0.00451	0.00559	0.0102
	(0.0161)	(0.0141)	(0.0149)	(0.0151)	(0.0114)
WR Cer and RT	0.0638***	0.0208	0.0229	0.0250	0.0301*
	(0.0204)	(0.0192)	(0.0204)	(0.0204)	(0.0162)
Precipitation	-0.0244***				
	(0.00850)				
Temperature		0.00996			
		(0.0127)			
Elevation			-0.00696		
			(0.00535)		
Ruggedness				0.00173	
				(0.00691)	
Abs Latitude					0.000277
					(0.000713)
CONTINENT FE	YES	YES	YES	YES	YES
r2	0.153	0.148	0.145	0.145	0.145
N	16850	16267	17076	17076	17076

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.34: Wild Relatives of Domesticated Crops and the Location of Ancient Cities. Robustness Checks: Controlling for Irrigation Potential, the Plow, Population Density, Excluding Europe and Deserts.

Dependent variable is the presence of cities/large settlements founded by AD 400					
	(1)	(2)	(3)	(4)	(5)
WR Cer	0.207***	0.194***	0.122***	0.102***	0.222***
	(0.0429)	(0.0352)	(0.0335)	(0.00468)	(0.0430)
WR RT	0.0286	0.0181	-0.0307**	-0.0224***	0.0251
	(0.0213)	(0.0174)	(0.0123)	(0.00659)	(0.0207)
WR RT and Cer	0.0585**	0.0565**	-0.0384**	-0.0117	0.0657**
	(0.0282)	(0.0230)	(0.0194)	(0.00728)	(0.0303)
Irrigation Potential	0.0277***				
	(0.0103)				
Plow Advantage		0.0383***			
		(0.00824)			
Pop Dens 1995			0.0608***		
			(0.00884)		
CONTINENT FE	YES	YES	YES	YES	YES
r2	0.171	0.165	0.185	0.0953	0.178
N	9086	17076	16848	13201	10091

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. In column 4 the sample excludes Europe, in column 5 the sample excludes deserts. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.35: The Origin of the Neolithic Transition and the Location of Ancient Cities. Robustness checks: Controlling for Geography.

Dependent variable is the presence of cities/large settlements founded by AD 400					
	(1)	(2)	(3)	(4)	(5)
DistanceCer	-0.00141**	-0.000710	-0.00148**	-0.00132**	-0.000710
	(0.000601)	(0.000922)	(0.000679)	(0.000630)	(0.00112)
DistanceAgr	0.000250	0.000340	0.000323	0.000101	0.000339
	(0.000576)	(0.000653)	(0.000609)	(0.000617)	(0.000662)
Precipitation	0.00166				
	(0.00772)				
Temperature		0.0413**			
		(0.0186)			
Elevation			-0.00706		
			(0.00848)		
Ruggedness				-0.00597	
				(0.00662)	
Abs Latitude					-0.00159
					(0.00110)
CONTINENT FE	YES	YES	YES	YES	YES
r2	0.0497	0.0593	0.0505	0.0501	0.0548
N	15862	15833	15927	15927	15927

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.36: The Origin of the Neolithic Transition and the Location of Ancient Cities. Robustness checks: controlling for irrigation potential, the plow, population density, excluding Europe and deserts.

Dependent variable is the presence of cities/large settlements founded by AD 400					
	(1)	(2)	(3)	(4)	(5)
DistanceCer	-0.00294***	-0.00136*	-0.00168**	-0.00144***	-0.00264***
	(0.00103)	(0.000710)	(0.000651)	(0.000245)	(0.000922)
DistanceAgr	0.000528	0.000271	0.00194***	0.000564**	0.000369
	(0.00125)	(0.000664)	(0.000636)	(0.000276)	(0.00103)
Irrigation Potential	0.00527				
	(0.0104)				
Plow Advantage		0.0358***			
		(0.0100)			
Pop Density 1995			0.0859***		
			(0.0137)		
CONTINENT FE	YES	YES	YES	YES	YES
r2	0.105	0.0689	0.153	0.0642	0.0836
N	8214	15927	15861	12052	8942

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. In column 4 the sample includes only Asia and Africa, in column 5 the sample excludes deserts. Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.37: The Origin of the Neolithic Transition and Archeological Ruins.

	Dependent variable is a dummy that identifies evidence of:						
	ancient archaeolog. sites	pyramids	ancient temples	ancient mines	ancient palaces	ancient sculptured stones	ancient standing stones
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DistanceCer	-0.00279***	-0.000282	-0.000636**	-0.000210**	-0.000132**	-0.000232**	-0.0000152
	(0.000824)	(0.000187)	(0.000311)	(0.000106)	(0.0000550)	(0.000108)	(0.0000706)
DistanceAgr	0.000864	0.000105	0.000316	0.0000109	0.0000689	0.000166	0.00000243
	(0.000753)	(0.000146)	(0.000330)	(0.000144)	(0.0000487)	(0.000105)	(0.000119)
CONTINENT FE	YES	YES	YES	YES	YES	YES	YES
r2	0.0328	0.00451	0.0105	0.00294	0.00189	0.00930	0.0187
N	15927	15927	15927	15927	15927	15927	15927

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. The dependent variable is a dummy that takes the value of one if there is archaeological evidence of either ancient sites from the Stone Age (column 1), or ancient pyramids or mastaba (column 2), or ancient temples (column 3), or ancient mines or quarries (column 4), or ancient palaces (column 5), or ancient sculptured stones (column 6). or ancient standing stones (column 7). Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.38: The Origin of the Neolithic Transition and Archaeological Ruins.

	Dependent variable is the log (1+ number of archaeological ruin)						
	ancient archaeolog. sites	pyramids	ancient temples	ancient mines	ancient palaces	ancient sculptured stones	ancient standing stones
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DistanceCer	-0.00359***	-0.000264	-0.000556*	-0.000153**	-0.000109**	-0.000193**	-0.0000245
	(0.00114)	(0.000170)	(0.000306)	(0.0000740)	(0.0000446)	(0.0000932)	(0.0000652)
DistanceAgr	0.00120	0.0000880	0.000167	0.0000140	0.0000581	0.000152	0.0000752
	(0.000981)	(0.000133)	(0.000332)	(0.000101)	(0.0000382)	(0.0000977)	(0.000157)
CONTINENT FE	YES	YES	YES	YES	YES	YES	YES
r2	0.0266	0.00256	0.00784	0.00260	0.00159	0.00800	0.0176
N	15927	15927	15927	15927	15927	15927	15927

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. The dependent variable is log of one plus the number of either ancient sites from the Stone Age (column 1), or ancient pyramids or mastaba (column 2), or ancient temples (column 3), or ancient mines or quarries (column 4), or ancient palaces (column 5), or ancient sculptured stones (column 6), or ancient standing stones (column 7). Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.39: The Origin of the Neolithic Transition and Archaeological Ruins. Robustness Checks: Excluding Europe

	Dependent variable is a dummy that identifies evidence of						
	ancient archaeolog. sites	pyramids	ancient temples	ancient mines	ancient palaces	ancient sculptured stones	ancient standing stones
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DistanceCer	-0.00279***	-0.000281	-0.000637**	-0.000208*	-0.000132**	-0.000231**	-0.0000128
	(0.000826)	(0.000181)	(0.000311)	(0.000122)	(0.0000558)	(0.000104)	(0.0000637)
DistanceAgr	0.000776	0.0000616	0.000362	-0.0000761	0.0000597	0.000124	-0.0000923
	(0.000528)	(0.000109)	(0.000328)	(0.000141)	(0.0000476)	(0.0000768)	(0.0000663)
CONTINENT FE	YES	YES	YES	YES	YES	YES	YES
r2	0.0410	0.00524	0.0135	0.00405	0.00265	0.00520	0.00416
N	12052	12052	12052	12052	12052	12052	12052

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. The sample excludes Europe. The dependent variable is a dummy that takes the value of one if there is archeological evidence of either ancient sites from the Stone Age (column 1), or ancient pyramids or mastaba (column 2), or ancient temples (column 3), or ancient mines or quarries (column 4), or ancient palaces (column 5), or ancient sculptured stones (column 6), or ancient standing stones (column 7). Robust standard errors, clustered at the country-level, in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.40: Potential Crop Yields and the Location of Ancient Cities.

	Dependent variable is the presence of cities founded by:							
	classical antiquity				AD 450		500 BC	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CerAdv	0.0469***	0.145***	0.129***	0.0340**	0.0174***	0.0161**	0.00882***	0.00875**
	(0.0143)	(0.0388)	(0.0380)	(0.0162)	(0.00621)	(0.00635)	(0.00335)	(0.00350)
LandProd		-0.0864***	-0.0744***	-0.0126	-0.0108**	-0.0106**	-0.00579**	-0.00640**
		(0.0267)	(0.0256)	(0.0128)	(0.00427)	(0.00462)	(0.00242)	(0.00278)
CONTINENT FE	NO	NO	YES	NO	NO	YES	NO	YES
COUNTRY FE	NO	NO	NO	YES	NO	NO	NO	NO
r2	0.0498	0.0841	0.0986	0.451	0.00758	0.0159	0.00316	0.0103
N	15927	15927	15927	15927	15927	15927	15927	15927

The table reports cross-sectional OLS estimates and the unit of observation is the 1x1 decimal degree square. Robust standard errors, clustered at the country-level, in parentheses. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Table F.41: Potential Crop Yields and the Location of Ancient Cities. Difference-in-difference analysis

	Dependent variable is:			
	archaeol. site (dummy)	Log(1+ # archaeol. site)	ancient settlem. (dummy)	Log(1+ # ancient settlem.)
	(1)	(2)	(3)	(4)
Post X CerAdv	0.0683**	0.117***	0.0668**	0.101***
	(0.0293)	(0.0417)	(0.0283)	(0.0365)
Post X LandProd	-0.0266	-0.0581**	-0.0226	-0.0456*
	(0.0208)	(0.0281)	(0.0203)	(0.0247)
CELL FE	YES	YES	YES	YES
TIME FE	YES	YES	YES	YES
r2	0.0710	0.0800	0.0738	0.0765
N	31854	31854	31854	31854

The table reports difference-in-difference OLS regressions. The unit of observation is the 1x1 decimal degree square either before or after the Neolithic transition. Robust standard errors, clustered at the country-level, in parentheses. *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

Figure F.1: Density plot of the focal year for societies in Murdock's Ethnographic Atlas.

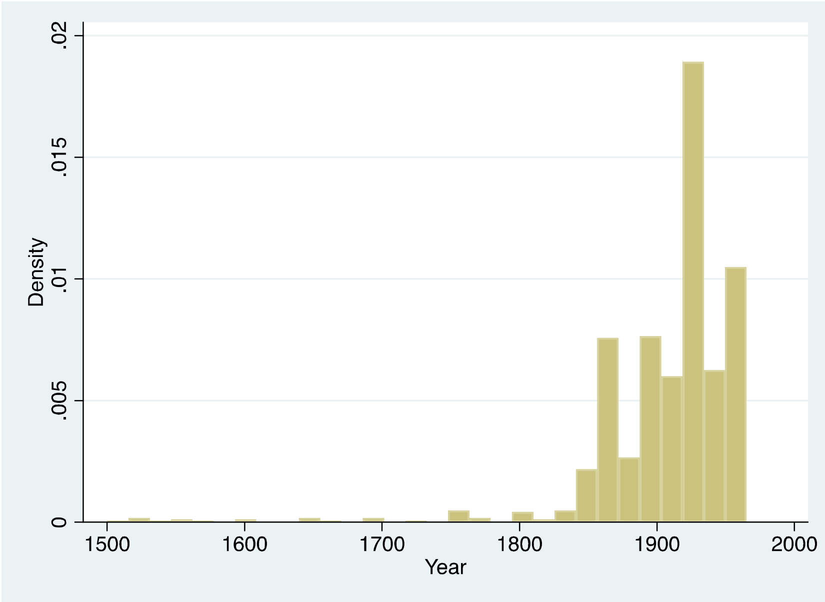

Figure F.2: Farming surplus in pre-industrial societies

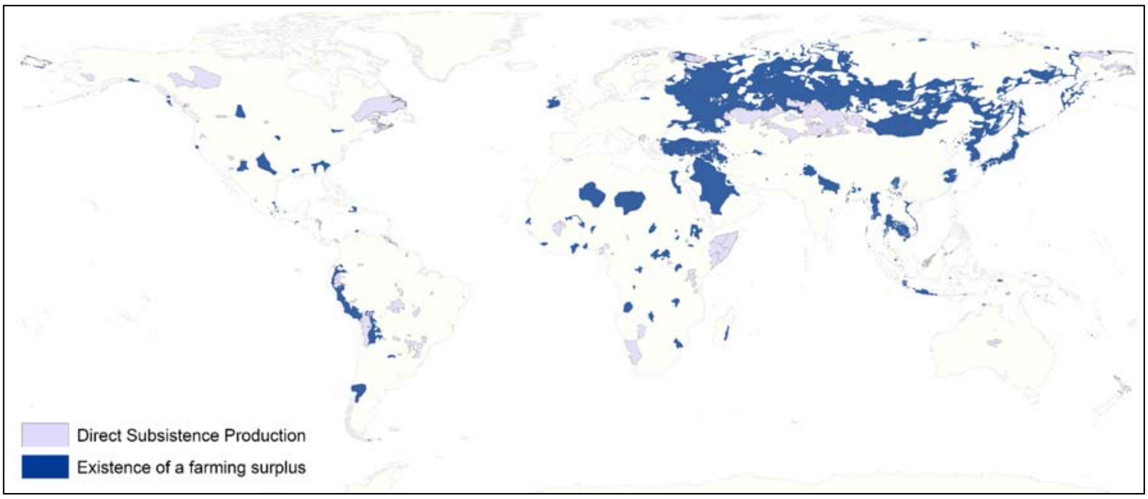

Figure F.3: Years of colonization

Figure F.4: Cities founded before 450 AD

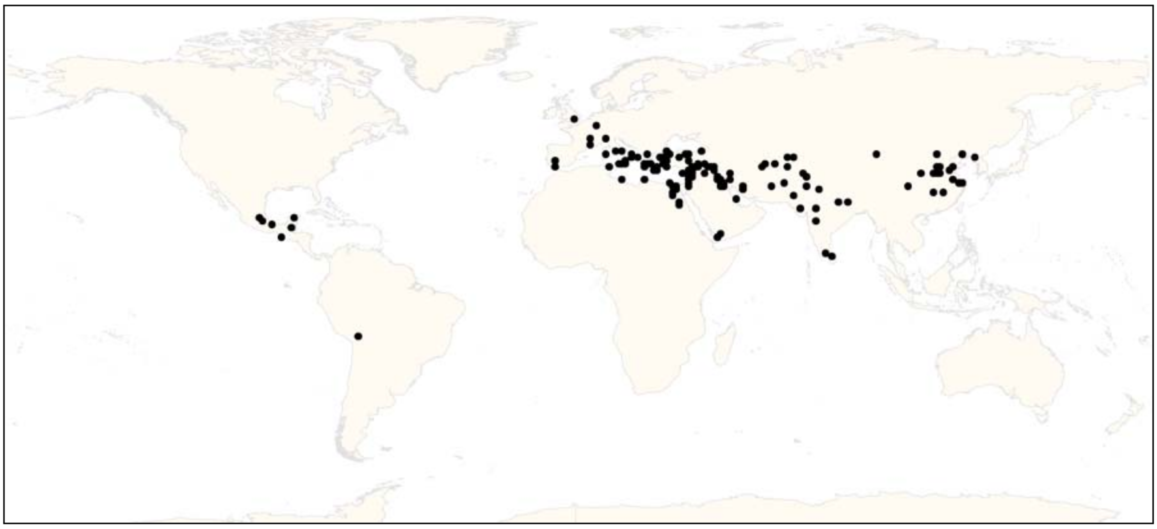

Figure F.5

Figure F.6: Cities founded before 500 BC

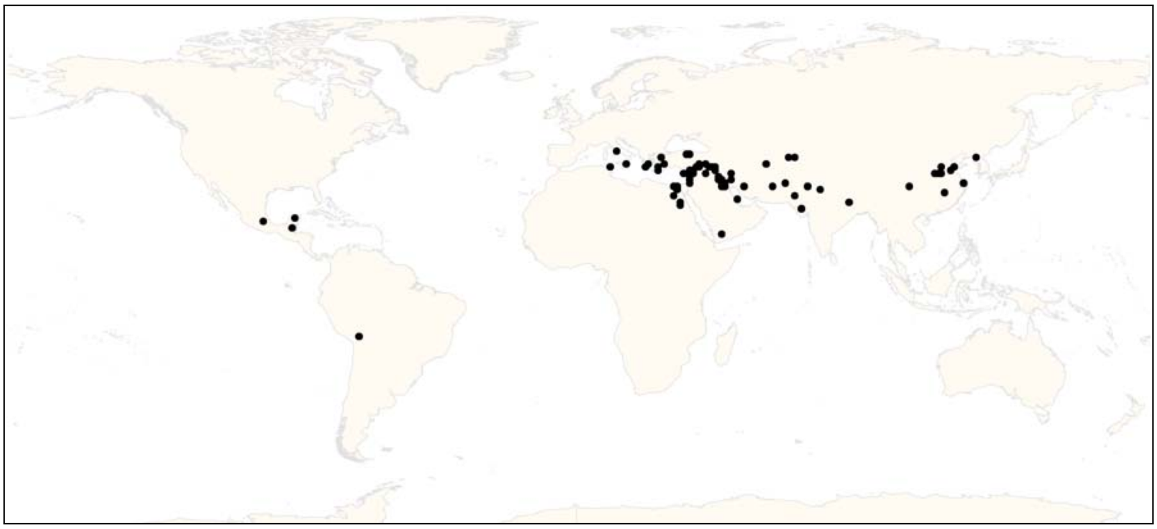

Figure F.7: Potential yields (calories per hectare) from cereal grains.

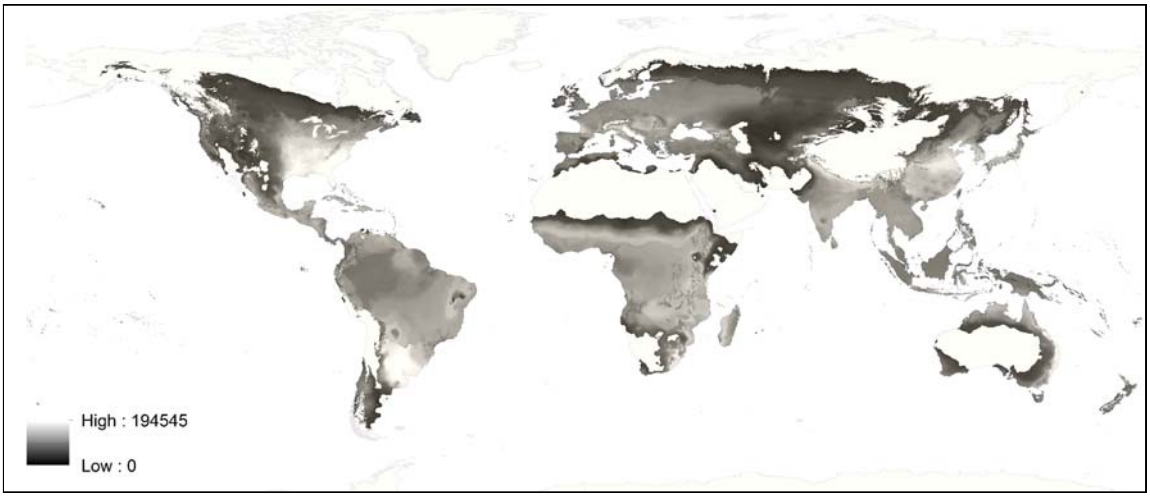

Figure F.8: Potential yields (calories per hectare) from roots and tubers

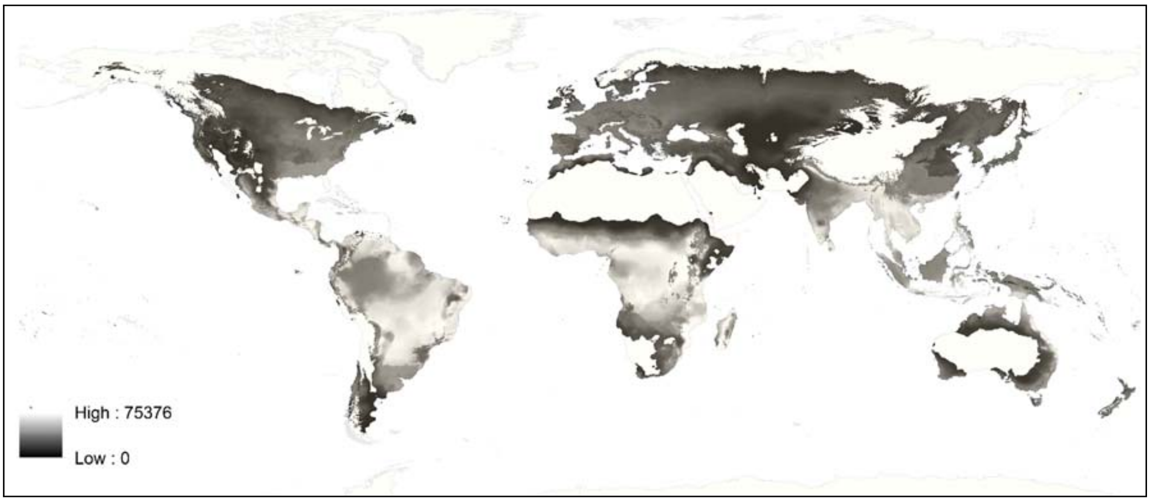

Figure F.9: Optimal crop in terms of caloric yields among cereals, roots and tubers

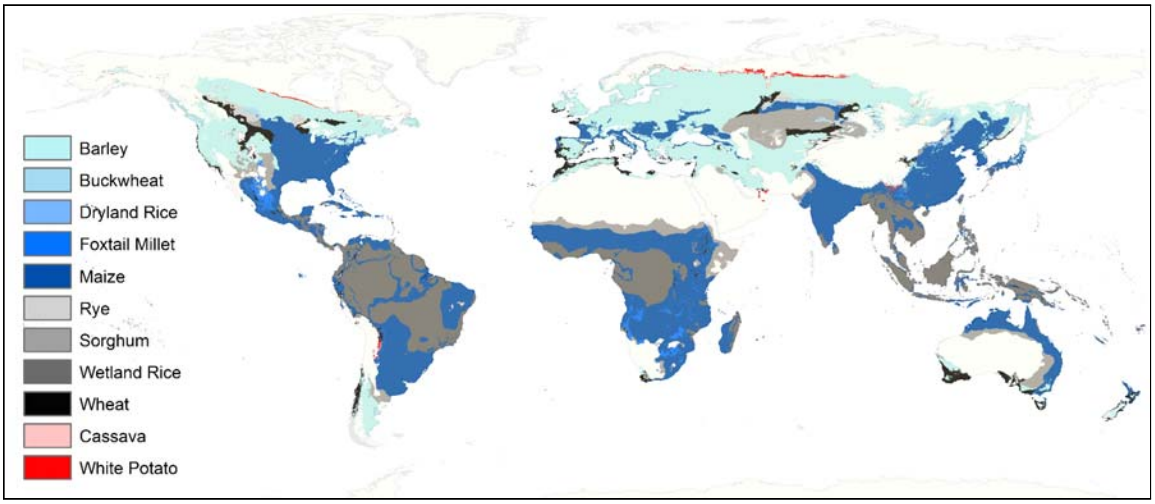

Figure F.10:

Figure F.11: Box plot: productivity advantage of cereals and hierarchy in pre-industrial societies

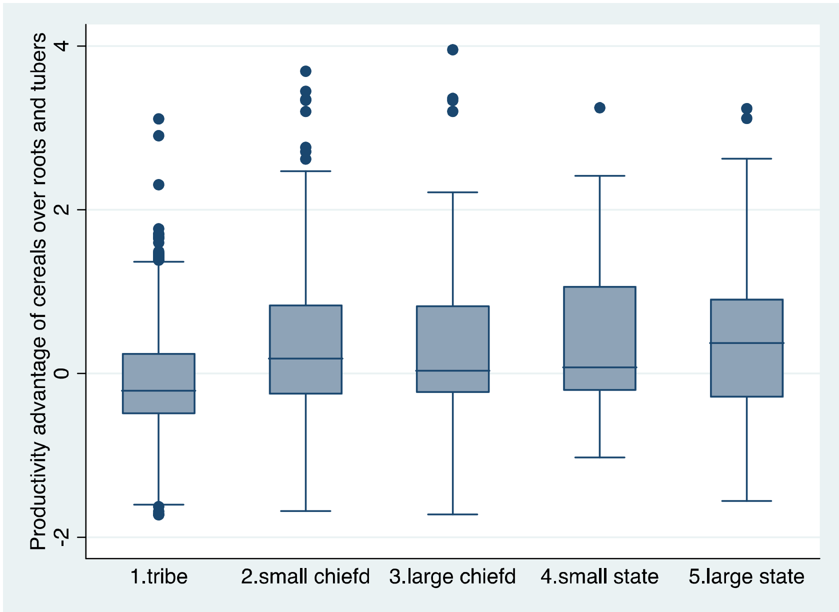

Figure F.12: Box plot: cereals and hierarchy in classical antiquity

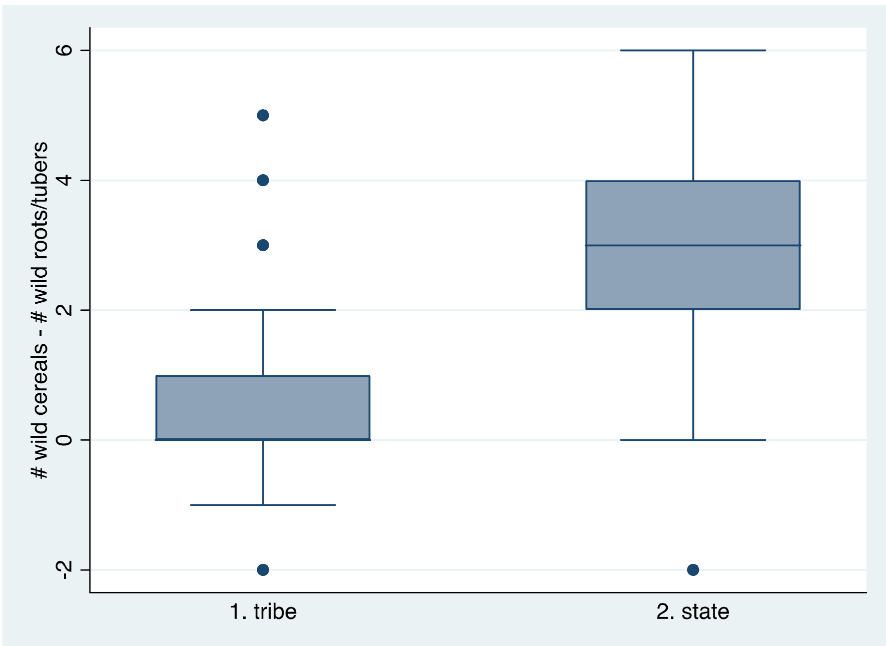

Figure F.13: Box plot: distance from areas of origin of agriculture and large human settlements founded before 400AD

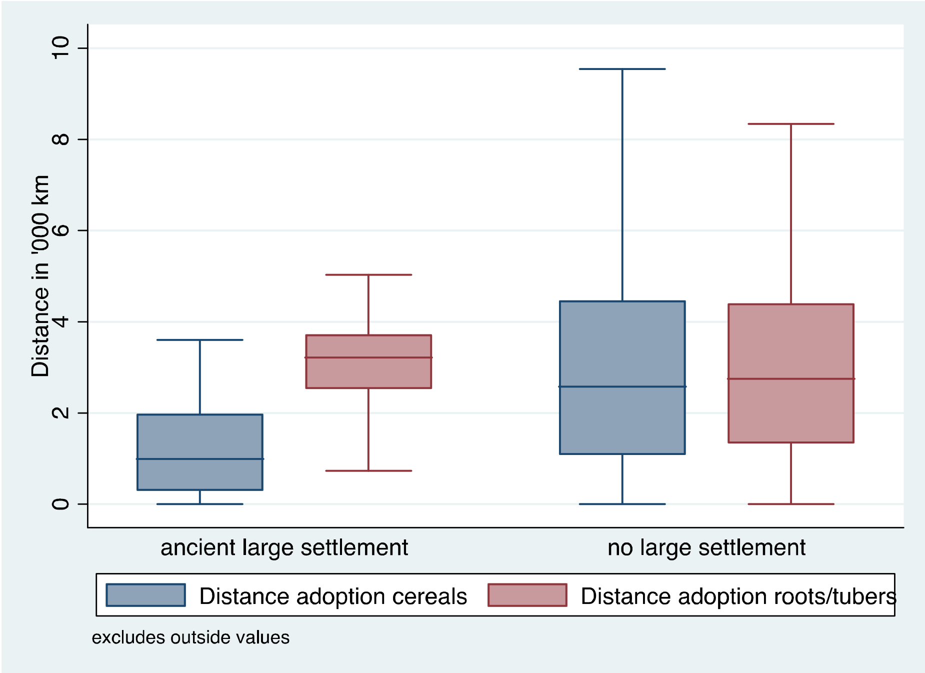

Figure F.14: Cities founded before 500 BC and centers of independent domestication