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CEREALS, APPROPRIABILITY AND HIERARCHY[†]

Abstract

We propose that the development of social hierarchy following the Neolithic Revolution was an outcome of the ability of the emergent elite to appropriate cereal crops from farmers and not a result of land productivity, as argued by conventional theory. We argue that cereals are easier to appropriate than roots and tubers, and that regional differences in the suitability of land for different crops explain therefore differences in the formation of hierarchy and states. A simple model illustrates our main theoretical argument. Our empirical investigation shows that land suitability for cereals relative to suitability for tubers explains the formation of hierarchical institutions and states, whereas land productivity does not.

JEL Classification: D02, D82, H10 and O43
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1 Introduction

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

We offer an explanation for the development of hierarchy and the emergence of states following the Neolithic Revolution, and for regional differences in these social institutions. The key factor for the emergence of hierarchy, we posit, is the ability of the elite to appropriate food crops from farmers. Thus, regional differences in the suitability of land for roots and tubers, which are less appropriable, or cereals, which are more appropriable, can lead to differences in the formation of hierarchy and state institutions, and thereby explain persistent differences in economic development. We further argue that the standard explanation, maintaining that the key factor for the emergence of hierarchy is land productivity, is flawed. Our empirical investigation supports both claims.

An extensive empirical literature has documented high correlations between income per capita across countries and geographic variables.[2] Ever since Montesquieu (1748, book 14) asserted that the tropics are backward because people in hot climates tend to be timid and lazy, various environmental theories have been proposed to explain the disparity between countries such as Ancient Egypt and New Guinea. Nowadays, two main geographic features of the tropics are typically suggested to have impeded its development: low agricultural productivity and high burden of disease.[3] Diamond (1997) emphasizes how the east-west orientation of Eurasia resulted in greater variety and productivity of cultivable crops and in more developed social institutions. In other parts of the world such as in New Guinea, he argues, low productivity prevented the formation of surplus and thus retarded the emergence of state institutions. Olsson and Hibbs (2005) support Diamond's theory by showing a strong effect of geography and plant variety on economic development.[4]

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

[2] For a survey and detailed references see Spolaore and Wacziarg (2013).

[3] Sachs et al., (2001) and Olsson and Hibbs (2005) provide further discussion and additional mechanisms.

[4] We have no intent to question the claim that the transition to agriculture increased productivity. Our argument

Acemoglu Johnson and Robinson (2001) de-emphasize the role of geography. They argue that it is not the tropical climate per se, nor the endemic disease inflicted on indigenous people, which are responsible for the underdevelopment of countries closer to the equator, but rather the institutions that colonizers established there. Similarly, Easterly and Levine (2003) and Rodrik et al. (2004) demonstrate empirically that the link between the tropics and underdevelopment is indirect due to the growth-retarding social institutions in tropical countries.[5] Acemoglu and Robinson (2012) argue further that geography has limited, if any, direct effect on economic growth, that extractive institutions are the key detrimental factor for economic prosperity, and that institutions are by and large exogenous, determined by the vagaries of human history.

In this paper, we contribute to this literature by examining the geographic origin of institutions. We are not concerned here with explaining income disparities, but are well aware of the literature that contends that deep rooted institutions which pre-date colonialism seem to affect both current institutions and economic outcomes, as illustrated by Bockstette, Chanda and Putterman (2002), Gennaioli and Rainer (2007), Spolaore and Wacziarg (2013) and Michalopoulos and Papaioannou (2013, 2014). It is from this perspective that we offer a new theory of how environmental factors can explain the emergence of complex social institutions in response to the transition to agriculture. Our contribution is in identifying a specific causal mechanism that connects the environment with social hierarchy, based on the elite's ability to appropriate produce from farmers.[6]

The standard explanation for the emergence of hierarchy (see section 2.1 for further details) maintains that higher productivity of agriculture relative to foraging created food surplus, which in turn facilitated, through various channels, the emergence of a non-food producing elite.[7] We contend that surplus was neither necessary nor sufficient for the emergence of hierarchy.

To understand why, consider a community of farmers who cultivate cassava, a perennial root which is highly perishable upon harvest, with annual output above subsistence. Since the crop isn't

is that the increase in productivity was not the mechanism by which agriculture led to the emergence of hierarchy.

[5] David 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.

[6] Mayshar, Moav and Neeman (2014) propose another link between geography and cross-regional institutional differences, emphasizing the effect of transparency of economic activity on the ability of the elite to tax. The concern of that paper is to explain differences between regions in state capacity, state centralization, and property rights, with a focus on the two earliest civilizations of Mesopotamia and Egypt.

[7] Dow and Reed (2013) share the view that the key exogenous change that led eventually to the emergence of inequality and elite was a rise in productivity. They posit that higher productivity led first comers to gain control over land, and then to employ outsiders as laborers and secure land rents for themselves.

stored and rots shortly after harvest, it may be impossible for anyone to appropriate the produce. The available surplus may be expected to lead to a population increase, but would not facilitate the emergence of hierarchy. Consider now another farming community growing a cereal grain, such as wheat, rice or maize, with an annual produce equal to each family's subsistence and no surplus. Since the grain has to be harvested within a short period and then stored for use until the next harvest, a visiting tax collector could readily confiscate part of the stored produce. Such ongoing confiscation may be expected to lead in the long-run to a downward adjustment in population density, but this scenario serves to indicate that surplus isn't a necessary precondition for taxation by the elite.

As an alternative to the productivity-and-surplus explanation, we argue that the crucial element for understanding why the transition to agriculture enabled hierarchy to emerge (in some regions) is that the cultivated crops were vulnerable to appropriation. In particular, the Neolithic emergence of fiscal capacity and hierarchy was conditioned on the cultivation of appropriable cereals as the staple crops, in contrast to other, less appropriable starchy crops such as roots and tubers.

According to this theory, the reason why complex hierarchy did not arise among hunter-gatherers is because hunter-gatherers essentially (though not always – see section 2.3 below) live from hand-to-mouth, with little that can be expropriated from them to feed a would-be elite. Thus, rather than surplus facilitating the emergence of the elite, we contend that the elite emerged only once the opportunity to expropriate arose, implying that, in effect, the emerging elite created food surplus (while also curtailing the growth of the farming population). The observed correlation between hierarchy and farming surplus is thus due to reverse causality of appropriation by the elite, rather than the conventional, opposite causal direction.

In a sense we suggest here a new version of Hobbes' theory that states emerged in order to protect individuals. Warfare among clans of hunter-gatherers over desirable land parcels, or for the capture of women, was apparently pervasive. But, contrary to Hobbes' theory, it did not lead to inheritable social hierarchy among simple hunter-gatherers. Nor did the transition to farming of non-seasonal crops give rise to complex (multi-level) social hierarchies. Such hierarchies emerged, we argue, only alongside the transition to reliance on appropriable food sources, and in particular to cereals, which left farmers vulnerable to expropriation. In adapting Hobbes, the greater incentives for thievery that the cultivation of cereals created, induced farmers to seek protection for their food stockpiles.[8] Due to increasing returns to scale in the provision of protection, these early farmers had to aggregate and cooperate to defend their stored grain seeds.

It does not matter for our case whether the demand for protection was met by outside roving bandits who turned stationary, as Olson (1993) posited, or by leaders from within, as is more conventionally assumed. Food storage and the demand for protection led to population agglomeration in villages and to the creation of a non-food producing elite that oversaw the provision of protection. Once a group became larger than a few dozens of immediate kin, it is unlikely that those who sought protection services were as forthcoming in financing the security they desired. This public-good nature of protection was overcome by the ability that storage provided to those in charge to appropriate the necessary means. The ability to tax contributed also to the specialization of those charged with protection and to hereditary leadership. That is, it was this transformation of the appropriation technology, due to the transition to cereals, which created both the demand for protection and the means for its provision. This is how we propose to explain the emergence of complex and hereditary social hierarchy, and eventually the state.

To indicate the applicability of our theory, reconsider the prototypic cases of Ancient Egypt and New Guinea. We suggest that the crucial distinction between these two areas was that farming in Ancient Egypt relied on the cultivation of cereals, while in New Guinea it relied mostly on the cultivation of tubers (yam and taro) and bananas, where long-term storage was neither feasible (due to perishability) nor necessary (because harvesting was essentially non-seasonal). This provided farmers in New Guinea with sufficient immunity against bandits, as well as against potential tax collectors. More generally, we contend that the underdevelopment of tropical areas is not due to low land fertility or harsh weather conditions, but rather the reverse. Farmers in the tropics can choose to cultivate highly productive, non-appropriable roots and tubers. This inhibits both the demand for socially-provided protection and the emergence of protection-providing elite. It is a curse of plenty.[9]

[8] In addition to the required storage of cereals which makes farmers vulnerable to appropriation, cereal producers are vulnerable also to extortion. The long gestation of cereals in the field exposes farmers to the threat of arson, and to the possibility that violence could be used to deny access to land or to water.

[9] In appendix A we support our various claims: (i) that reliance on roots and tubers is a major phenomenon in tropical regions; (ii) that roots and tubers are highly productive in the tropics; (iii) that their harvesting is in general non-seasonal; and (iv) that after harvest they are significantly more perishable than cereals.

Our contribution thus relates closely also to Besley and Persson (2009, 2014), who emphasize the high correlation between underdevelopment and low fiscal capacity.[10] However, whereas they view this correlation as a vicious cycle that could be broken by investment in the ability to tax, we propose a causal link whereby a particular environment leads to inherent low fiscal potential which leads to underdeveloped social institutions and ineffective government.

In our model farmers can allocate their land between two crops which we label as cereals and tubers.[11] We assume that the storage of cereals renders them relatively easy to confiscate while tubers, whose post-harvest storage is essentially infeasible and, more importantly, unnecessary, have opposite properties. For simplicity we assume that tubers are entirely immune from confiscation and taxation. As a result, cereals will be cultivated only if their productivity advantage over tubers is sufficiently high, given the risk of a raid by bandits, or the tax rate on cereals.

The productivity of the two crops is assumed to differ across geographic locations. In a regime identified as "anarchy," we assume that non farmers can engage either in banditry or in foraging. The number of bandits is thus endogenous, and in turn, determines the probability that cereals would be stolen. In a regime of "hierarchy," cereal crops are protected from bandits, but a fraction of this crop is taxed by the revenue maximizing elite. We assume that providing protection against bandits requires some fixed costs and that tax collection is costly as well. Finally, we assume that while bandits are unorganized and thus cannot credibly commit, a hierarchical elite is organized and can commit to any feasible rate of taxation.

The main prediction of the model is that if tubers are highly productive then a state cannot exist, since the state's potential revenue is insufficient to cover the fixed cost of deterring bandits. This result illustrates our key claim that it isn't low agricultural productivity that prevents the development of hierarchy, but rather high productivity of less appropriable crops. The model also reveals that whenever hierarchy exists it (weakly) dominates anarchy in welfare terms. Anarchy is

[10] Gennaioli and Voth (forthcoming) similarly emphasize investment in state capacity in response to conflict. Dincecco and Prado (2012) and Dincecco and Katz (2014) show that state capacity is persistent and has a positive effect on economic performance.

[11] For tractability, we ignore here other important food plants, such as legumes, and ignore also the cultivation of other crops, such as vegetables and fruit, or raising livestock. To the extent that these are not easily appropriable, we would lump them with tubers. We also ignore nutritional needs other than energy and the possibility that farmers could have partly engaged also in foraging. The biological distinction between roots (e.g., cassava) and tubers (e.g., potato, sweet potato and Yams) is complex (having to do mostly with regenerative functions). For brevity, we often refer to tubers only, but imply also to roots, mainly because cassava is an important crop.

more distortionary than hierarchy for two reasons. First, the state's ability to commit to a lower tax rate encourages the cultivation of cereals. Bandits, in contrast, cannot commit, leading farmers under anarchy to grow more tubers, even if they are relatively less productive. Second, because bandits rely on stealing, rather than productive foraging, their forgone earnings implies lower total income under anarchy.

This model thus captures the essence of the idea that when the elite can tax crops on an ongoing basis, it has the incentive to enhance productivity by providing protection, securing property rights, and committing to predictable and reasonably low taxation – even if it is non-benevolent and seeks to serve only its own interest. The appropriability of cereals, and the vulnerability that it imposed on farmers, has thus led to the development of a state, which contributes to farmers' welfare.[12] On the other hand, in tropical areas, where non-appropriable crops happened to be sufficiently productive, farmers prefer to enjoy the in-built protection that these crops provide, implying a limited potential for an elite to take over and inhibiting the formation of complex hierarchies. Our theory implies, therefore, that farming for subsistence, rather than foraging or herding, is more rewarding if tubers are highly productive and less so if cereals are equally productive. For the sake of simplicity, however, we do not include the decision to farm or forage in our model. The number of farmers is given exogenously.

In the empirical section of the paper we show how geography, through its effect on the type of crop cultivated, can explain differences in hierarchy. We further show that, in contrast to the standard theory (e.g., Diamond 1997), land productivity per se has no direct effect on hierarchy. We also show that, consistent with our theory, farming roots or tubers is more attractive than farming cereals, after controlling for their productivity, and is detrimental to hierarchy. We present these results by employing two alternative datasets with information on social hierarchy: a cross section of societies and a panel of countries.

For our cross section analysis we use Murdock's (1967) Ethnographic Atlas, which contains information on cultural, institutional and economic features of 1,267 societies from around the world at an idealized time period of first contact with Europeans.[13] In this cross-section inves-

[12] To the extent that the existence of a state may contribute directly to agricultural productivity, through publicly provided irrigation or the importation of improved farming techniques, the non-benevolent state may contribute much further to farmers' welfare.

[13] We realize that this time period is often much subsequent to the first adoption of farming. But in avoiding the

tigation, our main outcome variable is "Jurisdictional Hierarchy beyond the Local Community." The Ethnographic Atlas provides information on the major crop type for the societies that practice agriculture. However, as crop choice is endogenous, we instrument for crop type by using the data on crop suitability from matched modern data on the suitability of soil for different crops from the FAO-GAEZ. The outline for our empirical analysis follows:

1. With the intent to use potential agricultural yields as an instrument for actual crop choice, we start our investigation by showing that the decision whether to cultivate cereals as a main crop depends positively on the productivity advantage of cereals over roots and tubers (in terms of potential caloric yields per hectare). We also demonstrate that, once controlling for the productivity advantage of cereals, crop choice does not depend on the productivity of the land itself, as measured by the potential caloric yield per acre of the most productive crop in each area.

2. We then investigate the reduced-form relationship. We find that, in line with our theory, when cereals are more productive than roots and tubers, societies tend to have a more complex hierarchal organization. Moreover, we find that land productivity does not affect hierarchy, once we control for the productivity advantage of cereals. Thus, we challenge the standard argument that it is an increase in productivity of land that leads to more hierarchical societies.

3. Third, we report the 2SLS estimates, where we use the potential productivity advantage of cereals over roots and tubers as an instrument for the actual growing of cereals. Consistent with our theory, we find that cultivating cereals has a considerable positive impact on the hierarchical complexity of the societies in our sample. This result holds also when controlling for land productivity. Moreover, when comparing the impact on hierarchy of agriculture in general and the impact of cultivating cereals, we find that only the latter matters. Societies that practice agriculture are more hierarchical only where they cultivate cereals. This means that societies that cultivate roots or tubers have a similar level of hierarchy to that of non-farming, pastoral or foraging, societies.

4. Finally, we show that cereals are indeed necessary to sustain more complex hierarchical structures. For that end, we use data covering a subset of the societies in the Ethnographic Atlas for which we have information also on the sources of political power, wealth and influence that contribute to the status of the politically dominant class in society (Tuden and Marshall, 1972). 2SLS estimates confirm that the most prestigious members of society do not derive their income

impact of European colonialism, it still enables us to check our theory with data on indigenous social institutions.

from their own subsistence activities only in areas based on the cultivation of cereal.

These findings support our theory that it is not agricultural productivity and surplus that explains more complex hierarchical societies, but rather the productivity advantage of cereals over roots and tubers, the ensuing type of crop cultivated, and the resulting appropriability of the crop type.

Although the analysis accounts for a wide range of confounding factors, we cannot rule out completely that omitted variables may bias our cross section analysis. To overcome this concern, we employ another dataset compiled by Borcan, Olsson and Putterman (2014). This is a panel, based on present-day boundaries of 159 countries, with institutional information every five decades over the last millennium. This panel enables us to exploit the "Columbian exchange" as a natural experiment. The new crops that became available, as a result of the transfer of crops between the New and the Old World, changed both the productivity of land and the productivity advantage of cereals over roots and tubers in the majority of the countries in our sample. Consistent with our theory, the panel regressions confirm that an increase in the productivity advantage of cereals over roots and tubers has a positive impact on hierarchical complexity, and an increase in land productivity does not.

In section 2 we survey the available theories that seek to explain the emergence of hierarchy, and present some existing supportive evidence to our theory. In section 3 we present a model that captures our theoretical claims, and motivates our empirics presented in section 4.

2 Related Literature

2.1 The Surplus Theory

Anthropologists and archaeologists have long concluded that hunter-gatherer societies were fairly egalitarian and ostensibly leaderless – in sharp distinction to the hierarchical nature of apes. We shall not review the literature about this transition to egalitarianism (Boehm 1999). Neither shall we discuss the theories proposed to explain the transition of foragers to agriculture (Bar-Yosef and Meadow, 1995; Richerson, Boyd and Bettinger, 2001; Asouti and Fuller, 2013). Our focus is on the shift from egalitarianism to hierarchy and how it relates to the transition to agriculture.

Recent scholars avoid the once customary distinction between multiple stages of social organizations preceding the state, such as clans, tribes, and chiefdoms (Johnson and Earle, 2000), in analyzing more generally the emergence of: “inequality,” “stratification,” “complexity,” “hierarchy,” or “ranked society” (Price and Feinman, 2010). Indeed, our emphasis on the distinction between cereals and tubers leads us to question the basic logic behind the idea that chiefdom, which is typically associated with horticulture, is a necessary preliminary stage to statehood, associated with agriculture (see Lenski, 1966; and Johnson and Earle, 2000). For horticulture – which is characterized by small scale, slash and burn, and the use of the digging stick and the hoe instead of the plow – is often linked to the cultivation of roots and tubers, which, we argue, cannot facilitate complex social hierarchy and is to a major extent environmentally conditioned.

The twin ideas that the availability of surplus was a prerequisite for hierarchy and that agriculture was a prerequisite for surplus can be traced to Adam Smith and to earlier seventeenth century social thinkers.[14] According to Smith, government and property protection first emerged with the transition to pastoralism, and with the attendant need to protect herds from theft (Smith 1978, p. 16). It was, however, the subsequent transition to agriculture that generated surplus, division of labor, production by artisans, and exchange. And it was this transition that extended much further the role of government (1978, p. 409).[15]

Surplus was central also in Marx and Engels' social theory. Engels stated that in the earliest pre-agricultural stages of social evolution: “Food had to be won anew day by day” and “Human labor power… yielded no noticeable surplus as yet over the cost of its maintenance” (1902, p. 65). It was only the adoption of agriculture that marked a transition from such a proto-communistic classless society, to a class society in which the usurpation of labor surplus was the essential source of class division. For Marx and Engels, just as for Smith, the availability of surplus was thus a prerequisite for social hierarchy. Surplus had to be produced *before* the landlord, the capitalist or the ruler could seize it.

Childe (1936), who coined the terms Neolithic Revolution and Urban Revolution, was much influenced by Marx. Childe contended that the transition to agriculture resulted in food surplus,

[14] The surplus theories of Petty, Richard Cantillon, Francois Quesnay and Anne Robert Jacques Turgot, up to Adam Smith and Karl Marx, are surveyed by Meek (1976) and Aspromourgos (1996).

[15] In emphasizing the role of appropriable stockpiles and property among pastoralists, Adam Smith can be considered to have presented the essence of our proposed theory. However, when he turned to agriculture, he reverted to emphasize the role of surplus. Even in the case of pastoralists, though, he adopted a functionalist approach, emphasizing that government became “necessary,” rather than that it became possible.

which in turn enabled individuals to specialize in non-farming occupations.[16] This surplus, and the concomitant resort to trade, helped create "political integration," leading eventually to the formation of city-states under a state bureaucracy. The emergence of hierarchy was thus preconditioned by agricultural surplus in the countryside, which fed the elite and the artisans in the urban centers.

Lenski (1966) sought to integrate functionalist theories (or integrationist) theories with conflict theories for explaining social stratification.[17] He contends that hunter gatherers were egalitarian because they could produce no surplus (above subsistence needs). Considering technology as progressing from horticulture to agriculture to industry, he argues that technological advancement generates surplus of goods and services, and that social "power" then emerges to "determine the distribution of nearly all of the surplus possessed by a society" (p. 44). In analogy to Childe, Lenski's theory thus relates the emergence of "power" (or hierarchy) to the surplus created by increased productivity.

The idea that the transition to agriculture generated hierarchy through increased productivity and the creation of surplus has remained the conventional wisdom in the scholarly literature. Diamond (1997) illustrates his environmental explanation for income disparities by comparing two groups of seafaring migrants in the Pacific whose ancestors were farmers. One group settled on an island whose environment forced them to revert to hunting-gathering. As a result: "Since as hunter-gatherers they did not produce crop surpluses available for redistribution or storage, they could not support and feed non-hunting craft specialists, armies, bureaucrats, and chiefs." The other group landed in an island that was suitable for agriculture, and "With the crop surpluses that they could grow and store, they fed craft specialists, chiefs, and part-time soldiers." He summarizes his theory by stating (p. 92): "In short, plant and animal domestication meant much more food ... The resulting food surpluses ... were a prerequisite for the development of settled, politically centralized, socially stratified, economically complex, technologically innovative societies." Diamond then

[16] Childe states: "food production, even in its simplest form, provides an opportunity and a motive for the accumulation of a surplus. A crop must not be consumed as soon as it is reaped. The grains must be conserved and eked out so as to last till the next harvest, for a whole year. And a proportion of every crop must be set aside for seed. The conservation is easy. But it means on the one hand forethought and thrift, on the other receptacles for storage." (1936 pp. 82-83).

[17] Functional theories (including that of Hobbes) assert that social stratification emerged and persists in order to enhance social welfare through division of labor, and through the provision of security, enforcement of contracts, or the constructing of infrastructure. Conflict theories (starting with Rousseau, Marx and Engels) posit a class society with differential access to property, and envision state institutions as formed by the elite in order to protect its privileges.

applies this logic to explain the geographical advantage of Eurasia: due to its east-west orientation, countries in Eurasia were able to exploit a greater variety of domesticated plants and animals, and had thus access to more productive agriculture than countries in Africa, America and the Pacific.

In a recent survey of the literature that relates the emergence of inequality to early agriculture in the Ancient Near East, Price and Bar-Yosef (2010) provide a similar conclusion: "The success of early cultivation and the advantages afforded by the genetic mutations among plants and animals, allows for rapid increase in human population (. . .). Cultivation also supported a stable economy with surplus that resulted in the formation of elite groups as predicted by Lenski" (1966, p. 160).[18]

Our main critique of the productivity-surplus theory for the emergence of hierarchy is based on Malthusian considerations.[19] First we note that there was a gradual increase in productivity also among hunter-gatherers, due to improved hunting techniques and learning by doing. Yet, this increase in productivity was apparently translated in its entirety to an increase in population density, without leading to surplus or to hierarchy. In much the same way, given that the Neolithic revolution was extremely protracted and stretched over several millennia, one could expect that this gradual increase in productivity would have been dissipated through increased population.[20] The Malthusian argument, in conjunction with the comparisons to the effects of increased productivity among hunter gatherers and among farmers who rely on tubers, lead us to conclude that it could

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

[19] Ashraf and Galor (2011) support the applicability of Malthus's theory by demonstrating that technological improvements before the Industrial Revolution had a positive effect on population size but no effect on income per capita in the long run. In further support of Malthus's theory we note that Bellwood (2006:14-19) summarizes evidence of a phenomenal population growth rates through reproduction that resulted from the introduction of agriculture to some frontier environments (including one historical case of a seven-fold increase in 66 years). The rate of population growth during the Neolithic Period is estimated to have been about 0.01 per cent. Comparing this rate to the potential growth rates found by Bellwood suggests that population increase could have easily outpaced increases in productivity, leaving no surplus.

[20] The pace of the transition to agriculture has been debated in recent years by archaeologists and botanists. Purugganan and Fuller (2011) conclude that it must have lasted several thousand years. Childe was aware of the Malthusian argument, but, apparently, failed to realize its applicability, since he was unaware of the slowness of the transition. Thus he stated (1929, p. 141): "In the long run no doubt the population would adjust itself to the means of subsistence, but the immediate result of sedentary life in a congenial environment is a surplus that must overflow." It should be noted that we do not contend that random shocks to productivity or to population cannot give rise to a temporary surplus (or shortage). But foragers were most likely subject to similar shocks. Thus, the existence of temporary surpluses cannot in itself explain the association between the transition to farming and the emergence of hierarchy.

not have been an increase in productivity per se that led to the emergence of hierarchy.

In Appendix B we study the effect of increased productivity of an appropriable crop on the relative scale of the state (the share of taxes in total income), comparing a case with constant population with one where population adjusts in a Malthusian fashion. To capture the presumption that it is easier to tax surplus, we assume that farmers offer less resistance to taxation the higher their surplus is. Under the assumption that the elite choose the tax policy that maximizes net revenue, the model shows that when the population is constant, technological progress does indeed increase the scale of the state. However, once we allow the size of the population to adjust endogenously to prevent any surplus, technological progress results in increased output, but leaves the relative scale of the state intact.

2.2 Additional Theories

We are not the first to find fault with the surplus theory for the emergence of hierarchy. Others have already pointed that, in addition to Malthusian population increase, an increase in productivity may be dissipated in various ways, without leading to any surplus. Yet, as explained below, we find that the proposed alternatives to the surplus theory fall short of adequately accounting for the mechanism behind the correlation between the transition to agriculture and the rise of complex hierarchies.

Pearson (1957) objected to the surplus theory by pointing out that it confines attention to food necessities, whereas cultural needs would evolve to eliminate any surplus. Similarly, Sahlins (1972) claims that it is hunter-gatherers' choice to refrain from procuring food beyond their immediate needs. He infers that the first farmers, too, could have responded to the increase in productivity simply by working less hard, without producing anything beyond what was necessary.[21] In contrast to the conventional attribution of chieftainship to the production of surplus, Sahlins thus concludes (p. 140): "in the functioning of primitive society it is rather the other way round. Leadership

[21] Carneiro provides a similar argument in stating (1970, p. 734): "agriculture does not automatically create a food surplus. We know this because many agricultural peoples of the world produce no such surplus. Virtually all Amazonian Indians, for example, were agricultural, but in aboriginal times they did not produce a food surplus. That it was technically feasible for them to produce such a surplus is shown by the fact that, under the stimulus of European settlers' desire for food, a number of tribes did raise manioc in amounts well above their own needs, for the purpose of trading. Thus the technical means for generating a food surplus were there; it was the social mechanisms needed to actualize it that were lacking."

continually generates domestic surplus. The development of rank and chieftainship becomes, *pari passu*, development of the productive forces." This explanation, though, begs the key question raised here: what accounts for the rise of leadership and why does it correlate with agriculture?

Ames (2008, pp. 493-494) surveys more than a dozen theories that claim to explain the linkage between agriculture and hierarchy. The explanatory factors that Ames mentions include: increased population density; shift to sedentary living; storage; specialization and exchange; trade to exploit environmental heterogeneity; increased importance of property; competition and warfare; aggrandizing ideology; religion and more. These factors, though, are typically viewed as complementing rather than supplanting the conventional wisdom on the paramount role of productivity and surplus. As it happened, this long list of factors is almost identical to the list of attributes that anthropologists advance to distinguish "complex" and "hierarchical" societies from "simple" and "egalitarian" ones.[22] Indeed, we find that most of these proposed theories confuse correlates of the transitions to hierarchy with causal relations. In particular, they are typically vague in identifying the *mechanism* by which each of these factors may have contributed to increased complexity.

The literature about the effects of storage is discussed in the next sub-section. Of the remaining theories listed above, the most influential is the one invoking "population pressure." Anthropologists often argue that the increase in productivity due to agriculture led to population growth, to increased density and then to overpopulation which led to the deterioration of living conditions. This "population pressure" is presumed to have led to competition over resources, to violence and to warfare. These adverse social developments are claimed to have necessitated the reorganization of society into ever more complex social forms, leading ultimately to the formation of the central-state.[23] Motivated by comparing the political structures that evolved in the valleys of Peru with those in the Amazon Basin, Carneiro (1970) offers a variant of the conflict theory. He contends that states could not emerge in the Amazon Basin, with its "almost unlimited agricultural land," because "in Amazonia ... the vanquished could flee to a new locale, subsisting there about as

[22] See for example Kelly's (1995, p. 294) list of such correlates that distinguishes between simple and complex hunter-gatherer societies.

[23] For leading advocates of this theory see Johnson and Earle (2000). This "population pressure" approach seems to us inconsistent with the Malthusian argument that there would (almost) always be population pressure. From our point of view, though, it is possible that increased population density and sedentary forms of livelihood made the early farmers more vulnerable to exploitation by increasing the productivity of the tax technology and enhancing the *opportunity* for potential exploiters.

well as they had subsisted before, and retaining their independence" In contrast, "in Peru ... this alternative was no longer open to the inhabitants of defeated villages. The mountains, the desert, and the sea ... blocked escape in every direction" (p. 735). Accordingly, Carneiro's influential "circumscription theory" posits that states arise as a result of conflict among autonomous farming communities, when the losers cannot escape political subjugation to the victors through migration, thus enabling the latter to extract ongoing tribute and to integrate independent villages into a viable state.

Carneiro's puzzlement over the limited social complexity in the Amazon Basin is similar to Diamond's concern with the underdevelopment of New Guinea and the Pacific Islands. Yet we note that the environmental theory that each of them offers is incompatible with the geographical evidence that motivated the other. Diamond's theory about east-west continental orientation can hardly resolve Carneiro's comparison between the Amazon Basin and the western valleys of Peru. And Carneiro's theory fails to resolve Diamond's concern about limited social complexity in the circumscribed Pacific tropical islands. We believe that our appropriability theory provides a better environmental explanation for the observations that motivated both these scholars. In particular, whereas agriculture in the tropical Amazon and in New Guinea was based on tuber crops, farming in Eurasia and in the western valleys of the Andes relied mostly on cereals (primarily wheat, barley or rice in Eurasia and maize in Peru).[24]

Another functional theory focuses on the demand for law and order required to facilitate trade. On the basis of evidence from Africa, Bates (1983) argues that ecologically diverse environments increase the returns from trade, and thus increase the demand for hierarchy. Algaze (2008) proposes an analogous theory to explain the emergence of ancient Sumer. Fenske (2014) and Litina (2014) provide supportive evidence for this theory. We interpret these findings as consistent with our general appropriability approach, since trade also facilitates taxation.[25]

[24] Counter to Diamond's insistence on the lack of mobility of plant species across the equator, maize was apparently domesticated in the northern hemisphere, before reaching to South America (see Piperno and Pearsall, 1998). The formation of Mayan state societies in the tropical lowlands of Mexico, where maize was apparently first domesticated to become the staple crop, provides additional support for our theory on the preponderant importance of cultivating cereals rather than tubers for the emergence of hierarchy.

[25] Wittfogel (1957) proposed yet another influential functionalist theory to explain the formation of state hierarchies. He argued that strong central hierarchies arose in Mesopotamia, Egypt, China and Peru because despotic governments were required to realize the agricultural potential of large irrigation projects. Wittfogel's many critics pointed out that irrigation systems were in fact constructed in these countries by local communities, prior to the emergence of a strong central state. But these critics left unexplained the coincidence between the emergence of these major ancient

To conclude this subsection, we consider recent claims that reverse the conventional causal direction between agriculture and hierarchy.[26] Challenging materialistic socioeconomic explanations, Cauvin (2000) argues that the willingness of hunter gatherers to abandon their traditional ways of life, to settle down and to engage in farming is explained by a prior change in collective psychology that is associated with the rise of religion ("the birth of the Gods"). He bases this view primarily on evidence of the proliferation of artistic symbolism in a period that preceded the transition to agriculture. Acemoglu and Robinson (2012, pp. 139-142) carry this idea further. In retrojecting their general perception of institutional innovations, they suggest that an elite gained power among the semi-sedentary Natufians in the ancient Near East in order to extract resources from the rest of society. It is to this political elite that they attribute "the transition first to sedentary life and then to farming" (p. 140). This theory resembles ours in suggesting that hierarchy was the cause of surplus rather than its consequence. However, our theory is diametrically different in that we offer an explanation for the emergence of elite alongside the transition to farming. In particular, our theory does not posit that hierarchy lagged behind agriculture.[27] As we explain in the next sub-section, the early gathering of wild grain seeds for subsequent consumption, even prior to cultivation, already implied storage and engendered a fundamental shift in the ability of freeloaders to appropriate. The subsequent cultivation of grains by sowing previously harvested seeds made

civilizations and riverine environments. In Mayshar, Moav and Neeman (2014) we explain this coincidence by arguing that the direction of causality behind it is the reverse of Wittfogel's theory: it is not that a need for irrigation led to a powerful state, but rather that such irrigation systems enabled efficient control and appropriation by the elite – in analogy to our interpretation here that the need to store food facilitated confiscation. This explanation is indirectly supported by Bentzen et al. (2012), who show that irrigation-based societies are less likely to adopt democracy.

[26]The conventional explanation for the location and the timing of the initial transition to agriculture posits various climatic and environmental conditions that favored the Fertile Crescent in the Neolithic period. Thus, Diamond (1997, pp 135-138) stresses how extended seasonal variation with dry summers favored the evolution of large-seed annual grasses in the Ancient Near East; and Bar-Yosef (see for example, Bar Yosef and Meadow, 1995) emphasizes specific climatic changes that may explain the transition to sedentism and to cultivation at the onset of the critical period known as PPNA (Pre-Pottery Neolithic A). An opposing conventional explanation emphasizes food shortage due to "population pressure" as the main impetus that led hunter-gatherers to engage in farming. Richerson, Boyd and Bettinger (2001, pp. 388-389) debunk this theory of the transition to agriculture by employing a similar Malthusian argument to the one we use here against the idea that it was population pressure that led to the rise of hierarchy.

[27]Acemoglu and Robinson (2012) review the case of the Bushong people, along a tributary of the Congo River, whose political system was transformed in the seventeenth century by an entrepreneurial leader who initiated the adoption of maize. This example evidently illustrates their thesis, as the neighboring Lele people did not experience the same transformation despite similar conditions. We do not attempt to explain the different paths of the two societies, but suggest that the transformation of the Bushong is consistent with our proposed theory about the impact of the availability of maize on the emergence of hierarchy. However, this example also concerns a case of the adoption of fully developed maize farming technology, and thus does not provide evidence on the potential role of an elite during the protracted Neolithic transition to farming.

such storage mandatory. We argue that such storage increased the efficacy of thievery and led to the gradual rise of hierarchy, in parallel to the protracted evolution of cultivation, domestication, and increased population density.[28]

2.3 Storage and Appropriability: Supportive Evidence

Evidence of early dwellings, grinding stones and storage facilities are some of the most distinctive indicators that archeologists and anthropologists have for the early phases of the Neolithic Revolution. Hence it is no surprise that sedentism and storage are often cited in theories that relate the transition to agriculture and the rise of social hierarchy. As we see it, the main problem with these theories is that they do not provide the proper causal mechanisms by which storage was instrumental in the emergence of hierarchy.[29]

One strand of the functionalist approach maintains that storage had an important causal role in the emergence of complex society (see Halstead 1989, and Johnson and Earle 2000, pp. 251-256, 301-302). Halstead suggests that early farmers generated "normal surplus" above subsistence level in average years as a precautionary buffer against years of shortage. The elite, he proposed, emerged as a "social storage agent" for the purpose of coordinating between surplus and deficit households. Building on Polanyi (1944), this theory posits that early agricultural societies were "redistributive," where surplus output was (voluntarily) transferred to a central authority, and then "redistributed" or stored, with the elite serving in effect as an agency for mutual insurance. Leaving aside the plausibility of this theory and the underlying benevolence attributed to the elite, we note that this interpretation misses the point that storage of cereals was primarily a mandatory intra-annual affair, due to the seasonality of cereals.[30] In particular, while inter-annual storage of

[28] The conventional explanation for the onset of the Neolithic Revolution treats the political innovations as endogenous, and can account not only for the timing of the transition to agriculture but also for its multiple occurrences around the Globe. As explained next, our proposed mechanism can account also for the emergence of more rudimentary hierarchies among some "complex" foraging societies, and explain also why the transition to tuber-based farming did not promote hierarchies.

[29] The correlation between farming and sedentism is rather obvious; the crucial issue however, is whether it may have had a causal role, and what may have been the mechanism by which it could have led to hierarchy. We note that in considering pre-agricultural Egypt, Allen (1997, p. 140) did observe that the perishable food the foragers typically produce could not have served a would-be king. However, Allen doesn't distinguish between different crops and regions in farming societies, as we do, and his claim is within the "surplus theory" that we challenge.

[30] Contrary to Polanyi's presumption that the elite in chiefdoms provided distributive insurance services, Hayden remarks that he "was completely astonished ... that local elites provided essentially no help to other members of the community in times of crisis" (2001, p. 247). We conjecture that idiosyncratic shortfalls to individual early farmers

cereals as a buffer is possible, it is unlikely that it was significant among the early farmers who probably continued to forage.

Some of the most important studies to indicate the ubiquity of storage in hierarchical societies concern in fact complex hunter-gatherers, rather than farmers. In a survey of the evidence about Native Americans in the northwestern coast of America, Testart (1982) concludes that hunter-gatherers who relied on seasonal and storable resources such as acorns or dried salmon became more complex and acquired social features like those of the Neolithic societies that cultivated cereals. As Testart's critics pointed out, however, his study only identified correlates of storage and refrained from identifying the causal mechanism that relates storage to inequality.[31] Even so, in conjunction with Carneiro's (1970) observation of limited social complexity in farming societies in the Amazon Basin, we note that Testart's evidence on social complexity among foraging early Californians demonstrates that agriculture was neither necessary nor sufficient to explain social complexity.

Tushingham and Bettinger (2013) provide further evidence on storage among aboriginal Californians. They note that even though salmon is a better source of nutrition, earlier foragers preferred to store acorns, and propose to resolve this puzzle by applying Bettinger's (1999) earlier distinction between back-loaded and front-loaded food resources.[32] According to this explanation, the procurement and storage of back-loaded acorns involves little effort, but its subsequent preparation for

were taken care of within small kin groups, and did not require proto-state institutions.

[31] Testart referred to all the "usual suspects:" sedentary living, high population density, trading activity, prestige, and altered ideology. At one point, though, he also referred to the mechanism that we emphasize here: "stored food is the primary object of raids, and it may be stolen, monopolized by men of high status, or made the subject of rent or tribute" (p. 527).

[32] Woodburn (1980, 1982) offers a closely related distinction between "immediate return" food procuring practices, in which there is no delay between effort and food consumption, and "delayed return" practices, where such a delay exists. He argues that immediate-return systems are typical of foraging societies that live in the present and do not plan for the future, and associates the transition to the Neolithic, with a shift to delayed return system that he associates with some hunter-gatherers, pastoralists and farmers. These systems involve, he argues, profoundly different social norms, in which individuals plan for their future, produce surplus, postpone consumption, accumulate assets, and hold property rights, and thus become dependent "on cooperation with others for the protection of the growing crops." Woodburn contends that the difference between these two systems cannot be attributed simply to environmental factors, or to any technical difficulty that impedes members of immediate return societies from engaging in food production. Thus, he infers that it was the value systems and social norms of immediate return foragers that led them to extol egalitarianism and to effectively repudiate all measures of conservation and accumulation. The origin of inequality is thus attributed to the weakening of these norms. We note that in addition to ascribing farming and complexity to a change in social values, Woodburn emphasizes the delay between one's labor and its yield, whereas Tushingham and Bettinger (and us) place the emphasis on the time gap between harvesting the crop and its consumption, and thus on storage and appropriability.

consumption is laborious. The opposite pattern pertains to front-loaded salmon which is costly to catch and preserve, but easy to consume. Tushingham and Bettinger suggest that the advantage that back-loaded resources like acorns offered to earlier foragers was that the required significant post-storage processing increased the probability that the stored acorn would remain usable, since it made the caches less attractive to others, and thus effectively turned them into "private goods." In turn, Tushingham and Bettinger identify the key deterrent to reliance on stored salmon as: "the possibility that others will rob caches, which mobile foragers are not positioned to protect" (p. 533). They explain the late and rather abrupt transition to salmon intensification in coastal California, which coincided with the aggregation of people into permanent villages, by the conjecture that reliance on salmon became feasible only after a sedentary community reached some threshold size that enabled it to protect its stored food.[33]

Tushingham and Bettinger do not mention hierarchy and do not relate their observations to agriculture, yet their analysis appears to be perfectly consistent with our appropriability theory on the distinction between tubers and cereals and how cereal farming led to hierarchy. Chiwona-Karltun et al. (2002) provide another pertinent example that illustrates how farmers may protect themselves against expropriation by choosing inefficient crops. They report that women in modern Malawi, and particularly single women, prefer to grow a bitter and toxic cassava variant that requires significantly more processing after harvest than the available non-toxic variant. They explain this pattern as due not only to the resiliency against pests that this variant offers (and applies irrespective of farmers' gender), but mostly as due to the protection that this extra post-harvest drudgery provides. First, it protects these women against thievery, since thieves prefer to steal the non-bitter cassava variant that requires less processing. Second, the extra processing reduces the pressure on these women to share their cassava crop with neighbors.

The choices between acorns and salmon and between bitter and non-bitter cassava illustrate how reliance on food resources that offer in-built protection against robbers survival without the protection that large group size and hierarchy provide. In contrast, reliance on stored food sources that attract thieves and other freeloaders requires substantive social innovations, and in particular, the rise of villages and the emergence of hierarchy. Thus, we posit that our appropriability theory

[33] A vivid eye-witness description of these villages, with plank houses that functioned also as storage facilities, is available in James Cook's account of his voyages in the Pacific Ocean (1784, volume II, book IV).

provides the causal mechanism that is missing from Testart's analysis of the relation between storage and hierarchy, both among complex hunter-gatherers and among cereal-dependant farming societies. In turn, this theory also explains why complex hierarchies did not develop among non-storing societies, whether foragers or tuber-dependent farming communities.

We conclude this survey with evidence from the earliest phases of the transition to agriculture in the ancient Near East. At that period, known as the (late) Natufian age (ca. 12,500-9,500 BCE), foragers in the fertile crescent apparently adopted semi-sedentary living and relied at least in part on collecting varied plants, including wild cereals. The Natufians, however, apparently did not yet engage in farming, which would have required storage, or in the domesticating of wild cereals.[34] Farming apparently emerged in the early phase of the Neolithic period, known as Pre-Pottery Neolithic A (PPNA), though at that stage it only involved the cultivation of wild plant species, prior to domestication. Significantly, Kuijt and Finlayson (2009) report the archeological discovery of a large and elaborate communal storage pit in the Jordan Valley from about 9,000 BCE. This was in a camp of farmer-foragers who apparently collected and possibly cultivated wild cereals, still in a pre-domestication stage. Similar evidence, and from about the same period, was reported by Willcox and Stordeur (2012) from a site in northern Syria in which both large scale communal storage and communal grinding facilities were identified. This evidence indicates that storage was indeed an integral part of the earliest transition to farming, and that it was accompanied by social cooperation that required organization. From the subsequent period (PPNB) in which cereals were already domesticated, there is already abundant evidence of storage facilities and of inequality, indicative of hierarchy. The observation that hierarchy and inequality developed alongside the gradual intensification of cereal cultivation and its concomitant storage, is consistent with our proposed explanation of why the transition to cereal farming was associated with the profound development of complex social structures, while the adoption of farming based on tubers in the tropics did not.

Indeed, as noted already, even though farming of tubers was apparently practiced in New Guinea

[34] Kuijt (2008), Price and Bar-Yosef (2010) and Goring-Morris and Belfer-Cohen (2011, p. S200) note that even though the Natufians already harvested wild cereals, they apparently did not engage in intentional cultivation or in storage. This may be because they were still semi-sedentary foragers and packed the harvested seeds in woven baskets, and then used up the seeds to supplement their diet during the dry summer. They may not have stored grain over the mild rainy winter, which would have necessitated more substantial storage facilities to protect the stored grain from spoilage by moisture, insects or rodents.

in the 5th millennium BCE (Denham 2011), it did not generate hierarchies beyond the tribal leadership level. Moreover, Wiessner et al. (1998) report that once the sweet potato reached New Guinea from the Americas in the 17th century (indirectly, without colonization), it quickly became the staple cultivar in the fertile rugged highlands. The higher productivity of the new tuber crop was translated into an increase in population density and generated surplus that was transformed into prestige goods (pigs, slaughtered in communal festivals, and traded shell ornaments). But, significantly, the highland population remained fractured, characterized by endemic tribal warfare, without any consolidation of power or increase in social complexity.

3 A Model of Cereals and Hierarchy

The basic premise of the model is that regions of the world differ in their productivity of tubers relative to that of cereals, and that tubers are non-seasonal and thus harder to expropriate than cereals. To simplify, we take the latter distinction to an extreme by positing that tubers cannot be expropriated, and in this sense are just like the product of hunting and gathering. We model farmers' choices of what crop to grow in two different regimes: anarchy and hierarchy, and derive conclusions regarding the circumstances under which hierarchy can emerge.

The economy is populated by a measure one of farmers and a measure N of non-farmers. We consider the productivity of cereals as constant, and, with crop units measured by their nutritional value, normalize it to unity. Our main exogenous variable, δ, measures the productivity advantage of cereals over tubers, or the productivity disadvantage of tubers.[35] Thus, farmers can grow one unit of cereals, or $1-\delta$ units of tubers, or any linear combination thereof. Hence, a farmer who allocates a fraction $\beta \in [0,1]$ of his land to cereals and a fraction $1-\beta$ to tubers produces $\beta + (1-\beta)(1-\delta) = (1-\delta) + \beta\delta$ units of output.

The income of non-farmers who engage in foraging is assumed to be constant and denoted:

[35] The variable δ can be either positive or negative. However, if it is negative, then tubers dominate cereals in the sense of providing both protection and higher productivity, so that farmers would only grow tubers in equilibrium. As a result, the equilibrium would be a simple one: hierarchy would be impossible, and also anarchy would be degenerate. Given our simplifying assumption that tubers are immune from confiscation, this situation generates a third type of regime, which presumably prevails among hunter-gatherers, where there is nothing to steal from one another. We realize, though, that to the extent that farmers who cultivate tubers are sedentary whereas foragers are not, there is likely to be a difference in the social institutions also between bands of foragers and farming groups that rely on non-appropriable crops. However, we choose to focus the analysis on the more interesting case where δ is positive, and where cereals may be cultivated, which creates a tradeoff between protection and productivity considerations.

$s > 0$. In a state of anarchy, non-farmers can chose also to be bandits, in which case their income would consist of the output they expropriate from farmers. In a state of hierarchy, we assume that some non-farmers are hired by the state (or by the non-working elite) to serve as tax collectors, and are paid the wage s. We denote by λ the measure of bandits or tax collectors. This is then also the number of bandits, or tax collectors, per farmer. N is assumed to be large enough so that the measure of foragers, $N - \lambda$, is positive.

3.1 Anarchy

Under anarchy, farmers face a risk of a raid by bandits. We assume that a raided farmer loses his entire cereal crop, but none of his crop of tubers. Farmers are assumed here to be risk neutral.[36] A farmer who is facing a raid with probability τ thus chooses β to maximize his expected income I:

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

The probability τ, also referred to as the rate of expropriation, is a function of the measure of bandits λ, $\tau = \tau(\lambda)$. We assume that the function $\tau(\lambda)$ is strictly increasing and strictly concave, and satisfies: $\tau(0) = 0$, $\lim_{\lambda \searrow 0} \tau'(\lambda) = \infty$, $\lim_{\lambda \nearrow \infty} \tau'(\lambda) = 0$ with $\lim_{\lambda \nearrow \infty} \tau(\lambda) = \overline{\tau} \leq 1$.[37] The inverse function of $\tau(\lambda)$ is denoted by $\lambda(\tau)$. Our assumptions imply that $\lambda(\cdot)$ is strictly increasing, strictly convex, with $\lambda(0) = 0$, $\lim_{\tau \searrow 0} \lambda'(\tau) = 0$ and $\lim_{\tau \nearrow \overline{\tau}} \lambda'(\tau) = \infty$.

As formulated in (1), it is evident that in selecting how much cereal to cultivate, farmers weigh the productivity advantages δ of cereals over tubers, against the disadvantage, as measured by the expropriation rate τ. Bandits are identical and uncoordinated. Thus a bandit's expected income π is given by the total amount of cereals they confiscate from farmers divided by the measure of bandits:

$$\pi = \frac{\tau(\lambda)\beta}{\lambda}.$$

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

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

[36] In section 3.5 we show that our results are robust to the introduction of risk aversion.

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

2. *given β, non-farmers are indifferent between being foragers or bandits, so that $\pi = s$.*[38]

The last condition can be restated as requiring:

$$\frac{\tau\beta}{\lambda(\tau)} = s.$$

Define now a threshold rate δ_A by the implicit relationship:[39]

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

δ_A provides the lower bound for the productivity advantage of cereals above which only cereals are grown.[40]

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

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

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

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

In the alternative case $0 < \delta < \delta_A$, the productivity disadvantage of tubers is low. Our assumptions on $\tau(\cdot)$ imply that the confiscation rate, $\tau(\lambda)/\lambda$, or $\tau/\lambda(\tau)$, is monotonically decreasing in τ, from infinity towards zero. Thus, when $\delta < \delta_A$, we have: $\delta/\lambda(\delta) > \delta_A/\lambda(\delta_A) = s$. Hence,

[38] Our assumptions that $\lim_{\lambda \searrow 0} \tau'(\lambda) = \infty$ and that that N is "large enough" (in particular, for the δ_A defined below, we require that $N \geq \lambda(\delta_A)$) guarantee a solution with $\tau > 0$.

[39] 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.

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

there exists a unique $\beta_A \in (0,1)$ such that $\pi_A \equiv \delta\beta_A/\lambda(\delta) = s$. The last condition, in conjunction with the condition $\tau_A = \delta$, defines the combination (β_A, τ_A) in the mixed equilibrium. ■

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

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

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

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

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

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

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

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

3.2 Hierarchy

We assume that in a state of hierarchy the elite (the state) chooses its tax policy to maximize its revenue net of the cost of tax collection. In order to facilitate comparison between the regimes of hierarchy and anarchy, we assume that the state has access to the same expropriation technology as bandits. Namely, the state cannot tax tubers, and if it employs a measure λ of tax collectors at cost s per tax collector, it can generate revenue of $\tau(\lambda)\beta$ from the farming sector. In adopting Weber's definition, we also assume that a state has to be able to deter bandits, and thus has to have monopoly power over the use of force. In recognizing economies of scale in the use of force, we simplify by assuming that the army required to possess such a monopoly over the use of force entails fixed cost $G_0 > 0$.[41]

A key advantage that a state has, in comparison to anarchy, is that it is farsighted and organized, and can thus commit not to expropriate farmers beyond a certain tax rate.[42] That is, the state selects the number of tax collectors to maximize its net revenue, taking into account farmers' response to the implied tax rate. Farmers' freedom to choose to avoid taxation completely by cultivating tubers, implies that the state cannot gain from setting a tax rate higher than δ. Thus, the objective of the state is to choose a tax rate τ, and thus to hire $\lambda(\tau)$ tax-collectors at cost $s\lambda(\tau)$, to maximize its net revenue, subject to the constraint that farmers respond optimally to the tax rate:

[41] We distinguish here between the cost of maintaining an army and the costs of employing tax collectors. To the extent that these functions overlap, G_0 may be thought of as "small."

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

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

subject to

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

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

We have thus established:

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

Income distribution. Under hierarchy, farmers grow only cereals. Thus, their income is $1 - \tau_H = 1 - \min\{\delta, \delta_H\}$, which is weakly decreasing in the cereal productivity advantage over tubers δ. Total tax receipts equals τ_H, and the net tax revenue received by the elite, after paying the tax collectors and covering the cost of the army is:

$\tau_H - s\lambda(\tau_H) - G_0$. Both the gross and net tax receipts strictly increase in δ up to the threshold δ_H, where they remain constant.

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

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

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

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

.

3.3 Anarchy vs. Hierarchy

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

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

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

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

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

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

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

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

The main predictions of the analysis

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

2. If tubers are sufficiently productive in comparison to cereals ($\delta < \underline{\delta}$), then a state cannot exist. This result illustrates our claim that it isn't low productivity that restrains the development of hierarchy and related institutions, but rather high productivity of crops that are hard to expropriate. If, however, the reverse is true ($\delta > \underline{\delta}$) hierarchy could emerge and farmers would produce food surplus that would be taxed by the elite.

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

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

3.4 Example

Consider the following specification for the expropriation function:

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

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

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

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

Under hierarchy, $\delta_H = \alpha\rho^2/s$ and the lower limit for state existence, $\underline{\delta} > 0$, is implicitly defined by the quadratic equation: $\underline{\delta} - s\left(\frac{\underline{\delta}}{\rho}\right)^2 = G_0$.[43]

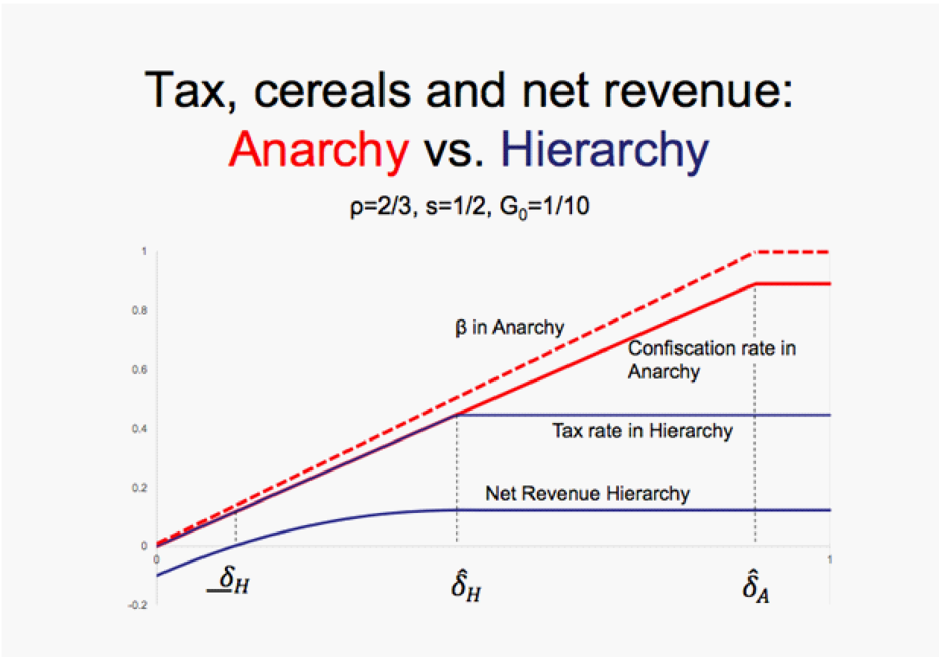
For $\underline{\delta} \leq \delta \leq \delta_H$ a state sets a tax rate equal to δ and generates net tax revenue: $R(\delta) = \delta - s\left(\frac{\delta}{\rho}\right)^2$, which increases in δ up to the point where $\delta = \delta_H$ upon which $R(\delta) = R(\delta_H)$. Figure 1 presents the comparison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

Risk-Averse Farmers

In this subsection we illustrate the robustness of the model's qualitative predictions when farmers are risk averse. The results are in a sense even stronger, given that risk-averse farmers under anarchy seek more protection by choosing a smaller share of cereals. Farmers' risk aversion does not affect the analysis of the model under a regime of hierarchy since in this case the tax rate that the state imposes is certain. We chose to illustrate the case of anarchy with risk-averse farmers by examining a case where a simple analytic solution can be obtained. For that purpose, we employ

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

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



the above specification of the expropriation function, $\tau(\lambda) = \rho\sqrt{\lambda}$, 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

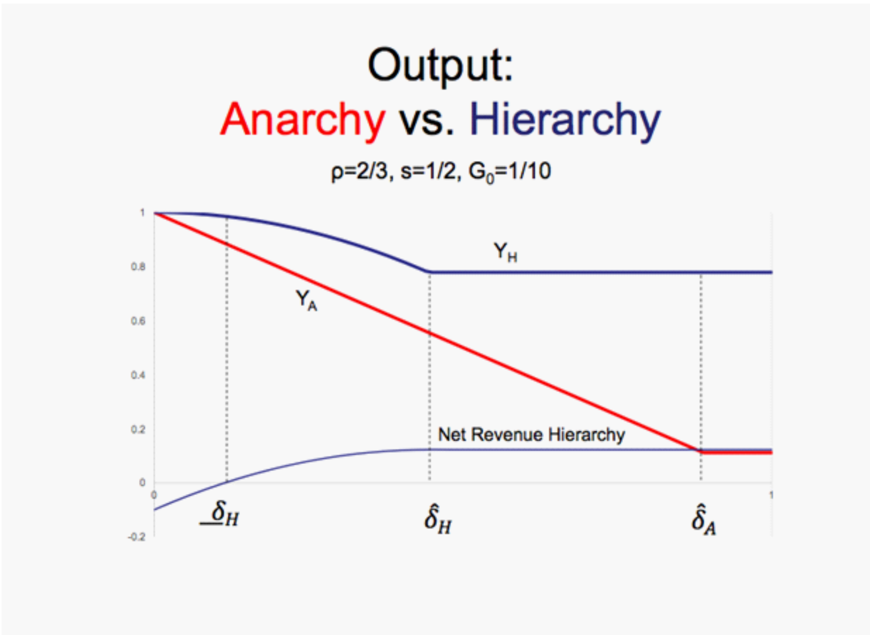
$$\beta_A = \max\left\{\frac{\delta - \tau}{\delta}, 0\right\}.$$

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 $\beta_A > 0$):

Figure 2: Output: Anarchy vs. Hierarchy



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

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.[44] Figure 3 illustrates the difference between the two types of equilibrium: the case of risk neutral farmers and risk averse farmers.

4 Evidence

In this section, we provide supportive evidence for our main theoretical predictions. We employ two alternative datasets with information on social hierarchy: a cross section of societies and a panel of countries. Our main regressors are two measures of agricultural productivity: the productivity of the soil (the maximum caloric yield that can be obtained from a given unit of land) and the productivity advantage of cereals over roots and tubers (the difference between the maximum calorie yield that can be obtained from cereals and roots or tubers) – a measure corresponding to δ in our model. Consistently with the main prediction of our theory, our empirical investigation shows that it isn't low agricultural productivity that retards development of hierarchy, but rather high productivity of less appropriable crops.

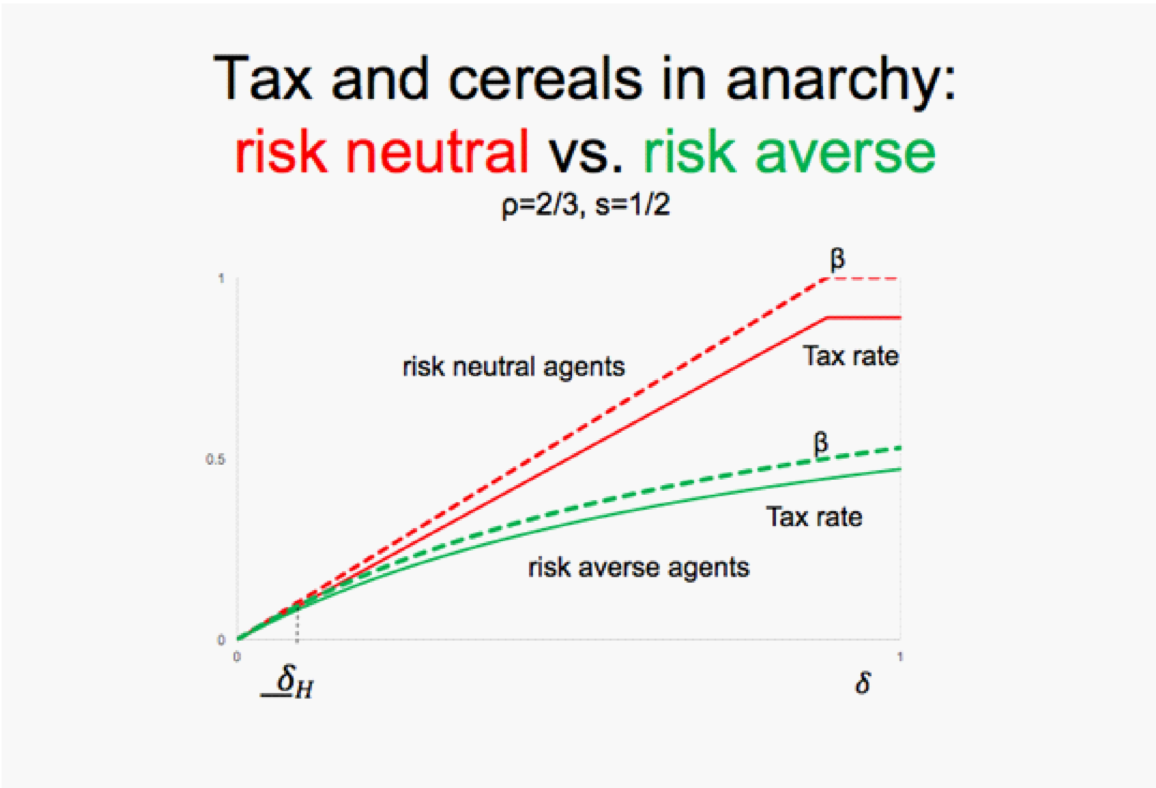
4.1 Data

4.1.1 Ethnographic Data

Murdock's (1967) Ethnographic Atlas provides a database of 1,267 societies from around the world. The database contains information on several cultural, institutional and economic features for these societies at an idealized moment of first contact with Europeans. From this sample, we remove

[44] 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 3: Output: Anarchy vs. Hierarchy



2 duplicate observations, 7 societies observed before 1500, and 10 societies for which the year of observation is missing, so that we are left with a total of 1,248 societies. These are matched to ethnic maps using either the geo-coordinates of each ethnicity provided by the Ethnoatlas or the maps on the spatial location of ethnicities constructed by Fenske (2013).[45]

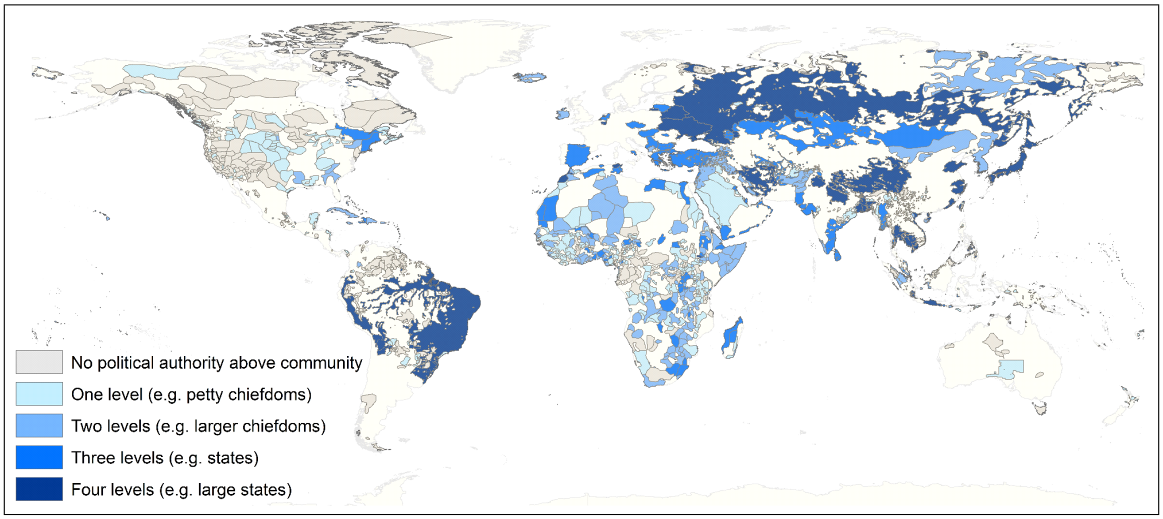
We measure pre-colonial hierarchical complexity using the variable “Jurisdictional Hierarchy beyond the Local Community.”[46] This is an ordered variable with five possible levels: (i) no political authority beyond community, (ii) petty chiefdoms, (iii) larger chiefdoms, (iv) states, and (v) large states. We plot this measure of hierarchy in Figure 4 and present the summary statistics in the first row of Table 1. The majority of our sample is composed of societies lacking any political

[45] 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).

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

integration above the local community, and groups where petty chiefs rule over very small districts. These societies prevail in North America, Australia and in Central Africa, but are rather rare in Northern Africa and in Asia, where large chiefdoms and states tend to prevail.

Figure 4: Jurisdictional hierarchy beyond the local community in pre-colonial societies

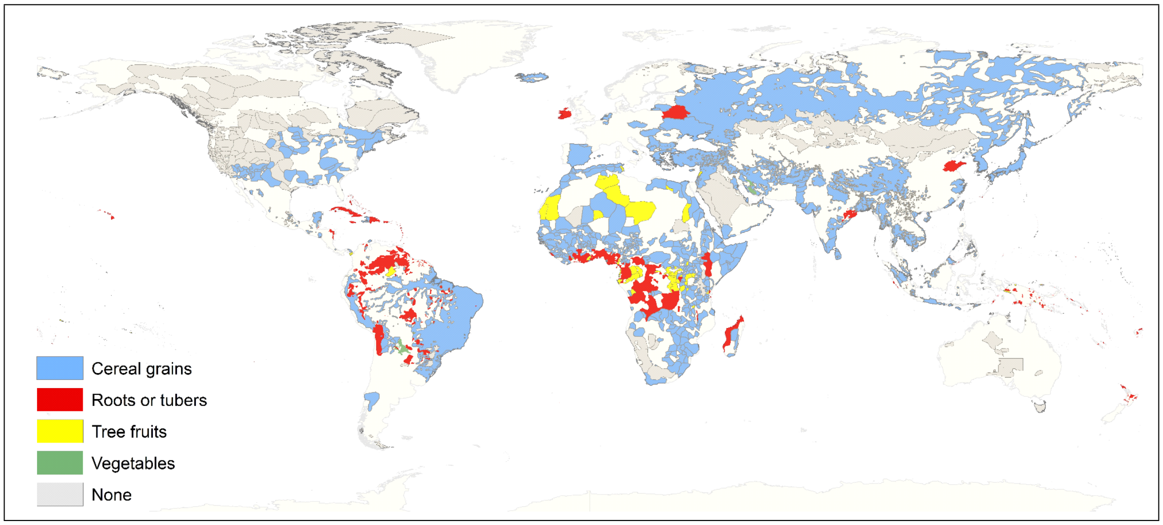


The Ethnoatlas also provides information on whether societies rely on agriculture for their diet, and on the major crop type of societies that practice agriculture. These two variables are plotted in Figure 5. with summary data in rows 2 and 3 of Table 1. As can be seen from Figure 5, approximately one fifth of the societies in the sample do not practice any form of agriculture. These societies are concentrated in North-West America, Central Asia, Australia and South-West Africa. The median society relies on agriculture for approximately 50% of its caloric needs. The great majority of the societies that practice some form of agriculture rely on either cereal grains (65.4 percent) or on roots and tubers (26.1 percent). The latter are concentrated in the tropics, while the former are scattered all over the world.[47] Using this information, we define a dummy that identifies societies whose primary crop is cereals and present summary statistics on the second row of Table 1.

Finally the Ethnoatlas provides information on the reliance of these societies on agriculture for their diet. As can be seen from Figure 5, approximately one fifth of the society in the sample do not

[47] Some societies in the temperate zones grow potatoes - a tuber crop that is in fact similar in its relevant properties to cereals in that it is seasonal and storable.

Figure 5: Major crop in pre-colonial societies

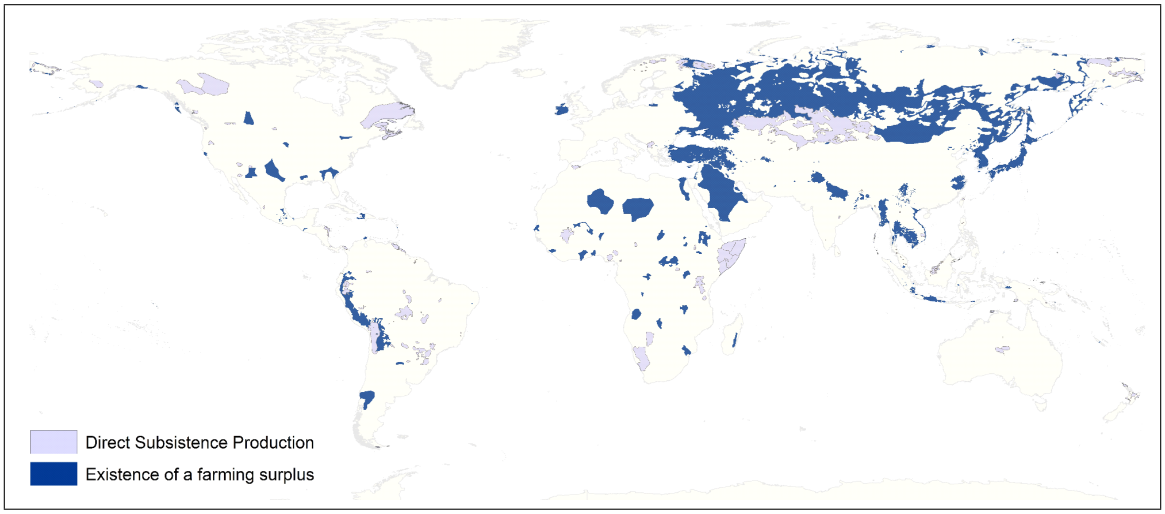


practice any form of agriculture. These societies are concentrated in North-West America, Central Asia, Australia and South-West Africa. The median society relies on agriculture for approximately 50% of its caloric needs.

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

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

Figure 6: Farming surplus in pre-colonial societies



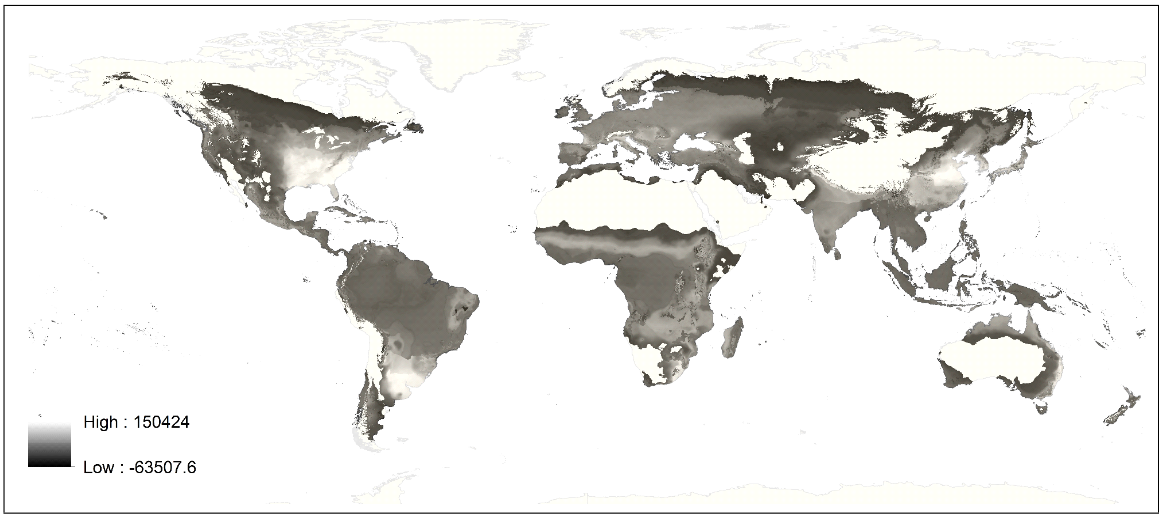
4.1.2 Country-level Data

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

4.1.3 Soil Suitability Data

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

Figure 7: Difference in potential yields (calories per hectare) of cereals versus roots and tubers.



GAEZ provides data on potential yields, in terms of tons per hectare per year, for 11 cereal grains and 4 roots and tubers. Following the same procedure as in Galor and Ozak (2014), 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. We then find the crop with the highest potential caloric yields for each raster point. The results are illustrated in figure C.3 in the 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 few very small areas in Siberia, Eastern Brazil and Central-East Africa.

On the basis of this data set we construct two measures: a measure of the productivity of land, measured as the maximum potential caloric yield per hectare; and a measure of the productivity advantage of cereals over roots and tubers, which equals the difference between the maximum caloric yield of cereals and the maximum caloric yield of roots or tubers. These measures are attributed to the different societies in the Ethnoatlas by taking an average of their values within a 20-miles radius around the geo-coordinates reported in the Ethnoatlas.[48] The two measures are attributed to the different countries by using the FAO country boundaries.

4.1.4 Other demographic and geographic data

The History Database of the Global Environment (HYDE) supplies global estimates on population density at the raster level between 1500 and 2000 with cell size of 5'x5'. To each society in the Ethnoatlas, we assign a value that is equal to the average population density across the raster points within its territories for the year of observation recorded in the atlas. The median community had historical population density of 41 inhabitants per square mile, while the community with the highest population density was the Okinawans in Japan with 3627 inhabitants per square mile. Data on population density for 1995 is provided by GAEZ and is similarly averaged within the territory of each society. Finally, we employ data on distance to major rivers or to the coast, precipitation, temperature, elevation, ruggedness, absolute latitude, incidence of malaria both at the society and the country level. Sources are detailed in Table 1.

[48] 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).

Table 1: Descriptive Statistics

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

std - a standardized variable that has been rescaled to have a mean of zero and a standard deviation of one.

4.2 Empirical Results

4.2.1 The Choice of Crop

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

The first three columns of Table 2 presents the results of the following regression:

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

Cer_i is a dummy variable that identifies that society i cultivates a cereal grain as its main crop; $CalDiff_i$ is the caloric advantage of cereals in the land of society i (the difference between the maximum potential calorie yield of cereals and of roots or tubers); and X_i is a set of control variables. Column 1 reports the bivariate relationship without any controls. The association is positive and statistically significant. An increase in the productivity advantage of cereals over roots and tubers by one standard deviation is associated with an increase in the probability of planting cereals as main crop in the order of 20 percent. Moreover, variation in this regressor alone is able to explain 13 percent of the entire variation in the dependent variable. The first concern is that the productivity advantage of cereals might reflect the potential caloric yield of the soil, since cereals grains are the most productive crops in most of the world. Column 2 reports the results when adding as a control variable the productivity of the soil (when cultivating the crop with the highest potential caloric yield). This variable does not produce any significant impact on the decision on whether to plant cereals or not, while the impact of the productivity advantage of cereals is unchanged. Adding this control leaves the R^2 of the regression practically unchanged, which suggests that soil productivity isn't relevant to explain the decision to cultivate cereals. Column 3 shows that the results are unchanged when only exploiting within-continent variation. Moreover, the results of the first three columns of Table 2 survive a battery or robustness checks that are detailed in the appendix of the paper. In table C.1, we control sequentially for precipitation, temperature, elevation ruggedness and absolute latitude, which are the main factors affecting crop productivity in the GAEZ dataset. In table C.2, we control for geographical isolation (proxied as the distance to the nearest major river or coast), malaria endemicity and actual and historical population density. In all cases, the qualitative results on the effect of the productivity advantage of cereals over roots and tubers are almost unaffected (coefficients vary from 0.139 to 0.276 and are always statistically significant at the 1 percent confidence level).

Table 2: Potential Crop Yields, Choice of Crops and Reliance on Agriculture

	Dependent variable is:					
	Major crop is cereal grains (dummy)			Reliance on agriculture		
	(1)	(2)	(3)	(4)	(5)	(6)
CALORIC DIFF	0.205***	0.210***	0.253***	0.0812***	-0.0978***	-0.0464***
(CER - TUB)	(0.0168)	(0.0310)	(0.0329)	(0.00945)	(0.0134)	(0.0136)
MAX CALORIES		-0.00664	-0.137***		0.230***	0.128***
(ALL CROPS)		(0.0338)	(0.0386)		(0.0153)	(0.0178)
CONTINENT FE	NO	NO	YES	NO	NO	YES
r2	0.132	0.132	0.359	0.0733	0.235	0.387
N	982	982	982	1063	1063	1063

The table reports cross-sectional OLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is either a dummy that identifies societies that cultivate cereal grains as main crop (columns 1-3) or the reliance of the these societies on agriculture (columns 4-6). CALORIC DIFF (CER-TUB) is the standardized difference between the maximum potential calorie yield per hectare that can be obtained from cereals versus the one that can be obtained from either roots or tubers. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. Robust standard errors in parentheses *** significant at less than 1 percent; ** significant at 5 percent; * significant at 10 percent.

The last three columns of Table 2 repeat the analysis of the first three columns, but with the reliance of the society on agriculture as the dependent variable. The results are striking. First, as expected, land productivity increases the probability of reliance on farming. Second, in line with our theory, the productivity advantage of cereals has a negative effect on practicing agriculture, when controlling for soil productivity.

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

4.2.2 Cereals and Hierarchy

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

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

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

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

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

Before presenting the 2SLS regressions that estimate the effect of cereals on hierarchy and surplus, we report in Table 3 OLS estimates of the reduced form of the analysis. Columns 1 illustrates that the higher the productivity advantage of cereals, the higher is the level of jurisdictional hierarchy that is reached by the societies in the Ethnoatlas. This result is unchanged when controlling for the productivity of the soil (column 2). More specifically, while one standard deviation increase

Table 3: Cereals, Surplus and Hierarchy - Reduced Form

	Dependent variable is:					
	Jurisdictional Hierarchy Beyond Local Community			Existence of farming surplus		
	(1)	(2)	(3)	(4)	(5)	(6)
CALORIC DIFF	0.244***	0.179**	0.274***	0.141***	0.241***	0.202***
(CER - TUB)	(0.0394)	(0.0732)	(0.0758)	(0.0319)	(0.0681)	(0.0742)
MAX CALORIES		0.0825	-0.188**		-0.132	-0.0985
(ALL CROPS)		(0.0713)	(0.0886)		(0.0870)	(0.0985)
CONTINENT FE	NO	NO	YES	NO	NO	YES
r2	0.0416	0.0429	0.249	0.0757	0.0911	0.157
N	952	952	952	140	140	140

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

in the relative productivity of cereals increases the hierarchy index by 0.18 (0.27 in the specification with continent fixed effects), an increase of soil productivity does not produce any significant impact on the dependent variable. In column 3, we control for continent fixed effects. The impact of the relative productivity of cereals becomes larger, while the impact of the soil productivity becomes negative. Columns 4-6 provide further support for the appropriability hypothesis versus the productivity-surplus hypothesis. In fact, the higher the productivity advantage of cereals, the higher is the probability of having an economy that produces a farming surplus – elite consumption isn't based on direct subsistence (column 4). When we run a horse race between the productivity advantage of cereals and the absolute productivity of the soil (columns 5 and 6), we find that only the former has a significant impact on surplus, independently on whether we control for continent fixed effects or not.

Table 4 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

Table 4: Cereals and Hierarchy - OLS and 2SLS

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP:	0.707***	1.170***	0.863**	1.040***	0.304***	0.892***	1.064***	0.993***
CEREALS	(0.0630)	(0.195)	(0.364)	(0.245)	(0.0762)	(0.261)	(0.332)	(0.277)
MAX CALORIES			0.0811				-0.0368	
(ALL CROPS)			(0.0714)				(0.0564)	
DEPENDENCE ON				0.334				-0.419
AGRICULTURE				(0.298)				(0.644)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	952	952	952	952	952	952	952	952
F excl instrum.		145.6	42.53	63.39		95.00	58.58	22.37
A-R Test (p-val)		0.000	0.0147	0.000		0.000	0.000	0.000

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

increase of 0.70 in the hierarchy measure. Clearly, this positive association cannot be interpreted as causal. In order to overcome the reverse causality problem, we switch to the 2SLS estimates in the next three columns. Cultivating cereals as the main crop increases the hierarchy measure by more than one (column 2), which is equivalent, for instance, to a move from a tribe to a small chiefdom or from a large chiefdom to a state. In the following two columns, we run a horse race between our appropriability hypothesis and the land productivity-surplus hypothesis. In column 3, we add the productivity of land as a control variable. As can be seen, it does not have any significant effect on hierarchical complexity. In column 4, we add the dependence of the society on agriculture as a second endogenous variable. The instruments now are both the caloric advantage of cereals and absolute soil productivity; where the intuition is that the latter influences only the decision whether to become farmers, but not the choice of the crop. The results are once gain striking: societies that practice agriculture are not characterized by more complex hierarchies, unless they cultivate cereals. In columns 5-8, we repeat the analysis adding continent fixed effects in the regression. The 2SLS results are practically unchanged.

Table 5: Cereals and Surplus - OLS and 2SLS

	Dependent variable: Existence of a farming surplus							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP:	0.359***	0.940***	0.846***	0.846***	0.299***	1.005***	0.797**	0.799**
CEREALS	(0.0791)	(0.260)	(0.273)	(0.275)	(0.0901)	(0.316)	(0.314)	(0.317)
MAX CALORIES			0.0186				0.0361	
(ALL CROPS)			(0.0626)				(0.0611)	
DEPENDENCE ON				0.191				0.438
AGRICULTURE				(0.663)				(0.775)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	139	139	139	139	139	139	139	139
F excl instrum.		16.08	17.37	5.486		15.35	12.44	4.338
A-R Test (p-val)		0.000	0.000	0.000		0.000	0.00878	0.000

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

The results of Table 4 survive a battery or robustness checks that are detailed in the appendix of the paper. In Table C.3, we control sequentially for precipitation, temperature, elevation ruggedness and absolute latitude, the main factors affecting crop productivities. In Table C.4, we control for geographical isolation, malaria endemicity and actual and historical population density. In 9 out of 10 cases, cultivating cereals as main crop exerts a statistically significant impact on hierarchical complexity. The results are also practically unaffected when using ethnic boundaries as defined by Fenske (2013) to extract data on crop productivities (Table C.5), or when the sample includes societies living in desertic soils (Table C.6). In all cases, the qualitative results on the effect of cultivating cereals as main crops are almost unaffected (the coefficients vary from 0.475 to 0.900).

Table 5 reports the OLS and 2SLS estimates of equation 2, when the dependent variable is the existence of a farming surplus in the society. The OLS estimates show that cultivating cereals is associated with an increase of 0.36 in the probability of producing a surplus (column 1). The coefficient more than doubles when turning to the 2SLS estimates (column 2). As in the previous table, also in this case absolute productivity of soil and reliance on agriculture do not affect the dependent variable (columns 3 and 4); and the results are robust when adding continent fixed effects in the specification (columns 5 to 8). Also in this case, the empirical results survive a long list of robustness checks reported in the appendix (Tables C.7-C.10).

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

In the New World, the only available roots and tubers Before 1500 were cassava, white potatoes and sweet potatoes; while the only available cereal grain was maize. In the Old World, the only available crop among roots and tubers were yams; while the available cereal grains were barley, buckwheat, foxtail millet, indigo rice, oat, pearl millet, rye, sorghum, wetland rice, and wheat – but not maze. Thus, for each raster point of the world we define the highest yielding crop among cereals and among roots and tubers both before and after the Columbian exchange. We then compute for each location the productivity advantage of cereals over roots and tubers and the absolute productivity of land before the Columbian exchange (prior to 1500) and after the Columbian exchange (in the years after 1600).[49]

Since the data in the Ethnographic Atlas pertains only to societies after the Columbian exchange, we exploit a different country-level panel dataset that reports on hierarchical complexity for the majority of the world over the last millennium. The unit of observation is the territory de-

[49] We exclude the years from 1500 to 1600 as the historical evidence points out that the New World's crops were adopted in Europe and Africa in the seventeeth century. For instance, the adoption of the potato in the Old World began in the late seventeeth century by Irish peasants (Nunn and Qian, 2011), while the first accounts on the adoption of maize in Africa date back to the very end of the sixteenth century (Miracle, 1966). In the appendix, we show that our results are robuts when excluding the years between 1500 and 1750 (see Table C.12).

limited by modern-day country borders for 159 countries every 50 years. Since we lack observations on the major crop cultivated in these territories for the period of analysis, we can only run the reduced form version of our empirical analysis, where we regress the hierarchy index on the productivity advantage of cereals and on the productivity of the soil. Country fixed effects control for all time invariant factors that differ between countries, while time period fixed effects control for any time patterns of hierarchical complexity that affects all countries. The identification assumption is that there are no events that occurred in the sixteenth century and are systematically correlated with the changes that were induced by the Columbian exchange in the productivity advantage of cereals and in the productivity of land.

Table 6: Cereals and Hierarchy - Panel Regressions

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

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

The results are illustrated in Table 6. Column 1 confirms that the higher the productivity advantage of cereals, the higher is the country's hierarchy index. This result is unchanged when controlling for soil productivity (column 2). More specifically, while a one standard deviation increase in the productivity advantage of cereals increases the hierarchy index by 0.19, soil productivity does not have any significant impact on the dependent variable. In the next five columns, we show that the results are robust when controlling for precipitation, temperature, elevation ruggedness and absolute latitude (interacted with the time-period fixed effects). In Table 7, we consider a host of additional factors (each interacted with time-period fixed effects) that might have affected hierarchical complexity. Our choice of controls is driven by the determinants of long-term economic development that have been emphasized in the literature. Sequentially, we control for: legal origin of the country; population density in 1500; settlers mortality; the number of exported slaves; distance to rivers and coast; endemicity of malaria; and the percentage of tropical land. Once again, our results are unaffected.

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

5 Concluding Remarks

The prevailing literature attributes the emergence of hierarchy to the increased productivity of agriculture. This increase in productivity is presumed to have generated food abundance (surplus), which, in turn, contributed to rising population, and facilitated specialization in crafts, exchange, and the rise of elite. Without denying that an increase in productivity did occur, we contend that the logic behind these proposed mechanisms is flawed. We argue that surplus was neither necessary nor sufficient for the rise of hierarchy. Moreover, its existence is altogether inconsistent with the Malthusian theory of endogenous population, given the extremely protracted Neolithic increase in productivity. Instead, we propose that the key feature of the Neolithic Revolution that brought about the rise of elite, and led to subsequent major developments in social hierarchy is that cereal farmers are more vulnerable to appropriation than foragers. Thus, while we do not challenge the prevailing perception that the transition away from egalitarianism towards hierarchy was correlated with the shift to agriculture, we contend that the causality is more nuanced than is

Table 7: Cereals and Hierarchy - Panel Regressions - Robustness Checks

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

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

commonly perceived.

In fact, rather than apply the common dualistic view of early human societies as either hunter-gatherers or agricultural, our framework accounts for the different social institutions among four prototypes of early societies. Within non-agricultural societies our appropriability theory explains the existence of hierarchy among what anthropologists call complex hunter-gatherers, even though they continue to procure food rather to produce it. And within agricultural societies, our theory explains the substantially higher degree of social hierarchy among societies that obtain their carbohydrates mostly from cereals, as distinct from those that rely on roots and tubers.

In each case, our neo-Hobbesian approach, which emphasizes the role of theft and expropriation, posits that greater efficacy for the appropriation of stored food by outsiders generates a demand for protection from thieves, and, simultaneously, facilitates the organized supply of protection by enabling leaders to tax their subjects.

Our theoretical claims are illustrated with a simple model that also motivates our empirical investigation. The main prediction of the model is that high productivity of crops that are harder to tax, such as roots and tubers, retards the emergence of hierarchy. This prediction highlights a key difference between our theory and the conventional approach for explaining why countries in the tropics lag behind (at least in the pre-industrial period). Whereas the conventional theories suggest that it is low agricultural productivity or disease that retards the development of tropical regions, our approach suggests that the true hurdle lies with the relatively high productivity of less appropriable crops which holds back the development of hierarchical social institutions. Consistently with these predictions, our empirical analysis shows a causal effect of cereals on the level of hierarchy.

Our empirical investigation is significant also for its contribution to the empirical research on the effect of institutions on economic development. Given that emergence of state institutions is often attributed to the rise of land productivity following the transition to farming, existing research that establishes a correlation between the nature of institutions and development, could be interpreted as reflecting a positive effect of land productivity on both output (or population density) and institutions. This coincidence of effects may hinder identifying the true causal effect of institutions on output. Our finding that land productivity (when coupled with a measure of the productivity advantage of cereals) has no direct effect on the formation of hierarchy and states, may thus lend credence to the presumed positive effect of state institutions on output.

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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.

Table A.1: Staple crops in sub-Saharan Africa and in Eurasia in 1961

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

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

Table A1 presents summary data on the main staple crops in sub-Saharan Africa and in Eurasia in 1961 – the earliest year for which the Food and Agriculture Organization, FAO, provides that information.[50] Its last column presents comparable data for Nigeria in 2013. In relying on relatively recent data, our presumption is that the soil and climatic conditions have not changed significantly

[50] 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 the total energy produced by the listed twelve major crops could roughly feed the entire population.

since the Neolithic period. We recognize, of course, that the starchy 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.[51]

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

2. 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).

3. The seasonality of cereals is well known. They have to be sown and reaped in a relatively fixed time in the year, and usually once a year. On the other hand, roots and tubers are generally perennial and may be harvested at any time during the year. In fact, cassava can be left intact in the ground for two years. This provides farmers with much flexibility as to the timing of the harvest, and prevents the need for significant storage. Rees et al. (2012, p. 394) report: "Harvest time [of Cassava] ranges from six to 24 months, and roots can be left in the ground until needed, making cassava a very useful food security crop."[52]

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

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

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

5. Finally, 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.

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

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Appendix B: Surplus and appropriation – the role of population

We develop here another 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,

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

Now,

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

Similarly,

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

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

Appendix C: Additional Evidence

Table C.1: Potential Crop Yields and Choice of Crops - Robustness Checks 1

	Dep. Variable: Major crop is cereal grains (dummy)				
	(1)	(2)	(3)	(4)	(5)
CALORIC DIFF	0.139***	0.268***	0.195***	0.198***	0.271***
(CER - TUB)	(0.0345)	(0.0334)	(0.0307)	(0.0315)	(0.0358)
MAX CALORIES	0.0791**	-0.103**	0.00835	0.0138	-0.0981**
(ALL CROPS)	(0.0374)	(0.0412)	(0.0336)	(0.0353)	(0.0457)
Precipitation	-0.0995***				
	(0.0238)				
Temperature Abs Latitude		0.0781***			
		(0.0183)			
Elevation			0.120***		
			(0.0154)		
Ruggedness				0.0302**	
				(0.0153)	
Abs Latitude					-0.0670***
					(0.0205)
r2	0.161	0.146	0.160	0.136	0.141
N	982	982	982	982	982

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

Table C.2: Potential Crop Yields and Choice of Crops - Robustness Checks 2

	Dep. Variable: Major crop is cereal grains (dummy)					
	(1)	(2)	(3)	(4)	(5)	(6)
CALORIC DIFF	0.211***	0.209***	0.256***	0.198***	0.207***	0.276***
(CER - TUB)	(0.0308)	(0.0310)	(0.0307)	(0.0313)	(0.0313)	(0.0630)
MAX CALORIES	-0.00949	-0.00947	-0.0804**	-0.0143	-0.00862	-0.235***
(ALL CROPS)	(0.0336)	(0.0338)	(0.0366)	(0.0341)	(0.0338)	(0.0758)
Major River	-0.0359**					
	(0.0144)					
Distance Coast		0.0355**				
		(0.0154)				
Pct. Malaria			0.0711***			
			(0.0152)			
Pop Dens. 1995				0.0668***		
				(0.0154)		
Hist Pop Dens					0.0324	
					(0.0323)	
Pop Dens						0.235***
						(0.0332)
r2	0.138	0.137	0.149	0.148	0.137	0.313
N	982	982	982	966	982	144

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

Table C.3: Cereals and Hierarchy - 2SLS. Controlling for geography.

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community				
	(1)	(2)	(3)	(4)	(5)
	2SLS	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.478	0.599**	0.900**	0.887**	0.590**
	(0.570)	(0.298)	(0.394)	(0.396)	(0.300)
MAX CALORIES	0.178	0.172***	0.0731	0.0725	0.167**
(ALL CROPS)	(0.120)	(0.0653)	(0.0771)	(0.0846)	(0.0693)
Precipitation	-0.112				
	(0.0744)				
Temperature		-0.0734*			
		(0.0394)			
Elevation			-0.0631		
			(0.0635)		
Ruggedness				-0.0126	
				(0.0377)	
Abs Latitude					0.0622
					(0.0402)
N	952	952	952	952	952
F excl instrum.	15.39	59.50	37.45	36.76	55.55
A-R Test (p-val)	0.403	0.0458	0.0185	0.0205	0.0502

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. "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 C.4: Cereals and Hierarchy - 2SLS. Controlling for isolation and population density.

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community				
	(1)	(2)	(3)	(4)	(5)
	2SLS	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.840**	0.870**	0.777**	1.317*	0.730**
	(0.356)	(0.366)	(0.329)	(0.685)	(0.328)
MAX CALORIES	0.0899	0.0835	0.0631	0.0250	0.0317
(ALL CROPS)	(0.0695)	(0.0706)	(0.0659)	(0.103)	(0.0636)
Major River	0.102***				
	(0.0356)				
Distance to Coast		-0.0323			
		(0.0364)			
Pop Density (HYDE)			0.257**		
			(0.125)		
Pop Density (SCSS)				0.415**	
				(0.183)	
Pop Density 1995					0.334***
					(0.0481)
N	952	952	952	142	936
F excl instrum.	43.86	41.93	40.91	17.63	37.13
A-R Test (p-val)	0.0160	0.0149	0.0161	0.0243	0.0223

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. "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 C.5: Cereals and Hierarchy - 2SLS. Potential calorie yields refer to ethnic boundaries in Fenske (2013)

	Dependent variable: Jurisdictional Hierarchy Beyond Local Community							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.707***	1.109***	0.845**	1.040***	0.304***	0.841***	1.080***	0.994***
	(0.0630)	(0.188)	(0.333)	(0.245)	(0.0762)	(0.236)	(0.302)	(0.257)
MAX CALORIES			0.0692				-0.0542	
(ALL CROPS)			(0.0646)				(0.0546)	
DEPENDENCE ON				0.334				-0.574
AGRICULTURE				(0.298)				(0.583)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	952	942	942	952	952	942	942	942
F excl instrum.		162.7	52.46	63.39		118.7	74.18	28.21
A-R Test (p-val)		0.000	0.00859	0.000		0.000	0.000	0.000

The table reports cross-sectional OLS and 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas. The dependent variable is Murdock's (1967) index of jurisdictional hierarchy beyond the local community and it takes the following values: 1 (no political authority beyond community), 2 (petty chiefdoms), 3 (larger chiefdoms), 4 (states), 5 (large states). The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from 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 C.6: Cereals and Hierarchy - 2SLS. Sample including societies living in desertic soils.

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

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

Table C.7: Cereals and Surplus - 2SLS. Controlling for geography.

	Dependent variable: Existence of a farming surplus				
	(1)	(2)	(3)	(4)	(5)
	2SLS	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.774**	0.764***	0.921***	0.930***	0.681**
	(0.375)	(0.261)	(0.301)	(0.315)	(0.267)
MAX CALORIES	0.0334	0.0387	0.00222	-0.0215	0.0534
(ALL CROPS)	(0.0793)	(0.0686)	(0.0677)	(0.0811)	(0.0637)
Precipitation	-0.0344				
	(0.0785)				
Temperature		-0.0281			
		(0.0475)			
Elevation			-0.155***		
			(0.0543)		
Ruggedness				-0.109	
				(0.0714)	
Abs Latitude					0.0511
					(0.0468)
N	139	139	139	139	139
F excl instrum.	10.41	19.42	15.50	14.83	15.68
A-R Test (p-val)	0.0162	0.00198	0.000	0.000875	0.00822

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. "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 C.8: Cereals and Surplus - 2SLS. Controlling for isolation and population density.

	Dependent variable: Existence of a farming surplus				
	(1)	(2)	(3)	(4)	(5)
	2SLS	2SLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.823***	0.851***	0.820***	0.848***	0.916***
	(0.277)	(0.275)	(0.300)	(0.288)	(0.314)
MAX CALORIES	0.0215	0.0191	0.0132	0.0208	0.0117
(ALL CROPS)	(0.0625)	(0.0626)	(0.0589)	(0.0530)	(0.0616)
Major River	0.0363				
	(0.0409)				
Distance to Coast		-0.0150			
		(0.0448)			
Pop Density (HYDE)			0.0291		
			(0.0379)		
Pop Density (SCSS)				-0.00815	
				(0.0847)	
Pop Density 1995					0.00146
					(0.0358)
N	139	139	139	139	137
F excl instrum.	15.86	17.09	13.35	17.91	12.99
A-R Test (p-val)	0.00127	0.000635	0.00353	0.000	0.00111

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. "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 C.9: Cereals and Surplus: Potential calorie yields refer to ethnic boundaries in Fenske (2013).

	Dependent variable: Existence of a farming surplus							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	2SLS	2SLS	OLS	2SLS	2SLS	2SLS
MAIN CROP: CEREALS	0.359***	0.909***	0.894***	0.846***	0.299***	0.953***	0.845**	0.864***
	(0.0791)	(0.274)	(0.297)	(0.275)	(0.0901)	(0.318)	(0.336)	(0.303)
MAX CALORIES (ALL CROPS)			0.00286				0.0196	
			(0.0657)				(0.0657)	
DEPENDENCE ON AGRICULTURE				0.191				0.210
				(0.663)				(0.723)
CONTINENT FE	NO	NO	NO	NO	YES	YES	YES	YES
N	139	138	138	138	139	138	138	138
F excl instrum.		15.52	17.23	5.486		16.90	13.56	4.786
A-R Test (p-val)		0.0000310	0.000326	0.0000119		0.0000802	0.00548	0.0000920

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. Societies that live on lands that are suitable for neither cereals nor roots and tubers are excluded from the sample. "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 C.10: Cereals and Surplus: OLS and 2SLS. Sample including societies living in desertic soils.

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

The table reports cross-sectional 2SLS estimates and the unit of observation is the society in Murdock's Ethnoatlas.The dependent variable is a dummy that identifies societies that produce a farming surplus. The main regressor is a dummy that identifies society in which the major crop is a cereal grain. MAX CALORIES (ALL CROPS) is the standardized maximum potential calorie yield per hectare that can be obtained from cultivating the most productive crop among cereal grains, roots and tubers. DEPENDENCE ON AGRICULTURE is the percentage calorie dependence on agriculture for subsistence. All societies included in the Ethnoatlas, for which the relevant data are available, are included in the sample. "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 C.11: Cereals and Hierarchy - Panel Regressions

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

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

Table C.12: Cereals and Hierarchy - Panel Regressions. Robustness Checks: Excluding years 1500-1750

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

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

Figure C.1: Potential yields (calories per hectare) from cereal grains.

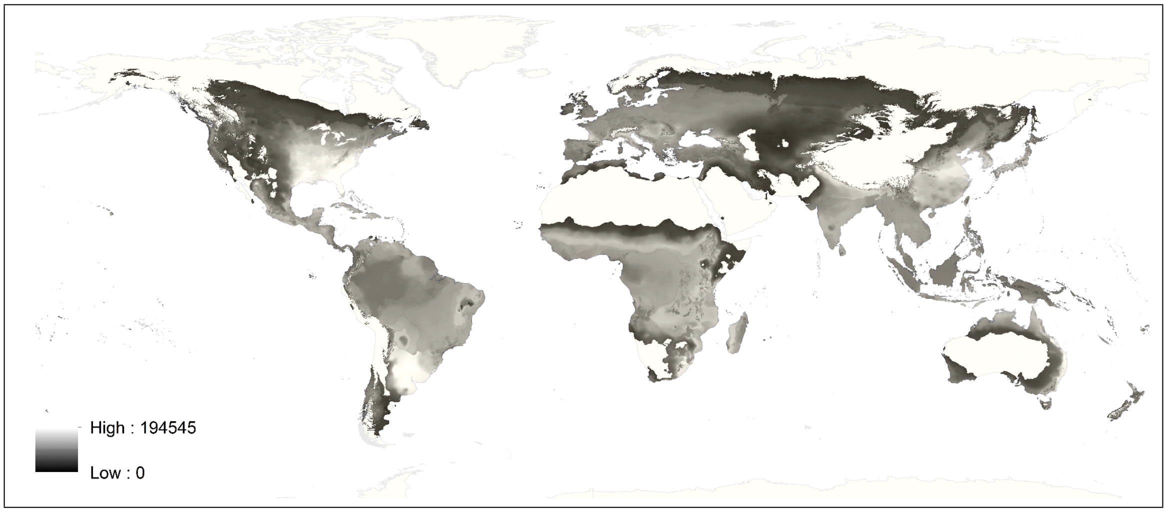

Figure C.2: Potential yields (calories per hectare) from roots and tubers

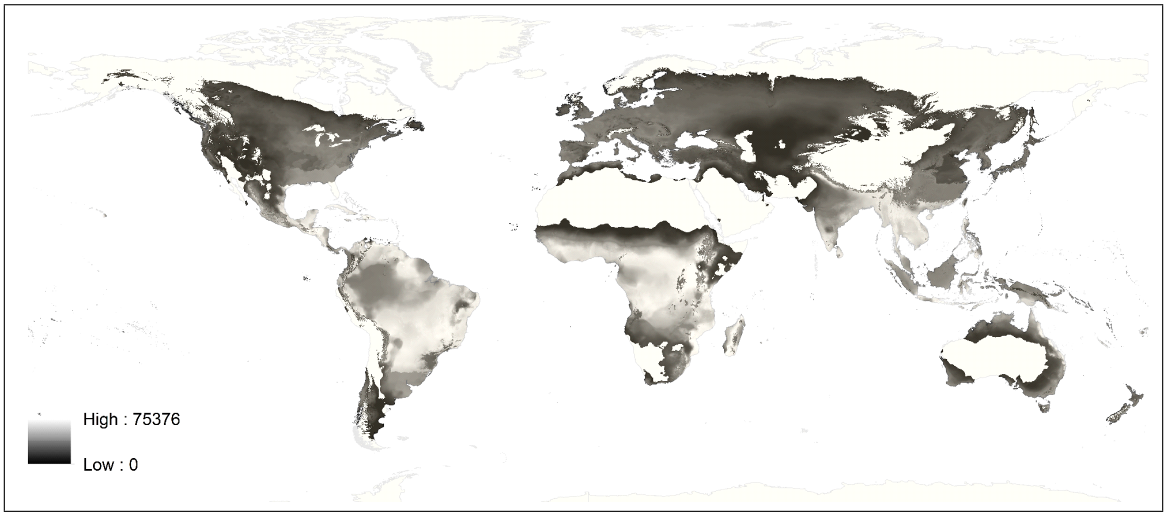

Figure C.3: Optimal crop in terms of caloric yields among cereals, roots and tubers