Overkill, Extinction, and the Neolithic Revolution[*]

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Abstract

This research explores the biogeographical origins of the emergence and diffusion of agriculture. I develop a model showing that large-herbivore extinction decreased hunting gains and permitted the agricultural transition. It also shows that mammals' biological vulnerability increased the extinction risk and promoted the transition. To test the predictions, I construct a novel measure of the loss of hunting resources resulting from mammal extinction. Using multiple datasets and exploiting the biological vulnerability as an instrument for the extinction, the research establishes a positive impact of the extinction on the timing and the likelihood of the agricultural transition. It also shows a persistent effect of the prehistoric extinction on socioeconomic development that lasted until the preindustrial period.

Keywords: Neolithic Revolution, extinction, transition, hunting, agriculture, cultivation, geography, climate, biogeography, persistence, history

JEL Codes: J10, N00, O11, O13, O40

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1 Introduction

Humans depended on hunting and gathering for 95% of the time since the origin of *Homo sapiens* 200,000 years ago (McDougall et al., 2005). The Neolithic Revolution, which is a transition from foraging to farming, is one of the most important transformations that humanity has experienced. The surplus generated by agriculture enabled a society to have non-food-producing classes that were crucial for the development of writing, science, cities, military weapons, and so forth (Diamond, 1997). The transition to agriculture preceded the emergence of states throughout the world (Borcan et al., 2021). The agricultural transition triggered the evolutionary process of human traits such as quantity/quality preference and longevity (Galor and Moav, 2002; Galor and Moav, 2007).[1] The Neolithic Revolution had a significant effect on the history of humankind and is at the roots of global inequality, due to its impact on the evolution of culture and institutions (Galor, 2022). Despite this central role of the Neolithic Revolution in humanity and the wealth of nations, we do not have a good grasp on the origin because of its complexity and data limitation. The how and the why of the agricultural transition remain among the more intriguing questions in human prehistory (Price and Bar-Yosef, 2011).

This study explores the biogeographical origins of this historic milestone. I hypothesize that the extinction of megaherbivores reduced hunting gains and permitted the Neolithic Revolution.[2] I find empirical evidence consistent with the predictions. The hypothesis has also been evoked by Vernon L. Smith (1975), the first economist who argued the origin of the agricultural transition. Furthermore, I demonstrate the long-run impact of megaherbivore extinction on socioeconomic development that lasted until the preindustrial period.

In the theoretical section, I build a model that links the agricultural transition to loss of biomass resulting from mammal extinction. The model also links the agricultural transition to the biological vulnerability of prey mammals. It shows that the vulnerability increases the extinction risk and permits the agricultural transition. Endogenous population growth is

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[1]There are further examples of the impact of the Agricultural Revolution on socioeconomic outcomes and humanity. Hibbs and Olsson (2004) and Olsson and Hibbs (2005), based on large macro regions, show the possibility that the timing of the agricultural transition explains variation in GDP per capita and in the quality of institutions today. Putterman (2008) also, using a number of countries, finds a strong positive association between the timing of the Neolithic Revolution and income. Dickens and Lagerlof (2020) find that the agricultural transition timing influenced present-day night light and population density as measured at a granular level. Olsson and Paik (2016) demonstrate that the agricultural transition has affected the norms on individualism and collectivism.

[2]Non-herbivores were likely too dangerous as prey mammals for primitive humans and reasonably they were out of food sources. Hart and Sussman (2008) provide a number of examples of non-herbivores— such as lions, tigers, and bears—hunting humans. Although many cases are of today, they indicate that in prehistoric times, humans were exposed to a much higher risk of being hunted and killed by these mammals. The number of dangerous mammals is much larger in prehistory and people were equipped with much less sophisticated weapons and shelters to protect themselves than today.

incorporated by introducing the Malthusian mechanism, in which an increase in productivity does not have any impact on income per capita.[3] Hunting by humans continuously decreases available biomass, though it recovers toward the natural level because biomass is replenishable. However, once biomass becomes so scarce that the natural birth rate is lower than the natural death rate, mammals inevitably go extinct. Permanent loss of biomass significantly decreases hunting gains, and thus some individuals begin to cultivate wild plants.

One might expect that cultivation is a temporary response to a decrease in the biological resource and that the economy will return to hunting if farmers cannot sustain the population. This scenario is possible if agricultural productivity remains low even after farming becomes an economically viable production mode for some individuals. However, once cultivation begins, the latent productivity of agriculture starts increasing via learning by doing (Dow et al., 2009). When learning by doing is fast enough, it sustains the population, and thus agriculture becomes a preferred production mode even in the long run.

Ethnographic and archaeological studies suggest that foragers enjoyed more leisure time than early farmers and that farmers did not obtain as much food as preceding foragers had (Armelagos and Cohen, 1984; Sahlins, 1972). The model also provides an explanation to this puzzle of the Neolithic Revolution: Why did early farmers decide to adopt agriculture even though it did not raise consumption but forced them to work more? While existing studies that claim the importance of greater gains from agriculture cannot explain this fact, the theory of extinction provides a simple explanation.

Although Smith (1975) argues the theoretical link between overhunting and the agricultural transition, he does not provide any data and empirical analysis. His model does not explain why the first farmers adopted agriculture even if they had to work more for less food. He also takes population pressure as an exogenous variable, which is problematic for two reasons. First, most of human history was governed by the Malthusian dynamics, in which population size is a function of income gains. Second, once population growth is endogenized through the Malthusian dynamics, his model would fail to link overhunting to the agricultural transition. This is because the Malthusian pressure and the nature of biological resources as replenishable ones allow the economy to keep enough biological resources that the society stays as a foraging society. In contrast, my model overcomes these limitations. It provides an explanation of the Neolithic puzzle. It endogenizes population growth by explicitly incorporating the Malthusian dynamics and derives testable implications that megaherbivore extinction triggered the Neolithic Revolution.

Investigating the impact of megaherbivore extinction on the agricultural transition comes with significant empirical hurdles. First, it is difficult to measure the prehistoric distribution

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[3]Since the period of the analysis is prehistory, it is natural to think that an economy was governed by the Malthusian pressure. For the empirical evidence of the existence of the Malthusian pressure in historic times, see (Ashraf and Galor, 2011).

of mammal species, their extinction status, and the loss of hunting resources resulting from extinction. Second, paleoclimatic characteristics are probably the most crucial confounding factors. Third, the observed relationship between extinction and the timing of the agricultural transition may be the result of reverse causality and endogeneity in extinction. My empirical analysis overcomes these challenges.

To deal with the first challenge, I combine datasets on the predicted spatial distribution of mammal species and their extinction status. Moreover, I calculate their predicted abundance. The Phylogenetic Atlas of Mammal Macroecology (PHYLACINE) database created by Faurby et al. (2018) provides information on the spatial distribution of all known mammal species since the last interglacial. One of the advantages of the database is that it includes range maps, which represent estimates of where species would live today if they did not experience any human influence. For the species in the PHYLACINE, the information on extinction status is available from Andermann et al. (2020). To calculate the abundance of species, I use the well-known fact that body mass is a powerful predictor of population density (Peters and Raelson, 1984; Damuth, 1987; Currie and Fritz, 1993; Silva and Downing, 1995; Silva et al., 2001; Byers and Ugan, 2005). Putting all this together enables me to construct a novel measure of biomass lost because of mammal extinction. Importantly, this measure of lost biomass is effective as long as the measure of biomass captures hunting potential in the past. Actually, the measure of megaherbivore biomass is a strong predictor of hunting dependency in traditional societies. In contrast, the association with other subsistence modes (gathering, fishing, animal husbandry, and agriculture) is not robust, or negative, if any (Kumagai, 2021). Moreover, as is explored in the data section, the measure of lost biomass resulting from megaherbivore extinction has a significant negative association with hunting dependency in traditional societies.

The second challenge is tackled by including paleoclimatic characteristics in my regressions. The data set recently developed by Beyer et al. (2020) provides a wealth of information on past climate spanning tens of thousands of years at a granular level. Climatic factors may have caused the mass extinction of mammals in the Late Pleistocene while recent economic studies demonstrate the critical role of climate in the agricultural transition. Therefore, I pay particular attention to past climate. Especially, this study uses the paleoclimatic data from Beyer et al. (2020) and directly accounts for the most important confounding factors.

The nature of the underlying data and an instrumental variable approach allow me to deal with the third challenge. The measure of interest is constructed using the *predicted* distribution of mammal species without human influence rather than the *actual* distribution. This feature alleviates the concern that agricultural activities altered the mammal distribution. Moreover, to deal with the endogeneity in extinction, I construct an instrument by replacing the actual extinction status in the measure of lost biomass with the predicted

likelihood of extinction. Motivated by the model's prediction, the predicted extinction risk is constructed based on the biological vulnerability of each species. In particular, it is calculated by regressing actual extinction status on body mass. Larger mammals are more vulnerable to hunting pressure because they tend to have: (i) longer periods of gestation and maternal care, (ii) older age at sexual maturity and the first parturition, and (iii) lower birth rate. All these characteristics decrease reproductive success. The vulnerability may have depended on the ecosystem in which mammals lived. Hence, I account for paleo-net primary production, which is a proxy for the productivity of ecosystem (Rosenzweig et al., 2012). Therefore, conditional on the ecosystem, the vulnerability is plausibly exogenous.

I account for a number of possible geographic confounding factors. Especially, given the possibility that geographical proximity to agricultural centers governs the observed association between the agricultural transition and extinction, I account for distance from the closest agricultural center. Furthermore, to deal with the possibility that the duration of human existence had affected the degree of extinction and likelihood of the agricultural transition, I control for migratory distance from East Africa. Out-migration is another concern because it makes the interpretation of lost biomass difficult. In particular, individuals may have moved when prey mammals became scarce. To deal with this issue, I account for biomass in surrounding regions. Since biomass is a strong predictor of hunting dependency in traditional societies, including neighboring regions' biomass controls for the incentive for out-migration.

My research, conducting cross-sectional and panel analyses, establishes in multiple ways that lost biomass due to megaherbivore extinction affected the onset and diffusion of agriculture. The analysis starts with a cross-section analysis across countries, which provides a global picture of the association between megaherbivore extinction and the timing of the agricultural transition. Since a country is a noisy proxy for the timing of the transition, I complement it with a cross-sectional analysis across archaeological sites, as the unit of analysis is closer to ideal. These analyses are complementary because the spatial coverage of the archaeological sites is only parts of Europe and the Middle East. Thus, it is much more limited than the global coverage of the country data.

Then I turn to a panel analysis by constructing country, archaeological-site and virtual-country (cell) panel data sets. Extinction, by its nature, is a *change* in the biological resource and is thus captured better in a panel setting than in a cross section. The panel also captures changes in paleoclimatic characteristics while the cross section does not capture them well. Thus, the analysis provides further robustness to controlling for paleoclimatic features. Unlike the country and archaeological-site panels, the virtual-country panel uses only variation in *independent* agricultural transitions across the globe. Therefore, the virtual-country panel analysis shows that loss of biomass resulting from megaherbivore extinction

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had a positive impact on the emergence of agriculture rather than its diffusion.

Having established a robust association of lost biomass with the timing and the likelihood of the agricultural transition, the research then explores the persistent effect of megaherbivore extinction on socio-economic development. I first use the data on radiocarbon-dated prehistoric and protohistoric archaeological sites reported by Whitehouse and Whitehouse (1975). Conducting a difference-in-differences regression, I show that the Neolithic Revolution led to more visible traces of human societies in areas that experienced larger biomass loss associated with megaherbivore extinction. Second, using the *Ethnographic Atlas*, I examine the association between megaherbivore extinction and ethnographic traits. Particularly, I show that the prehistoric extinction of megaherbivores had a long-lasting effect on the degree of centralization, hierarchy, and community size in preindustrial societies.

This research relates to several strands of literature. First, it connects to the literature exploring the origin of the Neolithic Revolution. The origin of agriculture is among the most hotly debated multidisciplinary topics, and it is related to economics, evolutionary biology, archaeology, anthropology, and other disciplines (for the survey in evolutionary biology, archaeology, and anthropology, see Weisdorf, 2005; Price and Bar-Yosef, 2011). The first economic study is by Smith (1975), who theoretically examines an economic incentive to overhunt prey mammals. The author links mammal extinction to the agricultural transition. Dow et al. (2009) theorize that agriculture occurred in areas that experienced an initial climatic improvement and subsequent climatic reversal. Ashraf and Michalopoulos (2015) show a hump-shaped relationship between climatic volatility and the timing of the agricultural transition. Matranga (2017) argues that climatic seasonality leads to sedentary settlements and hence it is conducive to the agricultural transition. Bowles and Choi (2019) theorize that farming facilitates and stabilizes private property and that these features promoted the agricultural transition. Riahi (2020) is another work that studies mammal extinction. The author finds an inverted-U-shaped association between it and the agricultural transition.[4] My research contributes to this literature by presenting the first empirical evidence for Smith's classic work that posits that the extinction of large mammals led to the Neolithic Revolution.

Second, my research relates to the literature examining the biogeographical origins of

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[4]Riahi's study and my study are different in many ways. First, his conceptual argument is mainly about the association between extinction and agricultural transition across continents; mine is related to the association both across continents and within a continent. Second, he considers all the large mammals while my focus is large herbivores. Third, his interest is in the extinction rates for large mammals which is the percentage of the total number of large species that have gone extinct, and his study does not capture the abundance and available energy of each species. My interest is in lost biomass and it captures both the abundance and available energy of each species. Fourth, he looks at only cross-sectional variation in extinction; I use variation both in space and time. Last, his unit of analysis is a large region that corresponds to a modern-day country. I use multiple units of analysis such as country, archaeological site, and virtual country (cell).

socioeconomic development. Diamond (1997) highlights the role of availability of domesticable animals and plants in the emergence of agriculture, institutions, the state, and so forth. Alsan (2015) finds that the prevalence of the tsetse fly in Africa reduced agricultural productivity, which in turn reduced political centralization and population density. Link (2022) empirically finds that the existence of transport mammals promoted long-distance trade and social hierarchy. My research contributes to this literature by presenting evidence that variation in loss of biogeographical resources promoted socioeconomic development.

Last, this paper connects to the persistence literature (see Voth, 2021, for a recent survey). Acemoglu et al. (2001) show the long-lasting effect of colonial institutions brought by European immigrants on economic performance.[5] Comin et al. (2010) find that historical adoption of technology has a significant impact on contemporary economic outcomes. Putterman and Weil (2010), based on a global sample, show countries whose territories agriculture and state developed earlier have higher incomes. Ashraf and Galor (2013) show that population diversity determined tens of thousands years ago has a hump-shaped association with economic development today. My research contributes to this literature by presenting evidence that prehistoric loss of hunting resources had a persistent effect on socioeconomic development until the preindustrial era.

The rest of the paper is organized as follows. Section 2 provides historical evidence on the chronology of large-herbivore extinction and pristine agricultural transitions. Section 3 develops the model of the transition from foraging to agriculture. Section 4 describes the data sets and construction of the main variables. Section 5 presents empirical evidence of the association between the agricultural transition and megaherbivore extinction, using cross-sectional and panel data. Section 6 examines the persistence effect of prehistoric loss of biomass on socioeconomic outcomes. Section 7 concludes.

2   Historical Evidence

In this section, I summarize the historical records of large-herbivore extinction and independent adoptions of agriculture for the following regions: the Levant, the Andes, North China, South-central China, Mesoamerica, Eastern North America, and the Sahel region. Although there are other possible places of the pristine agricultural transition, Purugganan and Fuller (2009) state that these places are well-accepted primary domestication centers, and Matranga (2017) uses these seven regions to examine the association between climatic seasonality and the emergence of agriculture. New Guinea, Japan, and south and southeast India are sometimes considered to be places of pristine transitions. In this section,

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[5]Chanda et al. (2014)'s result raises doubt about the reversal of fortune caused by the institutions. Their result supports that human capital is more fundamental than the quality of institutions.

following Matranga (2017), I describe historical and archaeological examples for only these seven regions. As shown in Figure 3, however, the data shows positive correlation between the extinction and the pristine transition in New Guinea, Japan, and south and southeast India. Therefore, including these regions would strengthen the argument. In many cases, whether humans were the ultimate causes of mammal extinction is disputable. Therefore, the purpose of this section is not to present the evidence that humans caused megaherbivore extinction. Instead of this, I present historical and archaeological evidence to support the sequence of megaherbivore extinction and the pristine transition to agriculture.

2.1 The Levant

The Levant is the best-known region that experienced the earliest transition to agriculture. This region is generally characterized by biogeographically, geographically, and climatically suitable conditions for agriculture. Some sites contain incontestable evidence of a set of domesticated crops and animals including barley, emmer wheat, einkorn wheat, flax, lentils, peas, goats, sheep, cattle, and pigs during the Pre-Pottery Neolithic B (PPNB; ca. 10,450-8,950 BP). Moreover, domesticated characteristics were already present in a few sites by 10,450 BP. Therefore, by 10,950-9,250 BP, domesticated crops had attained dominant roles in human subsistence within the Levant (Asouti and Fuller (2012); Bellwood (2006)).

The Levant experienced the shift from large to small animals in prehistoric times because of an overall increase in hunting of large mammals. Before the Pre-Pottery Neolithic A (PPNA; ca. 11,450-10,450 BP), people primarily depended on large species such as equids and aurochs. However, these mammals became rare and in some cases extinct because of intensive hunting. As a result, in the PPNA people were dependent upon small animals such as birds and fish (Davis et al., 1988). Some large herbivores disappeared from this region in the Late Pleistocene. In several areas in northern and central Israel—such as Mount Carmel, Ein Gev, and Fazael—there was a marked decrease in the number of, or even disappearance of, a deer species including some gazelle around 12-10,000 BP (Davis, 1982). Another example of extinction in this period is *Equus hydruntinus*, which survived until around 12,000 BP in northern Israel (Davis, 1980). The chronology and the shift of subsistence modes in the Levant are consistent with the proposed theory.

2.2 Eastern North America

Eastern North America saw independent domestication of several plants. Radiocarbon and archaeobotanical evidence show that the following plants were cultivated: marshelder (*Iva annua*), chenopod (*Chenopodium berlandieri*), squash (*Cucurbita pepo*), sunflower (*Helianthus annuus*), and bottle gourd (*Lagenaria siceraria*) (Smith and Yarnell, 2009). Genetic

and archaeological evidence, in particular, suggest that marshelder, chenopod, squash, and sunflower were independently domesticated and that they had been domesticated by approximately 4,400, 3,700, 5,000, and 4,800 BP, respectively.

The Americas are the main regions subject to Paul Martin's overkill hypothesis, according to which humans were the cause of megafauna extinction in the Pleistocene (Martin, 1967a; Mosimann and Martin, 1975; Martin and Klein, 1984). The initial colonization of North America by humans occurred about 15,000-13,000 BP (Braje and Erlandson, 2013; Stuart, 2015; Smith et al., 2018). Megafauna abruptly became extinct, and North America lost approximately three genera of elephants, six of giant edentates, fifteen of ungulates, and various giant rodents and carnivores. These extinctions between 11,450 and 10,450 BP coincide with the age of the Clovis foragers, who depended on large animal hunting as a subsistence mode (Davis, 2012). In eastern North America, for instance, *Cervalces scotti*, *Megalonyx jeffersonii*, *Platygonus compressus*, *Mylohyus nasutus*, *Castoroides ohioensis*, and *Mammut americanum* went extinct approximately 11,405, 11,430, 11,130, 11,860, 10,850, and 10,970 BP, respectively (Fiedel, 2009).

There are not many kill sites that show that humans were responsible for these extinction, and thus whether humans caused all these extinctions is disputable. However, the eastern North America case provides consistent chronology of extinction of large herbivore, plant cultivation, domestication and agriculture.

2.3   Mesoamerica

Maize (*Zea mays L.*) and squash (*Cucurbita spp.*) were the first crops to be domesticated in Mesoamerica. Strong evidence of the domestication comes from starch grain and phytolith residues from the ground and chipped stone tools found at the Xihuatoxtla Shelter in southwestern Mexico. They indicate that these crops had been domesticated by approximately 8,700 BP (Ranere et al., 2009).[6] Paleoecological and archaeological records also show evidence of agricultural intensification after this period. Between 7,000 and 5,550 BP, levels of the Asteraceae family of weeds increased, maize-pollen accumulation increased, and carbon deposits decreased. During a similar time period, new tool kits began to appear, such as levers, bifacial knives, and grinding handstones. These records indicate agriculture intensified during this period (Zizumbo-Villarreal and Colunga-GarcíaMarín, 2010).

Human skeletal remains found in caves near Tulum in Mexico indicate that humans were present in Mesoamerica as long ago as 13,000 BP (Stinnesbeck et al., 2017). There are many mammoth localities in Mexico, and some indicate mammoth-human relationships.

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[6]Based on molecular clock analysis, Zizumbo-Villarreal and Colunga-GarcíaMarín (2010) argue that wild and domesticated maize populations genetically separated by c. 9000 BP. This estimate is consistent with the result by Ranere et al., 2009.

Mammoth skeletons found at Santa Isabel Iztapa date to about 9,000 BP and earlier, and the skeletons had possible cut marks on the epiphyses and articulating facets of the long bones. Likewise, a tusk and a mandible found at La Villa de Guadalupe show extensive cut marks, and they have been dated to 11,320 BP (Arroyo-Cabrales et al. (2006)). El Fin del Mundo in the Mexican state of Sonora provides further evidence of the relationship between humans and large herbivores. Artifacts found in association with bones indicate that the Clovis people hunted gomphotheres (*Cuvieronius*) until c. 11,550 BP (Sanchez et al., 2014).

Mesoamerica is a good example of a sequential shift of human subsistence mode. Zizumbo-Villarreal and Colunga-GarcíaMarín (2010) argue that the Clovis people originally hunted large mammals. Because of mass extinction, they shifted to hunting small game and gathering in the dry tropical forest of the Balsal-Jalisco. Then the Clovis started plant domestication and agriculture in approximately 10,000 BP.[7]

2.4   The Andes

The history of agricultural transition in South America is not simple, and the dates of cultivation and domestication are differ a lot among species (Larson et al., 2014). Nevertheless, multifaceted archaeobotanical and artificial records indicate that the Andes is a center of pristine agriculture. In the Zaña Valley of Peru, by 8,800-7,600 BP a significant number of dietary calories and nutrients were coming from crop plants such as *Phaseolus*, *Cucurbita moschata*, peanuts, and *Inga feuillea* (Piperno, 2011). In northern and central Peru, irrigated agriculture had been practiced since the Late Preceramic Period. Subsistence depended on squash, beans, sweet potatoes, potatoes, achira, chili peppers, and avocados, and hence the region was home to large agricultural polities by 2000 BC (Bellwood, 2006).

South America was colonized by humans about 12,900-11,500 BP (Grayson and Meltzer, 2002; Barnosky et al., 2004), and there are many sites with remains of large mammals. The associations between humans and extinct megafauna are generally accepted (Koch and Barnosky, 2006). As for the Andean regions, the Quebrada Santa Julia and Cueva del Milodon in Chile are good examples of associations between artifacts and megafauna bones. For these sites, associated dates are about 10,200-11,090 BP (Fiedel, 2009). Given the available evidence, Fiedel favors the view that the Clovis people and their descendants caused the extinction of megafauna in South America. In the Andes, the chronology of human colonization, megaherbivore extinction and the beginnings of cultivation, domestication and agriculture is consistent with the proposed theory.

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[7]Piperno (2011) gives a similar argument based on the region from the Central Balsas of southwest Mexico to Bolivia.

2.5 North and South-Central China

In northern China, early agricultural activities started focusing on millets along the Yellow River by c. 8,000 BP; by this time, domestic pigs were prevalent (Larson et al., 2010). Zhao (2011) argues that the origin of dry-land agriculture in North China should be divided into three periods. The first period is cultivation and domestication of millet starting around 10,000 BP. The second period is a transitional phase from hunting and gathering to dry-land agriculture between 9,000 and 7,000 BP. The final period is from 7,000 to 6,000 BP, when millet-farming-based subsistence agriculture was established, which is consistent with estimates by Liu et al. (2012).

In south-central China, rice was first domesticated along the Yangze River. Sedentary hunter-gatherers started rice cultivation by c. 6,000 BP, and as in North China, pigs were domesticated in this region by at least 8,000 BP (Larson et al., 2010). Zhao (2011) argues that the origin of rice agriculture should be divided into three periods. The first is rice cultivation starting about 10,000 BP. The second, between 9,000 and 6,500 BP, is a transitional period from hunting and gathering to rice agriculture. The final period runs from 6,500 to 4,500 BP, when rice-agriculture-based subsistence was established. Zhao also states that the region fully shifted to rice agriculture about 6,400-5,300 BP.

Modern humans were present in China by at least 40,000 BP, and there is archaeological evidence for human hunting of large mammals across the Late Pleistocene and Pleistocene-Holocene transition (Turvey et al., 2013). Turvey et al. (2013)'s analyses indicate that both in northern and south-central China, megafauna that had been previously thought to be Holocene survivors were likely extinct before the Holocene. For example, from the assemblage found at Gulin, in Sichuan Province, they argue that megaherbivores such as *Megatapirus augustus, Rhinoceros sinensis,* and *Stegodon orientalis* became extinct by at least 10,175 BP. Kuzmin (2010) show that ^{14}C date on the rhinoceros bone found at the Hutouliang locality is approximately 11,000 BP, and argue that this date is likely to become older.

2.6 The Sahel

Although the Sahara today is a hot desert, this has not always been the case. During the 'African Humid Period,' which began in approximately 12,000 BP, the Sahara was wetter and covered by grasses, trees, and lakes; it has been called the 'Green Sahara.' (Manning and Timpson, 2014). This humid period abruptly ended around 6,000-5,000 BP, which made the region barren and lakes dried up. The first indigenous African crop appeared in the Sahara: pearl millet (*Pennisetum glaucum*). This crop is highly adapted to drought and poor soils, growing even in dry areas such as the Sahara after the African Humid Period

(Garí, 2002). Several studies show that domestication of pearl millet began at least as far back as approximately 4,500 BP (Manning et al., 2011; Fuller and Hildebrand, 2013).

The history of megafauna extinction in Africa seems different from that of other continents. Generally, Africa lost less megafauna than other continents, and it is considered 'a fortunate anomaly' (Faith (2014)). Many regions of Sub-Saharan Africa support the most diversity of terrestrial megafauna today (Faurby and Svenning, 2015). However, North Africa lost some large herbivores, although they have received the least attention. For instance, *Syncerus antiquus* and *Equus algericus* went extinct approximately 5,400 BP. When it comes to more local extinction, there are possibly more extinct megaherbivores in the Late Pleistocene and early Holocene such as *Bos primigenius* and *Equus mauritanicus* (Faith (2014)).

Due to the limited academic attention and archaeological records, it is difficult to understand megaherbivore extinction in Africa for now. However, the available evidence indicates the possibility of megaherbivore extinction in the Sahel region, followed by domestication of some plant crops.

3   The Model

This section provides the basic structure of a theory that explains the transition from a hunting to an agricultural regime. It shows that a sever mammal extinction leads to the transition. The model identifies the role of biological vulnerability in the variation in extinction and the emergence of the agricultural transition. It explicitly incorporates the Malthusian pressure and endogenizes population growth. It also provides a simple explanation of the fact that the first farmers adopted agriculture even if they had to work more without any increase in food.

Consider an overlapping-generations economy in which economic activity extends over infinite discrete time. The economy is composed of multiple species of megaherbivores. In every period, the economy produces a single homogenous final good from two possible production technologies: hunting (denoted as sector h) and agriculture (denoted as sector a). Hunting requires land, biomass, and labor as inputs, while agriculture requires land and labor as an inputs. The supply of land is exogenous and fixed over time. Biomass is a replenishable biological resource. The labor allocation is determined by the relative productivity of hunting and agriculture.

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3.1 Production of Final Output

In the hunting sector, production takes the form of a Cobb-Douglas function. The output produced at time t, Y_t^h, is

$$Y_t^h = A^h(B_t X^h)^\alpha (L_t^h)^{1-\alpha} \equiv Y^h(B_t, L_t^h; A^h, X^h), \qquad (1)$$

where A^h is the technological level of the hunting sector at time t, B_t is the stock of biomass at time t, X^h is the land employed in hunting, which for simplicity is normalized to 1, L_t^h is the labor force in the hunting sector at time t, and $\alpha \in (0, 1)$.

I focus on megaherbivores as prey because of the following observation.[8] Large mammals are economically more valuable. Their meat provides more calories and nutrition for humans than small mammals. Archaeological evidence shows that most extinct mammals in prehistoric times fall in this category (Martin, 1967b). Non-herbivores were likely too dangerous as prey mammals for early hunters and reasonably they were out of food sources.[9] Therefore, megaherbivores were hunters' main targets. The stock of biomass, B_t, is thus interpreted as megaherbivore biomass.

Output per hunter produced at time t, y_t^h, is

$$y_t^h = A^h B_t^\alpha (L_t^h)^{-\alpha} \equiv y^h(B_t, L_t^h; A^h). \qquad (2)$$

In a primitive society, there are no property rights over land, and hence the return to land is zero. Thus, the return per hunter is equal to the average product of labor engaged in hunting.

In the agricultural sector, land is abundant for farming purposes, particularly during the transition phase to agriculture. Thus, land is not a binding factor for production, implying constant returns to labor.[10] The output produced at time t, Y_t^a, is

$$Y_t^a = A_t^a X^a L_t^a \equiv Y^a(L_t^a; A_t^a, X^a), \qquad (3)$$

where A_t^a is the technological level in the agricultural sector at time t, X^a is land for farming,

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[8]The formal definition of megaherbivores is herbivores larger than 44 kg. This threshold is standard in the definition of megafauna, which are large terrestrial mammals (Faurby and Svenning, 2015).

[9]Martin (1967b) argues that the extinction of non-herbivores such as sabor-toothed tigers was a consequence of the extinction of megaherbivores that predator mammals depended on as food sources. Hart and Sussman (2008) provide a number of examples of non-herbivores—such as lions, tigers, and bears—hunting humans. Although many cases are of today, they indicate that in prehistoric times, humans were exposed to a much higher risk of being hunted and killed by these mammals. The number of dangerous mammals is much larger in prehistory and people were equipped with much less sophisticated weapons and shelters to protect themselves than today.

[10]This assumption has been widely accepted in the related literature (Weisdorf, 2005).

and L_t^a is labor force in the hunting sector at time t. When agriculture is practiced, the return per farmer at time t is equal to the average product of labor employed in agriculture at time t. Output per farmer produced at time t, y_t^a, is

$$y_t^a = A_t^a X^a \equiv y^a(A_t^a, X^a). \tag{4}$$

When agriculture is not economically viable, there is no technological progress in that sector. However, once cultivation occurs, it starts gradually increasing through learning by doing.[11] Hence, growth of agricultural technology is modeled as

$$A_{t+1}^a = F(A_t^a, L_t^a), \tag{5}$$

where $A_{t+1}^a = F(A_t^a, L_t^a) = A_t^a$ if $L_t^a = 0$, and $\partial F(A_t^a, L_t^a)/\partial L_t^a > 0$ if $L_t^a > 0$. Thus, when agriculture is latent, its productivity remains constant. When it is active, its productivity increases, especially when more labor is employed in it.

3.2 Evolution of the Biological Stock

In a natural equilibrium, biomass is stable at the maximum level supported by regional ecology. The amount of biomass declines when humans hunt mammals. Since biomass is a replenishable biological stock, it tends to recover toward its natural level when some of it is lost. However if enough is lost, it cannot replenish itself. Hence, the law of evolution of biomass is

$$B_{t+1} = \begin{cases} B_t + \kappa(v)(\overline{B} - B_t) - A^h B_t^\alpha (L_t^h)^{1-\alpha} & \text{if } B_t > B^*(v) \\ B_t - A^h B_t^\alpha (L_t^h)^{1-\alpha} & \text{if } B_t \leq B^*(v), \end{cases} \tag{6}$$

where κ is the rate of replenishment, $\overline{B}$ is the highest level of biomass sustained in a natural equilibrium, B^* is the threshold below which biological resources are not self-supported, v is the degree of biological vulnerability of mammals.

As long as biomass in period t, B_t, is larger than the biological threshold, B^*, some amount of biomass will recover at the natural replenishment rate of $\kappa(v)$, while biomass declines by the amount of hunting products, $A^h B_t^\alpha (L_t^h)^{1-\alpha}$. Therefore, whether the stock of biomass in the next period increases depends on the degree of biological recovery and

---

[11]Dow et al. (2009) theorize this aspect of agricultural technology. As examples of technologies improved by learning by doing, they mention optimal times for planting and harvesting; optimal locations; correct spacing and depth of seeds; the best methods of weeding; fertilizing; irrigating; artificial selection on the genetic traits of plants; and others. In contrast, the role of learning by doing in the hunting sector was much more limited. Including the evolution of hunting productivity does not change the qualitative results, but adds some complexity. Hence, I do not explicitly treat the evolution of hunting technology in the model.

hunting products. In contrast, once biomass becomes smaller than the biological threshold, the natural birth rate falls below the natural death rate (Koch and Barnosky, 2006). Thus, biomass never recovers toward the natural level. Humans keep hunting mammals, and biomass declines by the amount of hunting products.

Define $\mathcal{J}$ as the set of species in the economy. Each species $j \in \mathcal{J}$ has its own biological vulnerability, v_j. The vulnerability of the economy is an aggregated value of each species' vulnerability. Hence, it is expressed as $v = \mathbf{E}[v_j] = \frac{1}{N} \sum_{j \in \mathcal{J}} v_j N_j$, where N_j is the number of individuals of species j and $N = \sum_{j \in \mathcal{J}} N_j$. Higher vulnerability is to be interpreted as longer gestation periods, longer maternal care periods, older age at sexual maturity, fewer children per birth, and so on. All these factors reduce reproductive success. Therefore, the rate of replenishment, κ, is a decreasing function of v. Moreover, once biomass gets smaller than the biological threshold, B^*, it is not self-replenishing anymore. Hence, if the economy is characterized by higher biological vulnerability, it tends to cross this threshold more easily.

Hence, I assume

$$\frac{\partial \kappa(v)}{\partial v} < 0 \ \ and \ \ \frac{\partial B^*(v)}{\partial v} > 0. \tag{7}$$

3.3   Preferences and Constraints

In each period t, a generation consisting of L_t identical individuals joins the labor force. Each individual has a single parent, and members of generation t live for two periods. In the first period (childhood), $t-1$, individuals are economically inactive. In the second period (adulthood), t, individuals are endowed with one unit of time, which they optimally allocate between child-rearing and labor force participation.

The preferences of members of generation t are defined over consumption, leisure, and the number of their children. Their utilities are represented by the function

$$u_t = (1 - \gamma)(\ln c_t + \beta \ln l_t) + \gamma \ln n_t, \tag{8}$$

where c_t is the consumption of an individual of generation t, l_t is the leisure time, n_t is the number of children, and $\gamma, \beta \in (0, 1)$.

Income for a member of generation t, y_t, is the amount earned by supplying labor to the sector that produces higher output per individual. Child-rearing is costly and requires a fraction p of parental income per child. Individuals spend their time on work, child-rearing, and leisure. They use the income for consumption. Thus, in the second period of life, the individual faces the budget constraint

$$c_t \leq y_t(1 - pn_t - l_t), \tag{9}$$

where $y_t = \max\{y^h(B_t, L_t^h; A^h), y^a(A_t^a, X^a)\}$.

3.4 Optimization

Members of generation t choose their number of children, leisure time, and their own consumption to maximize their utility function subject to the budget constraint and subsistence-consumption constraint. Substituting (9) into (8), the optimization problem of a member of generation t is

$$
\begin{aligned}
\max_{n_t, l_t} \quad & (1-\gamma)\ln y_t(1 - pn_t - l_t) + (1-\gamma)\beta \ln l_t + \gamma \ln n_t \\
subject\ to \quad & y_t(1 - pn_t - l_t) \geq \tilde{c}; \\
& n_t, l_t \geq 0.
\end{aligned}
\tag{10}
$$

Let $\tilde{y}$ be the level of income above which the subsistence constraint is not binding; that is, $\tilde{y} = \tilde{c}[1 + (1-\gamma)\beta]/(1-\gamma)$. Define worktime as $w_t = 1 - pn_t - l_t$. It follows that for $y_t \geq \tilde{c}$,

$$
(c_t^*, n_t^*, l_t^*, w_t^*) =
\begin{cases}
\left(\frac{1-\gamma}{1+\beta-\gamma\beta} y_t, \frac{\gamma}{p(1+\beta-\gamma\beta)}, \frac{\beta(1-\gamma)}{1+\beta-\gamma\beta}, \frac{1-\gamma}{1+\beta-\gamma\beta} \right) & if \quad y_t \geq \tilde{y} \\[4mm]
\left(\tilde{c}, \frac{\gamma}{p[\gamma+\beta(1-\gamma)]} \left(1 - \frac{\tilde{c}}{y_t}\right), \frac{\beta(1-\gamma)}{\gamma+\beta(1-\gamma)} \left(1 - \frac{\tilde{c}}{y_t}\right), \frac{\tilde{c}}{y_t} \right) & if \quad y_t \leq \tilde{y}.
\end{cases}
\tag{11}
$$

As long as the income of a member of generation t is below $\tilde{y}$, the subsistence consumption is binding. As y_t increases (but remains below $\tilde{y}$), the individual spends a larger fraction of income for child rearing and leisure while maintaining subsistence consumption. As a result, they work less as they earn more income. In contrast, when y_t is larger than $\tilde{y}$, the number of children, leisure, and worktime are constant while an increase in income is devoted to consumption.

The focus of the model is the transitional phase from foraging to agriculture, and this period is governed by the Malthusian mechanism (Ashraf and Galor, 2011), in which the subsistence constraint is binding and the income elasticity of demand for children is positive. Therefore, I assume

$$
\tilde{c} \leq y_t \leq \tilde{y}.
\tag{12}
$$

Under this assumption, leisure is also a normal good, which is consistent with ethnographic studies (Sahlins, 1972).

3.5 Evolution of the Population

The evolution of the working population over time is

$$L_{t+1} = n(y_t)L_t, \tag{13}$$

where $L_t = L_t^h + L_t^a$ is the size of the population in period t. Given the optimal fertility choice, (11), and the Malthusian regime, (12), the dynamics of the population become

$$L_{t+1} = \frac{\gamma}{p[\gamma + \beta(1 - \gamma)]} \left(1 - \frac{\tilde{c}}{y_t}\right) L_t. \tag{14}$$

3.6 The Dynamic System

The development of the economy is governed by the endogenous evolution of the biological stock, the size of the population, and the level of agricultural technology. Therefore, the dynamics of the economy are fully determined by the sequence $\{B_t, L_t, A_t^a\}_{t=0}^{\infty}$ that satisfies (5), (6) and (14).

3.6.1 The Replacement Frontier

The *Replacement Frontier* is the geometric locus of (B_t, L_t) such that, given the latency of agriculture (that is, $y^h(B_t, L_t; A^h) > y^a(A_t^a, X^a)$), the fertility rate of members of generation t is at the replacement level (that is, $n(y_t) = n[y^h(B_t, L_t; A^h)] = 1$).

Hence, using (11), the set of (B_t, L_t) on the Replacement Frontier is expressed as

$$LL \equiv \left\{ (B_t, L_t) : L_t = \left(\frac{A^h}{\tilde{c}} \left(1 - \frac{p\left(\gamma + \beta(1 - \gamma)\right)}{\gamma} \right) \right)^{\frac{1}{\alpha}} B_t \right\}. \tag{15}$$

Let (B_t^{LL}, L_t^{LL}) be a pair of biomass and population size at time t in LL. Then, the direction of the evolution of the population size is determined by the following lemma.

Lemma 1 *Given (B_t, L_t), A^h, and A_t^a such that $y^h(B_t, L_t; A^h) > y^a(A_t^a, X^a)$,*

$$L_{t+1} \gtreqless L_t \Leftrightarrow L_t \lesseqgtr L_t^{LL}. \tag{16}$$

Proof. Since $\partial n(y_t)/\partial y_t > 0$ and $\partial y^h(B_t, L_t; A^h)/\partial L_t < 0$, the lemma follows from (14). ∎

3.6.2 The Biologically Stable Frontier

The *Biologically Stable Frontier* is the geometric locus of (B_t, L_t) such that, given the latency of agriculture, the biological resource is at the equilibrium level (that is, $\Delta \equiv B_{t+1} - B_t = 0$).

Hence, for $B_t > B^*$, using (6), the set of (B_t, L_t) on the Biologically Stable Frontier is expressed as

$$BB \equiv \left\{ (B_t, L_t) : L_t = \left[\frac{\kappa(v)}{A^h} \right]^{\frac{1}{1-\alpha}} B_t^{-\frac{\alpha}{1-\alpha}} (\overline{B} - B_t) \right\}. \tag{17}$$

In contrast, for $B_t \leq B^*$, it is expressed by $L_t = 0$ or $B_t = 0$.

Consider the case where $B_t > B^*$. Let (B_t^{BB}, L_t^{BB}) be a pair of biomass and population size at time t in BB. By calculating the first and second derivatives in terms of B_t and v, I can show that

$$\frac{\partial L_t^{BB}}{\partial B_t^{BB}} < 0, \qquad \frac{\partial^2 L_t^{BB}}{\partial (B_t^{BB})^2} > 0 \qquad and \qquad \frac{\partial L_t^{BB}}{\partial v} < 0. \tag{18}$$

Therefore, the Biologically Stable Frontier for $B_t > B^*$ is composed of a strictly convex, downward-sloping curve, which shifts downward as v increases.

The direction of the evolution of biomass is determined by the following lemma.

Lemma 2 *Given (B_t, L_t), A^h, and A_t^a, for $B_t > B^*$,*

$$B_{t+1} \gtreqqless B_t \Leftrightarrow B_t \lesseqqgtr B_t^{BB}.$$

For $B_t \leq B^*$, $B_{t+1} < B_t$.

Proof. The lemma follows from (6). ∎

3.6.3 The Hunting-Farming Frontier

The *Hunting-Farming Frontier* is the geometric locus of (B_t, L_t) such that, given exclusive employment of the labor force in the hunting sector (that is, $L_t = L_t^h$), a member of generation t is indifferent between supplying their labor to the hunting sector and supplying it to the agricultural sector (that is, $y^h(B_t, L_t; A^h) = y^a(A_t^a, X^a)$).

Hence, using (2) and (4), the set of (B_t, L_t) on the Hunting-Farming Frontier is expressed as

$$yy \equiv \left\{ (B_t, L_t) : L_t = \left(\frac{A^h}{A_t^a X^a} \right)^{\frac{1}{\alpha}} B_t \right\}. \tag{19}$$

Let (B_t^{yy}, L_t^{yy}) be the pair of biomass and population size at time t in yy. Taking the first derivative with respect to A_t^a yields

$$\frac{\partial L_t^{yy}}{\partial A_t^a} < 0. \tag{20}$$

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The average productivity of hunting in relation to agriculture is determined by the following lemma.

Lemma 3 *Given (B_t, L_t), A^h, and A_t^a,*

$$y^h(B_t, L_t; A^h) \gtreqqless y^a(A_t^a, X^a) \Leftrightarrow L_t \lesseqqgtr L_t^{yy}. \tag{21}$$

Proof. The lemma follows from $\partial y^h(B_t, L_t; A^h)/\partial L_t < 0$. ∎

Lemma 3 implies that a threshold level of L_t exists that is uniquely determined by each B_t and above which agriculture is a better subsistence mode than hunting. It also implies that the locus satisfying this association is given by the functional form in (19).

The following lemma summarizes the relationships between the Replacement Frontier, the Hunting-Farming Frontier and the fertility of individuals who engage in agriculture.

Lemma 4 *Given (B_t, L_t), A^h, and A_t^a,*

$$y^h(B_t^{LL}, L_t^{LL}; A^h) \gtreqqless y^a(A_t^a, X^a) \Leftrightarrow L_t^{yy} \gtreqqless L_t^{LL} \Leftrightarrow n\left[y^a(A_t^a, X^a)\right] \lesseqqgtr 1. \tag{22}$$

Proof. Noticing that

$$y^h(B_t^{LL}, L_t^{LL}; A^h) = \tilde{c}\left(1 - \frac{p(\gamma + \beta(1-\gamma))}{\gamma}\right)^{-1},$$

the lemma follows from (4), (15) and (19). ∎

Initially, agriculture is not productive and thus not economically viable. As long as it is latent, there is no technological improvement and thus the level of agricultural technology at time t is constant at the initial level. Therefore, I assume that as long as agriculture is latent, $n[y^a(A_t^a, X^a)] < 1$. By Lemma (4), it implies that $L_t^{yy} > L_t^{LL}$.

3.7   Transition to Agriculture

This section explores the impact of mammal extinction and biological vulnerability on the timing of the agricultural transition, based on the framework established in the previous subsection.

3.7.1   The Effect of Extinction on the Agricultural Transition

Figure 1 depicts the Replacement Frontier, the Biologically Stable Frontier, the Hunting-Farming Frontier, and a trajectory of the economy, showing the impact of extinction on the agricultural transition. Since $\overline{B}$ is the highest level of biomass sustained by a given ecological environment, it is a natural initial level of biomass. Therefore I assume that an

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(i) No Extinction   (ii) Extinction

(iii) Extinction and Learning by Doing
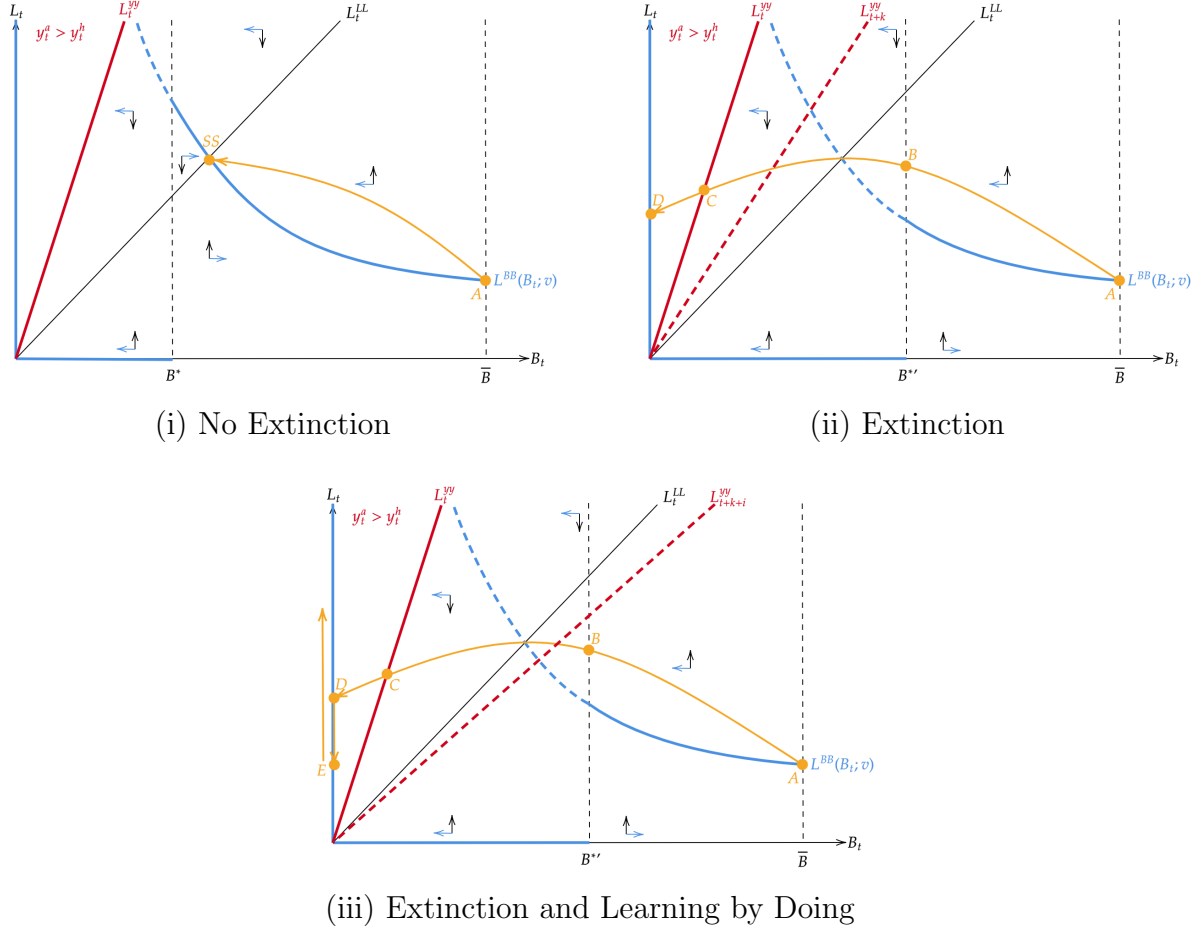
Figure 1: The Effect of Extinction

economy starts with $A = (B_0, L_t^{BB}(B_0))$, where $B_0 = \overline{B}$. As established by Lemmas 1 and 2, if an economy starts at A, it moves to the upper left corner while biomass declines and the population size increases. In the upper-left panel, (i), the economy monotonically converges to a steady state before crossing the biological threshold, B^*, and mammals do not become extinct. In contrast, in the upper-right panel, (ii), the economy crosses the biological threshold at B. Once the economy crosses the threshold, the qualitative features change. The economy keeps reducing biomass and increasing the population size, and it crosses the Replacement Frontier. Although humans keep hunting, the available biomass is not enough to sustain the population. The economy reduces biomass and population, ultimately crossing the Hunting-Farming Frontier at C. At this point, agriculture becomes an economically valid production mode, and some individuals start cultivation.

Immediately after cultivation begins, the technological level of agriculture is low, and it does not sustain population size. Since hunting continues, the economy faces reductions in both population and biomass, arriving at D. The lower panel, (iii), further depicts the

evolution of the economy accelerated by learning by doing. As long as individuals engage in agriculture, learning by doing increases agricultural productivity. As a result, at a point E, higher productivity allows the fertility rate to exceed one. Therefore, the population size begins increasing, ultimately making agriculture a subsistence production mode in this economy in the long run.

The following proposition shows that the first farmers work longer than the preceding foragers, as is consistent with archaeological and ethnographic studies (Armelagos and Cohen, 1984; Sahlins, 1972).

Proposition 1 *Suppose that $y_t^a < y_t^h$ and $y_d^a = y_d^h$ for $t \in [0, d-1]$, and that $\exists f \geq d+1$ s.t. $n[y_{f-1}^a] < 1 \leq n[y_f^a]$. Then, $\exists t^* \geq d+1$ s.t. for $i \in [d, t^*-1]$ and $m \in [0, d-1]$,*

  i. $y_i^a < y_m^h$; and

  ii. $w_i^a > w_m^h$.

Proof. Notice that the assumption is enough to guarantee that an economy transits to agriculture, as depicted in Figure 1.

Define c as the period when the economy crosses the Replacement Frontier, L^{LL}. First, I show that $\exists t^* \geq d+1$ s.t. $\forall i \in [d, t^*-1]$ and $\forall j \in [c+1, d-1]$, $y_i^a < y_j^h$. For $j \in [c+1, d-1]$, the economy is below the Hunting-Farming Frontier, L^{yy}. Thus, $L_j^h < (A^h/A_j^a X^a)B_j$. Since $y_d^a = y_d^h$, individuals are indifferent between hunting and farming, and some individuals start cultivation at the period d. Due to learning by doing, (5), it must be: $A_0^a = A_a^a = ... = A_d^a < A_{d+1}^a < ....$ Therefore, there exists $t^* \geq d+1$ s.t. for $j \in [c+1, d-1]$, $L_j^h < (A^h/A_{t^*-1}^a X^a)^{1/\alpha}B_j$ and $L_j^h \geq (A^h/A_{t^*}^a X^a)^{1/\alpha}B_j$. From (2) and (4), $y_i^a < y_j^h$.

Then, I show that for this t^*, $y_i^a < y_k^h \ \forall i \in [d, t^*-1]$ and $\forall k \in [0, c]$. For $k \in [0, c]$, the economy is below or on L^{LL} and for $j \in [c+1, d-1]$, it is above L_j^{LL}. Thus, $n[y_j^h] < 1 \leq n[y_k^h]$. From (11) and (12), $y_j^h < y_k^h$. Since $y_i^a < y_j^a$, we have $y_i^a < y_k^h$ for $i \in [d, t^*-1]$.

Therefore, I showed: $\exists t^* \geq d+1$ s.t. $\forall i \in [d, t^*-1]$ and $\forall m \in [0, d-1]$, $y_i^a < y_m^h$. As shown in (11), $\partial w_t^*/\partial y_t < 0$. Thus, $w_i^a > w_m^h$. ■

This proposition provides a simple explanation to a puzzle of the Neolithic Revolution: Why did the first farmers decide to adopt agriculture even if it required them to work more without any increase in food? Early humans overhunted their prey mammals and made them extinct. This unfortunate loss of hunting resources significantly reduced hunting gains, allowing some individuals to start cultivation even though the gains were smaller than those preceding hunters enjoyed. In the Malthusian economy characterized by the positive elasticity of demand for the number of children and leisure[12], a reduction in incomes forced farmers to work harder without any increase in food.

---

[12]For example, Sahlins (1972) provides examples of this relationship between food gains and worktime.

3.7.2 The Effect of Biological Vulnerability on the Agricultural Transition

(i) Low Vulnerability

(ii) High Vulnerability

(iii) High Vulnerability and Learning by
Doing

Figure 2: The Effect of Biological Vulnerability

Figure 2 depicts the effect of mammals' biological vulnerability on the agricultural transition. The upper-left panel, (i), depicts the economy with low vulnerability. Since this economy is invulnerable to hunting pressure, it arrives at the steady state, SS, without extinction. In contrast, the upper-right panel, (ii), is a counterfactual in which this economy is more vulnerable to hunting pressure. From (7) and (18), the biological threshold, B^*, moves to the right while the Biologically Stable Frontier, L_t^{BB}, moves downward. As a result, the economy crosses the biological threshold and experiences extinction. Following the same argument in the previous subsection, some individuals embark on cultivation at C. With the effect of learning by doing as in the lower panel (iii), agriculture becomes a permanent subsistence mode in the long run.

3.8   Testable Implications

The model's predictions are summarized by the following proposition.

Proposition 2

(i) *If the economy is characterized by large loss of biomass due to megaherbivore extinction, then the economy experiences an agricultural transition.*

(ii) *If the economy is characterized by high biological vulnerability, which increases the extinction risk of mammals, then the economy experiences an agricultural transition.*

Biological vulnerability of mammals affects the agricultural transition *only* through the possibility of extinction. Therefore, in the empirical section, to conduct the *two stage least square* (2SLS) regression I exploit this theoretically established association between biological vulnerability and the agricultural transition.

3.9   The Role of Out-migration

One concern is that when available biomass gets scarce, individuals leave to pursue prey mammals. This makes it difficult to interpret the association between megaherbivore extinction and the agricultural transition. However, in the proposed theory, this concern should be minor.

Out-migration becomes an issue if large parts of the population leave. I argue that this is unlikely in my model's setting. First, early humans did not develop communication or information technology, and thus they did not know whether the outside world had food resources and a safe environment. Second, after mammals went extinct, they could still engage in gathering in their original region. Given the significant uncertainty about the outside world and given the availability of wild plants in the original place, out-migration was a very risky choice. Therefore, those who left their region are likely to have been individuals whose risk preference was extremely high. It is likely that such risk-taking individuals constituted a minor part of the population, and hence the majority are likely to have remained in their original place when prey mammals became scarce. Moreover, gathering of wild plants is the start of the causal chain leading to agriculture, because a general sequence from foraging to agriculture is from (i) gathering wild plants to (ii) cultivation to (iii) domestication and finally to (iv) agriculture (Dow et al., 2009). This implies the shift from hunting to gathering increases the likelihood of the agricultural transition. Therefore, the out-migration concern does not defeat the proposed theory. Despite the potentially minor role of out-migration, to alleviate the concern, I account for the incentive for out-migration in the empirical analysis. Particularly, I control for available biomass in surrounding regions.

4 Data and Variable Construction

In this section, I describe data on the timing of the Neolithic Revolution, proxies for socioeconomic development, the distribution of prehistorical mammals, and their extinction status. I also explain how to construct a measure of lost biomass caused by mammal extinction. Given the potential concern that extinction is endogenous, I use an instrument which replaces the actual extinction status in the measure of lost biomass with the predicted extinction risk. I describe how to construct the instrument.

4.1 Dependent Variable: Time Elapsed since the Neolithic Revolution

The country-level data on the timing of the Neolithic Revolution are taken from a study by Borcan et al. (2018), who add to and correct original data in Putterman and Trainor (2006). By collecting a wide variety of both region-specific and country-specific archaeological studies, they provide information on the earliest dates of the agricultural transition, when people of a given area were getting more than half of their calories from cultivated foods and domesticated animals.

Figure A1 depicts the global distribution of years elapsed since the Neolithic Revolution. As is evident, there is large global variation in the number of years since the transition. The earliest transition was seen in the Middle East, followed by South Asia, Eastern Asia, and Europe. The Americas, Southeast Asia, and Northern Africa experienced intermediate timing while sub-Saharan Africa and Oceania were the last regions to transition.

Although these data provide the largest spatial coverage of the timing of the Neolithic transition, they undoubtedly represent a noisy proxy for actual timing. The ideal unit would be at the level of the human settlement rather than the country. Therefore, I also examine variation in the agricultural transition across archaeological sites as reported by Pinhasi et al. (2005).[13] They report estimated radiocarbon dates across archaeological sites in the Middle East and Europe (Figure A2). Although the data's spatial coverage is limited, they provide more accurate information on the timing of the agricultural transition.

To capture the association between megaherbivore extinction and the emergence of agriculture rather than its diffusion, I also exploit information on centers of plant domestication as reported by Purugganan and Fuller (2009) (Figure A3). Relying on archaeological and genetic evidence, they provide information on places and timing of independent plant domestication. Based on this information, I construct virtual countries (cells) in the spirit of Michalopoulos (2012), where the earth is divided into $1° \times 1°$ grid cells.

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[13]These data have been used earlier in the economics literature (Ashraf and Michalopoulos, 2015; Matranga, 2017; Olsson and Paik, 2020; Dickens and Lagerlof, 2020).

4.2 Dependent Variable: Proxies for Socioeconomic Development

The first data on proxies for socioeconomic development after the Neolithic transition—radiocarbon dated prehistori and protohistoric archaeological sites—are provided by White-house and Whitehouse (1975). Mayshar et al. (2022) georeference these sites and classify them according to whether they predate the Neolithic transition. As a result, they obtain a list of 825 sites that belong to pretransition years and 3,309 sites that belong to posttransition years. Based on the data compiled by Mayshar et al. (2022), I create virtual countries (cells) at the $1° \times 1°$ level. Each cell includes information on the number of pre-Neolithic and post-Neolithic sites. In the empirical analysis, I either use all ruins or only sites of prehistoric settlements.[14]

The second source is the *Ethnographic Atlas* by Murdock (1967). This database represents 1,267 societies from around the world as observed before industrialization or European contact. The sample is global, with an emphasis on North American and African groups. European groups are underrepresented. Giuliano and Nunn (2018) extend the original dataset by adding several ethnic groups from Europe. This increases the sample to 1,309 ethnic groups. The database contains information on cultural, institutional, and economic characteristics. As proxies for the socioeconomic development, I use the variables v31 (mean size of communities), v33 (jurisdictional hierarchy beyond local community", and v66 (class stratification). To calculate geographical variables, I create a 50 km buffer zone with the geocoordinate of an ethnic group as the centroid. Then I aggregate values in cells within the buffer area.

4.3 Independent Variable: Lost Biomass

This subsection introduces a novel measure: lost biomass resulting from megaherbivore extinction, measured at arbitrary scales such as country, archaeological site, virtual country, and ethnic homeland. The measure constructed from: (i) distributions of mammal species that would live today if there had been no human influences, (ii) the body mass and abundance of each species, and (iii) the species' extinction status.

The PHYLACINE, compiled by Faurby et al. (2018), provides information on spatial distribution for all 5,831 known mammal species that have lived since the beginning of the Late Pleistocene, which corresponds to the period between roughly 130,000 years ago and the present. The database also includes rich data on characteristics of each species such as the mean body mass of adult, diet composition, habitat, and so forth. One advantages of

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[14]The atlas classifies these ruins in ten categories: (1) undifferentiated sites and find-spots; (2) settlements; (3) funerary monuments; (4) religious monuments; (5) caves and rock shelters; (6) cave art and rock reliefs; (7) hoards and votive deposits; (8) mineral sources; (9) mineral workings; and (10) sites that combine several of the above categories.

the database is that it provides global maps at 110×110 km grid size, which are estimates of where species would live without human influences. Therefore, these maps are to be interpreted as the mammal distribution in prehistory. The importance of exploiting predicted distribution rather than current distribution is twofold. First, it allows me to identify the historical spatial distribution of extinct species, which is necessary to calculate loss of biomass resulting from their extinction. Second, it alleviates the potential concern of reverse causality from agriculture to mammal distribution.

For the extinct species in the PHYLACINE, Andermann et al. (2020) provide information on the dates of extinction. They collect this information from the peer-reviewed scientific literature and report the last occurrence date of species known to have become globally extinct since the Late Pleistocene. This information is available with uncertainty ranges from oldest to youngest dates. I use the median value of the range for each species. I manually match each species in the PHYLACINE and Andermann et al. (2020). Out of 352 extinct species, 337 are exactly matched (96 %). Regarding megaherbivores, 146 out of 151 extinct species are exactly matched (97 %).

For a given species, biomass is defined as the product of the average body mass and the number of individuals (abundance). To calculate the abundance of each species, I use the well-known fact that body mass is a powerful predictor of population density; more specifically, there is a strong negative log-log relationship between them (Peters and Raelson, 1984; Damuth, 1987; Currie and Fritz, 1993; Silva and Downing, 1995; Silva et al., 2001; Byers and Ugan, 2005).[15] My calculation uses a regression from Silva and Downing (1995): $\log_{10}(Population\ Density) = -0.44 \log_{10}(Body\ Mass) + 1.01$.[16]

Exploiting the prehistoric distribution, average body mass, and predicted abundance of each species, I construct the measure of lost biomass resulting from megaherbivore extinction. For the cross-section analysis, it is calculated according to the following formula:

$$LostBiomass_i = \frac{\sum_{j \in MH_i^{extinct}} \widehat{Abundance}_j \times BodyMass_j}{\sum_{j \in MH_i} \widehat{Abundance}_j \times BodyMass_j}. \tag{23}$$

Here, $MH_i^{extinct}$ is the set of extinct megaherbivore species in region i, MH_i is the set of both extinct and extant megaherbivore species in region i, $\widehat{Abundance}_j$ is a prediction of

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[15]Larger mammals tend to have longer periods of gestation and maternal care, older age at sexual maturity and the first parturition, and lower birth rate. These factors reduce reproductive success; thus, larger mammals tend to have lower population density. On another note, the procedure I use here is used in the field of paleoecology to predict abundance of species in prehistory (Byers and Ugan, 2005; Barnosky, 2008; Dusseldorp, 2009; Dusseldorp, 2012).

[16]Since predicted abundance may be sensitive to the study from which I borrow an estimate, I check for robustness to using estimates from different studies. As shown in the robustness sections, the result does not change.

the number of individuals of species j, and $BodyMass_j$ is the average body mass of species j.[17] Since anatomically modern humans lived only within Africa until about 90,000-70.000 BP (Ashraf et al., 2020), mammal extinction before then could not be caused by humans' overhunting. Therefore, to calculate the measure of lost biomass, I exclude mammal species that went extinct before 80000 BP.[18] I also exclude species that became extinct after the first Neolithic transition occurred in the sample to reduce the concern of reverse causality.

A similar measure of lost biomass for the panel-data analysis is calculated as

$$LostBiomass_{i,t} = \frac{\sum_{j \in MH_{i,t}^{extinct}} \widehat{Abundance}_j \times BodyMass_j}{\sum_{j \in MH_{i,t}} \widehat{Abundance}_j \times BodyMass_j}, \tag{24}$$

where $MH_{i,t}^{extinct}$ is the set of mammals that become extinct between time t and $t-1$ in region i, and $MH_{i,t}$ is the set of mammals that are still extant at time $t-1$ in region i.
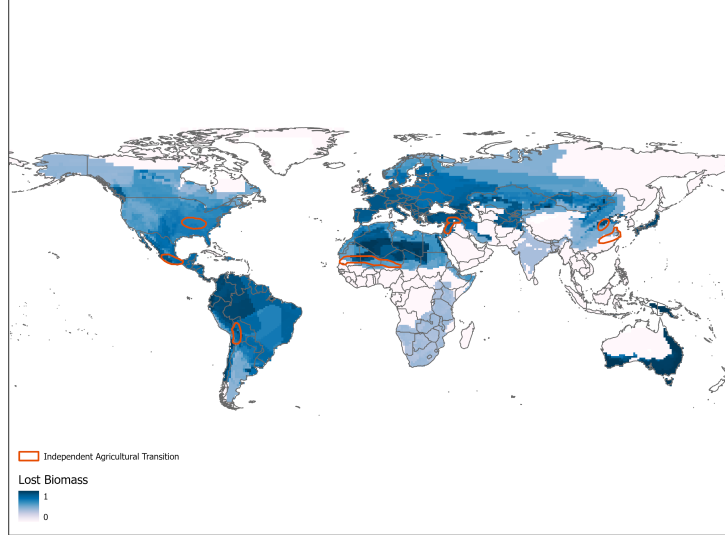
Figure 3: Lost Biomass resulting from Megaherbivore Extinction and Places of Pristine Agricultural Transition

The global distribution of lost biomass due to megaherbivore extinction is depicted in Figure 3. This figure also depicts seven regions where the independent plant cultivation occurred as reported by Purugganan and Fuller (2009). As is evident, there is large global

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[17]The focus of this study is wild mammal species rather than domesticable ones. Megaherbivore extinction is a demand-pull factor, and thus the model's prediction is derived based on demand-side elements. In contrast, the existence of domesticable mammals is a supply-push factor, especially during the transitional phase to agriculture, which is the period of analysis of this study. Hence, for theoretical and empirical consistency, I exclude from MH_i and $MH_i^{extinct}$, the fourteen domesticable species specified by Diamond (2017). However, as shown in the robustness sections, including those does not change the basic empirical results.

[18]This is the median of 90,000-70,000 BP.

variation in lost biomass both across and within continents. Although there are some exceptions such as Japan[19], the figure shows visual correlation between lost biomass and the independent plant cultivation.
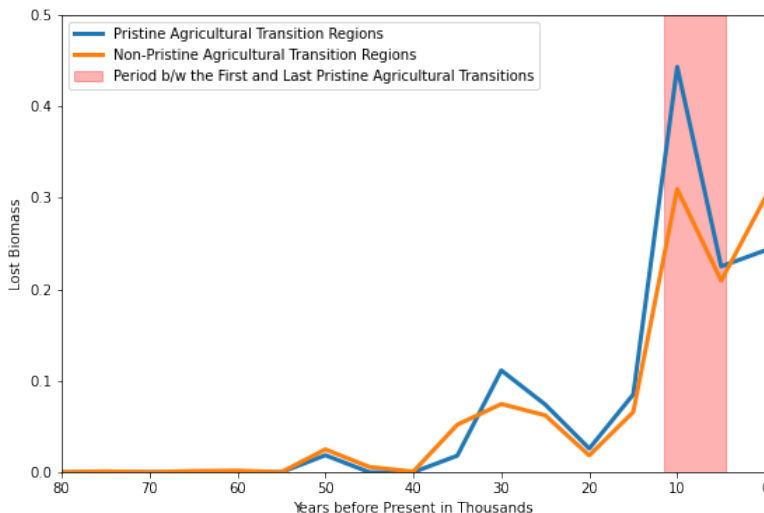
Figure 4: Evolution of Lost Biomass Resulting from Megaherbivore Extinction

Then, Figure 4 depicts the evolution of lost biomass resulting from megaherbivore extinction in two regions: pristine agricultural transition regions (blue) and non-pristine agricultural transition regions (orange).[20] The evolution of lost biomass, roughly speaking, follows a similar path in both cases: (i) There was little extinction until c. 40,000 BP, (ii) The first spike of extinction occurred between c. 40,000 and 20,000 BP, and (iii) After around 20,000 BP, the degree of extinction became significant. An important feature of the figure is that the regions of the pristine agricultural transition began to see a larger loss of biomass after c. 32,000 BP and that the difference became significant after c. 15,000 BP. The figure also depicts the period between the first and last pristine agricultural transitions by red. As seen in the figure, the period of the pristine transitions is included in the period when the independent transition places had seen severer extinction.

Importantly, this measure of lost biomass is effective as long as the measure of biomass calculated in this way captures hunting potential in the past. In fact, Kumagai (2021) constructs the measure of meagaherbivore biomass and establishes that megaherbiovre biomass

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[19]At first glance, Australia looks another exception. This is the case in the temperate zone located in the south-east, south, and south-west of the continent. However, in the tropical zone located the far north of the continent and in the arid zone that is the rest of the continent, there is little loss of megaherbivore biomass

[20]The information on places of the independent transition is taken from Purugganan and Fuller (2009).

is a strong predictor of hunting dependency in traditional societies. It is positively and significantly associated with dependence on hunting. In contrast, the association with other subsistence modes (gathering, fishing, animal husbandry, and agriculture) is not robust or negative, if any. Moreover, using the *Ethnographic Atlas*, Table C1 establishes that lost biomass resulting from megaherbivore extinction has a strong negative association with hunting dependency. Therefore, lost biomass due to megaherbivore extinction is certainly a good proxy for the loss of hunting resources.

4.4 Instrumental Variable: Predicted Probability of Extinction

This subsection provides an instrumental variable for lost biomass resulting from megaherbivore extinction. Culture of a foraging society may have affected both the agricultural transition and extinction. On one hand, long-term orientation, for instance, may have been conducive to agriculture because agriculture requires periods of investment (Galor and Özak, 2016). On the other hand, time spent on a non-hunting activity may have decreased the extinction of mammals. In this case, the OLS estimate would be biased downward.

The model presented in the theoretical section predicts that biological vulnerability increases the risk of extinction and hence affects the timing of the Neolithic transition. I exploit the positive association between body mass and vulnerability—that is, the fact that larger mammals are biologically more vulnerable because they tend to have longer periods of gestation and maternal care, older age at sexual maturity and the first parturition, and lower birth rate, all of which lower reproductive success (McDonald, 1984; Smith, 1975, 1992; Johnson, 2002; Brook and Bowman, 2004).

One may be concerned that biological vulnerability and body mass have been affected by the ecosystem where mammals live. To deal with this concern, I control for paleo-net primary production. Net primary production is the net amount of solar energy converted into plant organic through photosynthesis and it is used as a proxy for the productivity of the ecosystem (Rosenzweig et al., 2012). Therefore, conditional on the ecosystem productivity in prehistory, the biological vulnerability and body mass are plausibly biological restrictions independent of environmental elements that may deteriorate the exclusion restriction.

I construct an instrument as follows. First, I regress the actual extinction status on average body mass via logistic regression. Second, I obtain a measure of extinction risk, which is the predicted value of actual extinction. Third, I replace the actual extinction status in the above measures of lost biomass, (23) and (24), with the predicted extinction risk.[21]

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[21]When calculating the measure of lost biomass, I exploit the association between body mass and population density to predict abundance. Predicted abundance partly captures the relationship between body mass and extinction. This may reduce the variation in the endogenous variable that the instrument variable
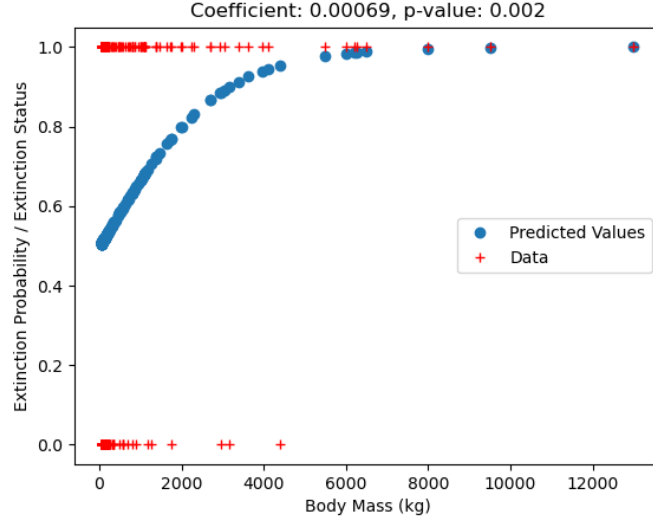
Figure 5: Association between Extinction Status and Body Mass

Figure 5 depicts the association of body mass with predicted extinction risk and actual extinction status. The blue dots show that body mass is a strong predictor of extinction status. As body mass increases, the extinction risk increases; this association is statistically significant at the 1% level.[22]

I replace the set of extinct megaherbivores in the measure of lost biomass (23) with predicted extinction risk. I then construct an instrumental variable for the cross-section analysis according to the following formula:

$$\widehat{LostBiomass}_i = \frac{\sum_{j \in MH_i} \widehat{\mathbb{1}_{j \in \text{Extinct}}} \times \widehat{Abundance}_j \times \widehat{BodyMass}_j}{\sum_{j \in MH_i} \widehat{Abundance}_j \times \widehat{BodyMass}_j}, \tag{25}$$

where $\widehat{\mathbb{1}_{j \in \text{Extinct}}}$ is the predicted value of the actual extinction status obtained by regressing the actual status on body mass via logistic regression.

The instrument for the panel is calculated using pseudo-time variation in extinction. In particular, it is constructed according to the following equation:

$$\widehat{LostBiomass}_{i,t} = \frac{\sum_{j \in MH_{i,0}} \frac{\widehat{\mathbb{1}_{j \in \text{Extinct}}}}{\#(T)} \cdot \left[1 - \frac{\widehat{\mathbb{1}_{j \in \text{Extinct}}}}{\#(T)}\right]^{t-1} \cdot \widehat{Biomass}_j}{\sum_{j \in MH_{i,0}} \left[1 - \frac{\widehat{\mathbb{1}_{j \in \text{Extinct}}}}{\#(T)}\right]^{t-1} \cdot \widehat{Biomass}_j}, \tag{26}$$

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explains in the first stage. However, this does not affect the exclusion restriction. In Appendix D, I prove this claim.

[22]The sample includes both extant and extinct megaherbivores, and the number of observations is 226.

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where $\widehat{Biomass}_j$ is a product of $\widehat{Abundance}_j$ and $BodyMass_j$, $\#(T)$ is the number of sample periods in the panel. Therefore, $\widehat{\mathbb{1}_{j\in\text{Extinct}}}/\#(T)$ and $1-\widehat{\mathbb{1}_{j\in\text{Extinct}}}/\#(T)$ represent the extinction risk and survival probability of species j in one period, respectively. Instead of using sets of megaherbivores in each period, $MH_{i,t}$, (26) uses only the initial set of megaherbivores, $MH_{i,0}$. Using $MH_{i,t}$ is problematic because it is affected by the extinction that occurred in previous periods. In contrast, $MH_{i,0}$ is not been affected by the past extinction, and thus using only $MH_{i,0}$ alleviates the concern that extinction is endogenous.

4.5   Control Variables: Paleo-Climatic Characteristics

In this study, paleo-climatic features are potentially the most crucial confounding factors. This is because: (i) it is well known that climate was one of the primary drivers of the mass extinction of megaherbivores in the Late Pleistocene (Barnosky et al., 2004), and (ii) climatic features are argued as determinants of the agricultural transition (Dow et al., 2009; Ashraf and Michalopoulos, 2015; Matranga, 2017). To deal with this issue, I draw on the data recently developed by Beyer et al. (2020). For a number of climatic variables, this database presents a $0.5°$ resolution bias-corrected information, covering the entire world and spanning the last 120,000 years at a temporal resolution of 1,000-2,000 years.

Using this database, I calculate the means of paleo-temperature and paleo-precipitation. I also construct measures of paleo-temperature volatility and its square as well as the seasonality of paleo-temperature and paleo-precipitation. Moreover, to account for ecosystem productivity, I calculate the mean of paleo-net primary production. Paleo-net primary product is a proxy for panelo-productivity of the ecosystem and hence it controls for the possibility that the difference in ecosystem systematically influences the extinction of megaherbiovres and the agricultural transition. As is described in the section on the instrumental variable, it also accounts for the possibility that the ecosystem productivity affects biological vulnerability and body size of mammals.

5   Empirical Association between the Agricultural Transition and Megaherbivore Extinction

This section provides empirical evidence that lost biomass resulting from megaherbivore extinction had a positive impact on the agricultural transition, using cross-sectional and panel frameworks.

5.1 Cross-Sectional Analysis

In this subsection, I present the association between the agricultural transition and mega-herbivore extinction, using cross-country data. To save space, I report the result of cross-archaeological-site analysis in Appendix E. The cross-country analysis also shows that the extinction of other mammals such as small herbivores and non-herbivores is not associated with the transition timing. Moreover, it accounts for a large set of possibly confounding climatic and geographical features. In particular, it controls for paleo-climatic characteristics that may have affected mass extinction and the Neolithic Revolution. Furthermore, to deal with the possible concern about endogeneity, the analysis also provides 2SLS estimates. To alleviate the concern about migration, it also accounts for biomass in surrounding regions, which captures the incentives of individuals to leave their area when available resources become scarce. Summary statistics for cross-country and cross-archaeological site analyses are reported in Table B5 and B6, respectively.

The effect of megaherbivore extinction on the timing of the Neolithic transition is estimated via the following specification:

$$YST_i = \alpha_0 + \alpha_1 LostBiomass_i + Geo_i\beta' + PaleoClim_i\gamma' + Region_i\delta' + \epsilon_i, \qquad (27)$$

where YST_i is the time elapsed since the Neolithic transition in country or archaeological site i, $LostBiomass_i$ is loss of biomass due to megaherbivore extinction in country or archaeological site i, Geo_i is a vector of geographical controls in country or archaeological site i, $PaleoClim_i$ is a vector of paleoclimatic controls in country or archaeological site i, $Region_i$ is a vector of region fixed effects, and ϵ_i is an error term. The theory predicts a positive effect of lost biomass on time since the agricultural transition; that is, $\alpha_1 > 0$.

The data on the timing of agricultural transition from Borcan et al. (2018) cover the entire world; thus, theirs is the most spatially comprehensive data set. By using their data, this subsection shows the global association between megaherbivore extinction and the agricultural transition.

I start by showing the unique role of megaherbivores in promoting the agricultural transition. Table 1 establishes that extinction of megaherbivores is significantly and positively associated with the timing of the transition, but extinctions of small herbivores and non-herbivores are not correlated with it.[23] The unconditional relationship between time since agricultural transition and megaherbivore extinction is significant and positive (column 1). The estimate of extinction of small herbivores is negative and insignificant (column 2) and that of non-herbivores is positive and significant (column 3). Columns 4-6 add continent fixed effects. The estimate of megaherbivore extinction is stable and significant (column

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[23]These categorizations are mutually disjoint sets of whole mammals.

4). The sign of extinction of small herbivores becomes positive and marginally significant when continent fixed effects are included (column 5) while non-herbivore extinction loses its significance (column 6). In column 7, I conduct a 'horse-race' regression. As shown, only megaherbivore extinction is significantly associated with the agricultural transition. A one-standard-deviation increase in lost biomass due to megaherbivore extinction is associated with agricultural transition 892 years earlier.

Table 1: Agricultural Transition and Extinction (Mutually Disjoint Sets)

	Years Since Agricultural Transition						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Lost Biomass (Herbivore > 44 kg)	5.283*** (1.823)			9.069*** (1.894)			8.917*** (1.944)
Lost Biomass (Herbivore ≤ 44 kg)		-1.967 (1.253)			1.740* (0.925)		0.430 (0.759)
Lost Biomass (Non-Herbivore)			30.485*** (11.089)			9.586 (6.749)	9.983 (6.116)
Continent FE				✓	✓	✓	✓
Mean of Dependent Variable	49.660	49.660	49.660	49.660	49.660	49.660	49.660
Std of Dependent Variable	24.275	24.275	24.275	24.275	24.275	24.275	24.275
Adjusted R^2	0.041	0.001	0.062	0.666	0.602	0.600	0.666
Observations	153	153	153	153	153	153	153

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent variable are standardized. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

I turn to an analysis of the positive association between megaherbivore extinction and time since agricultural transition. Column 1 of Table 2 reports the bivariate regression. This association is stable to the inclusion of continent fixed effects in column 2. Column 3 adds distance from the nearest agricultural center and migratory distance from East Africa. Distance from the closest agricultural center is a proxy for the adoption of agriculture from neighbors. Migratory distance from East Africa potentially captures two factors. Over time, humans acquired more knowledge about the environment in which they lived. This may have enabled them to experiment with plants and animals more, which affected the likelihood of domestication. It is also likely that the knowledge about their environment enabled them to be good hunters by enabling them to devise more effective hunting tools and strategies. Indeed, accounting for these distances reduces the estimated coefficient by about 41 %, although it is still highly significant. Column 4 controls for paleoclimatic characteristics. Despite these potentially crucial controls, the estimate of lost biomass is very stable. Adding a number of geographical features does not alter the estimate in column 5. Column 6 reports the 2SLS estimate, which is slightly larger than the OLS estimate. Reassuringly, the

estimated coefficient of lost biomass is stable and highly statistically significant across speci-fications. A one-standard-deviation increase in lost biomass due to megaherbivore extinction is associated with agricultural transition 661 years earlier.

Figure 6 depicts the positive effect of lost biomass caused by megaherbivore extinction on the timing of agricultural transition, conditional on the full set of controls in column 5. The figure shows no outliers and shows a robust positive association.

Figure 6: Scatter Plot (Cross-Country)

Robustness: Incentive to Migrate

When available hunting resources became scarce, individuals may have out-migrated. As explained in the theoretical section, this is not much of a concern in the setting of this study. However, to alleviate the concern, I account for neighboring regions' biomass to capture the incentive to migrate. Table C2 shows that the estimate of lost biomass is robust to the inclusion of biomass in surrounding regions.

Robustness: Estimates from Different Studies

The primary measure of lost biomass, (23), is constructed using an estimate from Silva and Downing (1995). Therefore, one may suspect that the result is driven by that study. Thus, I reconstruct the measure of lost biomass by exploiting different estimates from other studies. Table C3 shows that the result is robust to using these different estimates.

Table 2: Agricultural Transition and Megaherbivore Extinction

	Years Since Agricultural Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	5.396***	8.334***	4.900***	5.524***	6.420***	6.612***
	(1.896)	(1.848)	(1.769)	(1.497)	(1.803)	(1.742)
Dist. from the Closest Agricultural Origin				-10.591***	-8.652***	-5.996**	-5.983***
				(1.437)	(1.509)	(2.394)	(2.212)
Migratory Dist. from Addis Ababa				-17.823***	-15.868***	-22.019***	-22.072***
				(3.774)	(3.661)	(3.722)	(3.437)
Paleo-Temperature (Avg.)					7.751***	10.219***	10.212***
					(1.483)	(2.810)	(2.599)
Paleo-Precipitation (Avg.)					-1.096	1.324	1.401
					(2.059)	(2.342)	(2.153)
Paleo-Net Primary Product (Avg.)					-3.131	0.098	0.154
					(2.618)	(3.116)	(2.888)
Latitude						-2.498	-2.568
						(2.424)	(2.245)
Longitude						-10.146*	-10.071**
						(5.552)	(5.121)
Latitude × Longitude						7.627***	7.567***
						(2.470)	(2.281)
Elevation (Avg.)						3.653***	3.636***
						(1.335)	(1.230)
Land Productivity (Avg.)						-0.535	-0.533
						(1.103)	(1.014)
Island Dummy						-2.844	-2.827
						(4.022)	(3.717)
Dist. to the Closest Waterway						-0.007**	-0.007***
						(0.003)	(0.003)
Total Area						3.122***	3.141***
						(1.170)	(1.080)
# Native Plants						-4.665**	-4.795**
						(2.300)	(2.126)
Continent FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Statistics						1638.904
Adjusted R^2	0.044	0.663	0.768	0.803	0.849	
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Robustness: Domesticable Mammals, Domesticable Plants, and Extinction Rate

The existence of domesticable mammals and plants allowed an earlier transition to agriculture by providing biogeographically better initial conditions (Diamond, 2017; Olsson and Hibbs, 2005). A recent study by Riahi (2020) argues that large-mammal extinction has a

hump-shaped relationship with the timing of the agricultural transition. Hence, I add measures of domesticable mammals and wild relatives of domesticable plants in Table C4. I also control for extinction rate and its square in Table C5. As is evident, the estimate of lost biomass is robust to the inclusion of these variables.

Robustness: Temperature Volatility and Climatic Seasonality

Intermonthly temperature volatility and its square term as well as climatic seasonality have been shown to be related to agricultural transition (Ashraf and Michalopoulos, 2015; Matranga, 2017). As shown in Tables C6 and C7, the estimate of lost biomass is robust to the inclusion of these variables, showing that the basic result is not driven by these climatic aspects.

Robustness: Inclusion of Domesticable Mammals in Lost-Biomass Measure

I reconstruct the measure of lost biomass by including fourteen domesticable mammal species, although this measure is less consistent with the proposed theory. Table C8 shows that including domesticable mammals in the measure does not alter the result.

Robustness: Spatial Correlation

The basic result is robust to standard errors using the spatial correlation proposed by Conley (1999), as shown in Tables C9 and C10.

5.2 Panel Analysis

In this subsection, I examine the association between agricultural transition and lost biomass, using the archaeological site, virtual country (cell), and country panel data. Extinction is by its nature a change in available biological resources, and it is captured more properly in a panel setting than in a cross section. Furthermore, I directly account for paleoclimatic features by using new data sets recently developed by Beyer et al. (2020). This is important because climatic factors may have caused mass extinction of mammals in prehistoric times (Barnosky et al., 2004) and because they are important determinants of the Neolithic transition (Dow et al., 2009; Ashraf and Michalopoulos, 2015; Matranga, 2017).

I construct the panel data on virtual countries (cells) by combining information on independent agricultural centers reported by Pinhasi et al. (2005). This enables me to capture the association between lost biomass and independent transitions to agriculture, rather than between lost biomass and agricultural diffusion. Summary statistics for country, archaeological-site, and virtual-country panel analyses are reported in Tables B7-B9, respectively. To save

space, I report only the results of archaeological-site and virtual-country panel analyses here. I report the result of the county-panel analysis in Appendix F.

The effect of lost biomass due to megaherbivore extinction on the timing of the agricultural transition is estimated via OLS:

$$\mathbb{1}_{i,t} = \alpha_0 + \alpha_1 LostBiomass_{i,t-1} + PaleoClim_{i,t-1}\beta' + Unit_i\gamma' + Time_t\delta' + \epsilon_{i,t}, \qquad (28)$$

where $\mathbb{1}_{i,t}$ is a dummy variable that indicates whether agricultural transition occurs in country, archaeological site or virtual country i at period t, $LostBiomass_{i,t-1}$ is loss of biomass caused by megaherbivore extinction in country, archaeological site, or virtual country i in period $t-1$, which is defined by (24), $PaleoClim_{i,t-1}$ is a vector of paleoclimatic features as well as paleo-net primary product in country, archaeological site or virtual country i in period $t-1$, $Unit_i$ is a vector of country, archaeological-site or virtual-country fixed effects; $Time_t$ is a vector of time fixed effects; and $\epsilon_{i,t}$ is an error term.

The Neolithic transition dummy $\mathbb{1}_{i,t}$ is 0 for all periods representing times when the transition has not occurred. As soon as a unit in the data set experiences the transition, it is dropped from the panel since it is no longer possible for it to transition to agriculture. The period of analysis spans from 14,000 BP until the Neolithic transition occurs. A time window is 1,000 years. This starting year roughly corresponds to the Late Glacial Interstadial, during which the climate became warm and moist.[24]

5.2.1 Archaeological-Site Panel Data Analysis

This subsection analyzes the effect of lost biomass on agricultural-transition timing using arcaeological-site panel data constructed from the data sets by Pinhasi et al. (2005). Table 3 establishes a significant and positive impact of lost biomass on the probability of agricultural transition. Column 1 accounts for archaeological-site fixed effects; the estimate is highly significant and positive. Column 2 adds time fixed effects, and the magnitude of the estimate increases by 79 %. Columns 3-5 sequentially control for paleo-temperature, paleo-precipitation, and paleo-net primary production. These controls are particularly important, given the crucial roles of paleoclimate in mass extinction of large mammals and in the Neolithic transition. Moreover, paleo-net primary product accounts for the possibility that the difference in the ecosystem productivity systematically relates to the transition and extinction. Reassuringly, the estimated coefficient of lost biomass is very stable to the inclusion of the paleoclimatic features. Column 6 includes all of these variables together, which does not change the estimate of lost biomass. Column 7 reports the 2SLS estimate with full controls.

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[24]The Late Glacial Interstadial was followed by the Younger Dryas, during which the climate became harsh. Dow et al. (2009) theorize that agriculture occurred in areas that experienced an initial climatic improvement and subsequent climatic reversal.

The coefficient of lost biomass is statistically and economically highly significant, showing that lost biomass resulting from megaherbivore extinction triggered agricultural transition. The inclusion of paleo-net primary production deals with the concern that biological vulnerability may have been affected by the ecosystem productivity. Therefore, it increases the validity of the instrumental variable. A one-standard-deviation increase in lost biomass due to megaherbivore extinction increases the transition probability by 3.3 percentage points.

Table 3: Agricultural Transition and Megaherbivore Extinction

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.023***	0.028***	0.027***	0.030***	0.029***	0.029***	0.128***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.048)
Paleo-Temperature (Avg.)				-0.198***		-0.226***	-0.215***
				(0.014)		(0.019)	(0.020)
Paleo-Precipitation (Avg.)					-0.033**	-0.027**	-0.113**
					(0.014)	(0.013)	(0.044)
Paleo-Net Primary Product (Avg.)						-0.046*** 0.030***	0.028**
						(0.007) (0.011)	(0.011)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.123	0.123	0.123	0.123	0.123	0.123	0.123
Std of Dependent Variable	0.329	0.329	0.329	0.329	0.329	0.329	0.329
First-F							22.539
Observations	6070	6070	6070	6070	6070	6070	6070

Note: The unit of analysis is an archaeological site. The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Based on the information on the timing of the transition reported by Pinhasi et al. (2005), I assign 1 if the transition happens in the associated period. Once the transition occurs, I drop the site from the sample. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the archaeological site and period level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

This is a very demanding specification because lost biomass takes 0 for most observations. There are 6,070 observations that are the product of the number of sites and periods, and Figure 7 tells that lost biomass is 0 for about 85% of these 6,070 observations. Therefore, controlling for site and time-fixed effects as well as paleoclimatic characteristics absorbs much of the available variation. Despite this, lost biomass retains a highly significant positive effect on the probability of the agricultural transition.
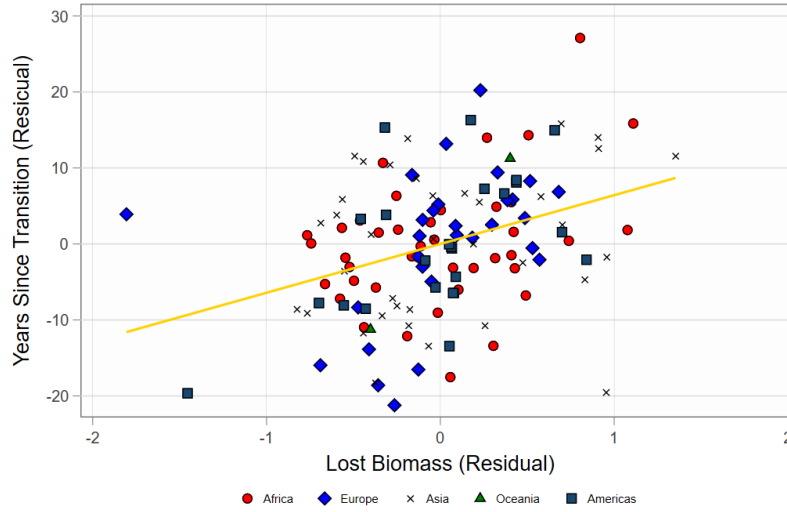
Robustness: Incentive to Migrate

When available hunting resources became scarce, individuals may have out-migrated. As explained in the theoretical section, this is not much of a concern in the setting of this study.
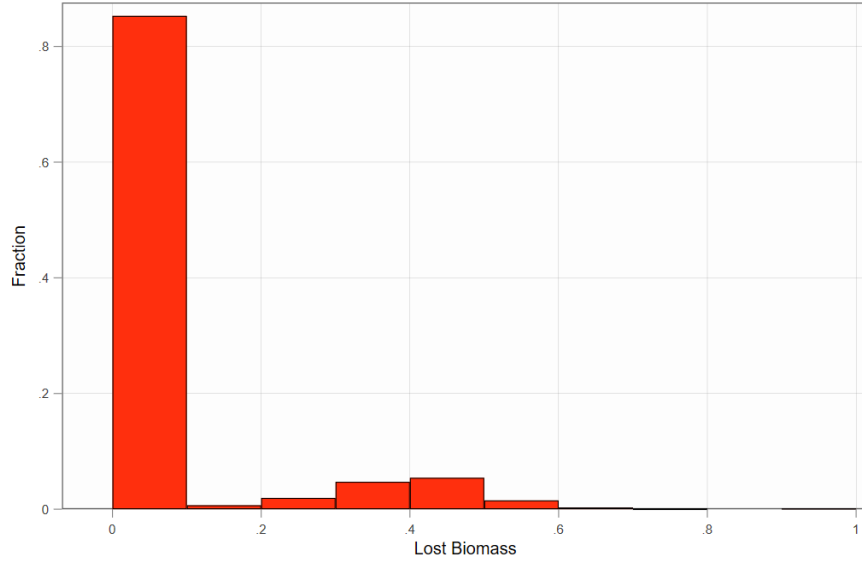
Figure 7: Variation in Lost Biomass (Archaeological Site Panel)

However, to alleviate the concern, I account for neighboring regions' biomass to capture the incentive to migrate. Table C11 shows that the estimate of lost biomass is robust to the inclusion of biomass in surrounding regions.

Robustness: Estimates from Different Studies

The primary measure of lost biomass, (24), is constructed using an estimate from Silva and Downing (1995). Therefore, one may suspect that the result is driven by that study. Thus, I reconstruct the measure of lost biomass by exploiting different estimates from other studies. Table C12 shows that the result is robust to using these different estimates.

Robustness: Temperature Volatility and Climatic Seasonality

Intermonthly temperature volatility and its square term as well as climatic seasonality have been shown to be related to agricultural transition (Ashraf and Michalopoulos, 2015; Matranga, 2017). As shown in Tables C13 and C14, the estimate of lost biomass is robust to the inclusion of these variables, showing that the basic result is not driven by these climatic aspects.

Robustness: Inclusion of Domesticable Mammals in Lost-Biomass Measure

I reconstruct the measure of lost biomass by including fourteen domesticable mammal species, although this measure is less consistent with the proposed theory. Table C15 shows that including domesticable mammals does not alter the result.

Robustness: Spatial Correlation

The basic result is robust to standard errors using the spatial correlation proposed by Conley (1999), as shown in Table C16.

5.2.2 Virtual-Country Panel Data Analysis

This subsection analyzes the effect of lost biomass on independent agricultural transitions using virtual-country (cell) panel data. Purugganan and Fuller (2009) identify seven accepted places of independent plant domestication (Figure A3). I first divide the earth into 1×1 grid cells and then assign the year of the transition to cells that lie within the seven agricultural centers. Figure A4 depicts a map of the constructed virtual countries. Darker colors indicate cells that experienced earlier independent transition, and white indicates cells that did not experience independent transitions.

Using this map, I construct virtual-country panel data. The association between lost biomass and independent agricultural transitions is estimated according to equation (5.2). The estimated coefficient of lost biomass captures the effect on independent transition rather than agricultural diffusion.

Table 4: Independent Agricultural Transition and Megaherbivore Extinction

	The Indicator of the Independent Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.011***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Paleo-Temperature (Avg.)			-0.006***			-0.006***	-0.009***
			(0.000)			(0.000)	(0.001)
Paleo-Precipitation (Avg.)				0.000		0.002***	0.004***
				(0.000)		(0.000)	(0.000)
Paleo-Primary Product (Avg.)					-0.001**	-0.000	0.001***
					(0.000)	(0.000)	(0.000)
Cell FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Std of Dependent Variable	0.042	0.042	0.042	0.042	0.042	0.042	0.042
First-F							793.673
Observations	230075	230075	230075	230075	230075	230075	230075

Note: The unit of analysis is a virtual country (cell). Dependent variable is a dummy variable that takes one if independent agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the virtual country and period level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table 4 establishes the positive association between lost biomass and independent transition to agriculture. The estimated coefficient of lost biomass is significant and positive, conditional on virtual-country (cell) fixed effects in column 1. This relationship is stable to the inclusion of time fixed effects (column 2), paleo-temperature (column 3), paleo-precipitation (column 4), and paleo-net primary production (column 5). As shown in column 6, the estimate is robust to the inclusion of all control variables. Column 7 reports the 2SLS estimate, which is larger than the OLS. The estimated coefficient of lost biomass is highly significant at the 1% level in all the specifications. A one-standard-deviation increase in lost biomass due to megaherbivore extinction increases the transition probability by 1.1 percentage points.

This is a very demanding specification because lost biomass takes 0 for most observations. There are 230, 075 observations that are the product of the number of cells and periods, and Figure 8 tells that lost biomass is 0 for about 87% of these 230, 075 observations. Moreover, as seen in Figure A4, the dependent variable has more limited variation because I use only the seven regions of pristine transitions. Therefore, controlling for cell and time-fixed effects as well as paleoclimatic characteristics absorbs much of the available variation. Despite this, lost biomass retains a highly significant positive effect on the probability of the agricultural transition.
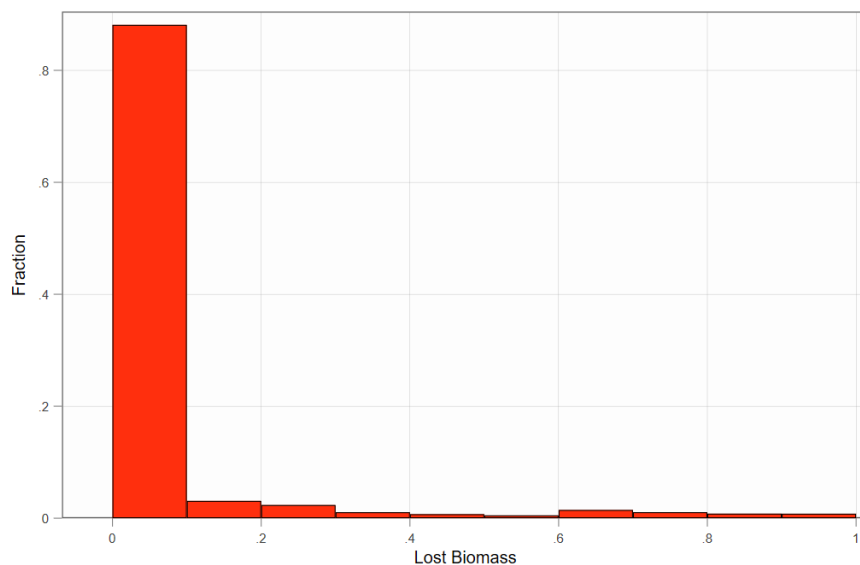
Figure 8: Variation in Lost Biomass (Virtual Country Panel)

Robustness: Incentive to Migrate

When available hunting resources became scarce, individuals may have out-migrated. As explained in the theoretical section, this is not much of a concern in the setting of this study.

However, to alleviate the concern, I account for neighboring regions' biomass to capture the incentive to migrate. Table C17 shows that the estimate of lost biomass is robust to the inclusion of biomass in surrounding regions.

Robustness: Estimates from Different Studies

The primary measure of lost biomass, (24), is constructed using an estimate from Silva and Downing (1995). Therefore, one may suspect that the result is driven by that study. Thus, I reconstruct the measure of lost biomass by exploiting different estimates from other studies. Table C18 shows that the result is robust to using these different estimates.

Robustness: Temperature Volatility and Climatic Seasonality

Intermonthly temperature volatility and its square term as well as climatic seasonality have been shown to be related to agricultural transition (Ashraf and Michalopoulos, 2015; Matranga, 2017). As shown in Tables C19 and C20, the estimate of lost biomass is robust to the inclusion of these variables, showing that the basic result is not driven by these climatic aspects.

Robustness: Inclusion of Domesticable Mammals in Lost-Biomass Measure

I reconstruct the measure of lost biomass by including fourteen domesticable mammal species, although this measure is less consistent with the proposed theory. Table C21 shows that including domesticable mammals does not alter the result.

Robustness: Spatial Correlation

The basic result is robust to standard errors using the spatial correlation proposed by Conley (1999), as shown in Table C22.

6 Persistent Effects of Megaherbivore Extinction

As is established in the previous sections, regions that saw a larger loss of biomass experienced an earlier agricultural transition. Since agriculture is the basis of development in the early phase of the economy (Diamond, 1997), these regions may have benefited from the earlier engagement in agriculture. Therefore, in this section, I briefly explain the persistent effect of lost biomass on socio-economic development *after* the Neolithic and *until* the pre-industrial periods. For the complete description, see Appendix G and H.

Appendix G examines the persistent effect after the Neolithic Revolution, using the data and methodology by Mayshar et al. (2022). I conduct the difference-in-differences analysis

and Table G1 establishes that a larger loss of biomass is associated with an increase in the probability of finding post-Neolithic ruins. This result is robust to using different proxies for the socioeconomic development such as the number of ancient ruins, the presence of ancient settlements, and the number of ancient settlements (Tables G5-G7). Appendix G also shows a number of robustness tests. The result is not driven by the neighboring regions' biomass, climatic seasonality, domesticable mammals, and domesticable plants. Reconstructing the measure of lost biomass by using different estimates from other studies does not change the basic result. Moreover, including fourteen domesticable mammals in the measure of lost biomass does not change the result. Therefore, the analysis shows that the Neolithic Revolution led to more visible traces of human societies in areas that experienced a larger loss of biomass resulting from megaherbivore extinction.

Appendix H then examines the persistent effect that lasted until the preindustrial period using the *Ethnographic Atlas*. It uses the degree of centralization, hierarchy, and community size to capture several dimensions of socioeconomic development. The analysis conducts both OLS and 2SLS estimates. Table H1 establishes that lost biomass resulting from megaherbivore extinction in prehistory affected these ethnographic characteristics. Appendix H also shows a number of robustness tests. The basic result is unaffected by the inclusion of neighboring regions' biomass, domesticable mammals, domesticable plants, large-mammal extinction rate, temperature volatility, and climatic seasonality. Reconstructing the measure of lost biomass by using different estimates from other studies does not change the result. Including fourteen domesticable mammals in the measure of lost biomass does not change the result. The basic result is also robust to standard errors using Conley's spatial correlation. Therefore, the analysis shows that preindustrial ethnic groups whose regions experienced a larger loss of biomass in prehistory develop more centralization, higher hierarchy, and a larger community.

A natural question is where this persistence comes from. Using the *Ethnographic Atlas*, Tables H2 and H4 demonstrate that agricultural activities had a primary role in the development of centralization and community size. However, as shown in Table H3, agriculture had only secondary importance for the development of hierarchy. Since the Neolithic Revolution triggered the evolution of culture and institutions, this result suggests that cultural and institutional aspects are the path from megaherbivore extinction in prehistory to hierarchy in preindustrial groups, rather than agriculture *per se*.

Using two different datasets and conducting difference-in-differences and 2SLS regression, I show that megaherbivore extinction in prehistoric times had a long-lasting impact on socioeconomic outcomes *after* the Neolithic and *until* preindustrial periods.

7 Concluding Remarks

This study establishes that loss of biomass associated with extinction of megaherbivores in prehistoric times was a trigger of the Neolithic Revolution. I develop a model showing the link between the lost biomass and the agricultural transition. The model also provides a simple explanation of the puzzle of the Neolithic Revolution. Early humans were forced to shift to cultivation because of a significant reduction in hunting resources resulting from extinction. Unlike the argument insisting greater gains from agriculture, this extinction story easily explains why early humans started farming even if they had to work harder without any increase in consumption.

The key prediction of the model is empirically explored by exploiting a number of data sets. In particular, this study exploits not only cross-sectional variation but also temporal variation. Moreover, it directly accounts for the most important confounding factors: paleoclimatic characteristics. It further addresses a potential endogeneity concern by exploiting biological vulnerability of each species as the exogenous source of variation in extinction. The study also finds the long-run impact of megaherbivore extinction on socioeconomic development by exploiting data sets about pre- and post-Neolithic sites as well as preindustrial societies.

Multiple places independently experienced an agricultural transition. The Neolithic Revolution has had significant impacts on humanity and socioeconomic outcomes this day. Understanding the origin of this historically important event is critical to understanding the variation in the wealth of nations today.

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Appendix A. Figure
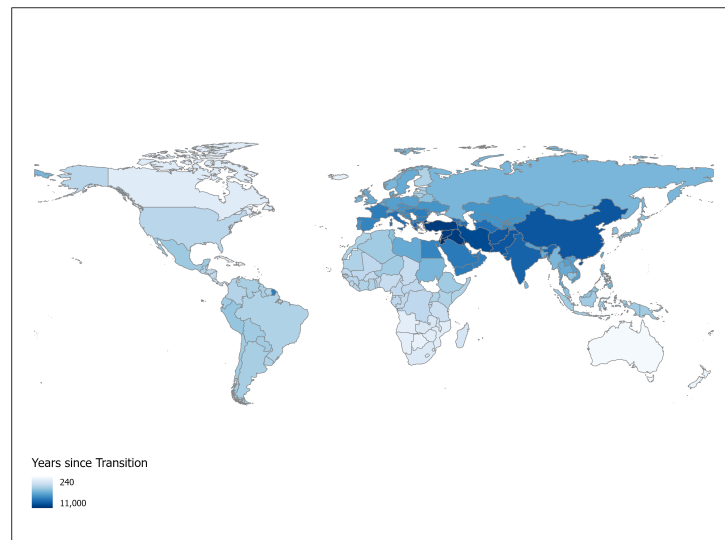
Figure A1: Years Elasped since the Neolithic Revolution (Borcan et al., 2018)
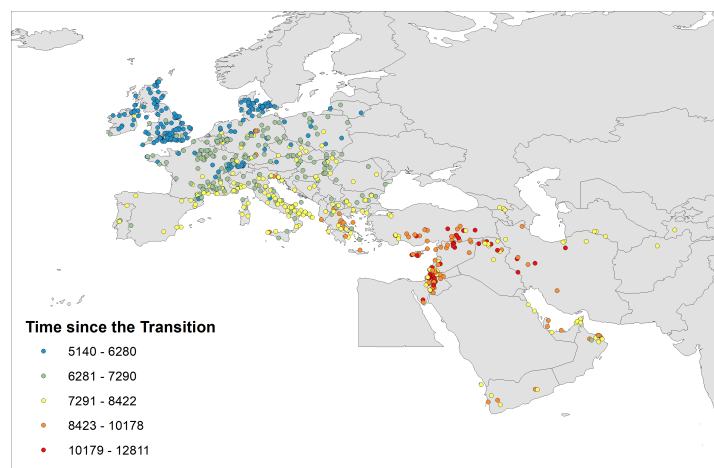
Figure A2: Locations of Archaeological Sites (Pinhasi et al., 2005)
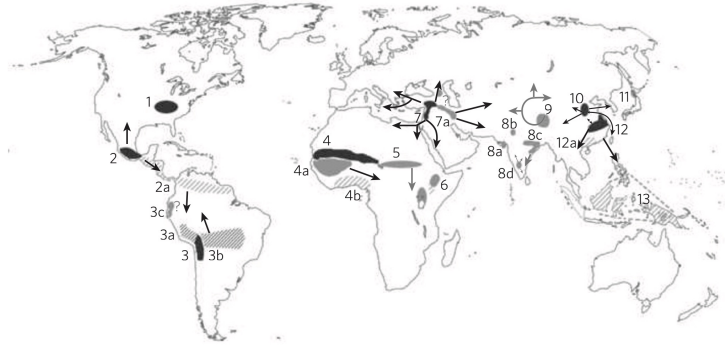
Figure A3: Locations of Centers of Agriculture (Purugganan and Fuller, 2009)
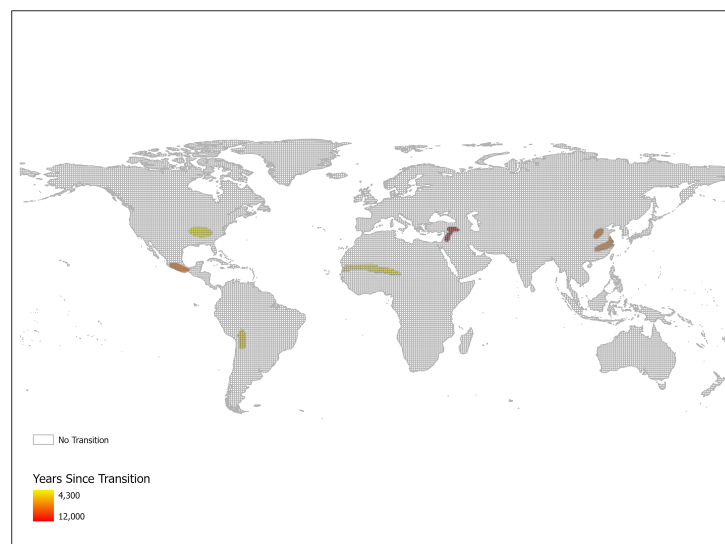
Figure A4: Centers of Independent Agricultural Transition (Virtual Country)

Appendix B. Table

Table B5: Summary Statistics (Cross-Country)

	Mean	SD	Min	Max	N
Dependent Variable					
Years Elapsed since Agricultural Transition (100 Years)	48.48	25.10	3.62	105.00	168
Independent Variables					
Lost Biomass (Herbivore > 44 kg)	0.41	0.34	0.00	1.00	166
Lost Biomass (Herbivore ≤ 44 kg)	0.01	0.04	0.00	0.36	173
Lost Biomass (Non-Herbivore)	0.01	0.03	0.00	0.45	179
Lost Biomass (Currie, 1993)	0.39	0.32	0.00	1.00	171
Lost Biomass (Damuth, 1987)	0.35	0.29	0.00	1.00	171
Lost Biomass (Peters and Raelson, 1984)	0.32	0.27	0.00	1.00	171
Lost Biomass (Peters and Wassenberg, 1983)	0.38	0.31	0.00	1.00	171
Lost Biomass (Silva et al., 2001)	0.37	0.30	0.00	1.00	171
Lost Biomass including Domesticable Mammals	0.35	0.31	0.00	1.00	167
Instrumental Variable					
Lost Biomass Based on Predicted Extinction Risk	0.36	0.30	0.00	0.85	166
Control Variables					
Dist. from the Closest Agricultural Origin	2176.06	1967.80	0.00	9378.58	234
Migratory Dist. from Addis Ababa	8113.31	6789.63	0.00	26770.69	151
Paleo-Temperature (Avg.)	13.43	10.90	-28.12	24.82	181
Paleo-Precipitation (Avg.)	87.91	59.53	3.32	253.55	181
Paleo-Net Primary Product	483.06	363.47	0.00	1476.94	181
Latitude	17.38	26.27	-54.28	78.22	201
Longitude	9.94	70.29	-176.17	174.78	201
Latitude × Longitude	395.26	1705.83	-7215.90	5120.53	201
Elevation (Avg.)	404.14	657.12	-2066.00	3059.91	226
Land Productivity (Avg.)	0.40	0.26	0.00	0.96	171
Island Dummy	0.33	0.47	0.00	1.00	224
Dist. to the Waterway	334.69	467.52	7.95	2385.58	164
Total Area	573490.07	1746482.05	0.71	16973512.00	234
# Native Plants	1459.56	850.30	68.96	3962.94	173
Neighboring Biomass	5.14e+14	6.62e+14	0.00	4.01e+15	190
Paleo-Temperature (Std.)	5.41	3.97	0.54	18.84	181
Paleo-Temperature (Seasonality)	9.39	6.25	0.02	27.01	181
Paleo-Precipitation (Seasonality)	150.59	59.57	34.90	295.62	181
# Domesticable Mammals	1.99	2.27	0.00	11.00	234
# Extinct Megafauna / # Total Megafauna	0.38	0.28	0.00	1.00	178
# Wild Relatives of Domesticable Crops	1.57	2.12	0.00	10.00	234

Table B6: Summary Statistics (Cross-Archaeological Site)

	Mean	SD	Min	Max	N
Dependent Variable					
Years Elapsed since Agricultural Transition (100 Years)	63.19	12.82	45.00	108.90	765
Independent Variables					
Lost Biomass (Herbivore > 44 kg)	0.69	0.24	0.00	1.00	749
Lost Biomass (Currie, 1993)	0.62	0.22	0.00	1.00	762
Lost Biomass (Damuth, 1987)	0.52	0.20	0.00	1.00	762
Lost Biomass (Peters and Raelson, 1984)	0.45	0.18	0.00	1.00	762
Lost Biomass (Peters and Wassenberg, 1983)	0.61	0.22	0.00	1.00	762
Lost Biomass (Silva et al., 2001)	0.57	0.21	0.00	1.00	762
Lost Biomass including Domesticable Mammals	0.59	0.23	0.00	1.00	750
Instrumental Variable					
Lost Biomass Based on Predicted Extinction Risk	0.64	0.22	0.00	0.83	749
Control Variables					
Dist. from Cayonu	2407.93	1019.39	0.00	4140.49	765
Migratory Dist. from Addis Ababa	5185.55	1052.76	2178.99	6876.85	765
Paleo-Temperature (Avg.)	13.57	8.57	1.13	39.39	752
Paleo-Precipitation (Avg.)	38.54	11.79	15.55	92.03	752
Paleo-Net Primary Product	235.10	124.54	3.82	559.15	752
Latitude	44.97	8.39	13.90	59.35	765
Longitude	15.28	16.29	-9.82	69.22	765
Latitude × Longitude	577.73	551.33	-510.42	2653.20	765
Elevation (Avg.)	372.09	356.43	-28.50	2253.11	764
Land Productivity (Avg.)	0.60	0.28	0.00	0.98	744
Island Dummy	0.01	0.10	0.00	1.00	765
Dist. to the Waterway	25.57	27.83	0.02	197.35	765
Total Area	6707.71	1805.98	115.86	7852.90	764
# Native Plants	1189.28	408.73	298.66	2664.88	740
Neighboring Biomass	1.34e+13	6.89e+12	0.00	3.29e+13	757
Paleo-Temperature (Std.)	26.65	12.71	9.15	62.36	752
Paleo-Temperature (Seasonality)	14.24	3.73	4.35	31.69	752
Paleo-Precipitation (Seasonality)	100.20	52.87	27.68	249.82	752
# Domesticable Mammals	3.25	0.97	0.00	6.00	764
# Extinct Megafauna / # Total Megafauna	0.47	0.14	0.17	1.00	764
# Wild Relatives of Domesticable Crops	0.71	0.92	0.00	6.00	764

Table B7: Summary Statistics (Country Panel)

	Mean	SD	Min	Max	N
Dependent Variable					
Neolithic Transition Dummy	0.104	0.305	0.000	1.000	1630
Independent Variables					
Lost Biomass (Herbivore > 44 kg)	0.043	0.144	0.000	1.000	1421
Lost Biomass (Currie, 1993)	0.041	0.139	0.000	1.000	1421
Lost Biomass (Damuth, 1987)	0.039	0.131	0.000	1.000	1421
Lost Biomass (Peters and Raelson, 1984)	0.04	0.13	0.00	1.00	1421
Lost Biomass (Peters and Wassenberg, 1983)	0.04	0.14	0.00	1.00	1421
Lost Biomass (Silva et al., 20021)	0.04	0.13	0.00	1.00	1421
Lost Biomass including Domesticable Mammals	0.04	0.13	0.00	1.00	1421
Control Variables					
Paleo-temperature (Avg.)	16.47	9.17	-26.90	26.88	1516
Paleo-Precipition (Avg.)	1183.78	769.63	37.64	3608.87	1516
Paleo-Net Primary Product (Avg.)	661.77	446.79	0.00	1813.39	1516
Neighboring Biomass	5.95e+10	7.36e+10	0.00	5.57e+11	1486
Paleo-Net Primary Product (Intermonthly Std.)	4.96	3.76	0.58	18.78	1543
Paleo-temperature (Seasonality)	9.88	7.08	0.15	37.05	1516
Paleo-Precipition (Seasonality)	150.66	62.49	25.01	323.74	1516

Table B8: Summary Statistics (Archaeological Site Panel)

	Mean	SD	Min	Max	N
Dependent Variable					
Neolithic Transition Dummy	0.124	0.329	0.000	1.000	6171
Independent Variables					
Lost Biomass (Herbivore > 44 kg)	0.050	0.136	0.000	1.000	6097
Lost Biomass (Currie, 1993)	0.043	0.117	0.000	1.000	6097
Lost Biomass (Damuth, 1987)	0.034	0.094	0.000	1.000	6097
Lost Biomass (Peters and Raelson, 1984)	0.03	0.08	0.00	1.00	6097
Lost Biomass (Peters and Wassenberg, 1983)	0.04	0.11	0.00	1.00	6097
Lost Biomass (Silva et al., 20021)	0.04	0.10	0.00	1.00	6097
Lost Biomass including Domesticable Mammals	0.04	0.10	0.00	1.00	6114
Instrumental Variable					
Lost Biomass Based on Predicted Extinction Risk	0.04	0.00	0.02	0.04	6154
Control Variables					
Paleo-temperature (Avg.)	8.69	4.91	-10.81	26.93	6141
Paleo-Precipition (Avg.)	753.02	312.05	46.94	2439.64	6141
Paleo-Net Primary Product (Avg.)	334.12	143.94	0.00	773.23	6141
Neighboring Biomass	1.05e+09	6.90e+08	0.00	3.79e+09	6148
Paleo-Net Primary Product (Intermonthly Std.)	7.53	1.70	3.19	12.95	6157
Paleo-temperature (Seasonality)	16.12	4.54	0.00	36.05	6141
Paleo-Precipition (Seasonality)	91.77	52.73	20.28	326.68	6141

Table B9: Summary Statistics (Virtual Country Panel)

	Mean	SD	Min	Max	N
Dependent Variable					
Neolithic Transition Dummy	0.0016	0.0402	0.0000	1.0000	276233
Independent Variables					
Lost Biomass (Herbivore > 44 kg)	0.0509	0.1670	0.0000	1.0000	234140
Lost Biomass (Currie, 1993)	0.0483	0.1557	0.0000	1.0000	234140
Lost Biomass (Damuth, 1987)	0.0444	0.1409	0.0000	1.0000	234140
Lost Biomass (Peters and Raelson, 1984)	0.04	0.13	0.00	1.00	234140
Lost Biomass (Peters and Wassenberg, 1983)	0.05	0.15	0.00	1.00	234140
Lost Biomass (Silva et al., 20021)	0.05	0.15	0.00	1.00	234140
Lost Biomass including Domesticable Mammals	0.04	0.15	0.00	1.00	246932
Instrumental Variable					
Lost Biomass Based on Predicted Extinction Risk	0.03	0.00	0.02	0.04	252230
Control Variables					
Paleo-temperature (Avg.)	5.48	16.46	-42.43	30.15	261899
Paleo-Precipition (Avg.)	682.65	685.48	0.00	7285.33	261899
Paleo-Net Primary Product (Avg.)	393.16	400.76	0.00	2271.00	261899
Neighboring Biomass	1.53e+09	1.77e+09	0.00	1.45e+10	273188
Paleo-Net Primary Product (Intermonthly Std.)	10.14	6.41	0.29	30.33	268135
Paleo-temperature (Seasonality)	11.01	7.53	0.00	41.91	261899
Paleo-Precipition (Seasonality)	158.98	73.06	8.07	365.00	261826

Table B10: Summary Statistics (Virtual Country Panel Using Pre- and Post-Neolithic Sites)

	Mean	SD	Min	Max	N
Dependent Variable					
Ancient Ruin (Dummy)	0.05	0.22	0.00	1.00	30754
Ancient Ruin (Count)	0.11	0.70	0.00	23.00	30754
Ancient Settlement (Dummy)	0.04	0.19	0.00	1.00	30754
Ancient Settlement (Count)	0.08	0.59	0.00	21.00	30754
Independent Variables					
Lost Biomass (Herbivore > 44 kg)	0.36	0.32	0.00	1.00	28854
Lost Biomass Based on Predicted Extinction Risk	0.29	0.28	0.00	0.99	28854
Control Variables					
Dist. from the Closest Agricultural Origin	2890.65	1521.64	0.00	6842.00	30754
Migratory Dist. from Addis Ababa	11360.30	6953.52	0.00	28058.71	30654
Paleo-Temperature (Avg.)	1.73	18.13	-43.35	26.58	30680
Paleo-Precipitation (Avg.)	49.75	53.14	0.04	499.06	30680
Paleo-Net Primary Product	283.96	314.13	0.00	1557.45	30680
Neighboring Biomass	2.33e+09	1.57e+09	0.00	8.16e+09	30494
Paleo-Temperature (Seasonality)	9.47	6.80	0.00	28.49	30680
Paleo-Precipitation (Seasonality)	178.22	71.77	14.81	365.00	30680
# Domesticable Mamals	1.92	1.51	0.00	7.00	30754
# Wild Relatives of Domesticable Crops	0.17	0.55	0.00	7.00	30754

Table B11: Summary Statistics (The Ethnographic Atlas)

	Mean	SD	Min	Max	N
Dependent Variable					
Dependence on Hunting	1.43	1.56	0.00	9.00	1308
Jurisdictional Hierarchy beyond Local Community	1.97	1.12	1.00	5.00	1173
Social Stratification	0.52	0.50	0.00	1.00	1127
Size of Local Community	3.66	2.28	1.00	8.00	620
Independent Variables					
Lost Biomass (Herbivore > 44 kg)	0.31	0.32	0.00	1.00	1168
Lost Biomass (Currie, 1993)	0.30	0.31	0.00	1.00	1176
Lost Biomass (Damuth, 1987)	0.28	0.29	0.00	1.00	1176
Lost Biomass (Peters and Raelson, 1984)	0.27	0.28	0.00	1.00	1176
Lost Biomass (Peters and Wassenberg, 1983)	0.30	0.31	0.00	1.00	1176
Lost Biomass (Silva et al., 2001)	0.29	0.30	0.00	1.00	1176
Lost Biomass including Domesticable Mammals	0.29	0.30	0.00	1.00	1172
Instrumental Variable					
Lost Biomass Based on Predicted Extinction Risk	0.25	0.27	0.00	0.99	1168
Control Variables					
Dist. from the Closest Agricultural Origin	2046.07	1440.18	0.00	8162.62	1258
Migratory Dist. from Addis Ababa	10032.62	7459.84	137.90	27963.48	1308
Paleo-Temperature (Avg.)	14.32	11.47	-31.83	25.73	1214
Paleo-Precipitation (Avg.)	95.40	65.56	0.81	531.00	1214
Paleo-Net Primary Product	532.29	367.95	0.00	1543.53	1214
Latitude	15.50	22.74	-55.00	78.00	1309
Longitude	3.16	84.42	-178.00	179.00	1309
Latitude × Longitude	-696.29	2634.36	-11147.00	11682.00	1309
Elevation (Avg.)	690.18	698.14	-1732.00	5477.84	1252
Land Productivity (Avg.)	0.36	0.29	0.00	1.00	1189
Island Dummy	0.00	0.06	0.00	1.00	1309
Dist. to the Waterway	61.91	91.39	0.03	1376.50	1309
Total Area	7066.08	1925.06	1.33	7852.90	1258
# Native Plants	1457.22	831.45	99.98	4760.43	1191
Neighboring Biomass	2.48e+11	1.44e+11	0.00	6.01e+11	1234
Paleo-Temperature (Std.)	4.87	4.42	0.56	25.27	1214
Paleo-Temperature (Seasonality)	7.76	6.02	0.00	25.75	1214
Paleo-Precipitation (Seasonality)	165.81	59.24	30.36	319.24	1214
# Domesticable Mammals	1.16	1.49	0.00	7.00	1258
# Extinct Megafauna / # Total Megafauna	0.34	0.31	0.00	1.00	1187
# Wild Relatives of Domesticable Crops	0.39	0.80	0.00	5.00	1258

Appendix C. Table

Table C1: Dependence on Hunting and Lost Biomass

	Dependence on Hunting				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass	-0.515***	-0.459***	-0.366***	-0.288***	-0.325***
	(0.114)	(0.112)	(0.061)	(0.073)	(0.071)
Dist. to the Closest Agricultural Origin		0.194**	0.117	0.015	0.015
		(0.078)	(0.071)	(0.102)	(0.101)
Migratory Dist. from Addis Ababa		-0.330	0.371*	0.136	0.137
		(0.244)	(0.214)	(0.181)	(0.184)
Paleo-Temperature (Avg.)			-0.625***	-0.706***	-0.699***
			(0.082)	(0.108)	(0.107)
Paleo-Precipitation (Avg.)			-0.108	-0.010	-0.016
			(0.086)	(0.074)	(0.072)
Paleo-Net Primary Product (Avg.)			0.063	0.089	0.089
			(0.106)	(0.110)	(0.109)
Latitude				-0.151	-0.146
				(0.171)	(0.169)
Longitude				0.483	0.462
				(0.299)	(0.290)
Latitude × Longitude				-0.246*	-0.236*
				(0.129)	(0.128)
Elevation (Avg.)				-0.182**	-0.180**
				(0.084)	(0.084)
Land Productivity (Avg.)				-0.079	-0.079
				(0.068)	(0.068)
Island Dummy				-0.063	-0.077
				(0.602)	(0.613)
Dist. to the Waterway				0.070***	0.076***
				(0.022)	(0.022)
Total Area				0.176***	0.173***
				(0.057)	(0.058)
# Native Plants				-0.106	-0.098
				(0.113)	(0.110)
Continent FE	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.516	1.516	1.516	1.516	1.516
Std of Dependent Variable	1.587	1.587	1.587	1.587	1.587
First Stage F-Statistics					1422.738
Adjusted R^2	0.403	0.416	0.485	0.503	
Observations	1151	1151	1151	1151	1151

Note: The unit of analysis is an ethnic group. Dependent variable is dependence on hunting as a subsistence mode. Megaherbivore is herbivore larger than 44 kg. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the language group level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C2: Agricultural Transition, Megaherbivore Extinction and Neighboring Biomass

	Years Since Agricultural Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	4.564**	8.043***	4.592**	5.389***	5.773***	6.055***
	(1.917)	(1.924)	(1.811)	(1.572)	(1.860)	(1.741)
Neighboring Biomass	-2.258	0.229	-0.021	1.329	-2.009	-1.991
	(2.412)	(1.151)	(1.240)	(1.185)	(1.815)	(1.662)
Dist. from the Closest Agricultural Origin			-11.032***	-8.603***	-6.544***	-6.519***
			(1.454)	(1.559)	(2.369)	(2.178)
Migratory Dist. from Addis Ababa			-17.671***	-15.459***	-19.312***	-19.423***
			(3.768)	(3.382)	(3.880)	(3.559)
Paleo-Temperature (Avg.)				8.865***	11.196***	11.176***
				(1.538)	(2.628)	(2.423)
Paleo-Precipitation (Avg.)				-1.131	0.751	0.869
				(2.093)	(2.305)	(2.111)
Paleo-Net Primary Product (Avg.)				-4.033	-1.141	-1.047
				(2.709)	(3.219)	(2.962)
Latitude					-2.611	-2.709
					(2.436)	(2.228)
Longitude					-7.184	-7.108
					(6.333)	(5.810)
Latitude × Longitude					6.006**	5.941***
					(2.471)	(2.271)
Elevation (Avg.)					4.066***	4.037***
					(1.282)	(1.174)
Land Productivity (Avg.)					0.302	0.296
					(1.066)	(0.974)
Island Dummy					-7.141	-7.070*
					(4.507)	(4.162)
Dist. to the Closest Waterway					-0.005	-0.005*
					(0.003)	(0.003)
Total Area					4.178**	4.195***
					(1.626)	(1.481)
# Native Plants					-4.874**	-5.059**
					(2.316)	(2.120)
Continent FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	48.788	48.788	48.788	48.788	48.788	48.788
Std of Dependent Variable	23.252	23.252	23.252	23.252	23.252	23.252
First Stage F-Statistics						1826.147
Adjusted R^2	0.044	0.651	0.761	0.807	0.849	
Observations	132	132	132	132	132	132

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C3: Agricultural Transition and Megaherbivore Extinction (Different Estimates)

	Years Since Agricultural Transition				
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS
Lost Biomass (Currie, 1993)	6.196*** (1.853)				
Lost Biomass (Damuth, 1987)		5.769*** (1.842)			
Lost Biomass (Peters and Raelson, 1984)			5.335*** (1.830)		
Lost Biomass (Peters and Wassenberg, 1983)				6.139*** (1.852)	
Lost Biomass (Silva et al., 2001)					5.985*** (1.848)
Continent FE	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓
Adjusted R^2	0.846	0.843	0.840	0.846	0.844
Observations	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. When constructing measures of lost biomass, I use estimates reported by different studies from the one that I use in the basic analysis. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. Controls are the distance to the closest agricultural center, migratory distance from Addis Ababa, average of paleo-temperature, average of paleo-precipitation, paleo-net primary product, latitude, longitude, the product of latitude and longitude, average of elevation, average of land productivity, island dummy, the distance to the closest waterway, total area and the number of native plants. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C4: Agricultural Transition, Megaherbivore Extinction, Domesticable Mammals and Plants

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
	Years Since Agricultural Transition					
Lost Biomass	2.605*	6.472***	4.200**	4.517***	5.001***	5.166***
	(1.464)	(1.892)	(2.010)	(1.526)	(1.766)	(1.676)
# Wild Relatives of Domesticable Crops	1.548	4.652***	3.008***	3.018***	2.118**	2.116**
	(1.366)	(1.022)	(0.899)	(0.742)	(0.925)	(0.845)
# Domesticable Mammals	16.125***	4.209**	3.019	4.928***	4.579***	4.530***
	(1.363)	(1.967)	(1.826)	(1.555)	(1.439)	(1.312)
Dist. from the Closest Agricultural Origin				-7.951***	-5.445***	-4.957*	-4.938**
				(1.434)	(1.430)	(2.655)	(2.428)
Migratory Dist. from Addis Ababa				-16.740***	-15.457***	-21.196***	-21.229***
				(3.468)	(3.182)	(3.630)	(3.321)
Paleo-Temperature (Avg.)					9.001***	8.939***	8.950***
					(1.393)	(2.856)	(2.617)
Paleo-Precipitation (Avg.)					-0.687	0.889	0.951
					(2.087)	(2.541)	(2.307)
Paleo-Net Primary Product (Avg.)					-2.809	0.927	0.963
					(2.644)	(3.027)	(2.781)
Latitude						-2.846	-2.878
						(2.488)	(2.280)
Longitude						-9.500*	-9.439*
						(5.317)	(4.863)
Latitude × Longitude						6.406**	6.373***
						(2.461)	(2.255)
Elevation (Avg.)						2.742**	2.736**
						(1.327)	(1.212)
Land Productivity (Avg.)						-0.906	-0.901
						(1.144)	(1.043)
Island Dummy						-1.295	-1.309
						(3.811)	(3.481)
Dist. to the Closest Waterway						-0.007***	-0.007***
						(0.003)	(0.002)
Total Area						1.505	1.533
						(1.069)	(0.981)
# Native Plants						-4.245*	-4.352*
						(2.422)	(2.223)
Continent FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Statistics						1579.666
Adjusted R^2	0.559	0.719	0.788	0.834	0.864	
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C5: Agricultural Transition, Megaherbivore Extinction and Extinction Rate

	Years Since Agricultural Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	6.709** (3.001)	9.472*** (2.027)	4.892** (2.146)	4.955*** (1.872)	6.185*** (2.174)	6.433*** (2.117)
# Extinct Megafauna / # Total Megafauna	76.844*** (25.668)	-27.445 (21.998)	-0.998 (24.852)	14.798 (25.532)	6.211 (20.053)	4.558 (18.520)
# Extinct Megafauna / # Total Megafauna (Square)	-112.967*** (22.648)	11.337 (20.069)	3.164 (23.427)	-12.719 (24.236)	-6.124 (18.849)	-4.993 (17.589)
Dist. from the Closest Agricultural Origin			-10.696*** (1.943)	-9.147*** (1.961)	-6.167** (2.499)	-6.089*** (2.277)
Migratory Dist. from Addis Ababa			-17.922*** (3.999)	-15.742*** (3.823)	-21.927*** (3.730)	-22.031*** (3.421)
Paleo-Temperature (Avg.)				7.980*** (1.440)	10.311*** (2.895)	10.284*** (2.658)
Paleo-Precipitation (Avg.)				-0.829 (2.149)	1.389 (2.378)	1.417 (2.176)
Paleo-Net Primary Product (Avg.)				-3.203 (2.631)	0.186 (3.126)	0.246 (2.869)
Latitude					-2.512 (2.417)	-2.578 (2.225)
Longitude					-10.433* (5.639)	-10.285** (5.152)
Latitude × Longitude					7.718*** (2.603)	7.672*** (2.392)
Elevation (Avg.)					3.671*** (1.343)	3.650*** (1.229)
Land Productivity (Avg.)					-0.520 (1.107)	-0.520 (1.010)
Island Dummy					-2.364 (4.583)	-2.344 (4.226)
Dist. to the Closest Waterway					-0.007** (0.003)	-0.007** (0.003)
Total Area					3.086** (1.181)	3.115*** (1.085)
# Native Plants					-4.741** (2.334)	-4.858** (2.136)
Continent FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Statistics						1492.131
Adjusted R^2	0.253	0.665	0.764	0.801	0.846	
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Extinction rate is a percentage of extinct large mammals to all the large mammals. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C6: Agricultural Transition, Megaherbivore Extinction and Temperature Volatility

	Years Since Agricultural Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	2.793*	6.768***	3.876**	4.195**	4.096**	4.044**
	(1.531)	(1.788)	(1.686)	(1.651)	(1.765)	(1.693)
Paleo-Temperature (Avg.)	8.402***	9.072***	3.073	2.109	3.441	3.436
	(3.001)	(2.544)	(2.415)	(2.527)	(3.169)	(2.891)
Paleo-Temperature (Std.)	11.347***	4.848***	3.358***	1.483	2.647*	2.668**
	(1.443)	(1.372)	(1.183)	(1.623)	(1.348)	(1.231)
Paleo-Temperature (Std. Square)	-0.489***	-0.229**	-0.240***	-0.175*	-0.290***	-0.291***
	(0.096)	(0.093)	(0.084)	(0.098)	(0.072)	(0.065)
Dist. from the Closest Agricultural Origin			-10.734***	-11.036***	-4.856**	-4.858**
			(1.675)	(1.751)	(2.270)	(2.074)
Migratory Dist. from Addis Ababa			-17.856***	-16.000***	-24.483***	-24.477***
			(3.364)	(3.304)	(3.663)	(3.351)
Paleo-Precipitation (Avg.)				-3.597	-1.298	-1.317
				(2.226)	(2.236)	(2.023)
Paleo-Net Primary Product (Avg.)				0.172	2.328	2.328
				(2.983)	(3.002)	(2.745)
Latitude					-0.634	-0.622
					(2.437)	(2.228)
Longitude					-12.565**	-12.592***
					(5.166)	(4.730)
Latitude × Longitude					11.720***	11.742***
					(2.207)	(2.043)
Elevation (Avg.)					-0.011	-0.014
					(1.494)	(1.368)
Land Productivity (Avg.)					-1.477	-1.482
					(1.137)	(1.040)
Island Dummy					-2.562	-2.556
					(4.141)	(3.783)
Dist. to the Closest Waterway					-0.003	-0.003
					(0.003)	(0.003)
Total Area					4.784***	4.784***
					(0.946)	(0.864)
# Native Plants					-1.210	-1.165
					(2.507)	(2.303)
Continent FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Statistics						1825.639
Adjusted R^2	0.449	0.725	0.815	0.818	0.869	
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent variable, dummy variable, intermonthly temperature volatility and its square are standardized. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C7: Agricultural Transition, Megaherbivore Extinction and Climatic Seasonality

	Years Since Agricultural Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	1.151	5.112***	2.737	3.751**	4.453**	4.576***
	(1.519)	(1.864)	(1.778)	(1.551)	(1.762)	(1.702)
Paleo-Temperature (Seasonality)	16.439***	7.774***	4.824***	3.378**	2.362	2.326
	(1.248)	(1.401)	(1.209)	(1.600)	(1.669)	(1.524)
Paleo-Precipitation (Seasonality)	-3.828***	-1.667	-4.073***	-3.910***	-4.320***	-4.301***
	(1.393)	(1.304)	(1.165)	(1.172)	(1.203)	(1.101)
Dist. from the Closest Agricultural Origin				-11.171***	-10.064***	-7.189*** -7.175***
				(1.404)	(1.597)	(2.360) (2.156)
Migratory Dist. from Addis Ababa				-14.289***	-14.870***	-19.032*** -19.085***
				(3.778)	(3.453)	(3.836) (3.513)
Paleo-Temperature (Avg.)					6.453***	10.144*** 10.149***
					(1.618)	(2.913) (2.663)
Paleo-Precipitation (Avg.)					1.404	3.176 3.205
					(1.996)	(2.165) (1.970)
Paleo-Net Primary Product (Avg.)					-4.333	-2.017 -1.985
					(2.713)	(3.215) (2.951)
Latitude						-0.981 -1.025
						(2.411) (2.216)
Longitude						-8.555* -8.522*
						(5.081) (4.642)
Latitude × Longitude						6.796*** 6.773***
						(2.458) (2.247)
Elevation (Avg.)						3.809*** 3.797***
						(1.238) (1.130)
Land Productivity (Avg.)						-1.073 -1.064
						(1.133) (1.034)
Island Dummy						-5.547 -5.531
						(4.333) (3.964)
Dist. to the Closest Waterway						-0.006** -0.006**
						(0.003) (0.002)
Total Area						3.160*** 3.172***
						(1.165) (1.069)
# Native Plants						-3.787* -3.870**
						(2.006) (1.842)
Continent FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Statistics						1697.149
Adjusted R^2	0.532	0.722	0.799	0.820	0.864	
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C8: Agricultural Transition and Megaherbivore Extinction (Inclusion of Domesticable Mammals)

	Years Since Agricultural Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	3.050	8.501***	5.268**	5.645***	5.889***	7.487***
	(1.899)	(2.150)	(2.138)	(1.796)	(2.060)	(2.063)
Dist. from the Closest Agricultural Origin				-10.875***	-8.989***	-6.371**	-6.361***
				(1.464)	(1.525)	(2.438)	(2.289)
Migratory Dist. from Addis Ababa				-18.541***	-16.464***	-21.771***	-22.188***
				(3.761)	(3.694)	(3.863)	(3.597)
Paleo-Temperature (Avg.)					7.415***	9.959***	9.826***
					(1.520)	(2.859)	(2.694)
Paleo-Precipitation (Avg.)					-1.134	0.715	1.251
					(2.072)	(2.320)	(2.171)
Paleo-Net Primary Product (Avg.)					-3.404	-0.382	-0.001
					(2.643)	(3.140)	(2.933)
Latitude						-2.162	-2.699
						(2.578)	(2.352)
Longitude						-11.029*	-10.590**
						(5.632)	(5.315)
Latitude × Longitude						7.796***	7.302***
						(2.468)	(2.290)
Elevation (Avg.)						3.822***	3.712***
						(1.358)	(1.256)
Land Productivity (Avg.)						-0.481	-0.445
						(1.152)	(1.036)
Island Dummy						-2.454	-2.201
						(4.088)	(3.831)
Dist. to the Closest Waterway						-0.006**	-0.006**
						(0.003)	(0.003)
Total Area						2.927**	3.040***
						(1.180)	(1.072)
# Native Plants						-3.872*	-4.836**
						(2.239)	(2.153)
Continent FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Statistics						538.187
Adjusted R^2	0.009	0.650	0.766	0.799	0.842	
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C9: Agricultural Transition and Megaherbivore Extinction (Spatial Correlation)

	(1) OLS (2000 km)	(2) 2SLS (2000 km)	(3) OLS (3000 km)	(4) 2SLS (3000 km)	(5) OLS (4000 km)	(6) 2SLS (4000 km)
	Years Since Agricultural Transition					
Lost Biomass (Herbivore > 44 kg)	6.420***	6.612***	6.420***	6.612***	6.420***	6.612***
	(1.571)	(1.529)	(1.135)	(0.964)	(0.970)	(0.676)
Dist. from the Closest Agricultural Origin	-5.996***	-5.983***	-5.996***	-5.983***	-5.996***	-5.983***
	(2.085)	(2.088)	(1.985)	(1.982)	(1.805)	(1.792)
Migratory Dist. from Addis Ababa	-22.019***	-22.072***	-22.019***	-22.072***	-22.019***	-22.072***
	(3.255)	(3.226)	(2.960)	(2.958)	(0.224)	(0.545)
Paleo-Temperature (Avg.)	10.219***	10.212***	10.219**	10.212**	10.219**	10.212**
	(3.457)	(3.470)	(3.977)	(3.991)	(4.193)	(4.211)
Paleo-Precipitation (Avg.)	1.324	1.401	1.324	1.401	1.324	1.401
	(3.086)	(3.070)	(3.282)	(3.240)	(3.166)	(3.138)
Paleo-Net Primary Product (Avg.)	0.098	0.154	0.098	0.154	0.098	0.154
	(2.519)	(2.553)	(2.797)	(2.839)	(2.665)	(2.689)
Latitude	-2.498	-2.568	-2.498	-2.568	-2.498	-2.568
	(1.675)	(1.635)	(2.166)	(2.156)	(1.801)	(1.826)
Longitude	-10.146	-10.071	-10.146*	-10.071*	-10.146*	-10.071*
	(6.507)	(6.519)	(5.373)	(5.378)	(5.637)	(5.670)
Latitude × Longitude	7.627***	7.567***	7.627***	7.567***	7.627***	7.567***
	(2.521)	(2.513)	(2.318)	(2.312)	(2.290)	(2.318)
Elevation (Avg.)	3.653***	3.636***	3.653***	3.636***	3.653***	3.636***
	(1.098)	(1.090)	(0.930)	(0.925)	(0.624)	(0.633)
Land Productivity (Avg.)	-0.535	-0.533	-0.535	-0.533	-0.535	-0.533
	(1.279)	(1.268)	(0.984)	(0.965)	(0.654)	(0.621)
Island Dummy	-2.844	-2.827	-2.844	-2.827	-2.844	-2.827
	(4.032)	(4.022)	(4.363)	(4.351)	(4.793)	(4.781)
Dist. to the Closest Waterway	-0.007**	-0.007**	-0.007**	-0.007**	-0.007**	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Total Area	3.122***	3.141***	3.122***	3.141***	3.122***	3.141***
	(1.078)	(1.089)	(0.950)	(0.950)	(0.845)	(0.833)
# Native Plants	-4.665**	-4.795**	-4.665*	-4.795*	-4.665*	-4.795*
	(2.310)	(2.329)	(2.566)	(2.555)	(2.834)	(2.823)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Stat.		2519.741		5105.175		3740.017
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses calculated using the spatial correlation proposed by Conley (1999) with a threshold of 2000 (columns 1 and 2), 3000 (columns 3 and 4) and 4000 (columns 5 and 6) kilometers. *** p<0.01, ** p<0.05, * p<0.10.

Table C10: Agricultural Transition and Megaherbivore Extinction (Bartlett)

			Years Since Agricultural Transition			
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS (2000 km)	2SLS (2000 km)	OLS (3000 km)	2SLS (3000 km)	OLS (4000 km)	2SLS (4000 km)
Lost Biomass (Herbivore > 44 kg)	6.420***	6.612***	6.420***	6.612***	6.420***	6.612***
	(1.845)	(1.940)	(1.781)	(1.854)	(1.696)	(1.743)
Dist. from the Closest Agricultural Origin	-5.996**	-5.983**	-5.996***	-5.983***	-5.996***	-5.983***
	(2.339)	(2.337)	(2.291)	(2.291)	(2.243)	(2.241)
Migratory Dist. from Addis Ababa	-22.019***	-22.072***	-22.019***	-22.072***	-22.019***	-22.072***
	(3.809)	(3.778)	(3.708)	(3.678)	(3.526)	(3.503)
Paleo-Temperature (Avg.)	10.219***	10.212***	10.219***	10.212***	10.219***	10.212***
	(3.036)	(3.042)	(3.183)	(3.191)	(3.340)	(3.349)
Paleo-Precipitation (Avg.)	1.324	1.401	1.324	1.401	1.324	1.401
	(2.706)	(2.702)	(2.796)	(2.784)	(2.858)	(2.844)
Paleo-Net Primary Product (Avg.)	0.098	0.154	0.098	0.154	0.098	0.154
	(2.763)	(2.789)	(2.772)	(2.802)	(2.757)	(2.787)
Latitude	-2.498	-2.568	-2.498	-2.568	-2.498	-2.568
	(2.214)	(2.216)	(2.169)	(2.166)	(2.158)	(2.157)
Longitude	-10.146*	-10.071*	-10.146*	-10.071*	-10.146*	-10.071*
	(5.556)	(5.556)	(5.535)	(5.535)	(5.516)	(5.521)
Latitude × Longitude	7.627***	7.567***	7.627***	7.567***	7.627***	7.567***
	(2.530)	(2.539)	(2.514)	(2.517)	(2.487)	(2.492)
Elevation (Avg.)	3.653***	3.636***	3.653***	3.636***	3.653***	3.636***
	(1.362)	(1.349)	(1.314)	(1.301)	(1.255)	(1.245)
Land Productivity (Avg.)	-0.535	-0.533	-0.535	-0.533	-0.535	-0.533
	(1.331)	(1.325)	(1.302)	(1.294)	(1.242)	(1.233)
Island Dummy	-2.844	-2.827	-2.844	-2.827	-2.844	-2.827
	(4.142)	(4.136)	(4.162)	(4.156)	(4.231)	(4.224)
Dist. to the Closest Waterway	-0.007**	-0.007**	-0.007**	-0.007**	-0.007**	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Total Area	3.122***	3.141***	3.122***	3.141***	3.122***	3.141***
	(1.065)	(1.072)	(1.060)	(1.068)	(1.040)	(1.045)
# Native Plants	-4.665*	-4.795*	-4.665*	-4.795*	-4.665*	-4.795*
	(2.522)	(2.542)	(2.508)	(2.525)	(2.546)	(2.560)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	48.239	48.239	48.239	48.239	48.239	48.239
Std of Dependent Variable	23.528	23.528	23.528	23.528	23.528	23.528
First Stage F-Stat.		1645.149		1830.121		1987.779
Observations	134	134	134	134	134	134

Note: The unit of analysis is a country. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses calculated using the spatial correlation proposed by Conley (1999) with a threshold of 2000 (columns 1 and 2), 3000 (columns 3 and 4) and 4000 (columns 5 and 6) kilometers, allowing for weights that are close to one for near countries and almost zero for countries close to the distant cutoff. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C11: Agricultural Transition, Megaherbivore Extinction and Neighboring Biomass

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.039***	0.030***	0.028***	0.031***	0.030***	0.029***	0.210***
	(0.003)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.072)
Neighboring Biomass	-8.949***	-1.254***	-0.679	-1.176***	-1.209***	-0.554	-2.457***
	(0.110)	(0.448)	(0.427)	(0.452)	(0.442)	(0.429)	(0.783)
Paleo-Temperature (Avg.)			-0.195***			-0.224***	-0.191***
			(0.015)			(0.020)	(0.025)
Paleo-Precipitation (Avg.)				-0.026*		-0.023*	-0.168***
				(0.014)		(0.013)	(0.061)
Paleo-Net Primary Product (Avg.)					-0.046***	0.030***	0.022*
					(0.007)	(0.011)	(0.012)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.123	0.123	0.123	0.123	0.123	0.123	0.123
Std of Dependent Variable	0.329	0.329	0.329	0.329	0.329	0.329	0.329
First-F							11.841
Observations	6061	6061	6061	6061	6061	6061	6061

Note: The unit of analysis is an archaeological site. The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Based on the information on the timing of the transition reported by Pinhasi et al. (2005), I assign 1 if the transition happens in the associated period. Once the transition occurs, I drop the site from the sample. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the archaeological site and period level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C12: Agricultural Transition and Megaherbivore Extinction (Different Estimates)

	The Indicator of the Neolithic Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass (Currie, 1993)	0.086***				
	(0.005)				
Lost Biomass (Damuth, 1987)		0.084***			
		(0.005)			
Lost Biomass (Peters and Raelson, 1984)			0.082***		
			(0.005)		
Lost Biomass (Peters and Wassenberg, 1983)				0.085***	
				(0.005)	
Lost Biomass (Silva et al., 2001)					0.085***
					(0.005)
Site FE	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓
Paleoclimatic Controls	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.022	0.022	0.022	0.022	0.022
Std of Dependent Variable	0.147	0.147	0.147	0.147	0.147
Observations	5318	5318	5318	5318	5318

Note: The unit of analysis is an archaeological site. The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Based on the information on the timing of the transition reported by Pinhasi et al. (2005), I assign 1 if the transition happens in the associated period. Once the transition occurs, I drop the site from the sample. Lost biomass is calculated using extinct megaherbivores. When constructing measures of lost biomass, I use estimates reported by different studies from the one that I use in the basic analysis. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. Paleoclimatic controls are average of paleo-temperature, average of paleo-precipitation and paleo-net primary product. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the archaeological site and period level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C13: Table. Agricultural Transition, Megaherbivore Extinction and Intermonthly Temperature Volatility

	The Indicator of the Neolithic Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	0.038***	0.024***	0.024***	0.024***	0.023***	0.086**
	(0.003)	(0.005)	(0.005)	(0.005)	(0.005)	(0.043)
Paleo-Temperature (Avg.)	0.309***	-0.264***	-0.260***	-0.273***	-0.272***	-0.264***
	(0.012)	(0.017)	(0.017)	(0.019)	(0.019)	(0.020)
Paleo-Temperature (Intermonthly Std.)	0.667***	0.240***	0.246***	0.238***	0.247***	0.224***
	(0.054)	(0.063)	(0.064)	(0.063)	(0.065)	(0.063)
Paleo-Temperature (Intermonthly Std. Square)	-0.035***	0.000	0.000	0.001	0.000	0.001
	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Paleo-Net Primary Product (Avg.)				0.010	0.009	0.009
				(0.011)	(0.011)	(0.011)
Paleo-Precipitation (Avg.)					0.010	-0.047
					(0.015)	(0.043)
Site FE	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	0.123	0.123	0.123	0.123	0.123	0.123
Std of Dependent Variable	0.329	0.329	0.329	0.329	0.329	0.329
First-F						21.516
Observations	6070	6070	6070	6070	6070	6070

Note: The unit of analysis is an archaeological site. The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Based on the information on the timing of the transition reported by Pinhasi et al. (2005), I assign 1 if the transition happens in the associated period. Once the transition occurs, I drop the site from the sample. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period. All the variables except for the dependent variable and intermonthly temperature volatility and its square are standardized. Robust standard errors clustered at the archaeological site and period level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C14: Table. Agricultural Transition, Megaherbivore Extinction and Climatic Seasonality

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.030***	0.029***	0.028***	0.030***	0.029***	0.029***	0.180***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.048)
Paleo-Temperature (Seasonality)	0.133***	0.053***	0.071***	0.050***	0.054***	0.072***	0.071***
	(0.018)	(0.015)	(0.014)	(0.015)	(0.015)	(0.014)	(0.015)
Paleo-Precipitation (Seasonality)	-0.112***	-0.005	-0.026**	-0.006	-0.012	-0.025**	-0.026**
	(0.017)	(0.012)	(0.012)	(0.012)	(0.012)	(0.011)	(0.012)
Paleo-Temperature (Avg.)			-0.214***			-0.245***	-0.227***
			(0.013)			(0.019)	(0.022)
Paleo-Precipitation (Avg.)				-0.021		-0.009	-0.140***
				(0.015)		(0.014)	(0.046)
Paleo-Net Primary Product (Avg.)						-0.049***	0.032***	0.028**
						(0.007)	(0.011)	(0.012)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.123	0.123	0.123	0.123	0.123	0.123	0.123
Std of Dependent Variable	0.329	0.329	0.329	0.329	0.329	0.329	0.329
First-F							23.400
Observations	6070	6070	6070	6070	6070	6070	6070

Note: The unit of analysis is an archaeological site. The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Based on the information on the timing of the transition reported by Pinhasi et al. (2005), I assign 1 if the transition happens in the associated period. Once the transition occurs, I drop the site from the sample. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the archaeological site and period level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C15: Table. Agricultural Transition and Megaherbivore Extinction (Inclusion of Domesticable Mammals)

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.017***	0.032***	0.030***	0.034***	0.032***	0.032***	0.103**
	(0.003)	(0.004)	(0.004)	(0.005)	(0.004)	(0.005)	(0.041)
Paleo-Temperature (Avg.)			-0.197***			-0.226***	-0.217***
			(0.013)			(0.019)	(0.020)
Paleo-Precipitation (Avg.)				-0.039***		-0.033**	-0.100**
				(0.014)		(0.013)	(0.041)
Paleo-Net Primary Product (Avg.)					-0.046***	0.031***	0.030***
					(0.007)	(0.011)	(0.011)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.123	0.123	0.123	0.123	0.123	0.123	0.123
Std of Dependent Variable	0.329	0.329	0.329	0.329	0.329	0.329	0.329
First-F							23.835
Observations	6085	6085	6085	6085	6085	6085	6085

Note: The unit of analysis is an archaeological site. The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Based on the information on the timing of the transition reported by Pinhasi et al. (2005), I assign 1 if the transition happens in the associated period. Once the transition occurs, I drop the site from the sample. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the archaeological site and period level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C16: Table. Agricultural Transition and Megaherbivore Extinction (Spatial Correlation)

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.023**	0.028***	0.027***	0.030***	0.029***	0.029***	0.128*
	(0.009)	(0.008)	(0.008)	(0.009)	(0.008)	(0.008)	(0.069)
Paleo-Temperature (Avg.)			-0.198***			-0.226***	-0.215***
			(0.032)			(0.035)	(0.040)
Paleo-Precipitation (Avg.)				-0.033		-0.027	-0.113*
				(0.028)		(0.028)	(0.066)
Paleo-Net Primary Product (Avg.)					-0.046***	0.030	0.028
					(0.014)	(0.019)	(0.022)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.123	0.123	0.123	0.123	0.123	0.123	0.123
Std of Dependent Variable	0.329	0.329	0.329	0.329	0.329	0.329	0.329
First-F							6.966
Observations	6070	6070	6070	6070	6070	6070	6070

Note: The unit of analysis is an archaeological site. The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Based on the information on the timing of the transition reported by Pinhasi et al. (2005), I assign 1 if the transition happens in the associated period. Once the transition occurs, I drop the site from the sample. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and are standardized. Robust standard errors are clustered using the spatial correlation proposed by Conley (1999) with a threshold of 200 kilometers, allowing for weights that are close to one for near sites and almost zero for sites close to the distant cutoff. It is also clustered at the period level. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C17: Agricultural Transition, Megaherbivore Extinction and Neighboring Biomass

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Neighboring Biomass	-0.003***	-0.001***	-0.001***	-0.001***	-0.001***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Paleo-Temperature (Avg.)			-0.007***			-0.007***	-0.008***
			(0.000)			(0.000)	(0.001)
Paleo-Precipitation (Avg.)				0.000		0.002***	0.003***
				(0.000)		(0.000)	(0.001)
Paleo-Primary Product (Avg.)					-0.001***	-0.001*	-0.000
					(0.000)	(0.000)	(0.000)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Std of Dependent Variable	0.042	0.042	0.042	0.042	0.042	0.042	0.042
First-F							1069.520
Observations	229839	229839	229839	229839	229839	229839	229839

Note: The unit of analysis is a virtual country (cell). Dependent variable is a dummy variable that takes one if independent agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the virtual country and period level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C18: Agricultural Transition and Megaherbivore Extinction (Different Estimates)

	The Indicator of the Neolithic Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass (Currie, 1993)	0.0006***				
	(0.0001)				
Lost Biomass (Damuth, 1987)		0.0006***			
		(0.0001)			
Lost Biomass (Peters and Raelson, 1984)			0.0005***		
			(0.0001)		
Lost Biomass (Peters and Wassenberg, 1983)				0.0006***	
				(0.0001)	
Lost Biomass (Silva et al., 2001)					0.0006***
					(0.0001)
Site FE	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓
Paleoclimatic Controls	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.002	0.002	0.002	0.002	0.002
Std of Dependent Variable	0.042	0.042	0.042	0.042	0.042
Observations	230075	230075	230075	230075	230075

Note: The unit of analysis is a virtual country (cell). Dependent variable is a dummy variable that takes one if independent agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. When constructing measures of lost biomass, I use estimates reported by different studies from the one that I use in the basic analysis. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. Paleoclimatic controls are average of paleo-temperature, average of paleo-precipitation and paleo-net primary product. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the virtual country and period level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C19: Table. Agricultural Transition, Megaherbivore Extinction and Intermonthly Temperature Volatility

	The Indicator of the Neolithic Transition					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) 2SLS
Lost Biomass	0.001***	0.001***	0.001***	0.001***	0.001***	0.013***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Paleo-Temperature (Avg.)	0.005***	-0.005***	-0.006***	-0.005***	-0.006***	-0.010***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Paleo-Temperature (Intermonthly Std.)	0.005***	-0.001***	-0.001***	-0.001***	-0.001***	-0.005***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Paleo-Temperature (Intermonthly Std. Square)	-0.000***	0.000**	0.000**	0.000**	0.000**	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Paleo-Precipitation (Avg.)			0.002***		0.002***	0.003***
			(0.001)		(0.001)	(0.001)
Paleo-Primary Product (Avg.)				0.001	0.000	0.002***
				(0.000)	(0.000)	(0.000)
Site FE	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓
Mean of Dependent Variable	0.002	0.002	0.002	0.002	0.002	0.002
Std of Dependent Variable	0.042	0.042	0.042	0.042	0.042	0.042
First-F						686.504
Observations	230083	230083	230083	230083	230083	230083

Note: The unit of analysis is a virtual country (cell). Dependent variable is a dummy variable that takes one if independent agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period. All the variables except for the dependent variable and intermonthly temperature volatility and its square are standardized. Robust standard errors clustered at the virtual country and period level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C20: Table. Agricultural Transition, Megaherbivore Extinction and Climatic Seasonality

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.011***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Paleo-Temperature (Seasonality)	0.001***	-0.002***	-0.000	-0.002***	-0.002***	-0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Paleo-Precipitaion (Seasonality)	0.000	0.002***	0.001***	0.002***	0.002***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Paleo-Temperature (Avg.)			-0.004***			-0.005***	-0.010***
			(0.001)			(0.001)	(0.001)
Paleo-Precipitation (Avg.)				0.002***		0.002***	0.004***
				(0.001)		(0.001)	(0.001)
Paleo-Primary Product (Avg.)					0.000	-0.000	0.001**
					(0.000)	(0.000)	(0.000)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Std of Dependent Variable	0.042	0.042	0.042	0.042	0.042	0.042	0.042
First-F							879.356
Observations	230044	230044	230044	230044	230044	230044	230044

Note: The unit of analysis is a virtual country (cell). Dependent variable is a dummy variable that takes one if independent agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the virtual country and period level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table C21: Table. Agricultural Transition and Megaherbivore Extinction (Inclusion of Domesticable Mammals)

	The Indicator of the Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.016***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)
Paleo-Temperature (Avg.)			-0.006***			-0.006***	-0.010***
			(0.000)			(0.000)	(0.001)
Paleo-Precipitation (Avg.)				0.000		0.002***	0.004***
				(0.000)		(0.001)	(0.001)
Paleo-Primary Product (Avg.)					-0.001**	-0.000	0.004***
					(0.000)	(0.000)	(0.001)
Site FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Std of Dependent Variable	0.042	0.042	0.042	0.042	0.042	0.042	0.042
First-F							304.794
Observations	242295	242295	242295	242295	242295	242295	242295

Note: The unit of analysis is a virtual country (cell). Dependent variable is a dummy variable that takes one if independent agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the virtual country and period level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table C22: Table. Agricultural Transition and Megaherbivore Extinction (Spatial Correlation)

	The Indicator of the Independent Neolithic Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.011***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)
Paleo-Temperature (Avg.)			-0.006***			-0.006***	-0.009***
			(0.001)			(0.001)	(0.001)
Paleo-Precipitation (Avg.)				0.000		0.002*	0.004***
				(0.001)		(0.001)	(0.001)
Paleo-Primary Product (Avg.)					-0.001	-0.000	0.001**
					(0.001)	(0.001)	(0.001)
Cell FE	✓	✓	✓	✓	✓	✓	✓
Time FE		✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Std of Dependent Variable	0.042	0.042	0.042	0.042	0.042	0.042	0.042
First-F							150.499
Observations	230075	230075	230075	230075	230075	230075	230075

Note: The unit of analysis is a virtual country (cell). The dependent variable is a dummy variable that takes one if the agricultural transition occurs. Lost biomass is calculated using extinct mega-herbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and are standardized. Robust standard errors are clustered using the spatial correlation proposed by Conley (1999) with a threshold of 200 kilometers, allowing for weights that are close to one for near cells and almost zero for cells close to the distant cutoff. It is also clustered at the period level. *** p<0.01, ** p<0.05, * p<0.10.

Appendix D. Validity of the Instrumental Variable

The endogenous variable and instrumental variable, by construction, both capture information on vulnerability of mammals. In this section, I show that the instrument is valid in this situation as long as the instrument is assumed to be exogenous.

Let y and x be the Neolithic Revolution timing and lost biomass that is potentially endogenous. Denote the instrumental variable by z. Then the variable construction are expressed as

$$x_i = x_i^* + f(v_i) \tag{29}$$

and

$$z_i = x_i^* + g(v_i), \tag{30}$$

where x_i^* is a true value of biomass in region i; v_i is vulnerability of species in region i; $f(\cdot)$ is a function that maps vulnerability onto lost biomass; and $g(\cdot)$ a function that maps vulnerability onto the IV.

The empirical model of interest is

$$y_i = \alpha_0 + \alpha_1 x_i + u_i, \tag{31}$$

where u_i is an error term.

Notice that the instrumental variable estimator asymptotically takes the form

$$\alpha_1^{IV} = \frac{Cov(z, y)}{Cov(z, x)}. \tag{32}$$

Given that v is exogenous, (29)-(32) imply $\alpha_1^{IV} = \alpha_1$.

Appendix E. Cross-Archaeological Analysis

Although the cross-country analysis covers the largest spatial distribution of the timing of agricultural transition, it is undoubtedly a noisy proxy for the actual transition timing. Thus this appendix provides the evidence using archaeological sites, which is more suitable unit of analysis than countries. Since the spatial coverage in this subsection is limited to the Middle East and Europe, the analysis is thought of as complementary with the cross-country analysis.

Table E1 shows that lost biomass caused by megaherbivore extinction has a positive impact on the timing of agricultural transition across archaeological sites. A bivariate correlation between lost lost biomass and the transition is insignificant and negative in column 1. However, once accounting for paleoclimatic characteristics, the estimate becomes positive and statistically significant in column 2.[25] This is because these paleoclimatic features highly correlate with the transition timing and lost biomass with different signs.[26] Therefore, it is crucial to account for confounding paleoclimate to reveal the relationship between agricultural transition and megaherbivore extinction. Columns 3 and 4 sequentially control for Europe fixed effects and country fixed effects. Country fixed effects reduce the estimate by 64 %, but it is statistically significant. Column 5 adds the distance from Cayonu and migratory distance from Addis Ababa, which does not change the estimate. It is also robust to the inclusion of a number of geographical features in column 6. The 2SLS estimate in column 7 shows a slightly larger impact of lost biomass on the transition timing than the OLS estimate. A one standard deviation increase in lost biomass due to megaherbivore extinction is associated with 87 years earlier agricultural transition.

Robustness: Incentives to Migrate

When available hunting resources got scarce, individuals may have moved to the outside of their original places. As is explained in the theoretical section, this is not much concern in the settings of this study. However, to further alleviate the concern of out-migration, I account for neighboring biomass that captures incentives to migrate. Table E2 shows that the estimate of lost biomass is robust to the inclusion of biomass in surrounding regions.

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[25]Moreover, R^2 dramatically improves from 0.014 to 0.547 by the inclusion of paleoclimatic features.

[26]Paleo-temperature is correlated with agricultural transition at 0.71 while correlation with lost biomass is -0.45. Paleo-precipitation is correlated with the transition at -0.3 while correlation with lost biomass is 0.31. Lastly, paleo-precipitation is correlated with the transition at -0.15 while correlation with lost biomass is 0.44.

Table E1: Agricultural Transition and Lost Biomass

	Years Since Agricultural Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	-1.709 (2.040)	3.105* (1.666)	3.012* (1.516)	1.094** (0.412)	0.866** (0.419)	0.800** (0.387)	0.869** (0.369)
Paleo-Temperature (Avg.)		10.504*** (1.220)	6.169*** (1.738)	2.986*** (0.867)	2.286** (0.949)	1.935 (1.650)	1.951 (1.650)
Paleo-Precipitation (Avg.)		-0.468 (0.804)	-0.053 (0.717)	0.368 (0.356)	0.489 (0.297)	0.396 (0.370)	0.399 (0.372)
Paleo-Net Primary Product (Avg.)		0.435 (0.820)	1.827** (0.682)	-0.423 (0.284)	-0.492 (0.298)	-0.189 (0.338)	-0.194 (0.338)
Dist. to Cayonu					-4.831 (4.135)	-8.790** (3.867)	-8.765** (3.865)
Migratory Dist. from Addis Ababa					1.109 (3.549)	3.822 (3.147)	3.858 (3.129)
Latitude						-1.973 (2.614)	-2.003 (2.590)
Longitude						4.772 (6.027)	4.710 (5.986)
Latitude × Longitude						-6.441 (4.166)	-6.365 (4.120)
Elevation (Avg.)						0.653 (0.792)	0.648 (0.789)
Land Productivity (Avg.)						-0.507 (0.487)	-0.513 (0.486)
Island Dummy						0.051 (1.622)	0.052 (1.624)
Dist. to the Waterway						-0.164 (0.373)	-0.163 (0.372)
Total Area						0.171 (0.515)	0.170 (0.514)
# Native Plants						-0.516 (0.824)	-0.515 (0.825)
Europe Dummy			✓				
Country FE				✓	✓	✓	✓
Mean of Dependent Variable	63.091	63.091	63.091	63.091	63.091	63.091	63.091
Std of Dependent Variable	12.863	12.863	12.863	12.863	12.863	12.863	12.863
First Stage F-Statistics							5109.587
Adjusted R^2	0.014	0.547	0.593	0.777	0.779	0.782	
Observations	717	717	717	717	717	717	717

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the country level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Robustness: Estimates from Different Studies

The measure of lost biomass, (23), is constructed utilizing an estimate from Silva and Downing (1995). Therefore, one may think that the result is driven by this particular study. Thus, I reconstruct the measure of lost biomass, exploiting different estimates from other independent studies. Table E3 shows that the result is robust to using these different estimates.

Table E2: Agricultural Transition, Megaherbivore Extinction and Neighboring Biomass

	Years Since Agricultural Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	-1.761 (2.337)	2.967* (1.686)	2.903* (1.532)	1.094** (0.411)	0.866** (0.413)	0.810** (0.368)	0.869** (0.348)
Neighboring Biomass	0.182 (1.989)	1.411 (1.001)	1.135 (0.960)	0.015 (0.480)	-0.113 (0.433)	-0.621 (0.608)	-0.622 (0.609)
Paleo-Temperature (Avg.)		10.669*** (1.239)	6.413*** (1.854)	2.992*** (0.875)	2.234** (0.984)	2.004 (1.676)	2.017 (1.676)
Paleo-Precipitation (Avg.)		-0.113 (0.868)	0.222 (0.728)	0.369 (0.356)	0.488 (0.296)	0.491 (0.419)	0.494 (0.420)
Paleo-Net Primary Product (Avg.)		-0.228 (0.670)	1.258** (0.552)	-0.428 (0.328)	-0.456 (0.334)	-0.080 (0.382)	-0.084 (0.381)
Dist. to Cayonu					-4.888 (4.208)	-8.663** (3.954)	-8.642** (3.953)
Migratory Dist. from Addis Ababa					1.150 (3.613)	3.777 (3.267)	3.808 (3.251)
Latitude						-1.833 (2.624)	-1.858 (2.603)
Longitude						3.718 (6.096)	3.663 (6.061)
Latitude × Longitude						-5.328 (4.301)	-5.260 (4.258)
Elevation (Avg.)						0.722 (0.792)	0.717 (0.789)
Land Productivity (Avg.)						-0.533 (0.478)	-0.538 (0.477)
Island Dummy						0.250 (1.628)	0.251 (1.630)
Dist. to the Waterway						-0.162 (0.368)	-0.161 (0.367)
Total Area						0.463 (0.612)	0.462 (0.611)
# Native Plants						-0.629 (0.814)	-0.629 (0.814)
Europe Dummy			✓				
Country FE				✓	✓	✓	✓
Mean of Dependent Variable	63.091	63.091	63.091	63.091	63.091	63.091	63.091
Std of Dependent Variable	12.863	12.863	12.863	12.863	12.863	12.863	12.863
First Stage F-Statistics							4703.638
Adjusted R^2	0.013	0.554	0.598	0.777	0.779	0.782	
Observations	717	717	717	717	717	717	717

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the country level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table E3: Agricultural Transition and Megaherbivore Extinction (Different Estimates)

	Years Since Agricultural Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass (Currie, 1993)	84.984* (47.487)				
Lost Biomass (Damuth, 1987)		89.831* (47.008)			
Lost Biomass (Peters and Raelson, 1984)			93.886* (47.568)		
Lost Biomass (Peters and Wassenberg, 1983)				85.707* (47.328)	
Lost Biomass (Silva et al., 2001)					87.525* (47.066)
Country FE	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓
Adjusted R^2	0.783	0.783	0.783	0.783	0.783
Observations	720	720	720	720	720

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. When constructing measures of lost biomass, I use estimates reported by different studies from the one that I use in the basic analysis. Controls are average of paleo-temperature, average of paleo-precipitation, average of paleo-net primary product, the distance from Cayonu, migratory distance from Addis Ababa, latitude, longitude, the product of latitude and longitude, average of elevation, average of land productivity, island dummy, the distance to the closeset waterway, total area and the number of native plants. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Robustness: Domesticable Mammals, Wild Relatives of Domesticable Plants and Extinction Rate

The existence of domesticable mammals and plants allowed an earlier transition to agriculture by providing biogeographically better initial conditions (Diamond, 2017; Olsson and Hibbs, 2005). Recent study by Riahi (2020) also argues that large mammal extinction has a hump-shaped relationship with the agricultural transition timing.[27] Hence, I add measures of domesticable mammals and wild relatives of domesticable plants in Table E4. I also control for extinction rate and its square in Table E5. As is evident, the estimate of lost biomass is robust to the inclusion of these variables.

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[27]He does not investigate this hump-shaped association using the dataset by Pinhasi et al. (2005), who focuse on the Middle East and Europe.

Table E4: Agricultural Transition, Megaherbivore Extinction, Domesticable Mammals and Plants

	Years Since Agricultural Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	-2.231 (1.433)	1.068 (1.176)	1.378 (1.262)	0.917** (0.451)	0.765* (0.430)	0.626 (0.377)	0.717* (0.366)
# Wild Relatives of Domesticable Crops	1.271 (1.269)	-0.112 (0.791)	-0.191 (0.755)	0.211 (0.363)	0.098 (0.352)	0.111 (0.349)	0.117 (0.350)
# Domesticable Mammals	7.633*** (1.510)	4.968*** (1.052)	4.179*** (1.029)	0.677 (1.096)	0.381 (0.764)	0.659 (0.674)	0.623 (0.677)
Paleo-Temperature (Avg.)		8.413*** (1.103)	6.578*** (1.651)	2.894*** (0.940)	2.272** (0.961)	1.781 (1.583)	1.804 (1.585)
Paleo-Precipitation (Avg.)		0.286 (0.639)	0.361 (0.596)	0.339 (0.392)	0.469 (0.313)	0.309 (0.391)	0.316 (0.392)
Paleo-Net Primary Product (Avg.)		1.522*** (0.536)	2.040*** (0.543)	-0.433 (0.293)	-0.505 (0.305)	-0.187 (0.333)	-0.194 (0.333)
Dist. to Cayonu					-4.072 (3.596)	-7.783** (3.725)	-7.792** (3.720)
Migratory Dist. from Addis Ababa					0.392 (2.920)	2.825 (3.011)	2.915 (2.969)
Latitude						-2.286 (2.533)	-2.315 (2.507)
Longitude						4.097 (6.313)	4.017 (6.261)
Latitude × Longitude						-6.163 (4.344)	-6.051 (4.285)
Elevation (Avg.)						0.611 (0.795)	0.606 (0.793)
Land Productivity (Avg.)						-0.580 (0.532)	-0.587 (0.531)
Island Dummy						0.127 (1.655)	0.127 (1.656)
Dist. to the Waterway						-0.197 (0.384)	-0.193 (0.382)
Total Area						0.136 (0.513)	0.135 (0.513)
# Native Plants						-0.475 (0.836)	-0.477 (0.836)
Europe Dummy			✓				
Country FE				✓	✓	✓	✓
Mean of Dependent Variable	63.091	63.091	63.091	63.091	63.091	63.091	63.091
Std of Dependent Variable	12.863	12.863	12.863	12.863	12.863	12.863	12.863
First Stage F-Statistics							4914.284
Adjusted R^2	0.382	0.630	0.640	0.777	0.779	0.782	
Observations	717	717	717	717	717	717	717

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Robustness: Temperature Volatility and Climatic Seasonality

Intermonthly temperature volatility and its square term as well as climatic seasonality are shown to be related with agricultural transition (Ashraf and Michalopoulos, 2015; Matranga,

Table E5: Agricultural Transition, Megaherbivore Extinction and Extinction Rate

	Years Since Agricultural Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	4.387***	4.202***	4.037***	1.254***	1.093**	0.999**	1.106**
	(1.061)	(1.054)	(1.114)	(0.421)	(0.462)	(0.447)	(0.421)
# Extinct Megafauna / # Total Megafauna	-246.623***	-206.359***	-192.093***	-8.135	-14.286	-6.600	-8.943
	(58.898)	(50.039)	(51.465)	(36.277)	(36.416)	(28.909)	(28.858)
# Extinct Megafauna / # Total Megafauna (Square)	215.831***	200.786***	194.602***	16.941	25.552	21.977	24.915
	(77.212)	(60.274)	(60.839)	(41.170)	(44.002)	(35.568)	(35.506)
Paleo-Temperature (Avg.)		6.423***	5.472***	3.095***	2.400**	2.147	2.171
		(1.102)	(1.539)	(0.855)	(0.944)	(1.620)	(1.619)
Paleo-Precipitation (Avg.)		0.108	0.189	0.393	0.528	0.474	0.480
		(0.553)	(0.548)	(0.373)	(0.314)	(0.391)	(0.393)
Paleo-Net Primary Product (Avg.)		2.302***	2.484***	-0.451	-0.526*	-0.229	-0.237
		(0.558)	(0.586)	(0.283)	(0.307)	(0.362)	(0.363)
Dist. to Cayonu					-4.989	-9.172**	-9.138**
					(4.090)	(3.690)	(3.680)
Migratory Dist. from Addis Ababa					1.134	3.814	3.833
					(3.341)	(2.836)	(2.824)
Latitude						-1.541	-1.562
						(2.413)	(2.386)
Longitude						7.815	7.802
						(5.967)	(5.971)
Latitude × Longitude						-8.759**	-8.712**
						(4.207)	(4.204)
Elevation (Avg.)						0.670	0.661
						(0.830)	(0.826)
Land Productivity (Avg.)						-0.463	-0.469
						(0.479)	(0.480)
Island Dummy						-0.040	-0.041
						(1.589)	(1.588)
Dist. to the Waterway						-0.154	-0.154
						(0.365)	(0.364)
Total Area						0.274	0.278
						(0.528)	(0.528)
# Native Plants						-0.500	-0.497
						(0.848)	(0.848)
Europe Dummy			✓				
Country FE				✓	✓	✓	✓
Mean of Dependent Variable	63.091	63.091	63.091	63.091	63.091	63.091	63.091
Std of Dependent Variable	12.863	12.863	12.863	12.863	12.863	12.863	12.863
First Stage F-Statistics							3358.587
Adjusted R^2	0.503	0.636	0.640	0.777	0.779	0.782	
Observations	717	717	717	717	717	717	717

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. Extinction rate is a percentage of extinct large mammals to all the large mammals. All the variables except for the dependent and dummy variables, extinction rate and its square are standardized. Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

2017). Therefore, I account for these variables. As shown in Table E6 and E7, the estimate of lost biomass is robust to the inclusion of these variables, showing that the basic result is not driven by these climatic aspects.

Robustness: Inclusion of Domesticable Mammals into Lost Biomass

I reconstruct the measure of lost biomass by including 14 domesticable mammalian species, although this inclusion is less consistent with the proposed theory. Table E8 shows that

Table E6: Agricultural Transition, Megaherbivore Extinction and Intermonthly Temperature Volatility

	Years Since Agricultural Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	3.189** (1.486)	3.058* (1.663)	2.984* (1.501)	1.085** (0.413)	0.844* (0.424)	0.792* (0.407)	0.875** (0.395)
Paleo-Temperature (Std.)	-0.049 (0.360)	-0.078 (0.347)	-0.034 (0.305)	-0.089 (0.218)	-0.160 (0.228)	-0.176 (0.217)	-0.175 (0.216)
Paleo-Temperature (Std. Square)	0.001 (0.005)	0.002 (0.005)	0.001 (0.004)	0.002 (0.004)	0.003 (0.004)	0.004 (0.003)	0.004 (0.003)
Paleo-Temperature (Avg.)	10.280*** (1.706)	10.056*** (1.713)	5.911** (2.204)	2.653 (1.683)	2.286 (1.649)	0.635 (3.052)	0.645 (3.057)
Paleo-Precipitation (Avg.)		-0.490 (0.808)	-0.059 (0.777)	0.285 (0.420)	0.438 (0.356)	0.317 (0.410)	0.320 (0.411)
Paleo-Net Primary Product (Avg.)		0.555 (1.003)	1.895** (0.846)	-0.411 (0.331)	-0.559 (0.372)	-0.197 (0.373)	-0.203 (0.373)
Dist. to Cayonu					-4.718 (3.750)	-9.200** (3.945)	-9.172** (3.945)
Migratory Dist. from Addis Ababa					0.728 (3.206)	3.910 (3.244)	3.955 (3.232)
Latitude						-3.457 (2.995)	-3.499 (2.963)
Longitude						3.803 (5.730)	3.736 (5.689)
Latitude × Longitude						-6.065 (4.109)	-5.980 (4.073)
Elevation (Avg.)						0.459 (0.759)	0.450 (0.753)
Land Productivity (Avg.)						-0.599 (0.495)	-0.607 (0.494)
Island Dummy						0.055 (1.621)	0.056 (1.624)
Dist. to the Waterway						-0.037 (0.410)	-0.035 (0.409)
Total Area						0.051 (0.465)	0.050 (0.465)
# Native Plants						-0.683 (0.764)	-0.683 (0.765)
Europe Dummy			✓				
Country FE				✓	✓	✓	✓
Mean of Dependent Variable	63.091	63.091	63.091	63.091	63.091	63.091	63.091
Std of Dependent Variable	12.863	12.863	12.863	12.863	12.863	12.863	12.863
First Stage F-Statistics							4870.953
Adjusted R^2	0.546	0.547	0.593	0.777	0.779	0.783	
Observations	717	717	717	717	717	717	717

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables, intermonthly temperature volatility and its square are standardized. Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

including domesticable mammals into the measure of lost biomass does not alter the result.

Table E7: Agricultural Transition, Megaherbivore Extinction and Climatic Seasonality

	Years Since Agricultural Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	2.611* (1.330)	3.047* (1.608)	2.978* (1.486)	1.140*** (0.403)	0.869** (0.399)	0.869** (0.382)	0.943** (0.367)
Paleo-Temperature (Seasonality)	4.844*** (1.058)	3.101** (1.228)	2.402** (1.101)	0.715 (0.555)	0.063 (0.582)	0.782 (0.614)	0.793 (0.612)
Paleo-Precipitation (Seasonality)	6.396*** (1.190)	1.189 (1.995)	0.918 (1.900)	0.989 (1.994)	0.220 (1.551)	2.115 (2.318)	2.126 (2.319)
Paleo-Temperature (Avg.)		7.725*** (2.335)	4.537* (2.502)	1.738 (2.274)	2.061 (1.738)	-1.436 (3.582)	-1.436 (3.588)
Paleo-Precipitation (Avg.)		0.448 (0.629)	0.607 (0.642)	0.402 (0.406)	0.479 (0.361)	0.322 (0.403)	0.325 (0.404)
Paleo-Net Primary Product (Avg.)		0.455 (0.780)	1.676** (0.751)	-0.419 (0.354)	-0.479 (0.367)	-0.157 (0.334)	-0.163 (0.334)
Dist. to Cayonu					-4.679 (4.321)	-8.552* (4.455)	-8.516* (4.453)
Migratory Dist. from Addis Ababa					0.996 (3.653)	3.718 (3.738)	3.748 (3.725)
Latitude						-3.922 (3.176)	-3.959 (3.148)
Longitude						6.096 (5.699)	6.036 (5.671)
Latitude × Longitude						-8.196* (4.262)	-8.124* (4.240)
Elevation (Avg.)						0.119 (0.939)	0.113 (0.934)
Land Productivity (Avg.)						-0.592 (0.501)	-0.600 (0.499)
Island Dummy						-0.128 (1.766)	-0.127 (1.769)
Dist. to the Waterway						-0.131 (0.389)	-0.129 (0.388)
Total Area						0.154 (0.493)	0.154 (0.492)
# Native Plants						-0.401 (0.850)	-0.399 (0.850)
Europe Dummy			✓				
Country FE				✓	✓	✓	✓
Mean of Dependent Variable	63.091	63.091	63.091	63.091	63.091	63.091	63.091
Std of Dependent Variable	12.863	12.863	12.863	12.863	12.863	12.863	12.863
First Stage F-Statistics							4949.054
Adjusted R^2	0.508	0.574	0.608	0.777	0.779	0.782	
Observations	717	717	717	717	717	717	717

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table E8: Agricultural Transition and Megaherbivore Extinction (Inclusion of Domesticable Mammals)

	Years Since Agricultural Transition						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass	-4.365*	2.160	2.627	1.097**	0.871	0.854*	1.113**
	(2.410)	(1.679)	(1.749)	(0.504)	(0.520)	(0.479)	(0.533)
Paleo-Temperature (Avg.)		10.543***	6.057***	2.969***	2.253**	1.938	1.992
		(1.176)	(1.839)	(0.896)	(0.964)	(1.674)	(1.662)
Paleo-Precipitation (Avg.)		-0.407	-0.004	0.366	0.491	0.393	0.402
		(0.806)	(0.717)	(0.361)	(0.298)	(0.369)	(0.371)
Paleo-Net Primary Product (Avg.)		0.610	1.937***	-0.433	-0.502*	-0.200	-0.223
		(0.799)	(0.666)	(0.276)	(0.297)	(0.345)	(0.346)
Dist. to Cayonu					-4.997	-9.021**	-9.006**
					(4.207)	(3.940)	(3.951)
Migratory Dist. from Addis Ababa					1.170	3.944	4.108
					(3.604)	(3.247)	(3.166)
Latitude						-1.910	-1.996
						(2.608)	(2.575)
Longitude						5.096	4.979
						(5.844)	(5.729)
Latitude × Longitude						-6.759	-6.588
						(4.044)	(4.001)
Elevation (Avg.)						0.685	0.675
						(0.798)	(0.794)
Land Productivity (Avg.)						-0.479	-0.492
						(0.479)	(0.487)
Island Dummy						0.029	0.026
						(1.614)	(1.619)
Dist. to the Waterway						-0.169	-0.165
						(0.380)	(0.375)
Total Area						0.171	0.168
						(0.513)	(0.512)
# Native Plants						-0.516	-0.515
						(0.827)	(0.829)
Europe Dummy			✓				
Country FE				✓	✓	✓	✓
Mean of Dependent Variable	63.091	63.091	63.091	63.091	63.091	63.091	63.091
Std of Dependent Variable	12.863	12.863	12.863	12.863	12.863	12.863	12.863
First Stage F-Statistics							259.517
Adjusted R^2	0.102	0.523	0.577	0.777	0.779	0.782	
Observations	717	717	717	717	717	717	717

Note: The unit of analysis is an archaeological site. Dependent variable is time elapsed since agricultural in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the country level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Robustness: Spatial Correlation

The result is robust to standard errors using the spatial correlation proposed by Conley (1999). As shown in Table E9 and E10, taking spatial correlation into account does not alter the basic result.

Table E9: Agricultural Transition and Megaherbivore Extinction (Spatial Correlation)

	Years Since Agricultural Transition					
	(1) OLS (200 km)	(2) 2SLS (200 km)	(3) OLS (400 km)	(4) 2SLS (400 km)	(5) OLS (600 km)	(6) 2SLS (600 km)
Lost Biomass	0.800**	0.869**	0.800**	0.869**	0.800	0.869*
	(0.362)	(0.372)	(0.397)	(0.393)	(0.526)	(0.525)
Dist. to Cayonu	-8.790***	-8.765***	-8.790***	-8.765***	-8.790***	-8.765***
	(2.812)	(2.823)	(2.332)	(2.360)	(2.008)	(2.033)
Migratory Dist. from Addis Ababa	3.822	3.858	3.822**	3.858**	3.822*	3.858**
	(2.990)	(2.989)	(1.846)	(1.810)	(2.000)	(1.963)
Paleo-Temperature (Avg.)	1.935	1.951	1.935	1.951	1.935	1.951
	(1.200)	(1.215)	(1.294)	(1.307)	(1.375)	(1.386)
Paleo-Precipitation (Avg.)	0.396	0.399	0.396	0.399	0.396	0.399
	(0.451)	(0.452)	(0.415)	(0.416)	(0.259)	(0.259)
Paleo-Net Primary Product (Avg.)	-0.189	-0.194	-0.189	-0.194	-0.189	-0.194
	(0.322)	(0.321)	(0.382)	(0.380)	(0.332)	(0.331)
Latitude	-1.973	-2.003	-1.973	-2.003	-1.973	-2.003
	(2.375)	(2.340)	(2.422)	(2.385)	(2.305)	(2.263)
Longitude	4.772	4.710	4.772	4.710	4.772	4.710
	(6.327)	(6.307)	(5.223)	(5.193)	(5.601)	(5.573)
Latitude × Longitude	-6.441	-6.365	-6.441	-6.365	-6.441	-6.365
	(4.629)	(4.598)	(4.417)	(4.395)	(4.265)	(4.236)
Elevation (Avg.)	0.653	0.648	0.653	0.648	0.653	0.648
	(0.602)	(0.602)	(0.509)	(0.509)	(0.609)	(0.610)
Land Productivity (Avg.)	-0.507	-0.513	-0.507	-0.513	-0.507	-0.513
	(0.474)	(0.472)	(0.492)	(0.495)	(0.529)	(0.534)
Island Dummy	0.051	0.052	0.051	0.052	0.051	0.052
	(1.307)	(1.309)	(1.608)	(1.613)	(1.637)	(1.637)
Dist. to the Waterway	-0.164	-0.163	-0.164	-0.163	-0.164	-0.163
	(0.257)	(0.258)	(0.193)	(0.190)	(0.140)	(0.137)
Total Area	0.171	0.170	0.171	0.170	0.171	0.170
	(0.416)	(0.415)	(0.422)	(0.422)	(0.483)	(0.483)
# Native Plants	-0.516	-0.515	-0.516	-0.515	-0.516	-0.515
	(0.745)	(0.745)	(0.813)	(0.813)	(0.747)	(0.747)
Country FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	63.191	63.191	63.191	63.191	63.191	63.191
Std of Dependent Variable	12.824	12.824	12.824	12.824	12.824	12.824
First Stage F-Statistics		4861.880		3531.689		3608.077
Observations	725	725	725	725	725	725

Note: The unit of analysis is an archaeological site. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses calculated using the spatial correlation proposed by Conley (1999) with a threshold of 200 (columns 1 and 2), 400 (columns 3 and 4) and 600 (columns 5 and 6) kilometers. *** p<0.01, ** p<0.05, * p<0.10.

Table E10: Agricultural Transition and Megaherbivore Extinction (Bartlett)

	(1) OLS (200 km)	(2) 2SLS (200 km)	(3) OLS (400 km)	(4) 2SLS (400 km)	(5) OLS (600 km)	(6) 2SLS (600 km)
			Years Since Agricultural Transition			
Lost Biomass	0.800*	0.869*	0.800*	0.869*	0.800*	0.869*
	(0.449)	(0.453)	(0.469)	(0.472)	(0.476)	(0.477)
Dist. to Cayonu	-8.790***	-8.765***	-8.790***	-8.765***	-8.790***	-8.765***
	(2.954)	(2.956)	(2.857)	(2.866)	(2.704)	(2.716)
Migratory Dist. from Addis Ababa	3.822	3.858	3.822	3.858	3.822	3.858
	(3.121)	(3.115)	(2.753)	(2.740)	(2.537)	(2.519)
Paleo-Temperature (Avg.)	1.935	1.951	1.935	1.951	1.935	1.951
	(1.248)	(1.253)	(1.269)	(1.278)	(1.292)	(1.302)
Paleo-Precipitation (Avg.)	0.396	0.399	0.396	0.399	0.396	0.399
	(0.452)	(0.453)	(0.443)	(0.444)	(0.414)	(0.415)
Paleo-Net Primary Product (Avg.)	-0.189	-0.194	-0.189	-0.194	-0.189	-0.194
	(0.383)	(0.382)	(0.359)	(0.358)	(0.347)	(0.346)
Latitude	-1.973	-2.003	-1.973	-2.003	-1.973	-2.003
	(2.166)	(2.149)	(2.284)	(2.257)	(2.319)	(2.288)
Longitude	4.772	4.710	4.772	4.710	4.772	4.710
	(6.452)	(6.443)	(6.188)	(6.173)	(6.013)	(5.988)
Latitude × Longitude	-6.441	-6.365	-6.441	-6.365	-6.441	-6.365
	(4.764)	(4.750)	(4.712)	(4.692)	(4.646)	(4.619)
Elevation (Avg.)	0.653	0.648	0.653	0.648	0.653	0.648
	(0.597)	(0.596)	(0.580)	(0.581)	(0.580)	(0.581)
Land Productivity (Avg.)	-0.507	-0.513	-0.507	-0.513	-0.507	-0.513
	(0.440)	(0.439)	(0.471)	(0.471)	(0.494)	(0.495)
Island Dummy	0.051	0.052	0.051	0.052	0.051	0.052
	(1.909)	(1.908)	(1.757)	(1.758)	(1.716)	(1.717)
Dist. to the Waterway	-0.164	-0.163	-0.164	-0.163	-0.164	-0.163
	(0.304)	(0.303)	(0.283)	(0.282)	(0.244)	(0.243)
Total Area	0.171	0.170	0.171	0.170	0.171	0.170
	(0.395)	(0.395)	(0.403)	(0.402)	(0.421)	(0.420)
# Native Plants	-0.516	-0.515	-0.516	-0.515	-0.516	-0.515
	(0.672)	(0.671)	(0.737)	(0.736)	(0.766)	(0.765)
Country FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	63.191	63.191	63.191	63.191	63.191	63.191
Std of Dependent Variable	12.824	12.824	12.824	12.824	12.824	12.824
First Stage F-Statistics		6522.459		4641.175		4264.986
Observations	725	725	725	725	725	725

Note: The unit of analysis is an archaeological site. Dependent variable is years elapsed since agricultural transition in 100 years. Lost biomass is calculated using extinct megaherbivores. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses calculated using the spatial correlation proposed by Conley (1999) with a threshold of 200 (columns 1 and 2), 400 (columns 3 and 4) and 600 (columns 5 and 6) kilometers, allowing for weights that are close to one for near countries and almost zero for countries close to the distant cutoff. *** p<0.01, ** p<0.05, * p<0.10.

Appendix F. Country Panel Analysis

This appendix analyzes the effect of lost biomass on the agricultural transition timing using country panel data constructed from the data sets by Borcan et al. (2018). Column 1 of Table F11 shows the significant and positive association between lost biomass and the probability of the transition, conditional on country fixed effects. Columns 2-4 sequentially account for paleo-temperature, paleo-precipitation and paleo-net primary product. The estimated coefficient of lost biomass is stable to this sequential inclusion of paleoclimate. Column 5 includes the paleoclimatic features all together, which does not alter the estimate of lost biomass. Reassuringly, the estimate is stable across specifications and significantly positive. A one standard deviation increase in lost biomass due to megaherbivore extinction increases the likelihood of the transition by 1.8 percentage points.[28]

Table F11: Agricultural Transition and Megaherbivore Extinction

	The Indicator of the Neolithic Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass	0.020**	0.020**	0.020**	0.016*	0.018**
	(0.009)	(0.009)	(0.009)	(0.010)	(0.009)
Paleo-Temperature (Avg.)		0.475***			0.408***
		(0.093)			(0.118)
Paleo-Precipitation (Avg.)			0.204***		0.051
			(0.034)		(0.081)
Paleo-Net Primary Product (Avg.)				0.275***	0.079
				(0.028)	(0.076)
Country FE	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.104	0.104	0.104	0.104	0.104
Std of Dependent Variable	0.306	0.306	0.306	0.306	0.306
Observations	1421	1421	1421	1421	1421

Note: The unit of analysis is a country. Dependent variable is a dummy variable that takes one if agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent are lagged by one period and standardized. Robust standard errors clustered at the country level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

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[28]Accounting for time fixed effects makes the estimate of lost biomass insignificant. This is possibly because there are very limited variations in both the dummy of the transition and measure of lost biomass. Indeed, 88 % and 85 % of the observations take zero for the transition dummy and measure of lost biomass, respectively. Hence further controlling for time fixed effects would absorb most variation available.

Robustness: Incentives to Migrate

When available hunting resources got scarce, individuals may have moved to the outside of their original places. As is explained in the theoretical section, this is not much concern in the settings of this study. However, to further alleviate the concern of out-migration, I account for neighboring biomass that captures incentives to migrate. Table F12 shows that the estimate of lost biomass is robust to the inclusion of biomass in surrounding regions.

Table F12: Agricultural Transition, Megaherbivore Extinction and Neighboring Biomass

	The Indicator of the Neolithic Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass	0.019**	0.019**	0.019**	0.016*	0.018**
	(0.009)	(0.009)	(0.008)	(0.009)	(0.009)
Neighboring Biomass	-0.123***	-0.042	-0.113***	-0.087***	-0.039
	(0.029)	(0.031)	(0.027)	(0.023)	(0.028)
Paleo-Temperature (Avg.)		0.443***			0.379***
		(0.093)			(0.118)
Paleo-Precipitation (Avg.)			0.177***		0.046
			(0.035)		(0.082)
Paleo-Net Primary Product (Avg.)				0.245***	0.079
				(0.027)	(0.077)
Country FE	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.104	0.104	0.104	0.104	0.104
Std of Dependent Variable	0.305	0.305	0.305	0.305	0.305
Observations	1408	1408	1408	1408	1408

Note: The unit of analysis is a country. Dependent variable is a dummy variable that takes one if agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent are lagged by one period and standardized. Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Robustness: Estimates from Different Studies

The measure of lost biomass, (24), is constructed utilizing an estimate from Silva and Downing (1995). Therefore, one may think that the result is driven by this particular study. Thus, I reconstruct the measure of lost biomass, exploiting different estimates from other independent studies. Table F13 shows that the result is robust to using these different estimates.

Table F13: Agricultural Transition and Megaherbivore Extinction (Different Estimates)

	The Indicator of the Neolithic Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass (Currie, 1993)	0.018* (0.009)				
Lost Biomass (Damuth, 1987)		0.018* (0.010)			
Lost Biomass (Peters and Raelson, 1984)			0.017* (0.010)		
Lost Biomass (Peters and Wassenberg, 1983)				0.018* (0.009)	
Lost Biomass (Silva et al., 2001)					0.018* (0.010)
Country FE	✓	✓	✓	✓	✓
Paleoclimatic Controls	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.022	0.022	0.022	0.022	0.022
Std of Dependent Variable	0.146	0.146	0.146	0.146	0.146
Observations	1421	1421	1421	1421	1421

Note: The unit of analysis is a country. Dependent variable is a dummy variable that takes one if agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. Paleoclimatic controls are average of paleo-temperature, average of paleo-precipitation and paleo-net primary product. All the variables except for the dependent are lagged by one period and standardized. Robust standard errors clustered at the country level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Robustness: Temperature Volatility and Climatic Seasonality

Intermonthly temperature volatility and its square term as well as climatic seasonality are shown to be related with agricultural transition (Ashraf and Michalopoulos, 2015; Matranga, 2017). Therefore, I account for these variables. As shown in Table F14 and F15, the estimate of lost biomass is robust to the inclusion of these variables, showing that the basic result is not driven by these climatic aspects.

Robustness: Inclusion of Domesticable Mammals into Lost Biomass

I reconstruct the measure of lost biomass by including 14 domesticable mammalian species, although this inclusion is less consistent with the proposed theory. As in Table F16, lost biomass becomes insignificant if paleo-net primary product is controlled for.

Table F14: Agricultural Transition, Megaherbivore Extinction and Intermonthly Temperature Volatility

	The Indicator of the Neolithic Transition			
	(1)	(2)	(3)	(4)
Lost Biomass	0.018*	0.018*	0.017*	0.017*
	(0.009)	(0.009)	(0.009)	(0.009)
Paleo-Precipitation (Avg.)	0.113***	0.113***	0.014	0.014
	(0.037)	(0.037)	(0.069)	(0.069)
Paleo-Temperature (Intermonthly Std.)	0.299***	0.299***	0.234***	0.234***
	(0.038)	(0.038)	(0.040)	(0.040)
Paleo-Temperature (Intermonthly Std. Square)	-0.004	-0.004	-0.003	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)
Paleo-Precipitation (Avg.)		0.000		0.000
		(.)		(.)
Paleo-Net Primary Product (Avg.)			0.119**	0.119**
			(0.058)	(0.058)
Country FE	✓	✓	✓	✓
Mean of Dependent Variable	0.104	0.104	0.104	0.104
Std of Dependent Variable	0.306	0.306	0.306	0.306
Observations	1421	1421	1421	1421

Note: The unit of analysis is a country. Dependent variable is a dummy variable that takes one if agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent are lagged by one period. All the variables except for the dependent variable, intermonthly temperature volatility and its square are standardized. Robust standard errors clustered at the country level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Table F15: Agricultural Transition, Megaherbivore Extinction and Climatic Seasonality

	The Indicator of the Neolithic Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass	0.022**	0.017*	0.021**	0.017*	0.016*
	(0.010)	(0.009)	(0.009)	(0.010)	(0.009)
Paleo-Temperature (Seasonality)	0.152***	-0.255***	0.206***	0.141***	-0.209***
	(0.043)	(0.060)	(0.043)	(0.040)	(0.074)
Paleo-Precipitaion (Seasonality)	-0.055	0.146***	0.011	0.067*	0.161***
	(0.040)	(0.042)	(0.043)	(0.039)	(0.042)
Paleo-Temperature (Avg.)		0.777***			0.703***
		(0.095)			(0.133)
Paleo-Precipitation (Avg.)			0.252***		0.043
			(0.045)		(0.079)
Paleo-Net Primary Product (Avg.)				0.286***	0.054
				(0.030)	(0.075)
Country FE	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.104	0.104	0.104	0.104	0.104
Std of Dependent Variable	0.306	0.306	0.306	0.306	0.306
Observations	1421	1421	1421	1421	1421

Note: The unit of analysis is a country. Dependent variable is a dummy variable that takes one if agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table F16: Agricultural Transition and Megaherbivore Extinction (Inclusion of Domesticable Mammals)

	The Indicator of the Neolithic Transition				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass	0.015*	0.015*	0.015*	0.011	0.014
	(0.009)	(0.008)	(0.009)	(0.009)	(0.009)
Paleo-Temperature (Avg.)		0.475***			0.407***
		(0.093)			(0.117)
Paleo-Precipitation (Avg.)			0.205***		0.049
			(0.033)		(0.080)
Paleo-Net Primary Product (Avg.)				0.277***	0.082
				(0.028)	(0.076)
Country FE	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.104	0.104	0.104	0.104	0.104
Std of Dependent Variable	0.306	0.306	0.306	0.306	0.306
Observations	1421	1421	1421	1421	1421

Note: The unit of analysis is a country. Dependent variable is a dummy variable that takes one if agricultural transition occurs. Lost biomass is calculated using extinct megaherbivores. The period of analysis spans from 14000 BP until the transition occurs with a 1000 years time window. All the variables except for the dependent variable are lagged by one period and standardized. Robust standard errors clustered at the country level are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Appendix G. Difference-in-Differences Using Pre- and Post-Neolithic Archaeological Sites

Mayshar et al. (2022) georeference archaeological sites reported by Whitehouse and Whitehouse (1975) and classify them according to whether they predate the Neolithic transition. Based on these data, I create 1×1 virtual countries (cells) in which every cell includes information on the number of pre- and post-Neolithic sites (summary statistics are available in Table B10). Following Mayshar et al. (2022), I run the following difference-in-differences regression:

$$y_{it} = \alpha_0 LostBiomass_i \times P_t + \eta_i + \eta_t + \epsilon_{it}, \tag{33}$$

where i indicates cell i, t indicates whether the site predates the Neolithic transition, η_i and η_t are cell and period fixed effects, P_t is a dummy variable that identifies archaeological sites after the Neolithic transition, $LostBiomass_i$ indicates lost biomass resulting from megaherbivore extinction, and ϵ_{it} is an error term.

Table G1: Difference-In-Difference Analysis (The Existence of Ancient Ruins)

	The Indicator of Ancient Ruins					
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Lost Biomass	0.024**	0.026**	0.024**			
	(0.010)	(0.010)	(0.010)			
Post × Lost Biomass Based on Predicted Extinction Risk				0.031***	0.031***	0.029***
				(0.009)	(0.010)	(0.010)
Post × Dist. from the Agricultural Origin		-0.012	-0.010		-0.010	-0.007
		(0.010)	(0.012)		(0.010)	(0.012)
Post × Migratory Dist. from Addis Ababa		-0.021**	-0.022**		-0.021**	-0.022**
		(0.010)	(0.010)		(0.010)	(0.010)
Post × Paleo-Temperature (Avg.)			0.011			0.010
			(0.012)			(0.012)
Post × Paleo-Precipitation (Avg.)			0.047**			0.046**
			(0.020)			(0.019)
Post × Paleo-Net Primary Product			-0.043**			-0.040**
			(0.019)			(0.019)
Cell FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.052	0.052	0.052	0.052	0.052	0.052
Std of Dependent Variable	0.223	0.223	0.223	0.223	0.223	0.223
Adjusted R^2	0.222	0.230	0.234	0.226	0.232	0.237
Observations	28782	28782	28782	28782	28782	28782

Note: The table reports difference-in-differences OLS regression. The unit of observation is the 1×1 virtual country (cell) before or after the Neolithic transition. Robust standard errors are clustered at the country level. All the variables except for the dependent variable and measures of distance are standardized. *** p<0.01, ** p<0.05, * p<0.10.

Columns 1-3 of Table G1 show the estimate of lost biomass calculated from (23) while columns 4-6 show the estimate of the instrument calculated from (25). In column 1, the

estimate of lost biomass is significant and positive, conditional on cell and time fixed effects. It shows that larger loss of biomass is associated with an increase in the probability of finding post-Neolithic sites, in comparison to finding pre-Neolithic sites. Column 2 adds the distance from the closest agricultural center and migratory distance from Addis Ababa; including these measures does not change the estimate of lost biomass. Column 3 further controls for paleoclimatic characteristics, which does not alter the estimate of lost biomass either. As shown in columns 4-6, using more exogenous variation in lost biomass increases the magnitude of the estimate, resulting in stronger statistical significance. The result reported in Table G1 confirms that the Neolithic Revolution led to more visible traces of human societies in areas that experienced larger loss of biomass associated with megaherbivore extinction.

Robustness: Incentive to Migrate

When available hunting resources became scarce, individuals may have out-migrated. As explained in the theoretical section, this is not much of a concern in the setting of this study. However, to alleviate the concern, I account for neighboring regions' biomass to capture the incentive to migrate. Table G2 shows that the estimate of lost biomass is robust to the inclusion of biomass in surrounding regions.

Robustness: Climatic Seasonality

Matranga (2017) argues that climatic seasonality is a determinant of the Neolithic Revolution. Table G3 shows the robustness of the basic result to adding measures of climatic seasonality.[29]

Robustness: Domesticable Mammals and Wild Relatives of Domesticable Plants

The existence of domesticable mammals and plants allowed an earlier transition to agriculture by providing biogeographically better initial conditions (Diamond, 2017; Olsson and Hibbs, 2005). Hence, I add measures of domesticable mammals and wild relatives of domesticable plants in Table G4. As is evident, the basic result is robust to the inclusion of domesticable mammals and plants.[30]

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[29]Ashraf and Michalopoulos (2015) argue for a hump-shaped relationship between intermonthly temperature volatility and agricultural transition. However, in the difference-in-differences setting, adding measures of intermonthly temperature volatility and its square term does not test the hump-shaped persistent effects of intermonthly temperature volatility. Thus, I do not explore this possibility here.

[30]Riahi (2020) argues for a hump-shaped relationship between the extinction rate of large mammals and the timing of the agricultural transition. However, in the difference-in-differences setting, adding measures of the extinction rate and its square term does not test the hump-shaped persistent effects of this variable. Thus, I do not explore this possibility here.

Table G2: Agricultural Transition, Megaherbivore Extinction and Neighboring Biomass

| | The Indicator of Ancient Ruins | | | | | |
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Lost Biomass	0.024**	0.026**	0.024**			
	(0.010)	(0.010)	(0.010)			
Post × Lost Biomass Based on Predicted Extinction Risk				0.031***	0.031***	0.029***
				(0.009)	(0.010)	(0.010)
Post × Neighboring Biomass	0.000	-0.003	-0.002	0.000	-0.002	-0.002
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Post × Dist. from the Agricultural Origin		-0.013	-0.010		-0.010	-0.007
		(0.010)	(0.012)		(0.010)	(0.012)
Post × Migratory Dist. from Addis Ababa		-0.021**	-0.022**		-0.021**	-0.022**
		(0.010)	(0.010)		(0.010)	(0.010)
Post × Paleo-Temperature (Avg.)			0.011			0.010
			(0.013)			(0.012)
Post × Paleo-Precipitation (Avg.)			0.047**			0.045**
			(0.019)			(0.019)
Post × Paleo-Net Primary Product			-0.042**			-0.039**
			(0.018)			(0.018)
Cell FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.052	0.052	0.052	0.052	0.052	0.052
Std of Dependent Variable	0.222	0.222	0.222	0.222	0.222	0.222
Adjusted R^2	0.223	0.230	0.235	0.226	0.233	0.237
Observations	28776	28776	28776	28776	28776	28776

Note: The table reports difference-in-differences OLS regression. The unit of observation is the 1×1 virtual country (cell) before or after the Neolithic transition. Robust standard errors are clustered at the country level. All the variables except for the dependent variable and measures of distance are standardized. *** p<0.01, ** p<0.05, * p<0.10.

Robustness: Other Dependent Variables

As dependent variables, I use different measures of the existence and degree of socioeconomic development after the Neolithic Revolution. Tables G5-G7 establish that lost biomass caused by megaherbivore extinction is significantly and positively associated with the number of ancient ruins, the existence of an ancient settlement, and the number of ancient settlements, respectively.

Table G3: Agricultural Transition, Megaherbivore Extinction and Climatic Seasonality

	The Indicator of Ancient Ruins					
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Lost Biomass	0.015*	0.019**	0.017*			
	(0.009)	(0.009)	(0.009)			
Post × Lost Biomass Based on Predicted Extinction Risk				0.023***	0.026***	0.023***
				(0.009)	(0.009)	(0.009)
Post × Paleo-Temperature (Seasonality)	0.013	-0.002	-0.003	0.010	-0.004	-0.004
	(0.009)	(0.009)	(0.011)	(0.009)	(0.009)	(0.011)
Post × Paleo-Precipitation (Seasonality)	-0.018***	-0.022***	-0.022**	-0.016**	-0.021**	-0.020**
	(0.007)	(0.008)	(0.010)	(0.007)	(0.008)	(0.010)
Post × Dist. from the Agricultural Origin		-0.013	-0.015		-0.011	-0.012
		(0.011)	(0.013)		(0.011)	(0.013)
Post × Migratory Dist. from Addis Ababa		-0.024**	-0.022**		-0.025**	-0.023**
		(0.010)	(0.009)		(0.010)	(0.009)
Post × Paleo-Temperature (Avg.)			0.013			0.012
			(0.013)			(0.013)
Post × Paleo-Precipitation (Avg.)			0.042**			0.041**
			(0.020)			(0.020)
Post × Paleo-Net Primary Product			-0.049**			-0.046**
			(0.020)			(0.020)
Cell FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.052	0.052	0.052	0.052	0.052	0.052
Std of Dependent Variable	0.223	0.223	0.223	0.223	0.223	0.223
Adjusted R^2	0.226	0.233	0.238	0.229	0.236	0.239
Observations	28782	28782	28782	28782	28782	28782

Note: The table reports difference-in-differences OLS regression. The unit of observation is the 1×1 virtual country (cell) before or after the Neolithic transition. Robust standard errors are clustered at the country level. All the variables except for the dependent variable and measures of distance are standardized. *** p<0.01, ** p<0.05, * p<0.10.

Table G4: Agricultural Transition, Megaherbivore Extinction, Domesticable Mammals and Plants

	The Indicator of Ancient Ruins					
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Lost Biomass	0.021**	0.022**	0.020*			
	(0.009)	(0.010)	(0.010)			
Post × Lost Biomass Based on Predicted Extinction Risk				0.027***	0.028***	0.026***
				(0.008)	(0.010)	(0.010)
Post × # Domesticable Mammals	0.027***	0.022**	0.025***	0.025***	0.021**	0.023***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Post × # Wild Relatives of Domesticable Crops	0.032***	0.029***	0.026***	0.031***	0.029***	0.026***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Post × Dist. from the Agricultural Origin		-0.009	-0.004		-0.006	-0.001
		(0.009)	(0.011)		(0.009)	(0.011)
Post × Migratory Dist. from Addis Ababa		-0.012	-0.013		-0.013	-0.014*
		(0.008)	(0.008)		(0.008)	(0.008)
Post × Paleo-Temperature (Avg.)			0.014			0.012
			(0.009)			(0.009)
Post × Paleo-Precipitation (Avg.)			0.036*			0.035*
			(0.019)			(0.019)
Post × Paleo-Net Primary Product			-0.030			-0.028
			(0.019)			(0.019)
Cell FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.052	0.052	0.052	0.052	0.052	0.052
Std of Dependent Variable	0.223	0.223	0.223	0.223	0.223	0.223
Adjusted R^2	0.240	0.242	0.246	0.242	0.244	0.248
Observations	28782	28782	28782	28782	28782	28782

Note: The table reports difference-in-differences OLS regression. The unit of observation is the 1×1 virtual country (cell) before or after the Neolithic transition. Robust standard errors are clustered at the country level. All the variables except for the dependent variable and measures of distance are standardized. *** p<0.01, ** p<0.05, * p<0.10.

Table G5: Difference-In-Difference Analysis (The Number of Ancient Ruins)

	Number of Ancient Ruins					
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Lost Biomass	0.105***	0.129***	0.121**			
	(0.036)	(0.049)	(0.047)			
Post × Lost Biomass Based on Predicted Extinction Risk				0.125***	0.143***	0.135***
				(0.037)	(0.050)	(0.047)
Post × Dist. from the Agricultural Origin		-0.001	-0.011		0.007	-0.002
		(0.035)	(0.035)		(0.035)	(0.035)
Post × Migratory Dist. from Addis Ababa		-0.111**	-0.109**		-0.106**	-0.106***
		(0.044)	(0.042)		(0.042)	(0.040)
Post × Paleo-Temperature (Avg.)			0.023			0.020
			(0.033)			(0.033)
Post × Paleo-Precipitation (Avg.)			0.207**			0.203**
			(0.083)			(0.081)
Post × Paleo-Net Primary Product			-0.200**			-0.188**
			(0.081)			(0.079)
Cell FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.111	0.111	0.111	0.111	0.111	0.111
Std of Dependent Variable	0.715	0.715	0.715	0.715	0.715	0.715
Adjusted R^2	0.176	0.188	0.196	0.181	0.191	0.199
Observations	28782	28782	28782	28782	28782	28782

Note: The table reports difference-in-differences OLS regression. The unit of observation is the 1×1 virtual country (cell) before or after the Neolithic transition. Robust standard errors are clustered at the country level. All the variables except for the dependent variable and measures of distance are standardized. *** p<0.01, ** p<0.05, * p<0.10.

Table G6: Difference-In-Difference Analysis (The Existence of Ancient Settlement)

	The Indicator of Ancient Settlement					
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Lost Biomass	0.023**	0.022**	0.021**			
	(0.009)	(0.010)	(0.010)			
Post × Lost Biomass Based on Predicted Extinction Risk				0.029***	0.027***	0.026**
				(0.009)	(0.010)	(0.010)
Post × Dist. from the Agricultural Origin		-0.017	-0.010		-0.014	-0.007
		(0.010)	(0.012)		(0.010)	(0.012)
Post × Migratory Dist. from Addis Ababa		-0.017	-0.019*		-0.017	-0.019*
		(0.011)	(0.010)		(0.010)	(0.010)
Post × Paleo-Temperature (Avg.)			0.016			0.015
			(0.013)			(0.012)
Post × Paleo-Precipitation (Avg.)			0.043**			0.042**
			(0.018)			(0.018)
Post × Paleo-Net Primary Product			-0.038**			-0.035**
			(0.018)			(0.017)
Cell FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.041	0.041	0.041	0.041	0.041	0.041
Std of Dependent Variable	0.199	0.199	0.199	0.199	0.199	0.199
Adjusted R^2	0.179	0.188	0.194	0.183	0.191	0.197
Observations	28782	28782	28782	28782	28782	28782

Note: The table reports difference-in-differences OLS regression. The unit of observation is the 1×1 virtual country (cell) before or after the Neolithic transition. Robust standard errors are clustered at the country level. All the variables except for the dependent variable and measures of distance are standardized. *** p<0.01, ** p<0.05, * p<0.10.

Table G7: Difference-In-Difference Analysis (The Number of Ancient Settlement)

	(1)	(2)	(3)	(4)	(5)	(6)
			Number of Ancient Settlement			
Post × Lost Biomass	0.079***	0.092**	0.085**			
	(0.028)	(0.038)	(0.036)			
Post × Lost Biomass Based on Predicted Extinction Risk				0.094***	0.101***	0.095**
				(0.029)	(0.038)	(0.037)
Post × Dist. from the Agricultural Origin		-0.018	-0.019		-0.012	-0.012
		(0.030)	(0.031)		(0.030)	(0.031)
Post × Migratory Dist. from Addis Ababa		-0.079**	-0.078**		-0.075**	-0.076**
		(0.036)	(0.034)		(0.034)	(0.033)
Post × Paleo-Temperature (Avg.)			0.027			0.025
			(0.029)			(0.029)
Post × Paleo-Precipitation (Avg.)			0.156**			0.153**
			(0.066)			(0.065)
Post × Paleo-Net Primary Product			-0.149**			-0.141**
			(0.065)			(0.064)
Cell FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.086	0.086	0.086	0.086	0.086	0.086
Std of Dependent Variable	0.603	0.603	0.603	0.603	0.603	0.603
Adjusted R^2	0.136	0.146	0.152	0.140	0.148	0.154
Observations	28782	28782	28782	28782	28782	28782

Note: The table reports difference-in-differences OLS regression. The unit of observation is the 1×1 virtual country (cell) before or after the Neolithic transition. Robust standard errors are clustered at the country level. All the variables except for the dependent variable and measures of distance are standardized. *** p<0.01, ** p<0.05, * p<0.10.

Appendix H. Long-Run Impact on Ethnographical Traits of PreIndustrial Societies

In this subsection, I explore the long-run association between socioeconomic development and lost biomass resulting from megaherbivore extinction, drawing on the *Ethnographic Atlas* (summary statistics is available in Table B11). Ethnic groups that experienced an early agricultural transition may have benefit from agriculture for a long time because early engagement in agriculture could promote the development of strong authority and complex social hierarchy and could sustain a large community. Therefore, groups that saw larger loss of biomass may have achieved more socioeconomic development, compared with groups that lost less biomass in prehistory.

Table H1 reports the OLS and 2SLS estimates with the degree of centralization, the existence of social hierarchy, and the local-community size as dependent variables. The OLS estimates are reported in odd columns, and the 2SLS estimates are reported in even columns. Every regression accounts for the same paleoclimatic and geographical variables as the previous cross-sectional regressions. All estimated coefficients of lost biomass are positive and statistically highly significant at the 1% level; the 2SLS estimates are slightly larger than the associated OLS estimates. This result supports the claim that loss of biomass due to megaherbivore extinction in prehistoric times supported socioeconomic development of preindustrial societies.

A natural question would be where this persistent effect comes from. Since the Neolithic Revolution is the transition from foraging to agriculture, a likely mechanism is agricultural activities. Agriculture enables traditional societies to enjoy surplus and hence ruling elites may have emerged, leading to socioeconomic development. The *Ethnographic Atlas* includes information on agricultural activities, and thus I add multiple variables of agriculture to the basic result. These measures are dependence on agriculture, the intensity of agriculture, plow use, and a dummy that indicates whether agriculture contributes the most as a subsistence mode.

Tables H2-H4 show the result of this exercise. As in H2 and H4, as for centralization and community size, lost biomass becomes insignificant once agriculture-related variables are included. Therefore, the persistent effect of lost biomass on centralization and community size would be largely through agriculture. However, as in H3, the association between hierarchy and lost biomass remains highly significant even if measures of agriculture are added. One interpretation is the following: Since the Neolithic Revolution had shaped culture, religion, and institutions as well as agriculture, lost biomass had a long-run effect on hierarchy through cultural and institutional paths rather than agriculture.

Table H1: Socioeconomic Development in Traditional Society and Lost Biomass

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass	0.370***	0.387***	0.143***	0.157***	0.470***	0.518***
	(0.079)	(0.077)	(0.031)	(0.033)	(0.121)	(0.125)
Dist. to the Closest Agricultural Origin	-0.064	-0.064	0.107**	0.107**	-0.783***	-0.782***
	(0.096)	(0.095)	(0.044)	(0.043)	(0.166)	(0.164)
Migratory Dist. from Addis Ababa	-0.033	-0.031	0.018	0.019	0.501	0.522
	(0.279)	(0.276)	(0.078)	(0.077)	(0.463)	(0.456)
Paleo-Temperature (Avg.)	-0.154	-0.157	0.040	0.038	0.178	0.174
	(0.100)	(0.099)	(0.057)	(0.057)	(0.179)	(0.178)
Paleo-Precipitation (Avg.)	-0.194***	-0.191***	0.050	0.052	-0.210	-0.209
	(0.063)	(0.063)	(0.040)	(0.040)	(0.183)	(0.183)
Paleo-Net Primary Product (Avg.)	0.091	0.091	-0.110***	-0.110***	-0.000	0.001
	(0.079)	(0.079)	(0.040)	(0.040)	(0.167)	(0.167)
Latitude	-0.307	-0.309	0.037	0.035	-0.121	-0.125
	(0.196)	(0.193)	(0.058)	(0.057)	(0.259)	(0.252)
Longitude	-0.344	-0.334	-0.214*	-0.204*	-0.655*	-0.608*
	(0.282)	(0.280)	(0.118)	(0.119)	(0.336)	(0.332)
Latitude × Longitude	-0.135	-0.141	0.016	0.012	-0.387*	-0.410**
	(0.149)	(0.149)	(0.048)	(0.048)	(0.195)	(0.197)
Elevation (Avg.)	-0.041	-0.042	0.019	0.018	0.047	0.045
	(0.063)	(0.063)	(0.034)	(0.034)	(0.137)	(0.137)
Land Productivity (Avg.)	0.151***	0.151***	0.056***	0.056***	0.605***	0.602***
	(0.034)	(0.035)	(0.016)	(0.016)	(0.089)	(0.089)
Island Dummy	-0.140	-0.134	-0.753***	-0.747***	0.000	0.000
	(0.134)	(0.132)	(0.123)	(0.118)	(.)	(.)
Dist. to the Waterway	-0.025	-0.027	-0.027	-0.029	-0.276**	-0.283**
	(0.027)	(0.028)	(0.022)	(0.022)	(0.106)	(0.109)
Total Area	-0.044	-0.043	-0.065**	-0.064**	-0.187	-0.186
	(0.057)	(0.058)	(0.026)	(0.026)	(0.169)	(0.170)
# Native Plants	-0.092	-0.096	-0.006	-0.010	-0.168	-0.182
	(0.070)	(0.069)	(0.039)	(0.039)	(0.165)	(0.166)
Continent FE	✓	✓	✓	✓	✓	✓
First Stage F-Statistics		1274.358		1253.234		1133.475
Mean of Dependent Variable	1.995	1.995	0.511	0.511	3.768	3.768
Std of Dependent Variable	1.146	1.146	0.500	0.500	2.341	2.341
Adjusted R^2	0.338		0.202		0.368	
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.

Robustness: Incentive to Migrate

When available hunting resources became scarce, individuals may have out-migrated. As explained in the theoretical section, this is not much of a concern in the setting of this study. However, to alleviate the concern, I account for neighboring regions' biomass to capture the

Table H2: Centralization and Agricultural Activities

	Jurisdictional Hierarchy beyond Local Community						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass (Herbivore > 44 kg)	0.370***	0.292***	0.220***	0.158**	0.366***	0.100	0.105
	(0.079)	(0.071)	(0.077)	(0.074)	(0.079)	(0.069)	(0.075)
Dist. to the Closest Agricultural Origin	-0.064	0.081	0.055	-0.088	-0.007	0.011	0.011
	(0.096)	(0.085)	(0.082)	(0.070)	(0.083)	(0.071)	(0.071)
Migratory Dist. from Addis Ababa	-0.033	-0.022	-0.052	-0.104	-0.029	-0.106	-0.105
	(0.279)	(0.226)	(0.171)	(0.170)	(0.264)	(0.149)	(0.149)
Latitude	-0.307	-0.239	-0.276**	-0.291**	-0.254	-0.279***	-0.280***
	(0.196)	(0.155)	(0.136)	(0.123)	(0.180)	(0.098)	(0.098)
Longitude	-0.344	-0.359	-0.474*	-0.059	-0.322	-0.198	-0.196
	(0.282)	(0.260)	(0.245)	(0.252)	(0.285)	(0.255)	(0.255)
Latitude × Longitude	-0.135	-0.124	-0.087	-0.149	-0.115	-0.119	-0.121
	(0.149)	(0.125)	(0.118)	(0.105)	(0.139)	(0.101)	(0.102)
Elevation (Avg.)	-0.041	-0.061	-0.121**	-0.081	-0.052	-0.116**	-0.116**
	(0.063)	(0.060)	(0.059)	(0.050)	(0.062)	(0.049)	(0.049)
Land Productivity (Avg.)	0.151***	0.120***	0.108***	0.101***	0.130***	0.081***	0.081***
	(0.034)	(0.029)	(0.029)	(0.022)	(0.031)	(0.025)	(0.025)
Island Dummy	-0.140	0.017	-0.039	-0.050	-0.118	0.028	0.029
	(0.134)	(0.127)	(0.097)	(0.100)	(0.116)	(0.154)	(0.155)
Dist. to the Waterway	-0.025	-0.009	-0.017	0.023	-0.001	0.018	0.017
	(0.027)	(0.033)	(0.030)	(0.033)	(0.033)	(0.029)	(0.029)
Total Area	-0.044	-0.085	-0.051	-0.032	-0.060	-0.050	-0.050
	(0.057)	(0.055)	(0.054)	(0.047)	(0.058)	(0.050)	(0.050)
# Native Plants	-0.092	-0.110	-0.040	-0.088	-0.107	-0.075	-0.076
	(0.070)	(0.069)	(0.051)	(0.055)	(0.070)	(0.051)	(0.051)
Paleo-Temperature (Avg.)	-0.154	-0.197*	-0.262***	-0.147	-0.154	-0.221**	-0.222**
	(0.100)	(0.100)	(0.095)	(0.090)	(0.107)	(0.092)	(0.092)
Paleo-Precipitation (Avg.)	-0.194***	-0.220***	-0.151**	-0.103	-0.220***	-0.109*	-0.108*
	(0.063)	(0.057)	(0.058)	(0.062)	(0.062)	(0.056)	(0.056)
Paleo-Net Primary Product (Avg.)	0.091	-0.006	0.025	0.099	0.047	0.046	0.046
	(0.079)	(0.065)	(0.064)	(0.082)	(0.073)	(0.064)	(0.064)
Continent FE	✓	✓	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓	✓	✓
Agriculture Dependency		✓				✓	✓
Agriculture Intensity			✓			✓	✓
Plow Use				✓		✓	✓
Agricultural Contribution					✓	✓	✓
First Stage F-Statistics							2565.722
Mean of Dependent Variable	1.995	1.995	1.995	1.995	1.995	1.995	1.995
Std of Dependent Variable	1.146	1.146	1.146	1.146	1.146	1.146	1.146
Adjusted R^2	0.338	0.392	0.415	0.451	0.360	0.476	
Observations	1032	1032	1032	1032	1032	1032	1032

Note: The unit of analysis is an ethnic group. The dependent variable is the degree of centralization. Lost biomass is calculated using extinct megaherbivores. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

incentive to migrate. Table H5 shows that the estimate of lost biomass is robust to the inclusion of biomass in surrounding regions.

Table H3: Hierarchy and Agricultural Activities

	Social Stratification						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass (Herbivore > 44 kg)	0.143***	0.139***	0.124***	0.117***	0.141***	0.112***	0.126***
	(0.031)	(0.031)	(0.034)	(0.033)	(0.031)	(0.033)	(0.035)
Dist. to the Closest Agricultural Origin	0.106**	0.122***	0.115***	0.104**	0.114***	0.110***	0.110***
	(0.044)	(0.038)	(0.040)	(0.044)	(0.042)	(0.040)	(0.040)
Migratory Dist. from Addis Ababa	0.018	0.014	0.021	0.013	0.020	0.013	0.014
	(0.078)	(0.077)	(0.068)	(0.072)	(0.077)	(0.071)	(0.072)
Latitude	0.037	0.050	0.036	0.043	0.044	0.044	0.043
	(0.058)	(0.050)	(0.053)	(0.054)	(0.054)	(0.051)	(0.050)
Longitude	-0.213*	-0.203	-0.227*	-0.179	-0.211*	-0.189	-0.180
	(0.119)	(0.127)	(0.119)	(0.121)	(0.125)	(0.129)	(0.129)
Latitude × Longitude	0.016	0.020	0.027	0.016	0.018	0.023	0.019
	(0.048)	(0.047)	(0.045)	(0.046)	(0.049)	(0.044)	(0.044)
Elevation (Avg.)	0.018	0.015	0.005	0.012	0.017	0.006	0.005
	(0.034)	(0.032)	(0.033)	(0.033)	(0.033)	(0.032)	(0.032)
Land Productivity (Avg.)	0.056***	0.049***	0.047**	0.049***	0.053***	0.039**	0.039**
	(0.016)	(0.017)	(0.018)	(0.017)	(0.017)	(0.019)	(0.019)
Island Dummy	-0.752***	-0.787***	-0.721***	-0.748***	-0.753***	-0.769***	-0.765***
	(0.123)	(0.085)	(0.104)	(0.116)	(0.121)	(0.080)	(0.077)
Dist. to the Waterway	-0.027	-0.027	-0.026	-0.020	-0.024	-0.028	-0.030
	(0.022)	(0.017)	(0.021)	(0.023)	(0.021)	(0.020)	(0.020)
Total Area	-0.065**	-0.071***	-0.062***	-0.063**	-0.069**	-0.062***	-0.062***
	(0.026)	(0.025)	(0.023)	(0.025)	(0.026)	(0.023)	(0.023)
# Native Plants	-0.007	-0.007	0.004	-0.005	-0.008	0.002	-0.001
	(0.039)	(0.038)	(0.035)	(0.038)	(0.039)	(0.035)	(0.035)
Paleo-Temperature (Avg.)	0.040	0.035	0.025	0.041	0.039	0.033	0.032
	(0.057)	(0.059)	(0.059)	(0.056)	(0.058)	(0.060)	(0.060)
Paleo-Precipitation (Avg.)	0.050	0.045	0.059	0.065	0.046	0.061	0.062
	(0.040)	(0.039)	(0.041)	(0.041)	(0.039)	(0.040)	(0.040)
Paleo-Net Primary Product (Avg.)	-0.109***	-0.124***	-0.110***	-0.110***	-0.116***	-0.110***	-0.110***
	(0.040)	(0.041)	(0.041)	(0.040)	(0.042)	(0.040)	(0.040)
Continent FE	✓	✓	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓	✓	✓
Agriculture Dependency		✓				✓	✓
Agriculture Intensity			✓			✓	✓
Plow Use				✓		✓	✓
Agricultural Contribution					✓	✓	✓
First Stage F-Statistics							2548.976
Mean of Dependent Variable	0.512	0.512	0.512	0.512	0.512	0.512	0.512
Std of Dependent Variable	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Adjusted R^2	0.201	0.208	0.211	0.211	0.203	0.219	
Observations	989	989	989	989	989	989	989

Note: The unit of analysis is an ethnic group. The dependent variable is social stratification. Lost biomass is calculated using extinct megaherbivores. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Robustness: Estimates from Different Studies

The primary measure of lost biomass, (23), is constructed using an estimate from Silva and Downing (1995). Therefore, one may suspect that the result is driven by that study. Thus, I

Table H4: Community Size and Agricultural Activities

	Community Size						
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) 2SLS
Lost Biomass (Herbivore > 44 kg)	0.470***	0.344***	0.059	0.019	0.304**	0.001	0.026
	(0.121)	(0.111)	(0.116)	(0.113)	(0.120)	(0.114)	(0.124)
Dist. to the Closest Agricultural Origin	-0.783***	-0.345***	-0.426***	-0.648***	-0.402***	-0.392***	-0.393***
	(0.166)	(0.128)	(0.126)	(0.136)	(0.139)	(0.106)	(0.106)
Migratory Dist. from Addis Ababa	0.501	0.210	0.396*	0.518*	0.321	0.158	0.166
	(0.463)	(0.278)	(0.219)	(0.300)	(0.316)	(0.303)	(0.302)
Latitude	-0.121	0.014	-0.023	0.126	0.169	0.041	0.038
	(0.259)	(0.142)	(0.140)	(0.172)	(0.191)	(0.132)	(0.133)
Longitude	-0.655*	-0.409	-1.081***	-0.266	-0.759***	-0.618**	-0.597**
	(0.336)	(0.276)	(0.296)	(0.312)	(0.252)	(0.290)	(0.284)
Latitude × Longitude	-0.387*	-0.185	-0.061	-0.258	-0.112	-0.004	-0.014
	(0.195)	(0.157)	(0.182)	(0.175)	(0.162)	(0.179)	(0.176)
Elevation (Avg.)	0.047	-0.117	-0.169*	-0.023	-0.022	-0.187**	-0.188**
	(0.137)	(0.095)	(0.093)	(0.109)	(0.093)	(0.078)	(0.079)
Land Productivity (Avg.)	0.605***	0.455***	0.521***	0.509***	0.483***	0.415***	0.415***
	(0.089)	(0.085)	(0.092)	(0.075)	(0.085)	(0.087)	(0.086)
Island Dummy	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Dist. to the Waterway	-0.276**	-0.141	-0.280**	-0.157***	-0.143	-0.147*	-0.150*
	(0.106)	(0.092)	(0.130)	(0.049)	(0.105)	(0.085)	(0.087)
Total Area	-0.187	-0.236	-0.060	-0.075	-0.247	-0.106	-0.106
	(0.169)	(0.156)	(0.117)	(0.153)	(0.162)	(0.133)	(0.133)
# Native Plants	-0.168	-0.166	0.051	-0.132	-0.107	-0.062	-0.068
	(0.165)	(0.138)	(0.087)	(0.132)	(0.139)	(0.094)	(0.095)
Paleo-Temperature (Avg.)	0.178	0.049	-0.098	0.187	0.196	0.020	0.020
	(0.179)	(0.127)	(0.126)	(0.139)	(0.140)	(0.109)	(0.108)
Paleo-Precipitation (Avg.)	-0.210	-0.338**	-0.142	0.026	-0.329*	-0.154	-0.154
	(0.183)	(0.162)	(0.158)	(0.153)	(0.167)	(0.124)	(0.124)
Paleo-Net Primary Product (Avg.)	-0.000	-0.248	-0.107	0.069	-0.215	-0.026	-0.025
	(0.167)	(0.160)	(0.148)	(0.172)	(0.150)	(0.137)	(0.136)
Continent FE	✓	✓	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓	✓	✓
Agriculture Dependency		✓				✓	✓
Agriculture Intensity			✓			✓	✓
Plow Use				✓		✓	✓
Agricultural Contribution					✓	✓	✓
First Stage F-Statistics							1905.259
Mean of Dependent Variable	3.768	3.768	3.768	3.768	3.768	3.768	3.768
Std of Dependent Variable	2.341	2.341	2.341	2.341	2.341	2.341	2.341
Adjusted R^2	0.368	0.537	0.542	0.503	0.495	0.616	
Observations	542	542	542	542	542	542	542

Note: The unit of analysis is an ethnic group. The dependent variable is the community size. Lost biomass is calculated using extinct megaherbivores. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

reconstruct the measure of lost biomass by exploiting different estimates from other studies. Table H6-H8 show that the result is robust to using these different estimates.

Table H5: Socioeconomic Development in Traditional Society, Lost Biomass and Neighboring Biomass

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass	0.362***	0.377***	0.134***	0.146***	0.437***	0.476***
	(0.080)	(0.078)	(0.028)	(0.028)	(0.117)	(0.117)
Neighboring Biomass	-0.036	-0.033	-0.041	-0.039	-0.176	-0.170
	(0.064)	(0.063)	(0.036)	(0.036)	(0.116)	(0.113)
Dist. to the Closest Agricultural Origin	-0.064	-0.064	0.107**	0.107**	-0.781***	-0.780***
	(0.098)	(0.097)	(0.045)	(0.045)	(0.173)	(0.171)
Migratory Dist. from Addis Ababa	-0.054	-0.051	-0.006	-0.004	0.375	0.396
	(0.264)	(0.262)	(0.069)	(0.069)	(0.466)	(0.460)
Paleo-Temperature (Avg.)	-0.152	-0.154	0.043	0.041	0.191	0.187
	(0.100)	(0.100)	(0.057)	(0.057)	(0.172)	(0.172)
Paleo-Precipitation (Avg.)	-0.194***	-0.192***	0.049	0.050	-0.229	-0.227
	(0.065)	(0.064)	(0.042)	(0.042)	(0.189)	(0.190)
Paleo-Net Primary Product (Avg.)	0.085	0.086	-0.116***	-0.116***	-0.011	-0.009
	(0.084)	(0.083)	(0.040)	(0.040)	(0.173)	(0.173)
Latitude	-0.320*	-0.321*	0.023	0.022	-0.180	-0.181
	(0.190)	(0.187)	(0.058)	(0.057)	(0.265)	(0.260)
Longitude	-0.323	-0.316	-0.190	-0.183	-0.569	-0.535
	(0.292)	(0.290)	(0.120)	(0.119)	(0.355)	(0.352)
Latitude × Longitude	-0.139	-0.143	0.012	0.008	-0.408**	-0.425**
	(0.149)	(0.149)	(0.049)	(0.049)	(0.199)	(0.201)
Elevation (Avg.)	-0.035	-0.036	0.026	0.025	0.074	0.072
	(0.072)	(0.072)	(0.033)	(0.033)	(0.135)	(0.135)
Land Productivity (Avg.)	0.157***	0.156***	0.063***	0.062***	0.631***	0.628***
	(0.036)	(0.036)	(0.017)	(0.017)	(0.093)	(0.093)
Island Dummy	-0.139	-0.134	-0.752***	-0.747***	0.000	0.000
	(0.135)	(0.133)	(0.125)	(0.120)	(.)	(.)
Dist. to the Waterway	-0.028	-0.030	-0.031	-0.033	-0.293***	-0.298***
	(0.029)	(0.030)	(0.021)	(0.021)	(0.105)	(0.107)
Total Area	-0.025	-0.026	-0.043	-0.043	-0.086	-0.089
	(0.067)	(0.067)	(0.032)	(0.033)	(0.183)	(0.184)
# Native Plants	-0.100	-0.102	-0.015	-0.017	-0.199	-0.209
	(0.072)	(0.072)	(0.039)	(0.039)	(0.170)	(0.170)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.995	1.995	0.511	0.511	3.771	3.771
Std of Dependent Variable	1.146	1.146	0.500	0.500	2.360	2.360
First Stage F-Statistics		1196.268		1178.316		1081.687
Adjusted R^2	0.338		0.204		0.370	
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Robustness: Domesticable Mammals, Wild Relatives of Domesticable Plants, and Extinction Rate

The existence of domesticable mammals and plants allowed an earlier transition to agriculture by providing biogeographically better initial conditions (Diamond, 2017; Olsson and

Table H6: Centralization and Megaherbivore Extinction (Different Estimates)

	Jurisdictional Hierarchy beyond Local Community				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass (Currie, 1993)	0.383***				
	(0.084)				
Lost Biomass (Damuth, 1987)		0.401***			
		(0.088)			
Lost Biomass (Peters and Raelson, 1984)			0.411***		
			(0.090)		
Lost Biomass (Peters and Wassenberg, 1983)				0.386***	
				(0.084)	
Lost Biomass (Silva et al., 2001)					0.393***
					(0.086)
Continent FE	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.995	1.995	1.995	1.995	1.995
Std of Dependent Variable	1.146	1.146	1.146	1.146	1.146
Adjusted R^2	0.339	0.340	0.341	0.339	0.340
Observations	1033	1033	1033	1033	1033

Note: The unit of analysis is an ethnic group. Dependent variables is the degree of centralization. Lost biomass is calculated using extinct megaherbivores. When constructing measures of lost biomass, I use estimates reported by different studies from the one that I use in the basic analysis. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. Controls are the distance to the closest agricultural center, migratory distance from Addis Ababa, average of paleo-temperature, average of paleo-precipitation, paleo-net primary product, latitude, longitude, the product of latitude and longitude, average of elevation, average of land productivity, island dummy, the distance to the closest waterway, total area and the number of native plants. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Hibbs, 2005). A recent study by Riahi (2020) argues that large-mammal extinction has a hump-shaped relationship with agricultural-transition timing. Hence, I add measures of domesticable mammals and wild relatives of domesticable plants in Table H9. I also control for extinction rate and its square in Table H10. As is evident, the estimate of lost biomass is robust to the inclusion of these variables.

Robustness: Temperature Volatility and Climatic Seasonality

Intermonthly temperature volatility and its square term as well as climatic seasonality have been shown to be related to the timing of the agricultural transition (Ashraf and Michalopoulos, 2015; Matranga, 2017). As shown in Tables H11 and H12, the estimate of lost biomass is robust to the inclusion of these variables, showing that the basic result is not driven by these climatic aspects.

Table H7: Social Hierarchy and Megaherbivore Extinction (Different Estimates)

	Social Stratification				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass (Currie, 1993)	0.133***				
	(0.032)				
Lost Biomass (Damuth, 1987)		0.124***			
		(0.033)			
Lost Biomass (Peters and Raelson, 1984)			0.113***		
			(0.034)		
Lost Biomass (Peters and Wassenberg, 1983)				0.132***	
				(0.033)	
Lost Biomass (Silva et al., 2001)					0.129***
					(0.033)
Continent FE	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓
Mean of Dependent Variable	0.511	0.511	0.511	0.511	0.511
Std of Dependent Variable	0.500	0.500	0.500	0.500	0.500
Adjusted R^2	0.197	0.193	0.189	0.196	0.195
Observations	991	991	991	991	991

Note: The unit of analysis is an ethnic group. Dependent variables is the existence of social hierarchy. Lost biomass is calculated using extinct megaherbivores. When constructing measures of lost biomass, I use estimates reported by different studies from the one that I use in the basic analysis. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. Controls are the distance to the closest agricultural center, migratory distance from Addis Ababa, average of paleo-temperature, average of paleo-precipitation, paleo-net primary product, latitude, longitude, the product of latitude and longitude, average of elevation, average of land productivity, island dummy, the distance to the closest waterway, total area and the number of native plants. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Robustness: Inclusion of Domesticable Mammals in Lost-Biomass Measure

I reconstruct the measure of lost biomass by including fourteen domesticable mammal species, although this measure is less consistent with the proposed theory. Table H13 shows that including domesticable mammals in the measure does not alter the result.

Robustness: Spatial Correlation

The result is robust to standard errors using the spatial correlation proposed by Conley (1999). As shown in Table H14 and H15, taking spatial correlation into account does not alter the basic result.

Table H8: Community Size and Megaherbivore Extinction (Different Estimates)

	Size of Local Community				
	(1)	(2)	(3)	(4)	(5)
Lost Biomass (Currie, 1993)	0.461***				
	(0.131)				
Lost Biomass (Damuth, 1987)		0.452***			
		(0.141)			
Lost Biomass (Peters and Raelson, 1984)			0.436***		
			(0.150)		
Lost Biomass (Peters and Wassenberg, 1983)				0.461***	
				(0.132)	
Lost Biomass (Silva et al., 2001)					0.458***
					(0.136)
Continent FE	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓
Mean of Dependent Variable	3.768	3.768	3.768	3.768	3.768
Std of Dependent Variable	2.341	2.341	2.341	2.341	2.341
Adjusted R^2	0.366	0.365	0.363	0.366	0.366
Observations	543	543	543	543	543

Note: The unit of analysis is an ethnic group. Dependent variables is the size of local community. Lost biomass is calculated using extinct megaherbivores. When constructing measures of lost biomass, I use estimates reported by different studies from the one that I use in the basic analysis. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. Controls are the distance to the closest agricultural center, migratory distance from Addis Ababa, average of paleo-temperature, average of paleo-precipitation, paleo-net primary product, latitude, longitude, the product of latitude and longitude, average of elevation, average of land productivity, island dummy, the distance to the closest waterway, total area and the number of native plants. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table H9: Socioeconomic Development, Megaherbivore Extinction, Domesticable Mammals and Plants

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass	0.291***	0.302***	0.121***	0.134***	0.329***	0.369***
	(0.094)	(0.095)	(0.032)	(0.035)	(0.117)	(0.125)
# Wild Relatives of Domesticable Crops	-0.040	-0.039	-0.022	-0.021	-0.008	-0.006
	(0.034)	(0.034)	(0.015)	(0.015)	(0.102)	(0.103)
# Domesticable Mammals	0.249**	0.246**	0.066*	0.062	0.434**	0.421**
	(0.105)	(0.106)	(0.036)	(0.037)	(0.190)	(0.188)
Dist. to the Closest Agricultural Origin	-0.113	-0.112	0.092*	0.093**	-0.841***	-0.838***
	(0.076)	(0.076)	(0.046)	(0.046)	(0.150)	(0.149)
Migratory Dist. from Addis Ababa	0.046	0.046	0.036	0.035	0.606**	0.618**
	(0.203)	(0.203)	(0.076)	(0.077)	(0.290)	(0.290)
Paleo-Temperature (Avg.)	-0.149	-0.151	0.039	0.037	0.169	0.166
	(0.100)	(0.100)	(0.057)	(0.056)	(0.166)	(0.166)
Paleo-Precipitation (Avg.)	-0.201***	-0.199***	0.049	0.050	-0.201	-0.200
	(0.056)	(0.055)	(0.036)	(0.036)	(0.166)	(0.167)
Paleo-Net Primary Product (Avg.)	0.138	0.137	-0.096**	-0.097***	0.110	0.108
	(0.087)	(0.087)	(0.037)	(0.036)	(0.168)	(0.169)
Latitude	-0.372**	-0.372**	0.017	0.017	-0.202	-0.202
	(0.145)	(0.144)	(0.056)	(0.056)	(0.222)	(0.220)
Longitude	-0.274	-0.269	-0.207*	-0.200*	-0.471	-0.439
	(0.283)	(0.282)	(0.114)	(0.116)	(0.331)	(0.339)
Latitude × Longitude	-0.230*	-0.232*	-0.005	-0.007	-0.521**	-0.534***
	(0.131)	(0.131)	(0.046)	(0.047)	(0.197)	(0.200)
Elevation (Avg.)	-0.031	-0.031	0.021	0.020	0.085	0.082
	(0.058)	(0.058)	(0.032)	(0.032)	(0.126)	(0.125)
Land Productivity (Avg.)	0.152***	0.152***	0.058***	0.058***	0.613***	0.611***
	(0.028)	(0.028)	(0.015)	(0.015)	(0.081)	(0.081)
Island Dummy	-0.166	-0.162	-0.761***	-0.756***	0.000	0.000
	(0.106)	(0.106)	(0.111)	(0.107)	(.)	(.)
Dist. to the Waterway	-0.033	-0.034	-0.030	-0.032	-0.286***	-0.291***
	(0.027)	(0.027)	(0.023)	(0.022)	(0.099)	(0.101)
Total Area	-0.076	-0.075	-0.075**	-0.073**	-0.254	-0.252
	(0.054)	(0.054)	(0.029)	(0.028)	(0.168)	(0.168)
# Native Plants	-0.071	-0.073	-0.002	-0.005	-0.141	-0.152
	(0.062)	(0.061)	(0.038)	(0.039)	(0.156)	(0.157)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.995	1.995	0.511	0.511	3.768	3.768
Std of Dependent Variable	1.146	1.146	0.500	0.500	2.341	2.341
First Stage F-Statistics		1163.226		1135.803		1109.003
Adjusted R^2	0.351		0.207		0.378	
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table H10: Socioeconomic Development, Megaherbivore Extinction and Extinction Rate

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass	0.223***	0.261***	0.128***	0.148***	0.347*	0.450**
	(0.078)	(0.076)	(0.042)	(0.041)	(0.174)	(0.171)
# Extinct Megafauna / # Total Megafauna	2.649***	2.409***	0.483	0.354	1.869	1.104
	(0.869)	(0.829)	(0.373)	(0.363)	(2.158)	(2.136)
# Extinct Megafauna / # Total Megafauna (Square)	-2.149**	-1.986**	-0.518	-0.432	-1.294	-0.750
	(1.003)	(0.969)	(0.371)	(0.374)	(2.236)	(2.246)
Dist. to the Closest Agricultural Origin	-0.157*	-0.148	0.092**	0.096**	-0.841***	-0.816***
	(0.090)	(0.089)	(0.044)	(0.044)	(0.154)	(0.155)
Migratory Dist. from Addis Ababa	0.075	0.070	0.047	0.044	0.580	0.570
	(0.266)	(0.262)	(0.074)	(0.074)	(0.522)	(0.513)
Paleo-Temperature (Avg.)	-0.145	-0.149	0.045	0.043	0.181	0.175
	(0.105)	(0.103)	(0.056)	(0.056)	(0.184)	(0.181)
Paleo-Precipitation (Avg.)	-0.143**	-0.144**	0.057	0.056	-0.182	-0.192
	(0.057)	(0.058)	(0.039)	(0.038)	(0.179)	(0.178)
Paleo-Net Primary Product (Avg.)	0.083	0.086	-0.103***	-0.101**	-0.007	-0.003
	(0.057)	(0.058)	(0.038)	(0.038)	(0.166)	(0.167)
Latitude	-0.309*	-0.313*	0.035	0.034	-0.115	-0.122
	(0.183)	(0.180)	(0.056)	(0.055)	(0.253)	(0.249)
Longitude	-0.423	-0.400	-0.219*	-0.206*	-0.715**	-0.638*
	(0.287)	(0.283)	(0.119)	(0.118)	(0.343)	(0.339)
Latitude × Longitude	-0.163	-0.167	0.011	0.009	-0.413**	-0.428**
	(0.153)	(0.152)	(0.046)	(0.047)	(0.199)	(0.198)
Elevation (Avg.)	-0.053	-0.053	0.019	0.019	0.035	0.038
	(0.064)	(0.065)	(0.034)	(0.033)	(0.143)	(0.143)
Land Productivity (Avg.)	0.129***	0.131***	0.053***	0.054***	0.592***	0.595***
	(0.040)	(0.040)	(0.017)	(0.017)	(0.097)	(0.096)
Island Dummy	-0.241**	-0.225**	-0.770***	-0.760***	0.000	0.000
	(0.114)	(0.111)	(0.117)	(0.112)	(.)	(.)
Dist. to the Waterway	-0.027	-0.031	-0.029	-0.032	-0.267**	-0.278**
	(0.031)	(0.032)	(0.022)	(0.022)	(0.112)	(0.114)
Total Area	-0.065	-0.062	-0.069***	-0.068**	-0.212	-0.201
	(0.055)	(0.056)	(0.026)	(0.026)	(0.160)	(0.163)
# Native Plants	-0.079	-0.086	-0.009	-0.013	-0.158	-0.177
	(0.064)	(0.064)	(0.037)	(0.038)	(0.161)	(0.163)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.995	1.995	0.511	0.511	3.768	3.768
Std of Dependent Variable	1.146	1.146	0.500	0.500	2.341	2.341
First Stage F-Statistics		3877.196		3825.928		3841.005
Adjusted R^2	0.345		0.202		0.367	
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Extinction rate is a percentage of extinct large mammals to all the large mammals. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent variable, dummy variables, extinction rate and its square term are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table H11: Socioeconomic Development, Megaherbivore Extinction and Temperature Volatility

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass	0.320***	0.336***	0.137***	0.150***	0.383***	0.426***
	(0.092)	(0.094)	(0.032)	(0.034)	(0.124)	(0.138)
Paleo-Temperature (Avg.)	-0.113	-0.115	-0.060	-0.061	0.009	0.006
	(0.089)	(0.089)	(0.075)	(0.074)	(0.240)	(0.238)
Paleo-Temperature (Std.)	0.145*	0.141*	-0.003	-0.006	0.201	0.191
	(0.074)	(0.075)	(0.028)	(0.028)	(0.139)	(0.143)
Paleo-Temperature (Std. Square)	-0.006	-0.006	-0.002	-0.002	-0.012*	-0.012*
	(0.004)	(0.004)	(0.001)	(0.001)	(0.007)	(0.007)
Dist. to the Closest Agricultural Origin	-0.018	-0.019	0.096**	0.096**	-0.740***	-0.741***
	(0.088)	(0.087)	(0.043)	(0.043)	(0.167)	(0.166)
Migratory Dist. from Addis Ababa	-0.064	-0.062	0.023	0.024	0.447	0.465
	(0.246)	(0.245)	(0.078)	(0.078)	(0.399)	(0.398)
Paleo-Precipitation (Avg.)	-0.142**	-0.141**	0.023	0.024	-0.197	-0.199
	(0.067)	(0.066)	(0.038)	(0.038)	(0.186)	(0.187)
Paleo-Net Primary Product (Avg.)	0.136	0.134	-0.086**	-0.087**	0.143	0.139
	(0.089)	(0.090)	(0.040)	(0.040)	(0.197)	(0.198)
Latitude	-0.344*	-0.346*	0.074	0.073	-0.109	-0.110
	(0.194)	(0.191)	(0.060)	(0.060)	(0.236)	(0.231)
Longitude	-0.334	-0.326	-0.165	-0.157	-0.567*	-0.528*
	(0.290)	(0.288)	(0.111)	(0.112)	(0.310)	(0.308)
Latitude × Longitude	-0.074	-0.081	0.047	0.041	-0.237	-0.260
	(0.156)	(0.157)	(0.048)	(0.049)	(0.208)	(0.214)
Elevation (Avg.)	-0.057	-0.057	-0.006	-0.006	-0.023	-0.024
	(0.067)	(0.067)	(0.037)	(0.037)	(0.152)	(0.152)
Land Productivity (Avg.)	0.153***	0.153***	0.057***	0.057***	0.610***	0.608***
	(0.034)	(0.034)	(0.016)	(0.016)	(0.085)	(0.085)
Island Dummy	-0.176	-0.172	-0.693***	-0.687***	0.000	0.000
	(0.119)	(0.119)	(0.109)	(0.105)	(.)	(.)
Dist. to the Waterway	-0.024	-0.026	-0.023	-0.025	-0.265**	-0.271**
	(0.026)	(0.027)	(0.022)	(0.022)	(0.101)	(0.104)
Total Area	-0.040	-0.040	-0.055**	-0.055**	-0.155	-0.155
	(0.059)	(0.060)	(0.024)	(0.024)	(0.158)	(0.159)
# Native Plants	-0.027	-0.032	-0.023	-0.027	-0.114	-0.129
	(0.073)	(0.072)	(0.035)	(0.035)	(0.159)	(0.161)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.995	1.995	0.511	0.511	3.768	3.768
Std of Dependent Variable	1.146	1.146	0.500	0.500	2.341	2.341
First Stage F-Statistics		1237.116		1222.711		1155.121
Adjusted R^2	0.344		0.210		0.374	
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent variable, dummy variable, intermonthly temperature volatility and its square are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table H12: Socioeconomic Development, Megaherbivore Extinction and Climatic Seasonality

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass	0.332***	0.349***	0.146***	0.161***	0.436***	0.489***
	(0.081)	(0.080)	(0.034)	(0.036)	(0.129)	(0.141)
Paleo-Temperature (Seasonality)	0.074	0.073	0.012	0.011	0.056	0.050
	(0.067)	(0.067)	(0.030)	(0.030)	(0.162)	(0.162)
Paleo-Precipitation (Seasonality)	-0.081	-0.079	0.019	0.021	-0.065	-0.054
	(0.051)	(0.051)	(0.033)	(0.034)	(0.122)	(0.126)
Dist. to the Closest Agricultural Origin	-0.062	-0.062	0.109**	0.110**	-0.780***	-0.779***
	(0.089)	(0.088)	(0.042)	(0.042)	(0.169)	(0.168)
Migratory Dist. from Addis Ababa	0.050	0.049	0.006	0.004	0.556	0.568
	(0.242)	(0.241)	(0.079)	(0.080)	(0.426)	(0.421)
Paleo-Temperature (Avg.)	-0.177*	-0.179*	0.028	0.026	0.147	0.146
	(0.105)	(0.105)	(0.056)	(0.056)	(0.177)	(0.177)
Paleo-Precipitation (Avg.)	-0.159**	-0.157**	0.051	0.052	-0.186	-0.187
	(0.062)	(0.062)	(0.040)	(0.040)	(0.172)	(0.172)
Paleo-Net Primary Product (Avg.)	0.044	0.046	-0.095**	-0.093**	-0.023	-0.017
	(0.095)	(0.095)	(0.046)	(0.046)	(0.199)	(0.199)
Latitude	-0.299*	-0.302*	0.027	0.025	-0.125	-0.129
	(0.178)	(0.176)	(0.053)	(0.052)	(0.233)	(0.228)
Longitude	-0.319	-0.310	-0.214*	-0.204*	-0.653*	-0.607*
	(0.284)	(0.282)	(0.118)	(0.118)	(0.329)	(0.326)
Latitude × Longitude	-0.137	-0.142	0.014	0.010	-0.390*	-0.412**
	(0.149)	(0.149)	(0.050)	(0.050)	(0.197)	(0.199)
Elevation (Avg.)	-0.056	-0.057	0.019	0.018	0.035	0.035
	(0.066)	(0.066)	(0.032)	(0.032)	(0.137)	(0.137)
Land Productivity (Avg.)	0.151***	0.150***	0.055***	0.055***	0.605***	0.603***
	(0.034)	(0.034)	(0.016)	(0.016)	(0.089)	(0.089)
Island Dummy	-0.101	-0.097	-0.764***	-0.760***	0.000	0.000
	(0.129)	(0.128)	(0.140)	(0.135)	(.)	(.)
Dist. to the Waterway	-0.030	-0.032	-0.026	-0.028	-0.281***	-0.287***
	(0.026)	(0.027)	(0.023)	(0.022)	(0.103)	(0.106)
Total Area	-0.032	-0.031	-0.066**	-0.066**	-0.179	-0.179
	(0.059)	(0.060)	(0.027)	(0.027)	(0.165)	(0.166)
# Native Plants	-0.070	-0.074	-0.002	-0.006	-0.152	-0.167
	(0.074)	(0.073)	(0.037)	(0.037)	(0.169)	(0.170)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.995	1.995	0.511	0.511	3.768	3.768
Std of Dependent Variable	1.146	1.146	0.500	0.500	2.341	2.341
First Stage F-Statistics		1283.723		1261.426		1285.179
Adjusted R^2	0.342		0.201		0.367	
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table H13: Socioeconomic Development and Megaherbivore Extinction (Inclusion of Domesticable Mammals)

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
avgexmh_mh_50 (standardized)	0.416***	0.437***	0.150***	0.178***	0.475***	0.591***
	(0.094)	(0.086)	(0.037)	(0.037)	(0.138)	(0.149)
Dist. to the Closest Agricultural Origin	-0.064	-0.063	0.107**	0.107**	-0.787***	-0.784***
	(0.096)	(0.094)	(0.044)	(0.043)	(0.167)	(0.163)
Migratory Dist. from Addis Ababa	-0.055	-0.055	0.010	0.010	0.463	0.504
	(0.274)	(0.271)	(0.079)	(0.079)	(0.467)	(0.452)
Paleo-Temperature (Avg.)	-0.175*	-0.180*	0.034	0.029	0.163	0.150
	(0.100)	(0.100)	(0.059)	(0.059)	(0.185)	(0.184)
Paleo-Precipitation (Avg.)	-0.199***	-0.196***	0.047	0.050	-0.219	-0.217
	(0.063)	(0.063)	(0.040)	(0.040)	(0.183)	(0.184)
Paleo-Net Primary Product (Avg.)	0.086	0.086	-0.112***	-0.112***	-0.015	-0.015
	(0.078)	(0.078)	(0.041)	(0.040)	(0.168)	(0.168)
Latitude	-0.309	-0.312	0.038	0.035	-0.117	-0.126
	(0.194)	(0.190)	(0.059)	(0.056)	(0.266)	(0.251)
Longitude	-0.398	-0.388	-0.239**	-0.224*	-0.748**	-0.657*
	(0.281)	(0.279)	(0.118)	(0.120)	(0.346)	(0.340)
Latitude × Longitude	-0.112	-0.117	0.027	0.021	-0.343*	-0.386*
	(0.152)	(0.153)	(0.048)	(0.050)	(0.199)	(0.203)
Elevation (Avg.)	-0.044	-0.045	0.018	0.017	0.046	0.041
	(0.060)	(0.060)	(0.034)	(0.034)	(0.137)	(0.137)
Land Productivity (Avg.)	0.148***	0.148***	0.055***	0.055***	0.604***	0.598***
	(0.035)	(0.035)	(0.016)	(0.016)	(0.090)	(0.090)
Island Dummy	-0.136	-0.129	-0.755***	-0.745***	0.000	0.000
	(0.132)	(0.131)	(0.127)	(0.117)	(.)	(.)
Dist. to the Waterway	-0.017	-0.019	-0.022	-0.025	-0.257**	-0.268**
	(0.027)	(0.028)	(0.023)	(0.022)	(0.102)	(0.109)
Total Area	-0.049	-0.048	-0.068**	-0.066**	-0.197	-0.197
	(0.058)	(0.059)	(0.026)	(0.026)	(0.167)	(0.169)
# Native Plants	-0.095	-0.100	-0.005	-0.011	-0.158	-0.189
	(0.072)	(0.070)	(0.040)	(0.040)	(0.166)	(0.167)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.995	1.995	0.511	0.511	3.768	3.768
Std of Dependent Variable	1.146	1.146	0.500	0.500	2.341	2.341
First Stage F-Statistics		345.234		333.891		283.382
Adjusted R^2	0.339		0.199		0.365	
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent fixed effects are Africa, Americas, Asia, Europe and Oceania. All the variables except for the dependent variable and dummy variables are standardized. Robust standard errors clustered at the language family level ("v98") are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table H14: Agricultural Transition and Megaherbivore Extinction (Spatial Correlation)

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass (Herbivore > 44 kg)	0.370***	0.387***	0.143***	0.157***	0.470***	0.518***
	(0.071)	(0.070)	(0.031)	(0.031)	(0.145)	(0.152)
Dist. to the Closest Agricultural Origin	-0.064	-0.064	0.107***	0.107***	-0.783***	-0.782***
	(0.087)	(0.087)	(0.041)	(0.041)	(0.178)	(0.177)
Migratory Dist. from Addis Ababa	-0.033	-0.031	0.018	0.019	0.501	0.522
	(0.239)	(0.240)	(0.093)	(0.094)	(0.486)	(0.481)
Latitude	-0.307***	-0.309***	0.037	0.035	-0.121	-0.125
	(0.114)	(0.115)	(0.052)	(0.053)	(0.226)	(0.225)
Longitude	-0.344	-0.334	-0.214*	-0.204*	-0.655	-0.608
	(0.268)	(0.267)	(0.116)	(0.117)	(0.564)	(0.565)
Latitude × Longitude	-0.135	-0.141	0.016	0.012	-0.387*	-0.410*
	(0.130)	(0.130)	(0.053)	(0.053)	(0.229)	(0.231)
Elevation (Avg.)	-0.041	-0.042	0.019	0.018	0.047	0.045
	(0.051)	(0.051)	(0.026)	(0.026)	(0.138)	(0.139)
Land Productivity (Avg.)	0.151***	0.151***	0.056**	0.056**	0.605***	0.602***
	(0.044)	(0.044)	(0.022)	(0.022)	(0.116)	(0.116)
Island Dummy	-0.140	-0.134	-0.753***	-0.747***	0.000	0.000
	(0.208)	(0.209)	(0.099)	(0.098)	(.)	(.)
Dist. to the Waterway	-0.025	-0.027	-0.027	-0.029*	-0.276***	-0.283***
	(0.030)	(0.030)	(0.017)	(0.016)	(0.085)	(0.085)
Total Area	-0.044	-0.043	-0.065**	-0.064**	-0.187	-0.186
	(0.071)	(0.071)	(0.030)	(0.029)	(0.193)	(0.193)
# Native Plants	-0.092	-0.096	-0.006	-0.010	-0.168	-0.182
	(0.078)	(0.078)	(0.037)	(0.037)	(0.180)	(0.177)
Paleo-Temperature (Avg.)	-0.154**	-0.157**	0.040	0.038	0.178	0.174
	(0.070)	(0.070)	(0.045)	(0.045)	(0.198)	(0.198)
Paleo-Precipitation (Avg.)	-0.194**	-0.191**	0.050	0.052	-0.210	-0.209
	(0.087)	(0.087)	(0.040)	(0.040)	(0.192)	(0.193)
Paleo-Net Primary Product (Avg.)	0.091	0.091	-0.110**	-0.110**	-0.000	0.001
	(0.097)	(0.097)	(0.049)	(0.049)	(0.253)	(0.254)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.965	1.965	0.517	0.517	3.665	3.665
Std of Dependent Variable	1.121	1.121	0.500	0.500	2.279	2.279
First Stage F-Statistics		2345.138		2259.084		1890.678
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses calculated using the spatial correlation proposed by Conley (1999) with a threshold of 400 kilometers. *** p<0.01, ** p<0.05, * p<0.10.

Table H15: Agricultural Transition and Megaherbivore Extinction (Bartlett)

	Centralization		Social Stratification		Community Size	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) 2SLS
Lost Biomass (Herbivore > 44 kg)	0.370***	0.387***	0.143***	0.157***	0.470***	0.518***
	(0.065)	(0.064)	(0.026)	(0.027)	(0.134)	(0.143)
Dist. to the Closest Agricultural Origin	-0.064	-0.064	0.107***	0.107***	-0.783***	-0.782***
	(0.077)	(0.077)	(0.034)	(0.035)	(0.165)	(0.165)
Migratory Dist. from Addis Ababa	-0.033	-0.031	0.018	0.019	0.501	0.522
	(0.223)	(0.224)	(0.089)	(0.090)	(0.469)	(0.467)
Latitude	-0.307***	-0.309***	0.037	0.035	-0.121	-0.125
	(0.102)	(0.102)	(0.046)	(0.046)	(0.199)	(0.198)
Longitude	-0.344	-0.334	-0.214*	-0.204*	-0.655	-0.608
	(0.263)	(0.263)	(0.110)	(0.110)	(0.557)	(0.562)
Latitude × Longitude	-0.135	-0.141	0.016	0.012	-0.387*	-0.410*
	(0.132)	(0.132)	(0.050)	(0.051)	(0.227)	(0.229)
Elevation (Avg.)	-0.041	-0.042	0.019	0.018	0.047	0.045
	(0.047)	(0.047)	(0.021)	(0.021)	(0.118)	(0.119)
Land Productivity (Avg.)	0.151***	0.151***	0.056***	0.056***	0.605***	0.602***
	(0.039)	(0.039)	(0.019)	(0.019)	(0.108)	(0.108)
Island Dummy	-0.140	-0.134	-0.753***	-0.747***	0.000	0.000
	(0.193)	(0.193)	(0.094)	(0.093)	(.)	(.)
Dist. to the Waterway	-0.025	-0.027	-0.027*	-0.029*	-0.276***	-0.283***
	(0.032)	(0.032)	(0.016)	(0.016)	(0.084)	(0.085)
Total Area	-0.044	-0.043	-0.065**	-0.064**	-0.187	-0.186
	(0.071)	(0.071)	(0.030)	(0.029)	(0.188)	(0.188)
# Native Plants	-0.092	-0.096	-0.006	-0.010	-0.168	-0.182
	(0.071)	(0.071)	(0.033)	(0.033)	(0.172)	(0.171)
Paleo-Temperature (Avg.)	-0.154**	-0.157**	0.040	0.038	0.178	0.174
	(0.067)	(0.067)	(0.037)	(0.037)	(0.177)	(0.177)
Paleo-Precipitation (Avg.)	-0.194**	-0.191**	0.050	0.052	-0.210	-0.209
	(0.079)	(0.079)	(0.038)	(0.038)	(0.199)	(0.199)
Paleo-Net Primary Product (Avg.)	0.091	0.091	-0.110**	-0.110**	-0.000	0.001
	(0.087)	(0.087)	(0.043)	(0.043)	(0.243)	(0.243)
Continent FE	✓	✓	✓	✓	✓	✓
Mean of Dependent Variable	1.965	1.965	0.517	0.517	3.665	3.665
Std of Dependent Variable	1.121	1.121	0.500	0.500	2.279	2.279
First Stage F-Statistics		3182.972		3068.604		2370.805
Observations	1032	1032	990	990	542	542

Note: The unit of analysis is an ethnic group. Dependent variables are the degree of centralization, the existence of social hierarchy and the mean size of local community. Lost biomass is calculated using extinct megaherbivores. Continent dummies are Africa, Europe, Asia, Oceania, and Americas. All the variables except for the dependent and dummy variables are standardized. Robust standard errors are in parentheses calculated using the spatial correlation proposed by Conley (1999) with a threshold of 400 kilometers, allowing for weights that are close to one for near countries and almost zero for countries close to the distant cutoff. *** p<0.01, ** p<0.05, * p<0.10.

Appendix I. Variable Definitions

Outcome Variables

- **Time Elapsed since the Neolithic Transition**: For a country, it is the number of years elapsed as of the year 2,000 since a substantial population residing within a country's modern national borders began practicing sedentary agriculture as the primary mode of subsistence. The data is taken from Borcan et al. (2018). For an archaeological site, it is the earliest date (in thousands of years before present) of Neolithic settlement estimated by radiocarbon dating methods. The data is taken from Pinhasi et al. (2005). For a virtual country, it is years elapsed since the first domestication occurs. The seven well-accepted agricultural centers (eastern North America, mesoamerica, centrl mid-altitude Andes, West-African sub-Sahara, Near East, northern China and Yangtze China) and associated date of the transition are taken from Purugganan and Fuller (2009). They also provide specific territories for these seven regions. I first create $1° \times 1°$ grid cells and overlayed these seven places to the grid-cell map. I assign the same year that elapsed since the transition to the cells within an associated territory.

- **Radiocarbon-Dated Prehistorical archaeological sites**: These variables are taken from Mayshar et al. (2022), who georeference the number of pre-Neolithic and post-Neolithic sites from Whitehouse and Whitehouse (1975).

- **Size of Local Community**: It is "v31" (Mean Size of Local Communities) in the *Ethnographic Atlas*.

- **Centralization**: It is "v33" (Jurisdictional Hierarchy Beyond Local Community) in the *Ethnographic Atlas*.

- **The Existence of Social Hierarchy**: It is based on "v66" (Class Stratification) in the *Ethnographic Atlas*. The indicator takes 1 if there is any type of stratification and 0 otherwise.

Main Independent Variables

Measures of lost biomass are constructed, using data sets from the PHYLACINE (Faurby et al., 2018) and Andermann et al. (2020). Biomass for a given species is defined by the product of the average body mass and the number of individuals of the associated species. Thus Biomass for a given area is calculated as sum of biomass of mammal species that reside in an area. The abundance of each species is predicted from the allometric relationship between body mass and population density. The estimate from Silva and Downing (1995) is

used to construct the main variable. Lost biomass for a given area is then defined as biomass of extinct species in the area normalized by the sum of biomass of extant and extinct species in the area.

- **Lost Biomass due to Megaherbivore Extinction**: The variable is constructed following the above definition. Megaherbivore is terrestrial herbivore larger than 44 kg.

- **Lost Biomass due to Non-Mega Herbivore Extinction**: The variable is constructed following the above definition. Non-mega herbivore is terrestrial herbivore smaller than 44 kg.

- **Lost Biomass due to Non-Herbivore Extinction**: The variable is constructed following the above definition. Non-Herbivore is composed of terrestrial carnivore and omnivore, which is a complement set of megaherbivore and non-mega herbivore.

Instrumental Variables

- **Lost Biomass Based on Predicted Extinction Probability**: The instrumental variable is constructed using the following procedure. First, actual extinction status is regressed on body mass by logistic estimation using 226 extant and extinct mammalian species. Second, extinction risk is obtained from the estimated result as a predicted value of the actual extinction status. Third, actual extinction status in the instrumented variable is replaced with the extinction risk.

Control Variables

- **Distance to the Neolithic Transition Frontier**: It is the geodesic distance from the closest agricultural origins among the seven well-accepted independent agricultural centers reported by Purugganan and Fuller (2009). These are eastern North America, mesoamerica, centrl mid-altitude Andes, West-African sub-Sahara, Near East, northern China and Yangtze China. The distance is from the nearest borders specified by them and calculated by the author using ArcGIS Pro 2.5.2.

- **Migratory Distance from Addis Ababa**: It is the distance from Addis Ababa in Ethiopia through five waypoints (Cairo, Instanbul, Phnom Penh, Anadyr and Prince Rupert). For a country, it is taken from Ashraf and Galor (2013). For other units of analysis, it is calculated by the author using ArcGIS Pro 2.5.2.

- **Latitude/Longitude**: For a country, it is the latitude and longitude of that country's approximate geodesic centroid, as reported by the CIA's World Factbook. For an ethnic group, it is the value of the latitude and longitude, as reported by the *Ethnographic Atlas* or Binford (2019). For a virtual country, it is the centroid of each grid cell.

- **Paleo-Temperature (Mean)**: Average of temperature within an associated area is calculated using the data set by Beyer et al. (2020). For cross-sectional analyses, it is the average across cells in the area over the period 80000-12000 BP (i.e., since the human left Addis Ababa until the first Neolithic Revolution occurred in Near East). For panel analyses, it is average across cells in the area in every associated period.

- **Paleo-Temperature (Intermonthly Volatility)**: For the cross-section analyses, the intermonthly temperature volatility is a standard deviation over the month during the period 80000-12000 BP (i.e., since the human left Addis Ababa until the first Neolithic Revolution occurred in Near East). The measure construction for the panel analyses is as follows. For the starting year of the panel, temperature volatility is a standard deviation, computed using monthly temperature data within the associated year. For the following time period, it is calculated using all the previous monthly temperature and corresponding period. Measures of temperature volatility are first computed at the grid-cell level, and they are then aggregated up to the arbitrary unit by averaging across the grid cells that are located within the unit's border. The data on temperature is taken from Beyer et al. (2020).

- **Paleo-Temperature (Seasonality)**: Temperature seasonality is computed following Matranga (2017), based on the data set by Beyer et al. (2020). First, I calculate the temperature of the warmest month and 0, whichever is greater in every cell. Second, I compute the temperature of the coldest month and 0, whichever is greater in every cell. Third, to obtain temperature seasonality, I subtract the latter valuer from the former in every cell. For cross-sectional analyses, it is the average across cells in the area over the period 80000-12000 BP (i.e., since the human left Addis Ababa until the first Neolithic Revolution occurred in Near East). For panel analyses, it is average across cells in the area in every associated period.

- **Paleo-Precipitation (Mean)**: Average of precipitation within an associated area is calculated using the data set by Beyer et al. (2020). For cross-sectional analyses, it is the average across cells in the area over the period 80000-12000 BP (i.e., since the human left Addis Ababa until the first Neolithic Revolution occurred in Near East). For panel analyses, it is average across cells in the area in every associated period.

- **Paleo-Precipitation (Seasonality)**: Precipitation seasonality is computed following Matranga (2017), based on the data set by Beyer et al. (2020). It is the difference between precipitation in the wettest month and driest month, nomalized by mean precipitation. For cross-sectional analyses, it is the average across cells in the area over the period 80000-12000 BP (i.e., since the human left Addis Ababa until the first Neolithic Revolution occurred in Near East). For panel analyses, it is average across cells in the area in every associated period.

- **Paleo-Net Primary Product**: Net primary product wthin an associated area is calculated using the data set by Beyer et al. (2020). For cross-sectional analyses, it is the average across cells in the area over the period 80000-12000 BP (i.e., since the human left Addis Ababa until the first Neolithic Revolution occurred in Near East). For panel analyses, it is average across cells in the area in every associated period.

- **Elevation (Mean)**: Average of elevation within an area. The data is taken from the Atlas of Bioshpere.

- **Land Suitability for Agriculture**: Average probability within a region that a particular grid cell will be cultivated as computed by Ramankutty et al. (2002).

- **Island Dummy**: For a country, it is an indicator for whether or not a country shares a land border with any other country, as reported by the CIA's World Factbook online. For an archaeoligical site, it is a dummy variable indicating if the land type of an site's geodesic centroid is a "small island" or a "very small island" as reported in the World Countries geographical dataset provided by ESRI.

- **Distance to the Nearest Waterway**: For a country, it is the nearest distance to a coast, major rive or lake, as reported by G-ECON. For other units of analysis, it is the distance from the centroid of an area to the nearest coast or river which are reported in the 1:10m Natural Earth Coastline and 1:10m Natural Earth River + Lake Centerlines Datasets.

- **Total Land Area**: For a country, it is the total land area of a country, in millions of square kilometers, as reported for the year 2000 by the World Bank's World Development Indicators online. For an archaeological site, it is the total land area of an archaeological site, in square kilometers, as calculated using ArcGIS Pro 2.5.2.

- **Number of Native Plants**: It is average of the number of native plants across cells of the associated area. The data is taken from Ellis et al. (2012).

- **Number of Domesticable Mammals**: It is the number of 14 ancient mammalian species, which is identified as domesticable mammals by Diamond (1997). These mammals are prehistorically native to the region to which the associated unit belongs. The variable is constructed using the present natural range maps in the PHYLACINE.

- **Wild Relatives of Domesticable Plants**: It is the number of wild plants that are genetically related to cultivated crops. These crops are identified by Mayshar et al. (2022). The associated data are taken from the Crop Wild Relatives Project (CWRP, 2021) and the measure is calculated by using ArcGIS Pro.

- **Extinction Rate**: The percentage of known extinct mammalian species larger than 44 kg to the total number of extinct and extant mammalian species larger than 44 kg from the Late Pleistocene to early Holocene (132,000 years before present - 1,000 years before present). It is calculated using the present natural range maps in the PHYLACINE.