Crop cycles and hierarchy: the agro-ecological origins of the state*

Preliminary draft

Matteo Sestito†

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Abstract

Where could states emerge in the pre-industrial era? Despite their contemporary ubiquity, centralised governments have been an ephemeral phenomenon for much of human history. Subject to popular flee, internal rebellions and diseases, states could develop only under very particular agro-ecological circumstances. As substantiated in this paper, the homogeneity of the agricultural calendar figures prominently among these. Using data from the Ethnographic Atlas, I provide evidence that the heterogeneity of agricultural growing seasons was a fundamental barrier to state centralisation. This holds true when controlling for a wide range of alternative determinants of state-building. The use of potential, rather than observed, agro-ecological data, as well as various robustness tests, give credit to an interpretation of the results beyond the mere correlation.
The findings lend themselves to different interpretations. First, where adjoining fields followed different crop cycles, taxation of the farming output required a prolonged and extended effort, which was often beyond the capacities of early states. Second, heterogeneous crop cycles mandated for different working and religious schedules, ultimately defying the homogenisation attempts of archaic central authorities.

JEL codes: D02, H10, N50, O43

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†PhD candidate at Aix-Marseille School of Economics

1 Introduction

I am Xerxes, the great king, the king of kings, the king of the provinces with many tongues, the king of this great earth far and near, son of king Darius the Achaemenian

Xerxes I

Despite the grandiose tone of the Achaemenid propaganda,[1] Xerxes' claims of a global monarchy were rather far-fetched when seen from a global perspective. During his reign (486-465 BCE), the Persian empire extended far and wide, from the Turkish coasts in the West to the Indus Valley in the East. Other kingdoms dotted the eastern Mediterranean basin as well as south-western and eastern Asia; centralised governments were consolidating in Meso-America and the northern portions of the Peruvian coast too. Yet, despite their sumptuous palaces and temples, states remained relatively isolated polities, confined to particular agro-ecological niches and submerged into a world made of tribal confederations, petty chiefdoms, acephalous forager bands, dispersed horticulturalist villages and nomadic maritime communities. While nowadays virtually all of humankind organise itself into states – that is, under centralised forms of government involving a bureaucratic apparatus with several layers of authority –[2] for much of human history, people have experimented and played with a great variety of social arrangements. It is, arguably, not until the 17^{th} century that the majority of humankind came to live under the yoke of a centralised government (Scott 2017).
Even on the eve of the industrial revolution, large swaths of the planet had never seen a state bureaucrat or had, at most, experienced weakly centralised forms of government. These lacks would often prove to be fatal. It was the complex of "guns, germs and steel" manned by Eurasian states that would eventually conquer, colonise and exterminate the various non-state polities spread across the rest of the globe (Diamond 1997). Understanding, why states emerged only in some areas of the world is thus a question with profound historic ramifications. It has also

1. The sentence comes from an trilingual inscription in Elamite, Old Persian and Babylonian at a fortress near the Lake of Van in eastern Anatolia (Dusinberre 2013, pp. 50-54).

2. There is not universally accepted definition of what exactly is a state. Jurists and political scientists tend to follow the Weberian tradition, describing states as communities that, enjoying a monopoly over the use of force, control a permanent population within a fixed territory (Mullerson 1993; Ikenberry 2011; Shaw 2014, ch. 5). As these features – monopoly of violence and territorial sovereignty – are notably lacking in many polities of the pre-industrial period, anthropologists and archaeologists have opted for more general definitions, identifying states on the base of the presence of a multi-tier political organisation, where decision-making is articulated over different administrative levels (Claessen 2004, Diamond 1997, Grinin 2004, Redmond and Spencer 2012, Trigger 2003, ch. 10).

direct economic consequences, as many economic studies have shown (Bockstette et al. 2002). For example, pre-colonial state centralisation in Sub-Saharan Africa has been associated to lower children mortality (Gennaioli and Rainer 2007) and higher economic development (Michalopoulos and Papaioannou 2013).

This work addresses the question on the origins of the state from a new angle. It tries to understand the spatial distribution of early states by putting the latter in relation to the concentration of the economic activity. Where this is spatially and temporally concentrated, centralised governments can arise and endure because they find easier to organise and tax production. In the Malthusian pre-industrial world, economic activity primarily consisted of agricultural production, and taxation was indeed mainly conducted through expropriation of part of the harvest.[3] Thus, in areas where neighbouring fields followed different agricultural calendars, taxation was inherently difficult because it required the deployment of tax collectors at different moments of the year.

To fix ideas, consider two regions: a first region A, where adjoining rural areas have crops with staggered maturities; and a second region B, whose cultivars are harvested at the same moment of the year. In order to collect taxes from A, government officials would have to travel to the region several times per year, at great logistical and economic cost. The taxation of B is, instead, inherently easier, being a one-stop affair: when government officials are dispatched here, they can appropriate the bulk of the total yearly production. Moreover, synchronous crop cycles make production more transparent: as cultivars are planted and mature at the same time, they are easily observed and registered in state bureaucracy, eventually helping central authorities in censusing agricultural production.[4]

While the above discussion might seem rather abstract, the control of the agricultural cycle has historically been of great concerns to state rulers. As noted by Scott (2017, p. 133): "Archaic states endeavoured, whenever possible, to mandate a planting time for a given district." For example, in archaic China fields were forcibly irrigated at the same time so as to impose a common growing season to all rice cultivators.

These policies shall be framed within the greater homogenisation effort sponsored by many agrarian states of the pre-industrial era. Indeed, the rise of centralised

3. For example, archaic China levied a 11% harvest tax; Pharaoh Egypt had similar tax rates on the agricultural production (Schönholzer 2020). The highly centralised Neo-Sumerian Empire of the Third Dynasty of Ur demanded tributes to its subject cities as high as 48% of the barley harvest (Adams 2007). Even in more recent periods, in-kind payment remained central to tax collection. Half of Tokugawa Japan's tax receipts were, for example, in rice until the late 18^{th} century (Sato 1990, p. 44).

4. On the importance of production transparency for state-building outcomes see: Mayshar et al. (2017), Sánchez De La Sierra (2020).

governments is almost everywhere accompanied by parallel attempts to standardise a wide host of vernacular practices so as to measure, predict and eventually appropriate the resources at their disposal. Hence, the imposition of standard weights, metrics, and units of account had the twofold effect of facilitating economic transactions and of making production more transparent to state bureaucrats. For example, during the late 3^{rd} millennium BCE, the introduction in Mesopotamia of the "labourer-day" unit of account made economic performances both comparable across different sectors and measurable in their own right, thus allowing the imposition of precise working duties (Carmona and Ezzamel 2007). But homogenisation went well beyond the mere economic sphere, touching even upon the sacred, with religious practices and architecture becoming increasingly standardised as states asserted themselves.[5] The rise of Monte Alban in the Mexican highland (500-300 BCE) or of the Mayan city-states in the Yucatan peninsula (250-500 CE), were, for example, characterised by the parallel emergence of standardised two-room temples (Redmond and Spencer 2012).
The homogenisation of the crop calendar should be thus read through these lenses and understood as a further attempt to homogenise the forms and tempo of social life. Indeed, much of the economic and religious life of agrarian communities rotates around the growing season of their main staple crop. This mandates for concrete working schedules – cleaning fields, sowing, planting, tending, harvesting – as well as for particular harvest celebrations and fertility gods. In short, heterogeneous crops growing seasons translated into heterogeneous social preferences, which ultimately represented a barrier to the homogenisation effort of early states.

The present paper brings this hypothesis to the data, exploring the impact of growing period heterogeneity onto state centralisation in the pre-industrial world. Measures of political hierarchy from the Ethnographic Atlas are combined with agro-ecological characteristics as retrieved from the Food and Agricultural Organisation.[6] Various other spatial databases are also used to gather geographical, climatic and socio-economic information. This allows for the construction of a sample spanning the whole globe, and including more than 1200 pre-industrial societies.
The empirical exercise is fraught with difficulties. As the above discussion should have made us well aware, there are obvious risks of reverse causality: crop cycle homogeneity facilitated the emergences of the state, which in turn endeavoured to establish agro-ecological settings marked by synchronous agricultural calendars.

5. See Flannery (1998), Diamond (1997, p. 280).

6. The Ethnographic Atlas is an anthropological database widely used in social sciences. See Michalopoulos and Papaioannou (2013), Fenske (2014), Enke (2019), and Mayshar et al. (2022) for works in economics employing, *inter alia*, the same variable on state centralisation here used. See Kelly (2007) for a review of some articles in anthropology using this dataset.

To circumvent these risks, I employ data on the potential, rather than actual, productivity of crops. Thanks to this largely exogenous measure, this work establishes a strong negative correlation between crop cycle heterogeneity and state centralisation. A wide set of controls ensures that the correlation is not driven by some omitted variable, ruling out that the effect of growing period heterogeneity is mediated by other factors traditionally associated to state-building, such as: the productive advantage of storable crops over perishable ones (Mayshar et al. 2022, Scott 2017); the degree to which societies are circumscribed by inhospitable lands (Carneiro 1970, Mayoral and Olsson 2019, Schönholzer 2020); the easiness at conducting trade (Algaze 2009, Fenske 2014, Litina 2014, Tedeschi 2021); the presence of waterways and irrigation canals (Allen et al. 2020). Various sensitivity tests, including the exclusion of each continent and of societies with low reliance on agriculture, confirm the robustness of the main findings. Overall, the analysis enriches our understanding on the origins of the state, shedding further lights on its agro-ecological limits.

The rest of the paper is organised as follows. The next section reviews the existing literature on state formation and offers a conceptual framework to understand state-building in the Malthusian era. Section 3 discusses the data sources used in the empirical analysis, which is presented at section 4. A final section concludes.

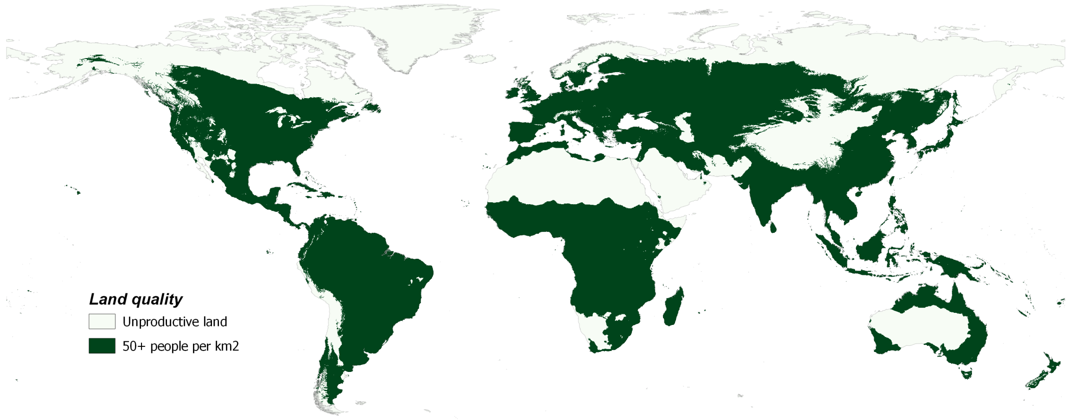
2 Conceptual framework

The origins of the state have stimulated the intellectual curiosity of scholars across the whole spectrum of social sciences. Particular attention has been spent on those supposed cases of pristine state emergence, that is, those instances where a centralised government emerged without any interference from other peer polities. The inherent problems in the notion of "pristine", not to say on that of "state", are now largely recognised and the attention has shifted towards more general treatments of state-building.[7] The traditional and arguably more popular view considers states as the more or less natural outcome of the domestication processes initiated during the Neolithic.[8] Where societies adopted intensive farming techniques and land was fertile enough, population densities rose spectacularly,

7. On this point see: Claessen (2004), Graeber and Wengrow (2021), Grinin (2004), Possehl (1998).

8. To put it as Gat (2006, p. 232): "State evolution was the almost 'necessary' culmination and fruition of processes set in motion by the transition to and growth of agriculture - at least where the right conditions were present." Similar arguments can be found also in Diamond (1997) and to a lesser extent in Harari (2014). Graeber and Wengrow (2021) discuss the poignancy of the idea even among specialists.

Figure 1: Land productivity



eventually paving the way to the emergence of state-like bureaucratic structures. Large societies, whose population numbers in the hundreds, are mainly composed of people who are strangers to themselves, thus requiring impersonal law and institutions to manage conflict, redistribution, or reach other types of communal decisions (Diamond 1997). As testified by the emergence of most of the early states on rich alluvial soils near centres of domestication, there is, indeed, a broad grain of truth in this.

Yet, the argument is somehow too general and has not much explanatory power. Figure 1 shows the portions of the globe that can support at least 50 people per square kilometre. The threshold has been purportedly set at a quite elevated level, higher than actual densities historically achieved in the pre-industrial world.[9] As clear from the figure, apart from some deserts and mountainous ranges, much of our planet is productive enough to sustain dense populations: land productivity by itself can not explain the rise of states.
The traditional view has received a lot of criticism also for its linear evolutionary flavour, whereby mankind is seen as progressing from simple nomadic hunter-gathering societies to settled farming communities and eventually to kingdoms and civilisation. In the journey, so the argument goes, we bartered equality (Marxist primitive communism) for peace and order. Yet, for how appealing in its simplicity, this account does not match well with historical reality. For example, we now have ample evidence that sedentism predated farming in many settings, such as

9. To give some context, Renaissance Italy had a population density of about 30 people per km^2, the highest in Europe at the time. India and Mexico in 1500 had population densities of 44 and 13 people per km^2. Population estimates are collected on the website Our World in Data, freely accessible at: https://ourworldindata.org/grapher/population-density?time=1500.

in the Levant and southeastern Turkey, Jomon Japan, Sudan, and perhaps central Mexico and the northern Andes too (Bellwood 2004). The construction of cities and the rise of political hierarchies, usually hailed as hallmarks of states and civilisation, are also found under previously unexpected circumstances. The monumental architecture at Goebli Tepe and Poverty Point was, for example, the making of foraging, rather than farming, societies (Graeber and Wengrow 2021). Similarly, the hunter-gathering aristocracies of the north-western coast of North America, with their slaves and retinues, further disprove the necessity of farming in fostering social inequality (Kelly 2007, ch. 9).
But perhaps the most severe flaw of the land productivity theory is its inability to explain the widespread opposition to states and central governments. Instead of being an irresistible force which everyone hailed to join, the imposition of vertical structures of power was usually hotly resisted. For any successful state-building attempt, there are many more that failed and were often lost in the dust of history: for any Alaric, there are several Maroboduus and Arminius whose royal aspirations were blocked by competing elites and commoners alike (Gat 2006). Even once states managed to assert themselves, they were extremely fragile entities constantly menaced by popular revolt and flee. The historical records is replenished of examples of people escaping what was perceived as a too onerous tax burden. From the Semang of Malaysia escaping the oppressive rule of Malay and colonial authorities (Scott 2009), to the Guayaki of Paraguay escaping the colonial reducciones and slave raids (Clastres 1987), many people preferred a life in the wood, distant from the "civilised" palaces of the early agrarian states. This is not to deny that people moved also in the other direction, abandoning the barbarian frontier when allured by the economic and religious power of early states. Yet, from the perspective of central authorities, the constant fear of a people haemorrhage was very much present and shall be taken into account when discussing the origins of the state. As put it bluntly by Scott (2017, p. 30): "The great walls of China were built as much to keep Chinese taxpayers in as to keep the barbarians out."

If then states were not the natural and much-awaited outcome of the Neolithic transition, how did they arise? There is not a single answer and a multiplicity of elements played a role, with varying importance depending on the context. Below I list several macro social phenomena that have been proposed as causes of the process of (early) state-building.[10] None of them shall be singularly understood as

10. Traditionally, theories on (pristine) state-formation have been divided in two types: voluntaristic and coercive. The first emphasise bottom-up process of state formation, whereby the latter developed because it performed some common-interest function. Coercive theories of state-building, instead, stress factors related to the ability of central authorities to tax and control subservient masses. I abandon this categorisation to eschew difficult, perhaps unanswerable, philosophical questions on the voluntaristic or coercive nature of the processes historically linked

necessary, let alone sufficient, and their effect clearly depends on other structural factors such as: subsistence systems, ideological constructs, and population size.[11]

Conflict is one of the most cited forces behind archaic state-building (Redmond and Spencer 2011, Webster 1975). In the first place, communal defence and security can be thought as public goods, making their central administration more efficient. Throughout history looming external threats have, indeed, repeatedly prompted loose tribal confederations to unite under a sole banner (*e.g.* Gallic tribes against Julius Caesar, Israeli tribes against Ammonites), paving the way to the development of centralised systems of control (Gat 2006). Moreover, taking the perspective of the attacker, territorial expansion by itself implies, beyond a certain range, the delegation of power and hence the establishment of bureaucratic structures of command (Spencer 2010). This mechanism is even more compelling when vanquished populations have no possibility to escape and are thus forced into a relation of subservience (Carneiro 1970, Dickson 1987). Econometric evidence on this latter channel comes from Schönholzer (2020), who find that pristine state formation is associated to land circumscription, measured as the differential in land productivity between a zone and the neighbouring areas.

The latter analysis, modelling land circumscription rather than warfare per se, is also coherent with a second factor traditionally associated to state-building, namely, the easiness whereby some central authority can extol taxes. Hence, land circumscription, by decreasing the possibilities of outmigration, makes population control and tax collection easier. Beyond the work of Schönholzer (2020), empirical evidence is available for ancient Egypt, where state power is correlated to positive productive shocks in the core Egyptian territories and negative agricultural shocks in its periphery (Mayoral and Olsson 2019).

Alongside migration possibilities, another element positively influencing the tax base of (would-be) states is the presence of patchy, regular, and appropriable resources (Smith, Mulder, et al. 2010). The presence of storable and predictable agricultural surpluses is particularly relevant in discussions on the consolidation of the first states and is often considered almost a necessary condition for their emergence (Scott 2017). Empirical evidence on this point comes from Mayshar et al. (2022), who find that archaic and pre-modern states were more centralised where the production of storable crops such as cereals enjoyed advantages over the cultivation of more perishable roots and tubers.

to state-building.

11. For a thorough discussion of how social stratification unfolds in different subsistence systems, the reader is referred to: Bowles et al. (2010), Smith, Hill, et al. (2010), Smith, Mulder, et al. (2010), Mulder et al. (2010), Gurven et al. (2010), Shenk et al. (2010). For the role of ideology and religion in shaping the early development of the Chinese state, see Baum (2004). Finally, for a theoretical model on the interactions between population size, technological innovation and labour & social stratification, the reader is referred to Henrich and Boyd (2008).

Crop cycles represent a new, relatively neglected, agro-ecological constraint on the fiscal capacity of pre-industrial polities. Importantly, as it will be shown in section 4, the impact of heterogeneous growing seasons on political centralisation is largely orthogonal to land circumscription and the so-called cereal advantage.

Other theories tend to emphasise not much the coercive side of state-building, but rather its benefits in terms of provision and maintenance of public infrastructures such as temples and irrigation networks. The most prominent among these theories is Karl Wittfogel's 'hydraulic hypothesis', which explained archaic state formation as a result of the collective effort geared towards irrigation. Archaeological discoveries have cast some doubts on the latter, illustrating how often states preceded large-scale centralised irrigation structures (Carneiro 1970, Carballo et al. 2014). Yet, recent econometric analysis by Allen et al. (2020) indicates that, at least in Mesopotamia, state-building in its early days responded to the collective action problems related to the construction and maintenance of irrigation canals.

A fourth set of causes connected to the consolidation of states, concerns those mechanisms based on economic exchange. Trade, for example, figures prominently in the rise of the city-state system of 4^{th} millennium BCE Mesopotamia (Algaze 2001, Algaze 2009). By fostering economic growth and labour specialisation, trade is generally associated to deepening social inequality, thus possibly resulting into more politically stratified societies. Evidence of these mechanisms is not limited to full-blown state polities, but include, for example, foragers of the north-western Pacific Coast (Kelly 2007) as well as the rural communities of archaic Thessaly (Halstead 1989). More generally, economic exchange between unrelated communities can strengthen the position of the elite by either giving them a public function (*e.g.* protection of trade, construction of roads) or directly enriching them (*e.g.* taxation on trade). The state trajectory of the Yoruba Oyo polity in present-day Nigeria and Benin, as well as that of many other pre-colonial African kingdoms, seems, indeed, to follow this scheme, whereby central authorities relied extensively on the control of trade activities. Fenske (2014) provides related econometric evidence on pre-industrial African state-building; Litina (2014) and Tedeschi (2021) uncover, instead, broad correlations between trade and state emergence at the global level.

Any attempt to rank by importance these factors is bound to be unsatisfactory. Each state society has its own unique story, involving a different sets of triggers and causes leading to the adoption of a centralised bureaucratic government. Yet, some general patterns can be discerned and some negative conclusions can be advanced. As noted by a leading scholar of early states: "It is surely striking that virtually all classical states were based on grain, including millets. History records no cassava states, no sago, yam, taro, plantain, breadfruit, or sweet potato states."[12] This is not to say that cereals caused political hierarchy. Maize cultivation was, after all, well known by the indigenous people of the northeastern and mid-western woodlands of North America (Graeber and Wengrow 2021). Cereals simply represented an efficient medium of taxation: where their cultivation was preferred to other perishable crops *and*, as we shall see, their growing seasons were homogenous, a central authority could sustain itself by extolling a tribute from the local population. Absent these ecological conditions, states could potentially emerge anyway; for example, in virtue of an incredibly strong and fervent ideology. Yet, episodes of this type are bound to be short-lived. The countless prophetic movements of the Lahu and Karen of mainland south-east Asia provide clear examples: these experiments of supra village governance and alliances faded away as soon as their charismatic momentum died out (Scott 2009, ch. 8). Hence the importance of some structural agro-ecological factors necessary to durably sustain taxation on large scale. As the rest of the paper will substantiate, historically the homogeneity of crop cycles has figured prominently among these.

3 Data

3.1 Dependent variable

Data on state centralisation is taken from the Ethnographic Atlas (EA), a dataset largely used in both the economic and anthropological literature.[13] The EA contains information on 1249 pre-industrial societies observed after 1500 CE.[14] The sample has a good coverage of North America and Africa, while reporting few European societies.[15]

The EA variable used to capture state centralisation measures the levels of jurisdictional hierarchy above the local community. This ordered variable is the standard measure of political complexity used in the literature. It ranges from 0 to 4 and has been coded without considering organizations not held to be legitimate, such as imposed colonial regimes (Murdock 1967, p. 52). A value of 0 indicates acephalous societies organised in autonomous villages. The presence of 1 jurisdictional level describes societies where local communities are directly politically subordinated to some elite, as in petty chiefdoms and Melanesian tribes

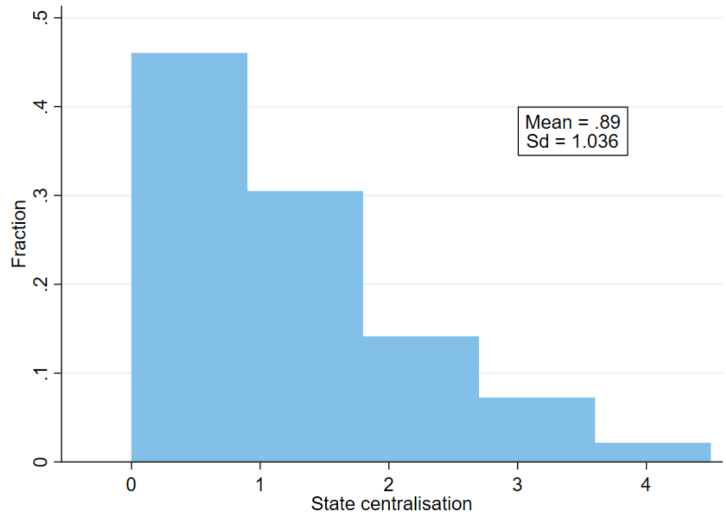
12. Scott (2017, p. 21).

13. See footnote 6 for a list of recent works employing the Atlas.

14. The original database includes 1265 societies. Eight observations have then been dropped because relative to pre-Columbian times; eight societies have been excluded from the analysis because the year of observation is missing.

15. All the empirical analysis exploits within-continent variation and results are robust to the sequential exclusion of each continent.

Figure 2: State centralisation - Histogram

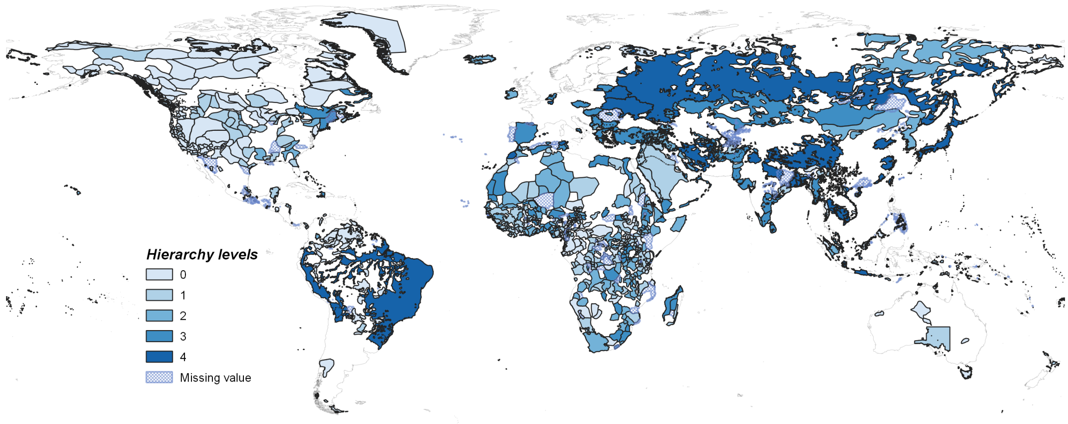


ruled by "big-men". Higher scores correspond to large chiefdoms and states, that is, societies endowed with a multi-layered administrative apparatus at their head. Examples of societies without any centralised political organisation are: the Comanche of the Southern Plains in US, the Herero pastoralists of Southern Africa, the Semang of the Malay peninsula, and the Amazonian Yanomamo. At the other extreme there are polities with four levels of jurisdictional hierarchy such as: the Siamese state in modern-day Thailand, the Punjabi people inhabiting the homonymous region between Pakistan and India, the Bubi of Equatorial Guinea, and the Kafa of Ethiopia.
The majority of the sample is, however, represented by acephalous societies. Figure 2 reports the histogram of the state centralisation variable: more than 70% of the societies have at most one level of political hierarchy. Figure 3 gives a visual representation of the societies in the Atlas, employing the ethnic maps assembled by Fenske (2014).[16] The ethnic polygons are shaded on the base of each society's centralisation level: stateless societies are particularly common in the Americas, while Eurasia shows deeper political hierarchies.

It shall be stressed that the societies of the Ethnographic Atlas have been sampled mostly towards the late pre-industrial era, with the focal year of their observation referring predominantly to the late 19^{th} century. A plausible concern is thus the idiosyncratic nature of these polities. For example, was the Kafa

16. The polygons have been developed by Fenske (2014) upon consultation of various sources, ranging from historic maps to current administrative boundaries.

Figure 3: Pre-industrial state centralisation



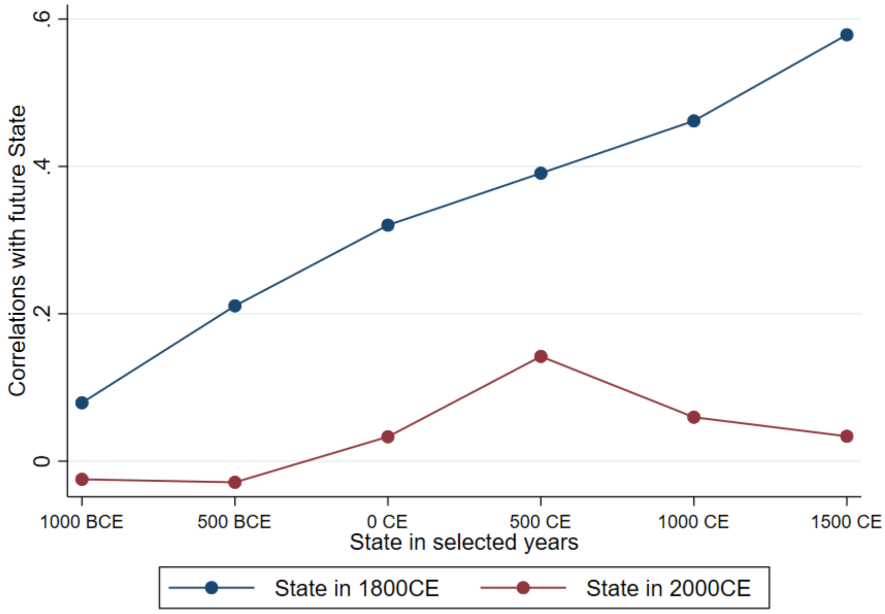
Kingdom an historical accident observed only in 1890 when it was sampled? Or its presence is a symptom of a longer state tradition? As any expert of Ethiopian history would know, the kingdom dates back to the late 15^{th} century and, more importantly, emerged in a region where states vied for power at least since the emergence of the Axum Empire in the 1^{st} century BCE (Butzer 2012).

Beyond the political vagaries of the Horn of Africa, state institutions are relatively persistent throughout history. Figure 4 shows the autocorrelation through time of an index of state centralisation developed by Borcan et al. (2018). The authors, extending the work of Bockstette et al. (2002), assign a measure of state presence to each present-day country at intervals of 50 years, from archaic to present times. The autocorrelation of past statehood with respect to statehood in 1800 CE is positive and increasing over time, peaking at almost 0.6 for statehood in 1500 CE. Importantly, state persistence is observed only in the pre-industrial period: state presence today is not predicted by past statehood, with autocorrelation coefficients hoovering around zero. While the projection of contemporary boundaries back in time is inherently problematic, the exercise gives credit to the idea that some relatively permanent constraints determined the emergence of states only in some specific areas of the world.

3.2 Growing period heterogeneity

The measure of crop cycle heterogeneity is built using the Global Agro-ecological Zones (GAEZ) dataset of the Food and Agriculture Organisation (FAO). GAEZ reports crop yields and growing seasons for a set of 40 edible crops. The data span the whole globe and are in raster format, with pixels at the 0.083° resolution ($\sim 70km^2$ at the equator). The data refer to *potential*, rather than observed,

Figure 4: Temporal autocorrelation of State index



productivity and growing seasons, and they are computed under consideration of agro-climatic constraints. Importantly, these constraints exclude agro-edaphic factors, such as soil salinisation, that are directly affected by human intensive farming techniques. GAEZ measures are thus largely exogenous to human activity, lessening the risks of reverse causality. Furthermore, among the various specifications, I employ FAO estimates based on farming practices relying on low inputs and rain-fed water supply. These conditions are arguably independent of human intervention and better describe pre-industrial agricultural settings.[17]

To capture the extent to which a given area has an heterogeneous crop cycle, I compute the fraction of the year whereby the main cultivar in pixel p does not grow at the same time of the major cultivars in the surrounding pixels. Define GP_p as the day-unit set describing the growing period of the most productive crop in pixel p.[18] Then, two cells p and k have different crop cycles when their main

17. This specification of GAEZ data – exclusion of agro-edaphic contraints, low-input & rain-fed farming regime – is the one most commonly used in the literature interpolating FAO data to the pre-industrial period. See for example: Galor and Özak (2016), Mayshar et al. (2022).

18. Productivity is measured in calories, with GAEZ ton/hectare data transformed into calorie/hectare using FAO nutritional tables. Details on the caloric content of each crop are given in the appendix.

growing seasons do not overlap too much throughout the year. Define thus:

$$GP^{het}_{p,k} = 1 - \frac{|GP_p \cap GP_k|}{365}$$

The measure has a simple interpretation as the fraction of the year where the main crops of p and k do not grow together. For example, $GP^{het}_{p,k} = 1$ indicates the maximum possible heterogeneity, attained when the main growing period of the two areas are completely disjoint (*i.e.* $GP_p \cap GP_k = \emptyset$). Similarly, $GP^{het}_{p,k} = 0.5$ indicates that for half of the year the two cells share the same agricultural calendar. To get a variable at the pixel level, this bilateral heterogeneity measure is aggregated over the cells surrounding each given pixel. Define N_p as the set of pixels within the neighborhood of p, then growing period heterogeneity at the pixel level is defined as:

$$GP^{het}_{p} = \frac{1}{|N_p|} \sum_{k \in N_p} GP^{het}_{p,k}$$

The baseline analysis employs the 8-pixel neighbourhood (*i.e.* $|N_p| = 8$), but in robustness exercises alternative neighbourhood sizes are checked.
Figure 5 shows the global distribution of GP^{het}_{p}. Already at first glance, it can be seen that some areas traditionally related to state presence (*e.g.* West Africa, East Asia) display more homogenous crop cycles relatively to the rest of their continent. The measure is then aggregated at the society level by averaging it across all pixels belonging to the ethnic polygon of a given society.[19] Figure 6 reports the distribution of the growing period heterogeneity variable at the societal level, showing that much of the variability is concentrated around intermediate levels of heterogeneity.

It shall be stressed that GAEZ data refer to the second half of the 20^{th} century. However, as noted by Nunn and Qian (2011, p. 611), who use the dataset to capture agricultural suitability in the 18^{th} century, GAEZ "measures should be good proxies for historical conditions because they are primarily based on climatic characteristics such as temperature, humidity, length of days, sunlight, and rainfall that have not changed significantly [over the last few centuries]". The authors also provide evidence that GAEZ suitability for potato well correlates with actual potato production in the 1900.
As a further test of the validity of GAEZ data to describe historical conditions prevalent in the late 19^{th} century, Table 1 reports the result of a regression of the subsistence practices reported in the EA on an index of land quality (*i.e.* the caloric yield of the most productive crop in each pixel). Dependence on agriculture and farming intensity are strongly positively correlated to land quality.

19. In robustness exercises, I check alternative geographical representations of the Ethnographic Atlas societies.

Figure 5: Growing period heterogeneity

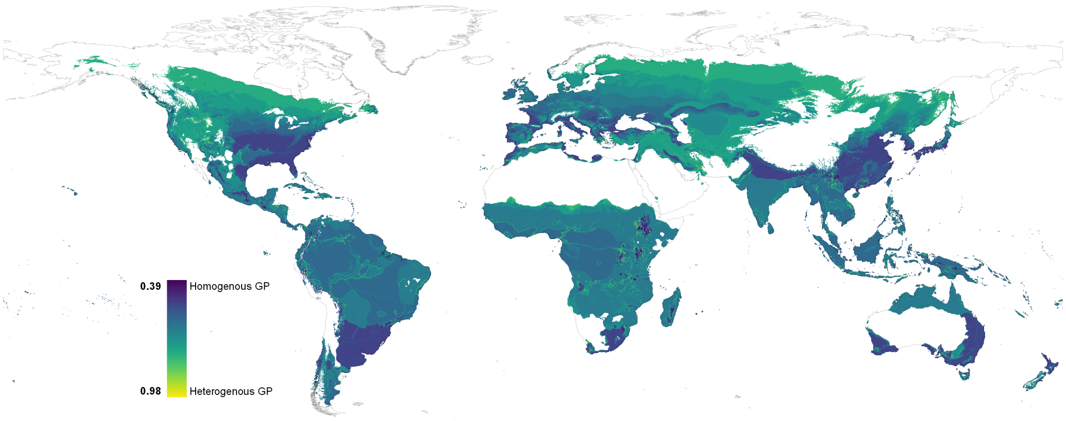


Figure 6: Growing period heterogeneity - Histogram of EA societies

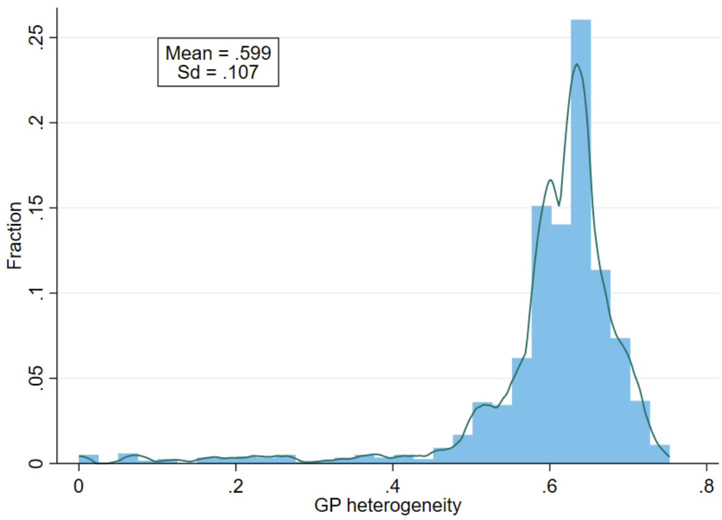


Table 1: Land quality and subsistence practices

	Gathering	Hunting	Fishing	Husbandry	Agriculture	Farming intensity
Land quality	-0.150	-0.027	-0.220	-0.209	0.606	0.147
	(0.058)***	(0.050)	(0.056)***	(0.053)***	(0.087)***	(0.057)***
R^2	0.34	0.39	0.24	0.35	0.42	0.26
N	1,246	1,246	1,246	1,246	1,246	1,153
Continent fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

The table report OLS estimates. Land quality is computed taking into account the most productive crop of each pixel. Standard errors are adjusted for spatial correlation using Conley (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

4 Econometric analysis

4.1 Baseline model

The baseline model is a linear equation with the Ethnographic Atlas societies as cross-sectional unit of observation:

$$y_s = \alpha + \beta GP_s^{het} + ContFE + W_s'\gamma + u_s \qquad (1)$$

Where: y_s is the measure of state-centralisation in society s, GP_s^{het} is the measure of GP heterogeneity as averaged across all the pixels in an ethnic polygon, $ContFE$ are continent fixed effects, W_s is a vector of controls, u_s are standard errors with arbitrary spatial correlation within a 200km radius from the polygon centroids.

The model estimates a reduced form, inasmuch as we observe only potential, rather than actual, growing period heterogeneity. While the measure is probably exogenous, claims of causality are limited by the cross-sectional nature of the data. A series of robustness tests gives, however, an interpretation of the results beyond the mere correlation.

Table 2 reports results from equation 1 as estimated through Ordinary Least Square (OLS), ordered Probit and Logit. All the point estimates of β are negative and highly significant. The effect is extremely large. The OLS estimate is almost equal to minus one, that is, almost one standard deviation of the dependent variable. To put it differently, a passage from full homogeneity to full heterogeneity of the crop cycle, decreases the jurisdictional hierarchy of the average society by one level: the passage from a petty chiefdom to an acephalous society.

Table 2: State centralisation and crop cycle heterogeneity - Baseline regressions

Dependent variable: Hierarchy levels above the local community			
	OLS	Logit	Probit
GP heterogeneity	-0.992	-2.868	-1.684
	(0.243)***	(0.536)***	(0.335)***
	{0.249}***	[0.811]***	[0.499]***
	{{0.257}}***		
	{{{0.269}}}***		
R^2	0.23	0.11	0.11
N	1,073	1,073	1,073
Mean dependent variable	.902	.902	.902
Continent fixed effects	Yes	Yes	Yes

The table report OLS estimates. Standard errors in square brackets are robust standard errors. Standard errors in single, double and triple curly brackets are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 50km, 100km and 200km, respectively. Standard errors in squared brackets are clustered at the regional level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

4.2 Ruling out alternative hypotheses

The baseline model substantiates a strong negative impact of the growing period heterogeneity on state-building. This section provides evidence that the observed correlation is not driven by some omitted variable related to both state centralisation and the variability of the agricultural calendar.

Table 3 reports results from equation 1 when controlling sequentially and cumulatively for various geographic characteristics of the societies: ruggedness, slope, polygon area, number of rivers, and average river discharge. The coefficients of these variables go in the expected direction (*e.g.* negative effect of ruggedness on state centralisation), but the magnitude and significance of growing period heterogeneity barely change.

Table 4 includes climatic controls: the average and standard deviation of rainfall and temperature over the 20^{th} century, absolute latitude. The coefficient of interest (β) remains always significant and, if anything, increases in absolute size.

Table 5 controls for agricultural factors traditionally associated to state-building: the productive advantage of cereals over other crops, the productive advantage of plough-intensive cereals over plough-negative cereals, land quality, land circumscription, the number of economically relevant crops. The marginal impact of growing period heterogeneity remains significant always at least at the 5% level and still hovers around minus one.

A fourth set of possible confounders is given by trade variables. Crop cycle heterogeneity could, indeed, be associated also to mutual insurance, given the potential different exposure of crops to common shocks. Table 6 shows that when controlling for various proxies of trade (*i.e.* an index of ecological fractionalisation and polarisation, the standard deviation of land quality, an index of subsistence fractionalisation), the results closely mimic baseline estimates.

Finally, Table 7 checks for a series of socio-economic variables that are closely connected to state centralisation. These are variables related to pastoralism (dependence on husbandry & presence of domesticated animals) and farming (use of plough, dependence on agriculture, cereal cultivation), as well as to historic conflict and population density. These results should be taken with a grain of salt, given the probable endogenous nature of most of these controls. Nevertheless, the point estimates of interest is always negative and statistically significant.

Table 8 shows the robustness of results to the control of all of the above-mentioned covariates: crop cycle heterogeneity has a sizeable negative impact on state centralisation that does not depend upon other omitted variables.

Table 3: State centralisation and crop cycle heterogeneity - Control for geographic factors
Dependent variable: Hierarchy levels above the local community

	(1)	(2)	(3)	(4)	(5)	(6)
GP heterogeneity	-1.026	-1.031	-1.124	-1.029	-0.992	-1.138
	(0.260)***	(0.260)***	(0.271)***	(0.266)***	(0.269)***	(0.265)***
Ruggedness	-0.035					0.407
	(0.036)					(0.358)
Slope		-0.038				-0.437
		(0.035)				(0.346)
Area			0.003			0.002
			(0.001)***			(0.001)
River count				0.001		0.000
				(0.000)***		(0.000)***
River discharge					0.002	-0.023
					(0.024)	(0.017)
R^2	0.23	0.23	0.25	0.25	0.23	0.25
N	1,073	1,073	1,073	1,073	1,073	1,073
Mean dependent variable	.902	.902	.902	.902	.902	.902
Continent fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

The table report OLS estimates. Standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Table 4: State centralisation and crop cycle heterogeneity - Control for climatic factors
Dependent variable: Hierarchy levels above the local community

	(1)	(2)	(3)	(4)	(5)	(6)
GP heterogeneity	-1.187	-1.440	-1.755	-1.673	-1.385	-1.673
	(0.307)***	(0.300)***	(0.321)***	(0.316)***	(0.306)***	(0.336)***
Latitude (abs)	0.015					0.010
	(0.004)***					(0.007)
Rain stdev		-0.003				0.005
		(0.002)*				(0.002)**
Rain avg			-0.002			-0.003
			(0.001)***			(0.001)***
Temperature stdev				0.383		0.117
				(0.106)***		(0.158)
Temperature avg					-0.014	0.010
					(0.007)**	(0.012)
R^2	0.25	0.24	0.25	0.25	0.24	0.26
N	1,073	1,066	1,066	1,066	1,066	1,066
Mean dependent variable	.902	.906	.906	.906	.906	.906
Continent fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

The table report OLS estimates. Standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Table 5: State centralisation and crop cycle heterogeneity - Control for agricultural factors
Dependent variable: Hierarchy levels above the local community

	(1)	(2)	(3)	(4)	(5)	(6)
GP heterogeneity	-0.899	-0.955	-0.922	-0.986	-1.293	-1.236
	(0.428)**	(0.268)***	(0.251)***	(0.362)***	(0.277)***	(0.471)***
Cereal advantage	0.199					0.700
	(0.031)***					(0.159)***
Plough advantage		0.134				0.153
		(0.051)***				(0.049)***
Land quality			0.181			-0.656
			(0.032)***			(0.183)***
Land circumscription				0.092		0.237
				(0.034)***		(0.063)***
Productive crops					0.026	0.032
					(0.006)***	(0.008)***
R^2	0.28	0.23	0.25	0.25	0.25	0.33
N	976	1,073	1,073	1,027	1,073	976
Mean dependent variable	.913	.902	.902	.906	.902	.913
Continent fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

The table report OLS estimates. Standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Table 6: State centralisation and crop cycle heterogeneity - Control for trade proxies
Dependent variable: Hierarchy levels above the local community

	(1)	(2)	(3)	(4)	(5)
GP heterogeneity	-1.265	-1.199	-0.855	-0.952	-1.034
	(0.290)***	(0.287)***	(0.265)***	(0.266)***	(0.282)***
Ecological fractionalisation	0.677				0.941
	(0.135)***				(0.333)***
Ecological polarisation		0.357			-0.343
		(0.099)***			(0.237)
Land quality variability			0.164		0.119
			(0.039)***		(0.038)***
Subsistence fractionalisation				-1.027	-0.965
				(0.292)***	(0.276)***
R^2	0.25	0.24	0.25	0.24	0.28
N	1,073	1,073	1,073	1,073	1,073
Mean dependent variable	.902	.902	.902	.902	.902
Continent fixed effects	Yes	Yes	Yes	Yes	Yes

The table report OLS estimates. Standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Table 7: State centralisation and crop cycle heterogeneity - Control for socio-economic factors
Dependent variable: Hierarchy levels above the local community

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
GP het	-0.986	-1.121	-1.068	-0.754	-0.971	-1.165	-0.741	-1.106
	(0.269)***	(0.259)***	(0.261)***	(0.265)***	(0.267)***	(0.559)**	(0.425)*	(0.471)**
Plough	0.000							0.000
	(0.000)							(0.000)
Cereal main		0.297						-0.073
		(0.088)***						(0.094)
Husbandry dep			0.123					0.173
			(0.023)***					(0.032)***
Agriculture dep				0.079				0.103
				(0.018)***				(0.028)***
Domestic animals					0.445			0.172
					(0.081)***			(0.100)*
Conflict						0.001		0.001
						(0.001)		(0.001)
Pop dens 1500							0.023	0.018
							(0.004)***	(0.004)***
R^2	0.22	0.23	0.25	0.25	0.25	0.25	0.28	0.36
N	1,070	1,064	1,073	1,073	1,070	815	1,038	803
Mean dep variable	.905	.898	.902	.902	.905	.924	.9	.924
Continent fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table report OLS estimates. Standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

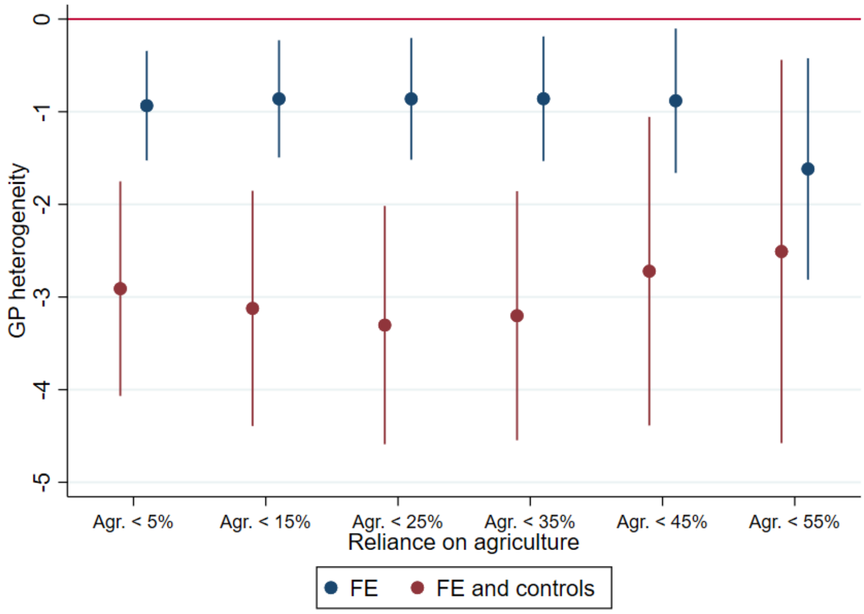
Table 8: State centralisation and crop cycle heterogeneity - Control for all covariates

Dependent variable: Hierarchy levels above the local community

	(1)	(2)	(3)	(4)
GP heterogeneity	-1.858	-2.066	-1.743	-1.545
	(0.320)***	(0.524)***	(0.543)***	(0.536)***
R^2	0.30	0.38	0.40	0.49
N	1,066	976	976	787
Mean dependent variable	.906	.913	.913	.928
Continent fixed effects	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes
Climatic controls	Yes	Yes	Yes	Yes
Agricultural controls	No	Yes	Yes	Yes
Trade controls	No	No	Yes	Yes
Social controls	No	No	No	Yes

The table report OLS estimates. Geographic controls include: terrain slope, ruggedness, polygon area, river flow discharge, and number of rivers. Climatic controls include: the average and standard deviation of rainfall and temperature over the 20^{th} century, absolute latitude. Agricultural controls include: the productive advantage of cereals over other crops, the productive advantage of plough-intensive cereals over plough-negative cereals, land quality, land circumscription, number of productive crops. Trade controls include: an index of ecological fractionalisation and polarisation, the standard deviation of land quality, an index of subsistence fractionalisation. Standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Figure 7: Sample robustness - Drop societies with low dependence on agriculture



4.3 Robustness tests

Two batteries of robustness tests are run. The first pertains sample-wide modifications whereby: (*i*) societies with low reliance on agriculture are excluded from the sample, inasmuch as the constraints of an heterogeneous agricultural calendar should be felt only by farming societies; (*ii*) each continent is dropped sequentially, given that estimates are based on within-continent variation; (*iii*) alternative geographical representations of the Ethnographic Atlas societies are employed.
Figure 7 shows that as we restrict the sample to societies with high reliance on agriculture, point estimates remain negative and significant. Similarly, when singularly excluding one continent at time, results are robust as shown in Figure 8. Table 9 reports, instead, estimates of equation 1 when Ethnographic Atlas societies are represented as circles of varying radii (25km, 50km, and 100km) built around the centroid of the society. Point estimates are highly significant and of a magnitude comparable to the baseline equation.

The second series of robustness tests concerns the definition of the main independent and dependent variables. Table 10 shows that growing period heterogeneity is also a good predictor of the extensive margins of state centralisation, that is, the presence of at least one level of jurisdictional hierarchy above the local community. Figure 9 checks robustness of the estimates to alternative pixel dimensions (0.083°, 0.25°, and 0.5°) and neighbourhood size (8, 24, 48). Results are negative

Figure 8: Sample robustness - Drop continents

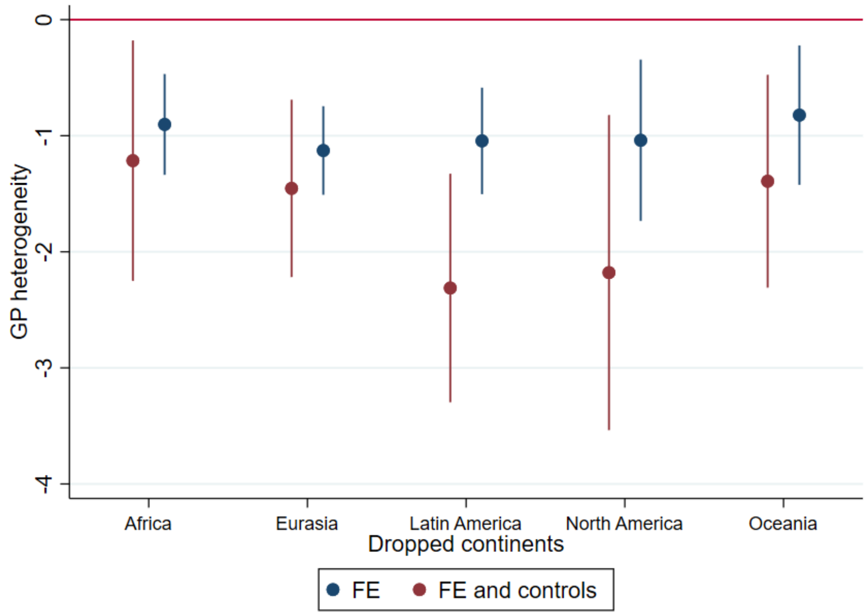
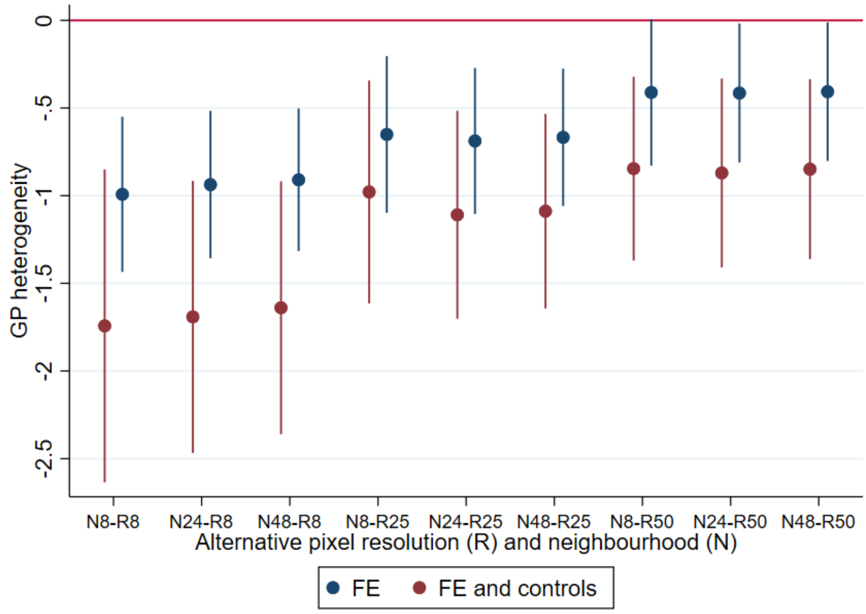


Table 9: State centralisation and crop cycle heterogeneity - Alternative samples
Dependent variable: Hierarchy levels above the local community

	Buffer 25		Buffer 50		Buffer 100	
GP heterogeneity	-0.704	-1.012	-0.877	-1.856	-0.978	-1.794
	(0.259)***	(0.465)**	(0.271)***	(0.452)***	(0.256)***	(0.505)***
R^2	0.22	0.34	0.22	0.35	0.22	0.34
N	1,024	891	1,037	936	1,056	981
Mean dependent variable	.897	.883	.902	.907	.895	.897
Continent fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes

The table report OLS estimates. Controls include: geographic variables (slope, ruggedness, area, river flow discharge, number of rivers), climatic covariates (mean rainfall and temperature, standard deviations of rainfall and temperature, absolute latitude), agricultural controls (cereal advantage, plough advantage, land quality and circumscription, number of productive crops), and proxies for trade incentives (ecological fractionalisation and polarisation, land quality standard deviation, subsistence fractionalisation). Standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

Figure 9: Alternative pixel and neighbourhood sizes



and significant, albeit they decrease in absolute magnitude as the pixel and neighbourhood sizes are increased. This perhaps signals that what really hampers state taxation is a very localised form of crop cycle heterogeneity.

Table 10: State centralisation and crop cycle heterogeneity - Alternative state centralisation measure

Dependent variable: Presence of hierarchy above the local community

	OLS		Logit		Probit	
GP heterogeneity	-0.746	-0.741	-3.458	-4.892	-2.055	-2.816
	(0.164)***	(0.258)***	(1.111)***	(1.688)***	(0.660)***	(0.945)***
R^2	0.23	0.33	0.17	0.28	0.17	0.28
N	1,073	976	1,073	976	1,073	976
Mean dependent variable	.547	.913	.547	.913	.547	.913
Continent fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes

The table reports different probability model estimates. Controls include: geographic variables (slope, ruggedness, area, river flow discharge, number of rivers), climatic covariates (mean rainfall and temperature, standard deviations of rainfall and temperature, absolute latitude), agricultural controls (cereal advantage, plough advantage, land quality and circumscription, number of productive crops), and proxies for trade incentives (ecological fractionalisation and polarisation, land quality standard deviation, subsistence fractionalisation). In OLS regressions standard errors are adjusted for spatial correlation using Conley's (1999) method with a distance cut-off of 200km. In Logit and Probit estimations standard errors are clustered at the regional level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels.

5 Conclusions

Contrary to popular perceptions, centralised governments have been rather fragile constructions for much of the pre-industrial era. Their emergence and consolidation was highly dependent on a set of very particular agro-ecological conditions, which allowed for a stable and regular tax base. As shown in this paper, the homogeneity of the agricultural calendar was among such constraints. Where crops in adjoining fields followed different growth cycles, the accounting and eventual taxation of agricultural output required a more prolonged and extended effort, which was often beyond the capabilities of most agrarian polities. Moreover, heterogeneous agricultural calendars translated into different social arrangements regulating the tempo and rhythm of communal life. The growing cycle of the main staple crop mandated, indeed, for particular working schedules and religious practices. Their fragmentation, as mandated by heterogeneous farming calendars, might have thus represented a further barrier to the emergence of centralised authorities, which have historically relied on a rather uniform social base. In short, centralised governments could not emerge in agro-ecological settings defying their homogenisation attempts.

Overall, this paper sheds lights on one of the most daunting question of comparative history and social sciences at large: the origin of the state. It does so by putting forward and testing empirically a relatively neglected dimension of state-building: the constraint represented by heterogeneous crop cycles. Its appreciation enrich our understanding on the uneven historical development of state institutions, providing further insights into the different development trajectories of the various areas of the world.

Appendix

Table A1: Crop calories

Crop	Calories per 100g	Crop	Calories per 100g
Buckwheat	330	Phaseolus bean	341
Cabbage	19	Pigeonpea	343
Carrot	38	Rapeseed	494
Chickpea	358	Silage maize	356
Cotton	253	Soybean	335
Cowpea	342	Spring barley	332
Dry pea	346	Spring rye	319
Dryland rice	357	Spring wheat	334
Flax	534	Sugarbeet	70
Foxtail millet	343	Sunflower	308
Gram	345	Sweet potato	92
Greater yam	101	Temperate maize	356
Groundnut	567	Temperate sorghum	343
Highland maize	356	Tomato	17
Highland sorghum	343	Wetland rice	357
Lowland maize	356	White potato	67
Lowland sorghum	343	White yam	101
Oat	385	Winter barley	332
Onion	31	Winter rye	319
Pearl millet	348	Winter wheat	334

Sources: Charlotte 1953, FAO 2001, Galor and Özak 2016.

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