Climate Change, State-Building and

Societal Resilience in Ancient Egypt.

Amin Ali Gholami Oskuyi[1], Carmine Guerriero[2*]

[1]Department of Economics, University of Bologna, Piazza Scaravilli 2, 40126 Bologna, Italy.
[2]Department of Economics, University of Bologna, Piazza Scaravilli 2, 40126 Bologna, Italy.
*Corresponding author. Email: c.guerriero@unibo.it

Abstract: *We combine the time inconsistency theory of state-building with the first provincial data set on the climatic conditions, institutional evolution and population dynamics of Bronze Age Egypt to document two key patterns inconsistent with the collapse archeology literature's mantra that the 4.2 ka BP megadroughts provoked Egypt's societal breakdown. First, the long period of low Nile floods and severe droughts started with the Sixth Dynasty pushed the Pharaohs to grant a larger fiscal autonomy to some of the provinces of Upper Egypt and the relative governors to use the tax revenues at their disposal to procure local public goods. Second, these discontinuities convinced the non-elites to cooperate in farming investments despite the worsened climate conditions and sustained settlement. Ultimately, climate change shaped ancient Egypt directly via deteriorated production conditions as well as indirectly through institutional resilience. Crucially, we also show that, contrary to the claims of the environmental circumscription theory of the state, this dimension is unrelated to state-building and societal resilience.* **Keywords:** *ancient Egypt; climate change; state-building; time inconsistency; collapse archaeology; circumscription.*

One Sentence Summary: *We combine the time inconsistency theory of state-building with the first regional data on the climate and institutions of Bronze Age Egypt to show that the 4.2 ka BP megadrought favored institutional resilience, over and above deteriorating production conditions.*

PRELIMINARY: DO NOT QUOTE WITHOUT PERMISSION

"Out of life's school of war: What does not destroy me, makes me stronger." F. Nietzsche, Twilight of the Idols.

1. Introduction

To clarify how environmental shocks shaped the rise of the first sedentary societies during the Neolithic Revolution (1-2), a ground-breaking archaeological literature has related the severity of climate conditions to state formation and evolution, i.e., state-building (3-4). In a nutshell, these correlations imply that severe droughts—"cold and dry spans" (5)—are bound to trigger economic crises and induce state dissolution (6-14), as it would have been the case of the late Old Kingdom in the aftermath of the 4.2 ka BP megadroughts (14). Yet, the credibility of the conclusions and gloomy policy implications of this "collapse archaeology" research program is undermined by three crucial limitations. First, it lacks an underlying theory identifying the strategic determinants of both state-building and societal resilience and, in turn, the functional form of the equations linking these variables (15-19). Second, it relies on proxies whose measurement is not theoretically informed and it is, thus, prone to large errors (20). To elaborate, these contributions proxy resilience with either anecdotal evidence on social breakdown or very coarse measures of external conflicts and/or settlement, and they capture state-building with the presence of jurisdictional hierarchies and/or internal conflicts (6-14). While, however, the first group of proxies are merely symptomatic of the ability of "all groups in society to move forward equally following a shock, making inclusivity an essential subject to tackle" (21), the second group of proxies do not capture exactly those inclusive political and legal institutions allowing the elites to convince the non-elites to cooperate in the face of adverse climate changes (22). To make matters worse, moreover, these contributions gauge environmental factors through the still limited coeval hydro-climatic records (6-10, 12, 14), which are only poor proxies of the climate prevailing in distant historical polities (23-24). Finally, the collapse archaeology literature focuses on the single impacts of environmental features on state-building overlooking their, possibly more relevant, combined and indirect effect (25-27).

We tackle these three issues together by applying a structural empirical model, which blends the time-inconsistency theory of the state (23-24), institutional proxies informed by this framework and highly granular climate data (28), to the analysis of the impact of climate change, and notably the 4.2 ka BP megadroughts, on state-building in the panel of 34 capitals of the Egyptian provinces spanning the 3050-1750 BCE period. Consistent with our model and at odds with the collapse archaeology's mantra, city fixed effects ordinary least squares—OLS, thereafter—suggest that worse climate conditions forced the Pharaohs to grant a larger fiscal autonomy to some of the provinces of Upper Egypt and the relative governors to employ the tax revenues at their disposal to procure local public goods. These discontinuities convinced the non-elites to keep cooperating in farming investments despite the worsened climate conditions and sustained settlement.

Crucially, these results holds across several identification strategies and, notably, when we control for the degree of climate volatility, which is closely linked to a culture of cooperation and, in turn, a more inclusive political process (21), and the degree of environmental circumscription, which is the difference between the productivity of a province and that of the surrounding areas and constitutes a deterrent to exit, unrest and, in turn, reforms towards a more inclusive social order (29-32). More important, they square with four stylized historical facts (see the SM appendix).

First, the mild climate of the pre-dynastic period (8000-3150 BCE) favored a high Nile river flow and in turn, the development of a settled agricultural economy that, by the onset of the 4th millennium, revolved around chiefdoms in Upper Egypt and loosely organized hierarchies in Lower Egypt (33-36). Against this heterogenous background, fierce inter-polity competition ended up in the creation by the Naqada culture of a unified proto-kingdom based in Hierakonpolis, first, and Abydos, later (33-34). The monarchs of the early-dynastic period (3150-2592 BCE) emerged from this experience, conquered Lower Egypt and controlled from Memphis the labor force necessary to support farming in the fertile delta region and the lucrative trade routes reaching the Levant (34). This organizational structure continued to characterize the first phase of the old Kingdom (2592-2181 BCE) until the 24th century BCE start of the Sixth Dynasty. Second, the extended period of low Nile floods and severe droughts of the 23rd and 22nd centuries BCE eased the rise of local elites nurturing their own cults and policy-making power within each province, i.e., Nome (37). Meanwhile, the governors—i.e., Nomarchs—of the Nomes located in the Delta region and northern part of Upper Egypt acted as Pharaoh's representatives directly from his palace, whereas those of the more distant Nomes became local barons able to keep part of the tax revenues and employing them to finance local public good provision (33, 36-38). Third, in concomitance with the renewed period of harsher climate of the first intermediate period (2181-2055 BCE), Egypt first split in a southern Theban reign and a northern Heracleopolitan kingdom under the ruling of the Eight Dynasty and, then, united under the former (35). Meanwhile, contrarily to the narrative depicted by a dated historical literature (34-35, 39), cities thrived and trade expanded, especially in the South (36, 40). Crucially, such a successful resilience of the Nomes of Upper Egypt laid its foundation on the respective Nomarchs' need of balancing the desiderata of the local elites—of which they were an expression–with the requests of rising merchant ranks (36, 41-42). Finally, the milder climate and consequent fluctuating moderate Nile flow of the Middle Kingdom (2055-1690 BCE) favored the reunification of the country by the Theban Kings of the Eleventh Dynasty**,** the relocation of the capital to Thebes and the expansion of the reign northward (33, 43). Nomarchs gradually lost their autonomy until the final Amenemhat III's victory over the provincial system (43). This success gave rise to a novel administrative system characterized by offices closely linked to the royal palace (43).

Next, we first illustrate our theoretical framework and, then, we discuss our empirical exercise. Finally, we close by illustrating a more general strategy for future research on the interplay among climate change, state-building and societal resilience able to inform analyses of the impact of climate extremes on developing countries and informing public policies (44-45).

2. A Time Inconsistency Model of State-Building

Our model is a simplified version of those proposed by (23) and (46). While we report the formal analysis in the SM appendix, we summarize the main intuitions of the model solution in this section.

Formally, we study the possible cooperation between elites and non-elites in a joint investment, e.g., a farming project. While the elites gather the part of the population with control over scarce resources and the institutional design, the non-elites assemble the initially rightless citizens (47). The joint activity delivers an output only if the non-elites commit a costly investment, and the output value is larger the more favorable are the production conditions, e.g., the milder the climate is. The elites keep the untaxed output and cannot commit to direct transfers in order to incentivize the non-elites, i.e., they are time-inconsistent. As clarified in the SM appendix, both assumptions can be easily relaxed. More important, these hypotheses incorporate in our theoretical framework the intuition of a long literature on the time inconsistency issues inherent to politics (48), and they are justified by, respectively, the distribution of property rights prevailing over our sample (34-43) and the fact that contracts tended to be enforced by courts controlled by the same elites promising not to renege on transfers (49). The elites can, however, try to entice the non-elites by enacting a more inclusive political process, which allows them to select the tax rate and their preferred public good.

Since all agents are risk neutral and their outside option is zero, two are the main features of the equilibrium. First, when the investment return is limited, but not so small to forbid cooperation, the non-elites cooperate only under strong political rights, which allow them to maximize their utility from cooperation by fully taxing the output and producing their preferred public good (50-53). Second, when the investment return becomes large, the elites, who prefer private to public consumption**,** keep the control over fiscal policies and select a tax rate sufficient to assure the non-elites' participation and, thus, falling with the output value. In an environment like Bronze Age Egypt, where the investment return was never tiny (34-43), our model entails two key predictions:

Testable predictions: *1. The inclusiveness of the political process will be larger the smaller is the investment return and, thus, the more severe are the elites' time inconsistency issues. 2. Reforms towards a more inclusive political process expand the provision of public goods preferred by the non-elites and, in turn, the degree of societal resilience to adverse climate shocks*.

Table 1. The Sample

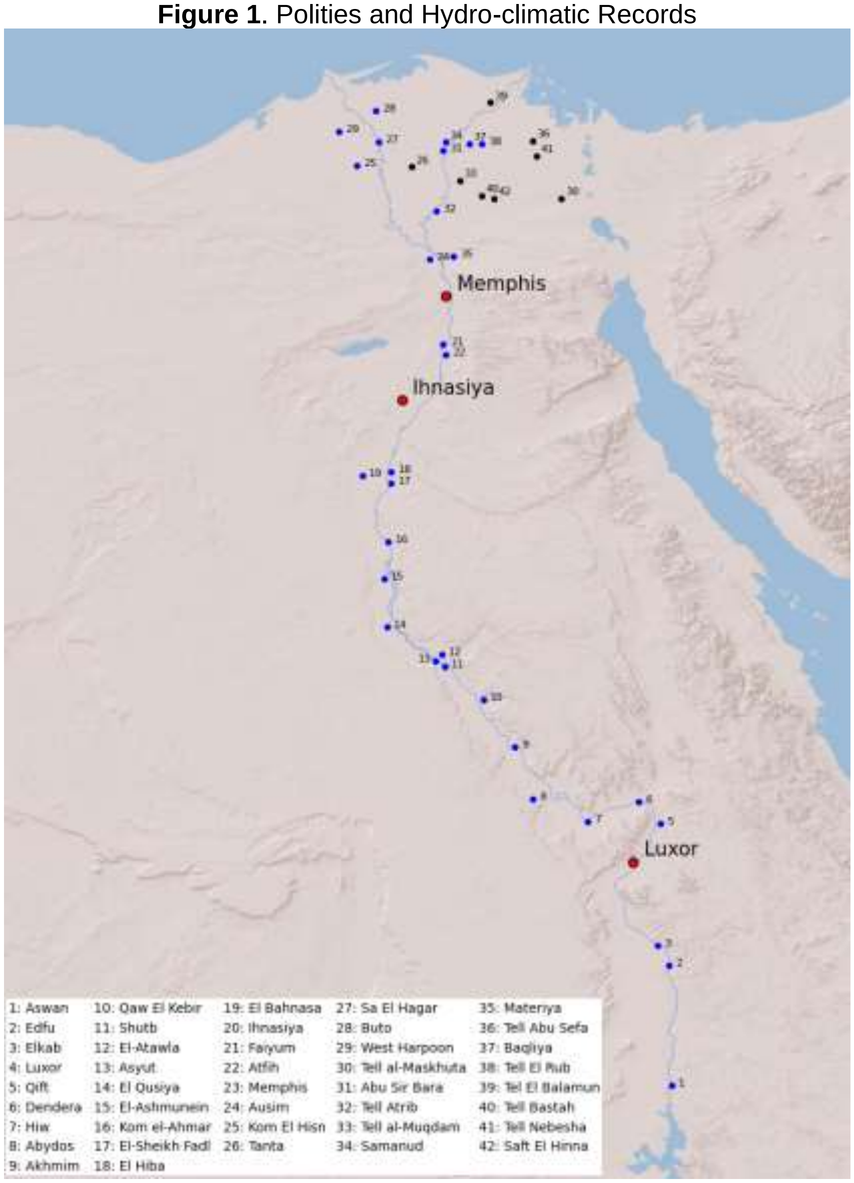
UPPER EGYPT: Elephantine (*Aswan*), Djeba (*Edfu*), Nekhen (*Elkab*), Thebes (*Luxor*), Gebtu (*Qift*), Iunet (*Dendera*), Hu-sekhem (*Hiw*), Abedju (*Abydos*), Apu (*Akhmim*)**,** Tjebu (*Qaw El Kebir*), Shashotep (*Shutb*), Per-nemty (*El-Atawla*), Zawty (*Asyut*), Qesy (*El Qusiya*), Tjerti (*El-Ashmunein*), Djed Medu (*Kom el-Ahmar*), Hardai (*El-Sheikh Fadl*), Hutnesut (*El Hiba*), Per-Medjed (*El Bahnasa*), Herakleopolis (Ihnasiya), Shenakhen (*Faiyum*), Tepihu (*Atfih*). LOWER EGYPT: Memphis (*Mit Rahina*), Khem (*Ausim*)*,* Imu (*Kom El Hisn*), Sais (*Sa El Hagar*), Per-Wadjet (*Buto*), Damanhur (*West Harpoon*), Djedu (*Abu Sir Bara*), Hut-hery-ib (*Tell Atrib*), Sebennytos (*Samanud*), Iunu (*Materiya*), Weprehwy (*Baqliya*), Djedet (*Tell El Rub*).

Note: The historical names of the polities that constitute the cross-section identifiers are in regular lowercase type, and those of the present-day archaeological sites and hydro-climatic records are in Italic lowercase font

3. Empirical Evidence

To construct our sample, we focus on the panel of the 34 capitals of the Nomes that were inhabited over the 3050-1750 BCE period and we consider the 27 half-centuries within this span as our time periods. While the names of these cities and the corresponding present-day archaeological sites are reported in table 1, their locations are displayed in figure 1. Regarding the span of our sample, two are the key constraints that have guided our choice. First, the polities that we select display sufficient settlement continuity and political relevance (54). Second, the institutional evolution of the period preceding the invention of the logo-graphic writing is still poorly understood, whereas the post-1750 BCE subjugation of Egypt to the Western Asian Hyksos populations obscuring the evolution of the single polities (34-38). By employing the chronology proposed by (55) and combining with annals and king-lists with C14 analyses of archaeological data,[1] it is, instead, possible to accurately link historical with archaeological data on the sample.

Figure 1. Polities and Hydro-climatic Records



Note: The figure depicts the locations of the polities and the hydro-climatic records.

---

[1] Since this chronology is affected by errors ranging between 20 and 30 years (55) and institutional proxies are based on events in a 40-year window around each date, measurement errors are limited. Moreover, they will only inflate standard errors without biasing the coefficients should institutions be dependent variables (56).

3.1 Measurement

First and foremost, we need proxies for the degree of societal resilience. In Malthusian economies, such as those part of our sample, technological innovations only produce population growth (57). Hence, the cooperation between elites and non-elites in handling adverse climatic shocks via a more inclusive social order fostering investment should logically result in larger levels of population and urbanization (21). Accordingly, we elect as measure of the degree of societal resilience the natural logarithm of the average population of the city over the previous half-century (see table 2 for the definition and sources of each of the variables that we employ). As the upper-left graph in figure 2 reveals, we only observe settlement information from the 2600 BCE on.

Turning to the provision of the public goods preferred by the non-elite, we follow (23, 26), and we rely on the average number of forts and temples built over the previous 50 years (58-60), i.e., *Public-Buildings*. Intuitively, while the palatial elites preferred the construction of colossal pyramid tombs, the non-elites favored the realization of defensive infrastructures and the distribution of food during the festivities organized by local temples (34-38). As in the case of the proxies for the non-elites' rights, these variables are based on historical analyses of the single periods and city-specific secondary sources informed by annals as well as archaeological data (58-60).

Regarding the inclusiveness of the political process, we follow (23, 26), and we build on the events in a 40-year window around each time period to construct a indicator equal to zero if the city was under domination of a ruler residing in another city, and one if the ruler, either a local Pharaoh or a Nomarch with the *hrj-tp* title, was fiscally autonomous, i.e., *Political-Institutions*. In an historical appendix available upon request, we detail the coding of this variable for each city and time period.

Table 2. Summary of Variables

	Variable	Definition and Sources	Statistics
State-building:	*Political-Institutions*	0 if the city was under domination of a ruler residing in another city, and 1 if the ruler, either a local Pharaoh or a Nomarch—i.e., hrj-tp, was fiscally autonomous. Sources: see the historical appendix.	0.052 (0.223)
	Public-Buildings	Average number of forts and temples built over the previous 50 years. Sources: Bard (1999), Wilkinson (2000) and Arnold (2003).	0.040 (0.310)
Societal resilience:	*Population*	Natural logarithm of the average population of the city over the previous 50 years. Source: Nielsen (2021).	7.779 (1.637)
Climate change:	*PDSI*	PDSI averaged over the previous 50 years. Source: AHV (2019); HWSD dataset, available at https://www.fao.org/soils-portal	- 0.433 (0.941)
	Sr-Ratio	87Sr/86Sr ratio normalized to range between 0 and 1. Source: Krom et al. (2022).	0.343 (0.320)

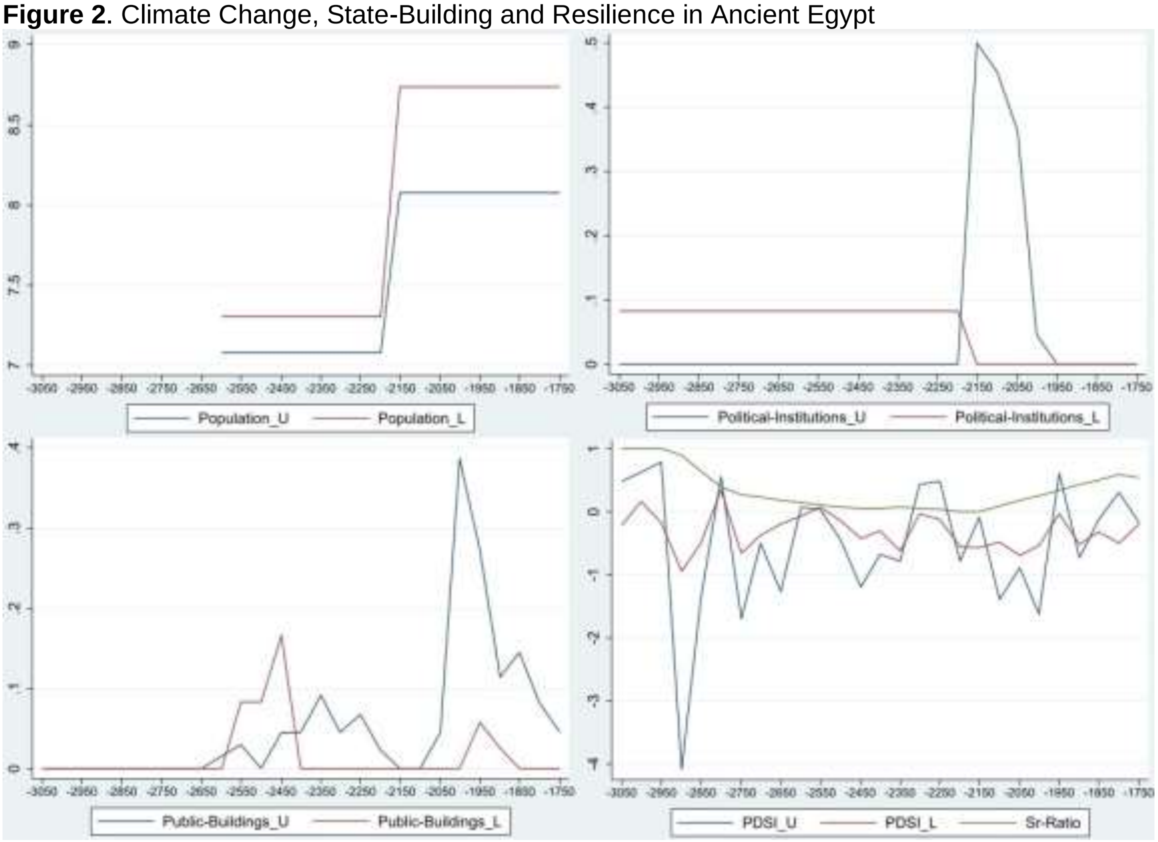
Note: The last column lists mean and, in parentheses, standard deviation of each variable, both calculated for the samples used in figure 2 and table 3.

Finally, to gauge the environmental factors key to the domestication of cereal grains, which were the most diffused crops (34-38), we build on broad botanical evidence suggesting that wheat and barley farming is favored by a more suitable land, needs a temperature ranging between 5 and 37 degrees Celsius, suffers from water scarcity and that the relative yield anomalies are mainly explained by climate extremes (61-62). Absent historical data on the land suitability (23-24) and being the Egyptian agriculture primarily irrigated, we then focus on two variables.

First, we follow (33) and we rely on the provenance patterns of the Nile River sediments as a proxy for paleoclimatic changes in East Africa. The 87Sr/86Sr ratio is particularly appropriate for such investigation since 95% of the transported sediments transported are derived from the Ethiopian Highlands through the Blue Nile, which, in turn, drains a catchment area with Cenozoic volcanic rocks with low 87Sr/86Sr ratio (33). Then, small 87Sr/86Sr ratios are indicative of larger sedimentation of terranes coming from the Ethiopian Highlands and, in turn, a more limited Nile flow. Crucially, (33) validate the time series variation of this proxy by showing its close correspondence with known change in Nile flow over the past 7000 yr. Ultimately, we focus on the 87Sr/86Sr ratio collected by (33) and, the, normalized to range between 0 and 1, i.e., *Sr-Ratio*.

Second, we calculate the Palmer drought severity index—i.e., PDSI—by assembling, as proposed by (63), temperature, rainfall, latitude and the available water storage capacity, all averaged over the previous half-century, i.e., *PDSI*. The PDSI ranges between -10—i.e., extreme droughts—and 10—i.e., extremely wet conditions, equals 0 if the soil moisture is normal and, different from its single components, is an—inverse—measure of the severity of droughts, i.e., periods over which the supply of soil moisture fails to meet its demand (64). Crucially, the degree of drought severity interacted with the abundance of the Nile inundation in shaping yields and affected also the efficiency of the storage of the harvest (65). Operationally, we collect the water storage capacity, which is defined as the mm/m of water that a soil can store and is available for use by plants, from the HWSD dataset developed by FAO at the 30 arc-second spatial resolution. The climate data, instead, are available from (28) for each month between 60,000 and 0 BP—i.e., 1950—and the northern hemisphere at a 0.5 degree spatial resolution.[2] The model underlying this last data set combines discrete equations for fluid motion with grid-specific information on land, plant and soil features to simulate the interactions among atmosphere, ice and land surface (28). Two pieces of evidence validate the construction of *PDSI*. First, (28) validate both the yearly time series variation and the spatial variation of their data employing, respectively, the available proxy and observational climatic data. Second, (26) shows that, for a panel of 44 Mesopotamian polities observed between 3050 and 1750 BCE, *PDSI* is positively and significantly correlated with coeval barley yields in liters per hectare reported by cuneiform administrative texts.

Figure 2. Climate Change, State-Building and Resilience in Ancient Egypt



Note: The upper-left, upper-right and bottom-left graphs display, respectively, the logarithm of the population, inclusiveness of political institutions and number of forts and temples averaged over the previous half-century and the cities in Upper and Lower Egypt. While the former are labeled with a subscript U, the latter are labeled with a subscript L. The bottom-right graph depicts, instead, the PDSI for the same two groups of cities as well as the 87Sr/86Sr ratio. While Table 1 reports the composition of each group of cities, table 2 details the definition and sources of each variable.

3.1 Basic Empirical Results

A glance at figure 2 reveals that the model predictions are confirmed by three patterns evident in our data on Bronze Age Egypt. First, the combination of intermediate droughts and very limited Nile flows of the 23rd and 22nd centuries BCE pushed the Pharaohs to grant a larger fiscal autonomy to some of the provinces of Upper Egypt and the relative governors to use the tax revenues at their disposal to procure local public goods (compare bottom-right graph with upper-right and bottom-

[2] We average these data over the entire year since growing and harvest lasted from October to May (65).

left graphs of figure 2). Second, these discontinuities convinced the non-elites to cooperate in farming investments despite the worsened climate conditions and sustained settlement (see upper-left graph of figure 2). Finally, the milder climate and consequent fluctuating moderate Nile flow of the Middle Kingdom favored the reunification of the country under a centralized monarchy.

Crucially, these patterns are confirmed by the city fixed effects OLS estimates reported in table 3 and further discussed in the SM appendix. In these regressions, we do not consider time fixed effects since *Sr-Ratio* does not variate across cities. We document, however, in the SM appendix that the message of our analysis is similar when we either cluster the standard errors at the city level or correct them for generic spatial dependence. The estimates in table 3 reveals three key patterns in our data. First, both a lower supply of soil moisture and a lower Nile flow are positively and statistically significantly related to the adoption of the more inclusive Nomarchy institution (see column (1)). Notably, a shift from extremely wet to extremely dry conditions leads to slightly more than a one-standard-deviation rise in *Political-Institutions*, whereas a fall in the Nile flow from his highest to his lowest level entails a 0.35-standard-deviation increase in the inclusiveness of the political process. Second, the adoption of a more inclusive political process is linked to a larger provision of forts and temples in the Nome (see column (2)). Finally, worsened climate conditions, had both the direct and negative impact of decreasing the population, mostly significantly through the Nile flow, and the indirect and positive effects of increasing it through the adoption of the more inclusive political process prevailing under the Nomarchy (see column (3)).

Table 3. Climate Change, State-building and Resilience in Ancient Egypt

	(1)	*(2)*	*(3)*
		The dependent variable is:	
	Political-Institutions	*Public-Buildings*	*Population*
Public-Buildings			0.086 (0.115)
Political-Institutions		0.141 (0.050)***	0.650 (0.189)***
PDSI	- 0.012 (0.007)*	- 0.006 (0.010)	- 0.140 (0.073)*
Sr-Ratio	- 0.077 (0.020)***	- 0.017 (0.030)	2.313 (0.255)***
Estimation		OLS	
Observations	918	918	369
R^2	0.02	0.01	0.21

Notes: 1. Standard errors in parentheses; *** denotes significant at the 1% confidence level; **, 5%; *, 10%.
2. All specifications include city fixed effects.

3.3 Gaining More Insights About Causality

Even if our fixed city OLS estimates are consistent with the testable predictions, they may be capturing reverse causality, they might be attenuated by measurement error and/or they may be driven by omitted variables. In the methodological section, we evaluate these issues in turn.

First, the independence of the proxies for the return on farming from human decisions excludes reverse causation from institutions to environmental conditions. Moreover, the fact that public good provision is not positively related to future values of the inclusiveness of the political process is inconsistent with the former driving the latter given the plausible lag with which institutions adjust.

Second, the message of our empirical exercise remains unchanged when we deal with measurement error by either considering an alternative measures of the provision of the public goods preferred by the non-elites, an alternative proxy for the fiscal autonomy of the Nome or an ordered indicator increasing in the inclusiveness of the political process.

Finally, we follow a two-step strategy to assess the role of unobserved heterogeneity. First, we document that our results are robust to considering both the degree of climate volatility and that of environmental circumscription. Second, we calculate how much greater the influence of factors that are unobservable, relative to that of climate volatility and environmental circumscription, would need to be to explain away the main estimated effects. We find that it would have to be on average more than 65 times greater than the influence of all observable factors, which seems unlikely.

Ultimately, these robustness checks make difficult to envision that our estimates are driven by mechanisms different from those we model and, thus, we take them as consistent with causality running causality running from climate shocks to the inclusiveness of political institutions and the degree of societal resilience and from inclusive political institutions to public good provision.

4. Conclusions

Building on the first regional data set on the climate, institutional evolution and population of Bronze Age Egypt, we document that the extended period of low Nile floods and severe droughts started with the Sixth Dynasty resulted in the rise of more inclusive political institutions in several of the Nomes of Upper Egypt. Consistent with our time inconsistency theory of state-building, these reforms granted to the regional Nomarchs the power to use part of the tax revenues to finance public good provision and, thus, convince the local non-elites to cooperate in farming and sustain settlement. Ultimately, and contrary to the collapse archeology mantra, the 4.2 ka BP megadrought did not provoke Egypt’s societal breakdown, but shaped these ancient societies directly via deteriorated production conditions as well as indirectly via institutional resilience.

Our methodological approach immediately implies a general three-step strategy for future research on the interplay among climate change, state-building and societal collapse (Benati and Guerriero, 2023). First, any such project should build on game theoretical models clarifying the incentives linking exogenous conditions to social evolution. Second, they should rely on up-to-date statistical methods. Finally, they should adopt measurement strategies informed by social sciences, geoscience and archaeology minimizing the errors introduced by differential quality of archaeological data and their aggregation process. This is particularly relevant to shed light on the pre-colonial institutional determinants of the present-day underdevelopment of Africa. The main insight about this link come from the correlations between the pre-colonial institutional data reported in the Murdock's (1967) Ethnographic Atlas of the World and present-day economic outcomes (Gennaioli and Rainer, 2007; Michalopoulos and Papaioannou, 2013). Over and above the lack of a model justifying these correlations, the main weakness of this literature is the limited reliability of the measurement of pre-colonial institutions. To elaborate, these data are based on colonial officials' records, rather than formal archaeological and anthropological literature.

Acknowledgments

General: We wish to thank Mark Altaweel, Giacomo Benati, Alessio Palmisano and David Stasavage for the insightful comments.

Funding: We wish to thank the 2015 Rita Levi-Montalcini program for generous funds.

Author Contributions: Amin Ali Gholami Oskuyi and Carmine Guerriero have equally contributed.

Competing Interest Statement: Amin Ali Gholami Oskuyi and Carmine Guerriero have no relevant or material financial interests that relate to the research described in the paper.

Data and material availability: All data, code, and materials used in the present analysis are available upon request.

This file includes: Main text, tables 1 to 5 and figures 1 to 4.

References

1. J. L. Brooke, *Climate Change and the Course of Global History. A Rough Journey*. (Cambridge University Press, Cambridge, UK, 2014).
2. N. Roberts, et al., Human Responses and Non-Responses to Climatic Variations during the Last Glacial-Interglacial Transition in the Eastern Mediterranean. *Quat. Sci. Rev.* **184**, 47-67 (2018).
3. J. Haldon, et al., History Meets Palaeoscience: Consilience and Collaboration in Studying Past Societal Responses to Environmental Change. Proc. Natl. Acad. Sci. U.S.A. **115**, 3210-3218 (2018).
4. G. K. Dow, C. G. Reed, Economic Prehistory. Six Transitions That Shaped the World (Cambridge University Press, Cambridge, UK, 2023).
5. H. Weiss (ed.), Megadrought and Collapse. From Early Agriculture to Angkor (Oxford University Press, Oxford, UK, 2017).
6. D.J. Kennett, et al., Development and Disintegration of Maya Political Systems in Response to Climate Change. *Science* **338**, 788-791 (2012).
7. Z. Wei, et al., Macro-economic Cycles Related to Climate Change in Dynastic China. *Quat. Res.* **83**, 13-23 (2015).
8. A. Sinha, et al., Role of Climate in the Rise and Fall of the Neo-Assyrian Empire. *Sci. Adv.* **5**, eaax6656 (2019).
9. D. Fleitmann, et al., Droughts and Societal Change: The Environmental Context for the Emergence of Islam in Late Antique Arabia. *Science* **376**, 1317-1321 (2022).
10. S.W. Manning, C. Kocik, B. Lorentzen, J.P. Sparks. Severe Multi-year Drought Coincident with Hittite Collapse Around 1198–1196 bc. *Nature* **614**, 719-724 (2023).
11. E. Chaney, Revolt on the Nile: Economic Shocks, Religion and Political Power. *Econometrica* **81**, 2033-2053 (2013).
12. J. G. Manning, et al., Volcanic Suppression of Nile Summer Flooding Triggers Revolt and Constrains Interstate Conflict in Ancient Egypt. *Nat. Commun.* **8**, 1-8 (2017).
13. J. Mayshar, O. Moav, Z. Neeman, Geography, Transparency, and Institutions. *Am. Political Sci. Rev.* **111**, 622–636 (2017).
14. L. Mayoral, O. Olsson, Floods, Droughts, and Environmental Circumscription in Early State Development: The Case of Ancient Egypt. SSRN [Preprint] (2024). https://dx.doi.org/10.2139/ssrn.3496225 (Accessed on the 31/01/2024).
15. Degroot, D., et al., 2021. Towards a Rigorous Understanding of Societal Responses to Climate change. *Nature* **591**, 539e550.
16. V. P. J. Arponen, et al., Environmental Determinism and Archaeology. Understanding and Evaluating Determinism in Research Design. *Archaeol. Dialogues* **26**, 1-9 (2019).
17. P. A. McAnany, N. Yoffee (eds.), *Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire* (Cambridge University Press, Cambridge, UK, 2009).

18. J. A. A. Guedes, et al., Twenty-First Century Approaches to Ancient Problems: Climate and Society. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 14483-14491 (2016).
19. K. W. Butzer, Collapse, Environment, and Society. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 3632–39 (2012).
20. K. W. Butzer, G. H. Endfield, Critical Perspectives on Historical Collapse. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 3628–3631 (2012).
21. J. P. Burgess, What Is Societal Resilience? (2022) https://preprod-axaresearch.axa.com/en/news/what-is-societal-resilience (Accessed on the 31/01/2024)
22. G. Benati, C. Guerriero, Climate Change and State Evolution. *Proc. Natl. Acad. Sci. USA* **118**, e2020893118 (2021).
23. G. Benati, C. Guerriero, F. Zaina, The Origins of Political Institutions and Property Rights, *J. Comp. Econ.* **50**, 946-968 (2022).
24. G. Benati, C. Guerriero, Against Historical Determinism: Embracing a Multidisciplinary Approach to Study State-Building. Unpublished.
25. C. Zhao, et al., Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 9326-9331 (2017).
26. G. Benati, C. Guerriero, Combining Social Sciences, Geoscience and Archaeology to Understand Societal Collapse. *Quat. Sci. Rev.* **314**: 108217 (2023).
27. G. Benati, C. Guerriero, F. Zaina, The Economic and Institutional Determinants of Trade Expansion in Bronze Age Mesopotamia. *J. Archaeol. Sci.* **131**, 105398 (2021).
28. E. Armstrong, P. O. Hopcroft, P. J. Valdes, A Simulated Northern Hemisphere Terrestrial Climate Dataset for the Past 60,000 Years. *Sci. Data* **6**, 265 (2019).
29. R. L. Carneiro, A Theory of the Origin of the State. *Science*, **169**: 733-738 (1970).
30. R. C. Allen, Agriculture and the Origins of the State in Ancient Egypt. *Explor. Econ. History*, **34**: 135-154 (1997).
31. D. Schönholzer, The Origin of the Incentive Compatible State: Environmental Circumscription. SSRN [Preprint] (2024). https://dx.doi.org/10.2139/ssrn.2944106 (Accessed on the 31/01/2024).
32. A. Ahmed, D. Stasavage, Origins of Early Democracy. *Am. Political Sci. Rev.* 114, 502–518 (2020).
33. M. D. Krom, J.D. Stanley, R.A. Cliff, J. C. Woodward, Nile River Sediment Fluctuations Over the Past 7000 yr and Their key Role in Sapropel Development. *Geology* **30**, 71-74 (2002).
34. I. Shaw, *The Oxford History of Ancient Egypt* (Oxford, UK: Oxford University Press, 2003).
35. E. C. Köhler, Prehistoric Egypt. In: *The Oxford History of the Ancient Near East*, K. Radner, N. Moeller, and D. T. Potts, eds., (Oxford, UK: Oxford University Press, 2020), pp. 95-162.
36. J. C. Moreno Garcia, *The State in Ancient Egypt: Power, Challenges and Dynamics* (London, UK: Bloomsbury Publishing, 2020).
37. M. Bárta, A View from Within. In: *The Oxford History of the Ancient Near East*, K. Radner, N. Moeller, and D. T. Potts, eds., (Oxford, UK: Oxford University Press, 2020), pp. 316.
38. A. B., Lloyd, *Ancient Egypt: State and Society* (Oxford, UK: Oxford University Press, 2014).
39. J. C. Moreno García, Egypt in the First Intermediate Period. In: *The Oxford History of the Ancient Near East*, K. Radner, N. Moeller, and D. T. Potts, eds., (Oxford, UK: Oxford University Press, 2020), pp. 47–120.
40. J. C. Moreno García, *Ancient Egyptian Administration* (Leiden, NLD: Brill, 2013).
41. É. Martinet, *L'Administration Provinciale sous l'Ancien Empire Égyptien* (Leiden, NL: Brill, 2019).
42. N. Favry, *Le Nomarque Sous le Règne de Sésostris I* (Paris, FR: Sorbonne Université Presses, 2004).
43. H. Willems, Egypt's Middle Kingdom: A View from Within. *The Oxford History of the Ancient Near East* **2**: 310–407 (2022).
44. G. Benati, C. Guerriero, Climate Shocks and State-Building. SSRN [Preprint] (2024). http://dx.doi.org/10.2139/ssrn.3868082 (Accessed on the 31/01/2024).
45. G. Benati, C. Guerriero, Climate Shocks, Democratization and (a Culture of) Cooperation. SSRN [Preprint] (2024). http://dx.doi.org/10.2139/ssrn.3912442 (Accessed on the 31/01/2024).

46. C. Guerriero, L. Righi, The Origins of the State's Institutional Capacity. SSRN [Preprint] (2024). https://dx.doi.org/10.2139/ssrn.4124110 (Accessed on the 31/01/2024).
47. G. Benati, C. Guerriero, The Origins of the State: Technology, Cooperation and Institutions. *J. Institutional Econ.* **18**, 29-43 (2022).
48. S. Boranbay, C. Guerriero, Endogenous (In)Formal Institutions. *J. Comp. Econ.* **47**, 921-945 (2019).
49. D. Acemoglu, Why not a Political Coase Theorem? Social Conflict, Commitment, and Politics. *J. Comp. Econ.* **31**: 620-652 (2003).
50. G. Benati, C. Guerriero, The Origins of (a Culture of) Cooperation. SSRN [Preprint] (2024). https://dx.doi.org/10.2139/ssrn.4181876 (Accessed on the 31/01/2023).
51. R. E. Blanton, L. Fargher, *Collective Action in the Formation of Pre-Modern States* (Springer, New York, NY, 2008).
52. R. E. Blanton, L. Fargher, *How Humans Cooperate. Confronting the Challenges of Collective Action* (Boulder, CO: University of Colorado Press 2016).
53. M. Levi, *Of Rule and Revenue* (Los Angeles, CA: University of California Press, 1988).
54. B.A. Nielsen, The Size of Towns in Ancient Egypt 2500, 1850, 1250 and 200 BC - a Reconstruction. Academia [Preprint]. https://204.academia.edu/BentAnkerNielsen.
55. E. Hornung, R. Krauss, D.A. Warburton, *Ancient Egyptian Chronology* (Leiden, NLD: Brill, 2019).
56. J. D. Angrist, J. Pischke. *Mostly Harmless Econometrics* (Princeton, NJ: Princeton University Press, 2009).
57. G. Clark, *A Farewell to Alms* (Princeton, NJ: Princeton University Press, 2005).
58. K. A. Bard. *Encyclopedia of the Archaeology of Ancient Egypt* (London, UK: Routledge, 1999).
59. R.H. Wilkinson. *The Complete Temples of Ancient Egypt* (London, UK: Thames & Hudson, 2000).
60. D. Arnold. *The Encyclopedia of Ancient Egyptian Architecture* (Princeton, NJ: Princeton University Press, 2005).
61. S. O. Serna-Saldivar, *Cereal Grains: Properties, Processing, and Nutritional Attributes* (CRC Press, Boca Raton, FL, 2010).
62. E. Vogel, et al., The Effects of Climate Extremes on Global Agricultural Yields. *Environ. Res. Lett.* **14**: 054010 (2019).
63. D. Jacobi, et al., A Tool for Calculating the Palmer Drought Indices. *Water Resour. Res.* **49**, 6086-6089 (2013).
64. K. T. Redmond, K. T. The Depiction of Drought: Commentary. *Bull. Am. Meteorol. Soc.* **83**, 1143-1148 (2002).
65. P.T. Nicholson, I. Shaw, *Ancient Egyptian Materials and Technology* (Cambridge, UK: Cambridge University Press, 2000).

Supplementary Materials for

Climate Change, State-Building and Resilience in Ancient Egypt.

Amin Ali Gholami Oskuyi[1], Carmine Guerriero[2*]

[1]Department of Economics, University of Bologna, Piazza Scaravilli 2, 40126 Bologna, Italy.

[2]Department of Economics, University of Bologna, Piazza Scaravilli 2, 40126 Bologna, Italy. *Corresponding author. Email: c.guerriero@unibo.it

Supplementary Materials for this manuscript include:

Historical Evidence

A Time Inconsistency Model of State-Building

Tables S1 to S4

SM References

I. Historical Evidence

Pre-dynastic period (8000-3150 BCE).—The fertile floodplain of the Nile valley favored since 8000 BCE the development of a settled agricultural economy (1). As, however, the North African climate gradually grew more arid, the population concentrated along the river region (2) and reconstructed funerary practices suggest that, by the onset of the 4th millennium BCE, Upper Egypt was dominated by chiefdoms, such as those controlling Abydos, Naqada, and Hierakonpolis, whereas Lower Egypt was characterized by a lower degree of social differentiation (2). Against this heterogeneous background, fierce inter-polity competition induced by 3500 BCE the creation by the Naqada culture of a unified proto-kingdom around Hierakonpolis, first, and Abydos, later (1). The 3300 BCE advent of written records allowed these rulers to maintain comprehensive records and organize both an incipient bureaucracy and a centralized government (2).

Early-dynastic period (3150-2592 BCE).—The monarchs of the First Dynasty emerged from this experience. To elaborate, king Narmer of Upper Egypt conquered Lower Egypt and established a capital at Memphis (3). From here, he could control both the labor force necessary to support farming in the fertile delta region as well as the lucrative trade routes reaching the Levant (3). Even if the bureaucratic machinery had not yet reached full maturity, the centralized state soon stretched from Elephantine to the Mediterranean (3). To control this vast territory, the royal household relied on the “mswr.w,” i.e., a biennial inspection of the reign aimed to oversee tax collection and justice administration (4). A further institutional innovation, the “w.t” or “hut” center, emerged during the reign of Djer. Organized around tower-like structures directly controlled by the king, these centers played, together with the temples, a pivotal role in organizing the labor force, managing production, facilitating storage, and overseeing tax collection (3). Cities, instead, played apparently no key role in the royal administrative. This organization started to change during the Old Kingdom.

Old Kingdom (2592-2181 BCE).—Spanning the period dominated the Pharaohs produced by the Third Dynasty and those part of the Eighth Dynasty, the Old Kingdom can be divided into two distinct phases (5). A first period witnessed the construction of the first pyramids symbolizing the Pharaohs’ dominance, the rise of religion practices undermining the importance of Horus and exalting the sun god Ra, intensified foreign expeditions and the centralization of administrative offices under the royal household (3, 5). This bureaucratic rank, who was initially based in the capital Inbu-hedj—later known as Menefar or Memphis, managed the state affairs through both hut centers and temples (5). Only with the Fourth Dynasty, some innovations were introduced whereby the organization of production and taxation was entrusted to a vizier selected among the Pharaoh's sons and the temples strengthened their role of guardians of the Pharaoh's political power (5).

A second period, beginning with the Fifth Dynasty, was characterized by the rise of provincial elites cultivating their own cults and policy-making independence (3). To counteract such centrifugal forces, the Pharaohs shifted their effort from the construction of huge pyramids to the organization of diplomatic marriages between their household and non-royal elites, the erection of new sun temples and the empowerment, especially in Upper Egypt, of the cities (5). Moreover, during the Djedkara's reign, provinces—i.e., Nomes—denominated according to their protective deity gained greater relevance, and their governors, the Nomarchs—i.e., "great chief" or "overseer", started to collect taxes and manage public building construction on behalf of the Pharaoh (5, 6). Despite these attempts, affluent non-royal households acquired an elite status, which they showcased by shoring up the more democratic afterlife cult of Osiris and erecting tombs in their own provinces (5).

In correspondence of the extended period of low Nile floods and severe droughts of the Sixth Dynasty, the Nomarchs of the Delta region and the northern part of Upper Egypt continued to govern their provinces from the royal palace, whereas the rest carried out their duties from their more distant Nomes (5, 7, 8). This discontinuity opened the way to the hereditary transmission of the provincial administration and the transformation of the peripheric Nomarchs in local barons able to keep part of the tax revenues and employ them to finance local public good provision (5, 7, 8). The Nomarchs, moreover, could build their own tombs and donate land to the provincial temples to earn the favor of the local gods (5, 7, 8). To fend off these continuous independentist attacks, the Pharaohs also distributed lands to the provincial temples and established seats of the vizier in Edfu, first, and Abydos, later (5). Despite these attempts, Merenra had to endure the rising independence of the Elephantine, Edfu, Thebes, Coptos, Dendara, Qasr el-Sayad, Abydos, Akhmim, Deir el-Gebrawi, Meir, Sheikh Said, Zawyet el-Maytin, Kom el-Ahmar and Deshasha provinces (5), and Pepi II was the last powerful king of the Old Kingdom. The Seventh Dynasty, in fact, ruled only for a brief—estimated—period of 32 years without de facto control over the southern Nomes (5).

First intermediate period (2181-2055 BCE).—In concomitance with a renewed period of harsh climate, Egypt split in a northern Heracleopolitan kingdom under the ruling of the Eight Dynasty and a southern Theban reign revolving around the Thebes Nomarchy. Such a territorial antagonism endured for approximately a century and culminated in the military triumph of the Theban kings over their northern rivals and the consequent reunification of Egypt (3). Meanwhile, contrarily to the narrative depicted by a dated historical literature (2, 3, 9), cities thrived and trade expanded, especially in the South (3, 10).[3] Crucially, this successful resilience of the Nomes of Upper Egypt primarily hinged on the social pact reached by the ruling elites, of which the Nomarchs was an expression, an a rising merchant class that, by the 3rd millennium BCE reunification, determined the zenith of the Nomarchy model (3). Lower Egypt, instead, never experienced a similar inclusive political order and remained under the autocratic control of the Pharaohs of Heracleopolis (3).

Middle Kingdom (2055-1690 BCE).—Characterized by a milder climate and a fluctuating moderate Nile flow (6), the Middle Kingdom opened with the reunification by the Theban Kings of the Eleventh Dynasty**,** the relocation of the capital to Thebes and the expansion of the reign northward (11). The key Theban victory of Asyut prompted several Nomarchs, who had until then supported the Heracleopolitan kings, to switch side (11). While many Nomarchs lost autonomy, some of the Middle Egypt ones retained their status, and the Aswan Nomarch was even reinstated in response to the burgeoning influence of the emerging Nubian Kingdom of Kush (11). The tension between the central government and the Nomarchs, however, continued until the late Twelfth Dynasty, when Amenemhat III was finally able to wipe out the Nomarchy system (11). This success

[3] During this period, the hut centers were replaced by harbors, i.e., "*demi*" (2, 3, 8).

gave rise to a novel administrative system characterized by offices intimately linked to the royal palace (11). To elaborate, local administrators assumed the title of town mayors and served as an instrument for the enforcement of royal authority over cities and regions (12). At an intermediate administrative level, the "Head of the South" linked the South with Thebes (12).

II. A Time Inconsistency Model of State-Building

The economy.—We consider a representative elite interested in maximizing the payoff obtained from cooperating with a representative non-elite in a joint investment activity. The output value Y equals $V > 0$ if the elite entrusts an input to the non-elite and the non-elite incurs the investment cost $\gamma > 0$ and zero otherwise. We normalize the elite's cost of providing her input to zero. Both groups are risk-neutral and their outside options is zero.[4]

The non-elite's utility under the regime r—i.e., U_r—equals the payoff from public good consumption net of the investment cost, whereas the elite's payoff under the same regime—i.e., π_r—equals the sum of the untaxed output and the payoff from public good consumption. Hence, we are implicitly embracing two hypotheses. First, we maintain that the elite keeps both control and transfer rights to the input, leaving to the non-elite only the use rights. Accordingly, she appropriates the entire untaxed output (13-14).[5] Second, we assume that the elite lacks the ability to commit to direct transfers to the non-elite (16-19). Both assumptions can be relaxed (see footnote 14).

The elite can incentivize the non-elite by enacting an inclusive political institution $r = I$, which allows the non-elite to select the tax rate and his preferred public good. To elaborate, the tax rate δ_r is selected by the elite under the autocratic regime $r = A$, and it is chosen by the non-elite under $r = I$. Moreover, a provision of public good g_r delivers a sub-utility ρg_r to the group designing fiscal policies—i.e., elite (non-elite) under $r = A$ (I)—and βg_r to the other group. We posit that $0 < \beta < \rho < 1$. In words, $\rho < 1$ implies that everybody prefers the private to the public good, and $\rho - \beta$ captures the degree of heterogeneity in the preferences for the public good and/or the lower ability of each group to provide the common good preferred by its partner. In our sample, the elite liked better (was better at) waging war than constructing public—non burial—building, the non-elite had opposite preferences (abilities). The public good technology is linear in the tax revenues $V\delta_r$.

Timing of events.—At time t_0, the elite picks r. At time t_1, the tax rate δ_r is chosen. At time t_2, the elite decides whether to entrust the input to the non-elite who, in turn, chooses whether to invest. At time t_3, private and public goods are possibly produced and the payoffs are realized.

Discussion.—In evaluating our setup, several remarks should be heeded. First, the interaction between elite and non-elite should be envisioned between any two consecutive and unforeseen technological shocks, each endowing the non-elite with a more efficient technology and leaving to the elite the control over scarce resources and the institutional design (20). Second, our results will be similar should we allow the decision-maker to select the type of public good (21). Finally, our analysis will deliver a similar message should we assume that $(\rho - \beta)g_r$ is the share of output expropriated by a group selecting fiscal policies, should we let the elite commit to direct transfers or should we allow her to offer to the non-elite a high-powered contract (see footnote 14). These last three robustness checks confirm that our assumptions on the asymmetry in the preferences, ability and power of the two groups can be easily relaxed and are not restrictive.

Equilibrium.—Since the game is of perfect information, we solve it by backward induction. Being the outside options weakly positive, the two groups participate only to invest. Being, moreover, private good consumption preferred to public good consumption, the elite decreases taxation as the output value rises if she is sure of the non-elite's participation in investment.

Once the elite has enacted the inclusive political institution, a non-elite foreseeing to participate selects at time t_1 a δ_I maximizing his utility from redistributing via public spending the output value, subject to assuring the elite's participation in investment. To illustrate, after having committed the investment, the non-elite obtains $U_I = \rho\delta_I V - \gamma$ and the elite gets $\pi_I = (1 - \delta_I)V + \beta\delta_I V$. Hence,

---

[4](15) allow also for positive elite's and non-elite's outside options.

[5] We refer to the elite as ``she'', to the non-elite as ``he'' and to a generic party as ``it.''

the non-elite maximizes the part of the output value that he can appropriate through public good provision by selecting $\delta_I = 1$. This choice does not discourage the elite from participating being $\beta V > 0$. Overall, for $r = I$ and $V \geq \frac{\gamma}{\rho} \equiv \widehat{\Omega}$, $\delta_I^* = 1$ and all the individual rationality constraints hold. Once the elite has picked $r = A$, she selects the δ_A maximizing $(1 - \delta_A)V + \rho\delta_A V$, subject to satisfying all individual rationality constraints. While the elite's individual rationality constraint is always met, the non-elite's individual rationality constraint fails when he does not invest or when he does and $V < \frac{\gamma}{\beta} \equiv \overline{\Omega}$. It can, instead, be satisfied when the non-elite cooperates, $V \geq \overline{\Omega}$ and $\delta_A^* = \frac{\gamma}{\beta V} \leq 1$. This is the lowest possible tax rate such that the non-elite's individual rationality constraint $U_A = \beta\delta_A^* V - \gamma \geq 0$ holds. The elite gains $\pi_A = (1 - \delta_A^*)V + \rho\delta_A^* V > \beta V = \pi_I$, and $\widehat{\Omega} < \overline{\Omega}$.

While production is unfeasible under any regime for $V < \widehat{\Omega}$, granting the inclusive political institution is the only way to garnering the non-elite's cooperation for $\widehat{\Omega} \leq V < \overline{\Omega}$. Cooperation, instead, can be elicited under any regime for $V \geq \overline{\Omega}$. In this last case, the elite prefers $r = A$ over $r = I$ since $\pi_A > \pi_I$. More important, the larger γ is, the more difficult is to support production and the larger will be the ability of the inclusive political regime to elicit cooperation when autocracy cannot, i.e., the larger $\overline{\Omega} - \widehat{\Omega} = \frac{\gamma(\rho-\beta)}{\rho\beta}$ is. The following proposition summarizes our analysis:

Proposition: For $0 < \beta < \rho < 1$: 1. If $V < \frac{\gamma}{\rho}$, production is unfeasible; 2. If $\frac{\gamma}{\rho} \leq V < \frac{\gamma}{\beta}$, the elite grants the inclusive political institution, whereas the non-elite picks the maximum tax rate $\delta_I^* = 1$ and invests; 3. If $V \geq \frac{\gamma}{\beta}$, the elite picks the autocratic regime, $\delta_A^* = \frac{\gamma}{\beta V} \leq 1$, and the non-elite invests.

In a world of inefficient public good provision, reforms towards inclusive political institutions make possible for $\widehat{\Omega} \leq V < \overline{\Omega}$ a cooperation otherwise unattainable given the elite's time inconsistency issues. When these institutional arrangements are unavailable, the elite can elicit cooperation for $\frac{\gamma}{\zeta} < V \leq \frac{\gamma}{\beta}$ and $\zeta > \beta$ only if able to credibly offer to the non-elite ζV as either a direct transfer or an high-powered trade contract.[6] When, finally, the output value is sufficiently large—i.e., $V \geq \overline{\Omega}$, the elite prefers to direct fiscal policies and decrease taxation.

[6] Should this payment be always possible, the elite will rely on it only for $\frac{\gamma}{\zeta} < V \leq \frac{\gamma}{\rho}$, $\zeta > \rho$ and no taxation. Intuitively, since she values public good, she also prefers it over wasteful transfers.

III. Supplementary Tables

Table S1. Summary of Extra Variables

	Variable	Definition and Sources	Statistics
State-building:	*Political-Institutions-A*	*Political-Institutions* variable constructed considering that the capital of the reign between 1950 and 1750 BCE, Itjtawy, was in the vicinity of Memphis. Sources: see the historical appendix.	0.058 (0.233)
	Political-Institutions-O	1 if the city was under domination of a ruler residing in another city, 2 if it was administered by a Nomarch gathering taxes on behalf of the Crown, 3 if the ruler, either a local Pharaoh or a Nomarch—i.e., hrj-tp, was political autonomous. Sources: see the historical appendix.	1.146 (0.479)
	Public-Buildings-A	Average number of mastabas, forts, temples and pyramid tombs built over the previous 50 years. Sources: Bard(1999),Wilkinson(2000)Arnold (2003).	0.082 (0.533)
Control variables:	*PDSI-SD*	Standard deviation of PDSI over the previous 50 years. Source: AHV (2019).	2.605 (0.625)
	Circumscription	Average over the previous half-century of the ratio of a dummy for the PDSI lying between – 4 and 0 to the average of the same dummy across remaining cities weighted by their inverse distance. Source: AHV (2019).	0.538 (0.121)

Note: The last column lists mean and, in parentheses, standard deviation of each variable, both calculated for the samples used in figure 2 and table 3.

Table S3. Clustered, Wild Bootstrapped and Spatially-corrected Standard Errors

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
	The dependent variable is:								
	Political-Institutions	*Public-Buildings*	*Population*	*Political-Institutions*	*Public-Buildings*	*Population*	*Political-Institutions*	*Public-Buildings*	*Population*
Public-Buildings			0.086 (0.050)*			0.086 (1.72)			0.086 (0.056)
Political-Institutions		0.141 (0.132)	0.650 (0.203)***		0.141 (1.06)	0.650 (3.21)***		0.141 (0.153)	0.650 (0.105)***
PDSI	- 0.012 (0.005)**	- 0.006 (0.006)	- 0.140 (0.068)*	- 0.012 (- 2.27)**	- 0.006 (- 1.09)	- 0.140 (-2.05)***	- 0.012 (0.007)*	- 0.006 (0.011)	- 0.140 (0.046)***
Sr-Ratio	- 0.077 (0.018)***	- 0.017 (0.017)	2.313 (0.690)***	- 0.077 (- 4.37)***	- 0.017 (- 1.00)	2.313 (3.36)***	- 0.077 (0.017)***	- 0.017 (0.017)	2.313 (0.229)***
Estimation	OLS								
Observations	918	918	369	918	918	369	918	918	369
R^2	0.02	0.01	0.21	0.02	0.01	0.21	0.28	0.18	0.72

Notes: 1. Standard (T-test obtained from wild bootstrapped standard) errors clustered at the city level in the parentheses of columns (1) to (3) ((4) to (6)) and Conley's (1999) standard errors with Bartlett kernel in those of columns (7) to (9). The distance beyond which the correlation between error terms is assumed to be zero is 23.8 km.
2. *** denotes significant at the 1% confidence level; **, 5%; *, 10%. All specifications include city fixed effects.

Table S2. Ordinal Measures of the Inclusiveness of the Political Process

	(1)	*(2)*	*(3)*	*(4)*
	The dependent variable is:			
	Political-Institutions	*Political-Institutions-O*	*Public-Buildings*	*Population*
Public-Buildings				0.098 (0.116)
Political-Institutions-O			0.059 (0.023)***	0.261 (0.089)***
PDSI	- 0.358 (0.184)*	- 0.025 (0.120)	- 0.008 (0.010)	- 0.167 (0.072)**
Sr-Ratio	- 3.251 (0.875)***	- 3.067 (1.164)***	- 0.015 (0.030)	2.300 (0.257)***
Estimation	Logit	Ordered Logit	OLS	OLS
Observations	405	864	918	369
Pseudo R^2		0.10		
R^2			0.01	0.20

Notes: 1. Standard errors in parentheses; *** denotes significant at the 1% confidence level; **, 5%; *, 10%.
2. All specifications include city fixed effects.

Table S4. Gaining More Insights About Causality

	(1)	(2)	(3)	(4)	(5)
	Panel A. The dependent variable is:				
	Public-Buildings	*Population*	*Political-Institutions-A*	*Public-Buildings*	*Population*
Public-Buildings		0.062 (0.126)			0.097 (0.115)
Public-Buildings(+1)		0.095 (0.128)			
Political-Institutions	0.233 (0.059)***	0.506 (0.231)**			
Political-Institutions(+1)	- 0.175 (0.059)***	0.208 (0.229)			
Political-Institutions-A				0.156 (0.052)***	0.589 (0.192)***
PDSI	- 0.006 (0.010)	- 0.142 (0.073)**	- 0.011 (0.007)*	- 0.006 (0.010)	- 0.145 (0.073)**
Sr-Ratio	- 0.026 (0.030)	2.346 (0.260)***	- 0.070 (0.019)***	- 0.017 (0.030)	2.235 (0.253)***
Estimation			OLS		
Observations	918	369	918	918	369
R^2	0.02	0.22	0.02	0.01	0.21
	Panel B. The dependent variable is:				
	Public-Buildings-A	*Population*	*Political-Institutions*	*Public-Buildings*	*Population*
Public-Buildings					0.087 (0.116)
Public-Buildings-A		0.012 (0.072)			
Political-Institutions	0.240 (0.082)***	0.660 (0.192)***		0.141 (0.050)***	0.640 (0.190)***
PDSI	0.00002 (0.017)	- 0.142 (0.073)**	- 0.013 (0.007)*	- 0.005 (0.011)	- 0.131 (0.076)*
Sr-Ratio	- 0.079 (0.049)*	2.334 (0.254)***	- 0.074 (0.020)***	- 0.017 (0.030)	2.293 (0.261)***
PDSI-SD			- 0.007 (0.016)	- 0.004 (0.024)	- 0.082 (0.172)
Circumscription			0.026 (0.070)	- 0.025 (0.105)	- 0.444 (0.651)
Estimation			OLS		
Observations	918	369	918	918	369
R^2	0.01	0.21	0.02	0.01	0.21

Notes: 1. Standard errors in parentheses; *** denotes significant at the 1% confidence level; **, 5%; *, 10%.
2. All specifications include city fixed effects..

Table S5. Using Selection on Observables to Assess the Bias from Unobservables

	(1)	(2)	(3)
		The dependent variable is:	
	Political-Institutions	*Public-Buildings*	*Population*
The index is calculated for			
Public-Buildings			87
Political-Institutions		141	64
PDSI	13		14.6
Sr-Ratio	24.7		114.7

Note: Each index is calculated as explained in the methodological section. The restricted set of controls includes those employed in the specifications reported in table 3, whereas the "full set" of covariates gathers those used in the specifications listed in columns (4) to (6) of table S4. The sample sizes in columns (1) to (3) are respectively 918, 918 and 369.

IV. References

1. I. Shaw, *The Oxford History of Ancient Egypt* (Oxford, UK: Oxford University Press, 2003).
2. E. C. Köhler, Prehistoric Egypt. In: *The Oxford History of the Ancient Near East*, K. Radner, N. Moeller, and D. T. Potts, eds., (Oxford, UK: Oxford University Press, 2020), pp. 95-162.
3. J. C. Moreno Garcia, *The State in Ancient Egypt: Power, Challenges and Dynamics* (London, UK: Bloomsbury Publishing, 2020).
4. E.-M. Engel, The Organisation of a Nascent State: Egypt until the Beginning of the 4th Dynasty. In: *Ancient Egyptian Administration*, J. C. Moreno García, ed., (Leiden, NLD: Brill, 2013), pp. 19-40.
5. M. Bárta, A View from Within. In: *The Oxford History of the Ancient Near East*, K. Radner, N. Moeller, and D. T. Potts, eds., (Oxford, UK: Oxford University Press, 2020), pp. 316.
6. Cooper, L. M., *Hry-tp3 n sp3t (Great Overlord of the Nome): The Office of Nomarch During the First Intermediate Period* (Tennessee, TN: University of Memphis Press, 2009).
7. M. D. Krom, J.D. Stanley, R.A. Cliff, J. C. Woodward, Nile River Sediment Fluctuations Over the Past 7000 yr and Their key Role in Sapropel Development. *Geology*, **30**, 71-74 (2002).
8. A. B., Lloyd, *Ancient Egypt: State and Society* (Oxford, UK: Oxford University Press, 2014).
9. J. C. Moreno García, Egypt in the First Intermediate Period. In: *The Oxford History of the Ancient Near East*, K. Radner, N. Moeller, and D. T. Potts, eds., (Oxford, UK: Oxford University Press, 2020), pp. 47–120.
10. J. C. Moreno García, *Ancient Egyptian Administration* (Leiden, NLD: Brill, 2013).
11. H. Willems, Egypt's Middle Kingdom: A View from Within. *The Oxford History of the Ancient Near East*, **2**: 310–407 (2022).
12. J. Taylor, Hazannum: The Forgotten Nayor. City Administration in the Ancient Near East. *Proceedings of the 53e Rencontre Assyriologique Internationale*, **2**: 207-222 (2010).
13. C. Guerriero, Endogenous Property Rights. *J. Law. Econ.* **59**, 313-358 (2016).
14. C. Guerriero, Property Rights, Transaction Costs, and the Limits of the Market. *Econ. Gov.* **24**, 143-176 (2023).
15. C. Guerriero, L. Righi, The Origins of the State's Institutional Capacity. SSRN [Preprint] (2024). https://dx.doi.org/10.2139/ssrn.4124110 (Accessed on the 31/01/2024).
16. D. C. North, B. R. Weingast, Constitutions and Commitment: The Evolution of Institutions Governing Public Choice in Seventeenth-Century England. *J. Econ. Hist.* **49**, 803-832 (1989).
17. Y. Barzel, E. Kiser, The Origins of Democracy in England. *Ration. Soc.* **3**, 396-422 (1991).
18. R. K. Fleck, F. A. Hanssen, The Origins of Democracy: a Model with Application to Ancient Greece. *J. Law. Econ.* **49**, 115-146 (2006).
19. R. B. Myerson, The Autocrat's Credibility Problem and Foundations of the Constitutional State. *Am. Political Sci. Rev.* **102**, 125-139 (2008).
20. G. Benati, C. Guerriero, The Origins of the State: Technology, Cooperation and Institutions. *J. Institutional Econ.* **18**, 29-43 (2022).
21. S. Boranbay, C. Guerriero, Endogenous (In)Formal Institutions. *J. Comp. Econ.* **47**, 921-945 (2019).
22. C. Guerriero, Endogenous Institutions and Economic Outcomes. *Economica* **87**, 364-405 (2020).
23. A. Litina, Natural Land Productivity, Cooperation and Comparative Development. *J. Econ. Growth* **21**, 351-408 (2016).
24. Q. Ashraf, O. Galor, 2013. Genetic Diversity and the Origins of Cultural Fragmentation. *Amer. Econ. Rev.* **103**, 528–533 (2013).
25. O. Olsson, C. Paik, Long-run Cultural Divergence: Evidence from the Neolithic Revolution. *J. Dev. Econ.* **122**, 197–213 (2016).
26. N. Voigtländer, H. Voth, Malthusian Dynamism and the Rise of Europe: Make War, Not Love. *Amer. Econ. Rev.* **99**, 248–254 (2009).