Climate Change, State-Building and Societal Resilience in Bronze Age Egypt.

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Abstract: *We combine the time inconsistency theory of state-building with the first provincial data set on the climate, state institutions and population dynamics of Bronze Age Egypt to document two crucial patterns inconsistent with the collapse archeology literature mantra that the 4.2 ka BP megadrought induced societal breakdown. First, an enduring period of low Nile floods and droughts pushed the Pharaohs of the late Old Kingdom and First Intermediate Period to acquiesce to—if not favor—a larger fiscal autonomy of the provinces hit the hardest by climate shocks. This institutional discontinuity allowed locally-selected governors to provide the public goods preferred by provincial non-elites. Second, the stronger provincial non-elites' control over fiscal policies, which, in our model, sustains cooperation in farming investments, was associated to a more resilient settlement. Crucially, our estimates are inconsistent with the appropriability theory of the state and unaffected by considering either the degree of environmental circumscription or the severity of conflicts. In addition, they are consonant with the idea that climate change shaped ancient Egypt directly via worse production conditions and indirectly via institutional resilience.* **Keywords:** *ancient Egypt; climate change; state-building; time inconsistency; collapse; environmental circumscription.*

Summary: *We combine the time inconsistency theory of state-building with the first provincial data set on the climate, state institutions and population dynamics of Bronze Age Egypt to show that the 4.2 ka BP megadrought favored institutional resilience, while worsening production conditions.*

"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 state societies during the Neolithic Revolution (1-2), a pioneering archaeological literature has correlated the severity of climate change to state formation and evolution, i.e., state-building (3-4). This evidence suggests that persistent droughts—"cold and dry spans" (5)—invariably triggered economic crises and state dissolution (6-13). This dynamics would, for instance, explain the weakening of the Pharaohs' power and an alleged societal collapse in the aftermath of the 4.2 ka BP megadrought (13).[1]

Yet, the credibility of the conclusions of this "collapse archaeology" literature is undermined by three limitations. First, this strand of research lacks a formal theorical foundation identifying the strategic determinants of state-building and societal resilience and, thus, helping selecting the functional form of the equations linking these variables (14-18). Second, it relies on proxies whose measurement is not theoretically informed and is, thus, prone to large errors (19). To elaborate, these contributions capture societal resilience via either anecdotal evidence or very coarse proxies for limited external conflicts, and they measure state-building with the presence of jurisdictional hierarchies and/or the lack of internal conflicts (6-13). While, however, the first group of proxies is merely symptomatic of societal resilience, intended as the ability of "all groups in society to move forward equally following a shock, making inclusivity an essential subject to tackle" (20), the second group of proxies does not pick those institutions allowing the elites to convince the non-elites to cooperate in the face of adverse shocks (21).[2] To make matters worse, the collapse archaeology literature gauges climate change through the still limited coeval hydro-climatic records (6-10,12,13), which are only poor proxies for the climate conditions prevailing in distant polities (23-24). Finally, this literature focuses on the single impact of environmental shocks on state-building overlooking their, possibly more relevant, combined and indirect effects (25-27).

We tackle all these issues by blending the "time inconsistency" theory of state-building (23-24), novel institutional proxies informed by this model and highly granular climate data (28) to study the impact of the 4.2 ka BP megadrought on the institutional evolution and degree of resilience of the 34 capitals of the main Egyptian provinces, which we observe for each half-century between 2900 and 1750 BCE. Our capital fixed effects ordinary least squares—OLS—reveal two patterns that are inconsistent with the collapse archeology literature mantra (29-30). First, an enduring period of low Nile floods and droughts pushed the Pharaohs of the late Old Kingdom and First Intermediate Period to acquiesce to—if not favor—a larger fiscal autonomy of the provinces hit the hardest by climate shocks. This institutional discontinuity allowed locally-selected governors to provide the public goods preferred by provincial non-elites, i.e., irrigation projects, defensive walls and temples. Second, the stronger control over fiscal policies by the provincial non-elites, which, in our model, sustains cooperation in farming investments, was associated to a more resilient settlement.

Our results hold across identification strategies and, notably, when we control for the: 1. degree of climate volatility, which is linked to the strength of norms of cooperation and, in turn, a more inclusive political process (21); 2. degree of environmental circumscription, which is the difference between the productivity of a province and that of the surroundings and, thus, should discourage exit, unrest and the rise of a more inclusive social order (31-34); 3. severity of internal and external conflicts capturing the elites' need to share their power with the non-elites to, respectively, avoid expropriation and encourage them to fight invaders (35,36). Moreover, the fact that high Nile floods, reducing output observability, were positively linked to jurisdictional hierarchy is inconsistent with the appropriability theory of the state, which maintains, instead, that an opaquer production process should have pushed the elites to share their power to incentivize the non-elites (37).

Our estimates square with four stylized facts (see SM appendix). First, the mild climate and high Nile flow of the late Neolithic and Predynastic periods (8000-2900 BCE) favored the rise of an agrarian society that, because of the peculiar structure of the floodings, could not be organized around centrally-planned feeder canals parallel to the river but necessitated the cooperation of

[1] Albeit the Egyptian term "pr-aA" leading to the English word "Pharaoh" was introduced only in the New Kingdom, we follow the vast majority of the social sciences literature and we stick with the term "Pharaoh."

[2] Our view of resilience is then consistent with (22)'s one, i.e., a drop in social complexity without disintegration.

large groups of farmers in the management of local irrigation basins (38,39). By the onset of the 4th millennium, this regionally fragmented economy was coordinated by chiefdoms in southern—Upper—Egypt and loosely organized hierarchies in northern—Lower—Egypt (40-42). Against this background, inter-polity competition raged until the creation by the Naqada culture of a unified kingdom revolving around a capital (40,41). The kings of the Early-dynastic period (2900-2593 BCE) emerged from this experience, strengthened their control over Lower Egypt and managed from Memphis the labor force necessary to support farming in the delta region and the lucrative long-distance trades reaching the Levant (40). This structure continued to characterize the first phase of the Old Kingdom (2592-2120 BCE) until the extended period of low Nile floods and droughts of the 23rd and 22nd centuries BCE forced the Pharaohs to grant increasing power to rising local elites promoting their cults (43). While the governors—i.e., nomarchs—of the provinces—i.e., nomes—located in the delta region and northern part of Upper Egypt helped the Pharaoh's control these provinces from his palace, those of the southern nomes, which were hit the hardest by climate shocks (38), acquired the fiscal autonomy of keeping part of the tax revenues and employing them to provide local public goods (42-44). Third, in concomitance with the new series of droughts of the First Intermediate Period (2119-1980 BCE), Egypt first split in a northern Heracleopolitan kingdom under the ruling of the Ninth and Tenth Dynasties and a southern Theban reign under the power of the Eleventh Dynasty and, then, reunited under the latter (45). Contrarily to the conjecture of the collapse archaeology literature, the southern capitals thrived and local trade expanded (42,45,46). Crucially, the resilience of Upper Egypt rested on the Pharaoh's need of reaching a new social contract with local farmers by acquiescing to—if not favoring—their fiscal autonomy and, in turn, the provision of their preferred public goods, i.e., irrigation projects, defensive walls and temples (42,47,48). The temples, in turn, provided justice as well as key risk-sharing activities, like grain storage and local market organization (42,46,48). Finally, the milder climate of the Middle Kingdom (1979-1630 BCE) favored the reunification of Egypt, a northward territorial expansion and an increasing fiscal centralization (39,40). With Amenemhat III's reign indeed, a novel administrative system characterized by local offices closely linked to the royal palace slowly prevailed (39).

Next, we first illustrate our theoretical framework and then, we discuss our empirical exercise. We close by proposing a more general strategy for future research on the interplay among climate change, state-building and societal resilience able to structure credible assessments of the impact of climate shocks on developing countries and, thus, inform environmental policies (49-50).

2. A Time Inconsistency Model of State-Building

Our model is a simplified version of those proposed by (23) and (51). While we report the formal analysis in the SM appendix, we summarize the main intuitions of the model solution in this section.

We study the possible cooperation between elites and non-elites in a joint activity, e.g., farming. While the elites gather the agents with control over scarce resources and the institutional design, the non-elites assemble the initially rightless agents (52). In our historical case, the Pharaoh, his family and the royal administration represent the former, whereas each nome stands for the latter (53). The joint activity delivers an output only if the non-elites commit a costly investment—e.g., cooperate in a local irrigation project, and the output value is larger the more favorable are the production conditions, e.g., milder climate. The elites keep the untaxed output and cannot commit to direct transfers to incentivize the non-elites, i.e., they are time-inconsistent. These hypotheses build in our model the intuition of a long literature on the time inconsistency issues inherent to politics (54). More important, they can be relaxed, and they are justified by, respectively, the distribution of property rights over our sample and the fact that contracts tended to be enforced by courts controlled by the same elites promising not to renege on transfers (see the SM appendix). The elites can, however, entice the non-elites by enacting a more inclusive political process, which grants them the power to pick the tax rate and their preferred public good. Crucially, the gist of our analysis will be the same should we maintain that: 1. either the elites or the non-elites must assure, when designing fiscal policies, a reservation utility to a Nomarch, who gathers the tax revenues and might pocket the untaxed output; 2. the elites can try to incentivize the non-elites by punishing them, since they would be unable to do it because participation cannot be always attained (23).

Since all agents have a zero outside option, two are the main features of the equilibrium. First, if 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 fully tax the output and produce their preferred

public good (55-58). Through these choices, the non-elites maximize their utility from cooperation and, in turn, their fitness as well as society's resilience to adverse production shocks. Second, if the investment return is sufficiently large and, thus, time inconsistency issues are less severe, the elites, who prefer private to public consumption**,** keep the control over fiscal policies. To illustrate, they select a tax rate leaving the non-elites at their reservation utility and, thus, decreasing with the output value. In the case of an economy for which the production conditions were never too adverse, like the portion of Bronze Age Egypt that we study (59), our model entails two predictions:

Predictions: *1. The adoption of a more inclusive political process is more likely, the smaller is the investment return. 2. Such an institutional discontinuity fosters the provision of the public goods preferred by the non-elites and is associated to a larger degree of societal resilience.*

Table 1. Capitals of the Nomes Part of the Sample

Upper Egypt: Elephantine (*Yebu*), Edfu (*Edjbo*), Elkab (*Nekheb*), Thebes (*Weset*), Qift (*Gebtyu*), Dandara (*Inu*), Hiw (*He-sekhem*), Abydos (*Abdju*), Akhmim (*Khant-min*), Qaw el-Kabir (*Tjebu*), Shutb (*Shashotep*), El-Atawla (*Per-nemty*), Asyut (*Saut*), El-Qusiya (*Qesy*), El-Ashmunein (*Tjerti*), Kom el-Ahmar (*Hebnu*), El-Sheikh Fadl (*Hardai*), El-Hiba (*Hutnesut*), El-Bahnasa (*Spermeru*), Heracleopolis (*Henennesut*), Kafr Ammar (*Shenakhen*), Atfih (*Tepihu*). Lower Egypt: Memphis (*Mit Rahina*), Ausim (*Khem*), Kom El-Hisn (*Imu*), Sais (*Zau*), Buto (*Per-wadjet*), Damanhur (*Ament*), Abu Sir Bara (*Djedu*), Tell Atrib (*Hut-hery-ib*), Samanud (*Sebennytos*), Materiya (*Iunu*), Baqliya (*Weprehwy*), Tell El Rub (*Djedet*).

Note: The names of the present-day archaeological sites are in regular lowercase type, whereas the corresponding names of the capitals of the nomes, which constitute the cross-section identifiers of our analysis, 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 mostly populated over the 2900-1750 BCE period and we consider the 24 half-centuries within this temporal span as our time periods. While the names of these capitals and the corresponding present-day archaeological sites are reported in table 1, their locations are displayed in figure 1.

Two are the key constraints that have guided our choice. First, the polities that we select display sufficient settlement continuity and political relevance (60). As shown by figure 1, there were eight other nomes whose capitals were mostly unpopulated over the sample because of their distance to the Nile (61).[3] As discussed in the SM appendix, our results are qualitatively similar when we include the information available for these capitals. Second, the institutional evolution of the period preceding the invention of the hieroglyphic writing is still poorly understood, whereas the post-1750 BCE ascendancy of the Hyksos population in the Nile delta and Middle Egypt obscured the evolution of the single provinces (40). By employing instead the "low" chronology, which has been proposed by (62) and combines king lists with Carbon-14 evidence, it is, instead, possible to quite accurately link historical with archaeological data and, therefore, minimize measurement errors.[4]

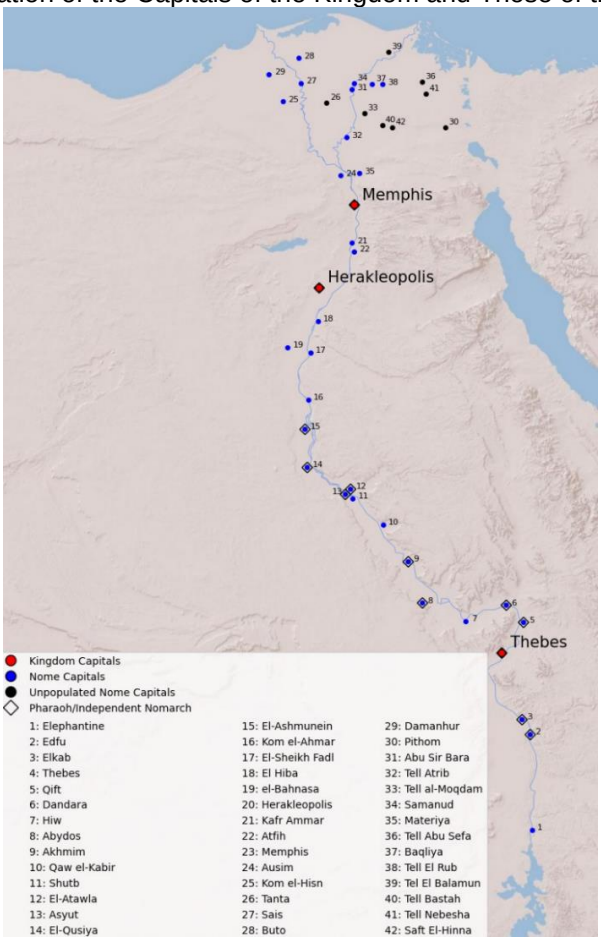
3.1 Measurement

In Malthusian economies, like those part of our sample, technological innovations only produce population growth (65). Hence, the degree of inter-group cooperation that was only made possible, despite the adverse climatic shocks, by a more inclusive social order should result in a more resilient settlement (21). Building on this remark, we elect as proxy for the degree of societal resilience the natural logarithm of the population of the capital averaged over the previous half-century and estimated by (60) (see table 2 for definition and sources of the variables that we employ in the basic estimates), i.e., *Population*. To illustrate, (60) provides an assessment of the average population of some our capitals over the Old Kingdom as well as over First Intermediate Period and Middle Kingdom by combining the size of each archaeological site with estimates of the relative population density and reports the strong correlation between the resulting figures and a measure of the Nile delta capacity to sustain settlement (see the bottom-right graph in figure 2).

[3] The estimates of an Heckman model run on data from all 42 nomes suggest the residuals of regression and selection equations are unrelated. To identify the latter, we build on the fact that the excluded polities lie in north-east Egypt and, thus, selection is negatively related to latitude, longitude and distance to the Nile (61).

[4] Since our institutional proxies are based on the 40 years around each date, the impact of the dating errors of the low chronology, which range between 12 and 25 years (62), is limited and will just inflate standard errors when institutions are the dependent variables (63). The alternative "high" chronology produces similar results (see the SM appendix), but displays errors ranging between 20 and 200 years (64). Finally, results available upon request and comparing Old with Middle Kingdoms are even more consistent with our model.

Figure 1. Location of the Capitals of the Kingdom and Those of the Nomes



Note: The figure depicts the locations of the capitals of the kingdom, nomes included and those excluded.

Turning to the provision of the public goods preferred by the non-elite, we follow (23), and we rely on the average number of forts and temples built over the previous half-century (66-68), i.e., *Public-Buildings*. While the palatial elites preferred the construction of colossal pyramid tombs, the non-elites favored the realization of defensive infrastructures and the management by local temples of justice and risk-sharing activities, like grain storage and local market organization (42-48,67). As the proxies for the non-elites' political rights, these variables are based on historical analyses of the single periods and capital-specific secondary sources informed by archaeological data (66-68).

Table 2. Summary of Variables

	Variable	Definition and Sources	Statistics
State-building:	*Political-Institutions*	1 if the nome was fiscally autonomous in a 40-year window around each time period and 0 otherwise. Sources: see the SM appendix.	0.058 (0.233)
	Public-Buildings	Average number of forts and temples built over the previous 50 years. Sources: (66-68).	0.045 (0.331)
Societal resilience:	*Population*	Natural logarithm of the population of the capital averaged over the previous 50 years. Source: (60).	7.779 (1.637)
Climate change:	*PDSI*	PDSI averaged over the previous 50 years. Sources: (28) and HWSD dataset, available at https://www.fao.org/soils-portal	- 0.535 (0.934)
	Sr-Ratio	87Sr/86Sr ratio normalized to range between 0 and 1 and averaged over the previous 50 years. Source: (38).	0.290 (0.260)

Note: The last column lists mean and, in parentheses, standard deviation, all calculated for the samples used in table 3.

Regarding the inclusiveness of the political process, which in our model corresponds to fiscal autonomy, we follow (23), and we build on the events in a 40-year window around each time period to construct a dummy for fiscally autonomous nomes, i.e., *Political-Institutions*. As detailed in the SM appendix, the fiscally autonomous nomes appeared with the Seventh Dynasty and were

administered by either a local ruler or a Nomarch with the title of *ḥrj-tp ʿ*, i.e., Great Chief of nome X. More generally, *Political-Institutions* can also be seen as a direct measure of political decentralization and/or an inverse proxy for jurisdictional hierarchy (37). Finally, to gauge the environmental factors key to the domestication of cereal grains, which were the most diffused crops (40-44), we build on broad botanical evidence showing that: 1. wheat and barley farming is favored by a more suitable land, needs a temperature ranging between 5 and 37 degrees Celsius and suffers from water scarcity; 2. cereal yield anomalies are mainly explained by climate extremes (69-70). Absent historical data on the land suitability (23-24) and being the Egyptian agriculture primarily irrigated, we then focus on the following two proxies for investment return.[5]

First, we consider the provenance patterns of the Nile sediments as a time-varying and capital-invariant proxy for the Nile flow level. This choice is quite appropriate since 95% of the sediments derive from the Ethiopian Highlands via the Blue Nile (38), which drains a catchment area with Cenozoic volcanic rocks with low 87Sr/86Sr ratios. Hence, their observation is indicative of larger sedimentation of the terranes coming from the Ethiopian highlands and, thus, of a limited Nile flow. Ultimately, we employ as a Nile flow proxy the normalized—to range between 0 and 1—87Sr/86Sr ratio averaged over the previous half-century and collected from the Manzala Lagoon by (38), i.e., *Sr-Ratio*. The following three remarks support this choice. First, (38) validate the time series dimension of *Sr-Ratio* by documenting its correlation with known changes of the Nile flow. Second, the correlation between *Sr-Ratio* and a marker of the delta freshwater obtained from pollen records collected from Sais by (71) is positive—0.24—and significant at 1%, conditional on a marker of drought severity also obtained by (71) and temperature and rainfall proxies simulated by (28). Finally, the correlation between *Sr-Ratio* and our inverse proxy for drought severity evaluated at the source of the Blue Nile in lake Tana is positive and significant at 5%, conditional on temperature and rainfall proxies collected from (28) and evaluated at lake Tana and temperature, rainfall and inverse drought severity measures collected from (28) and evaluated at Manzala Lagoon.[6]

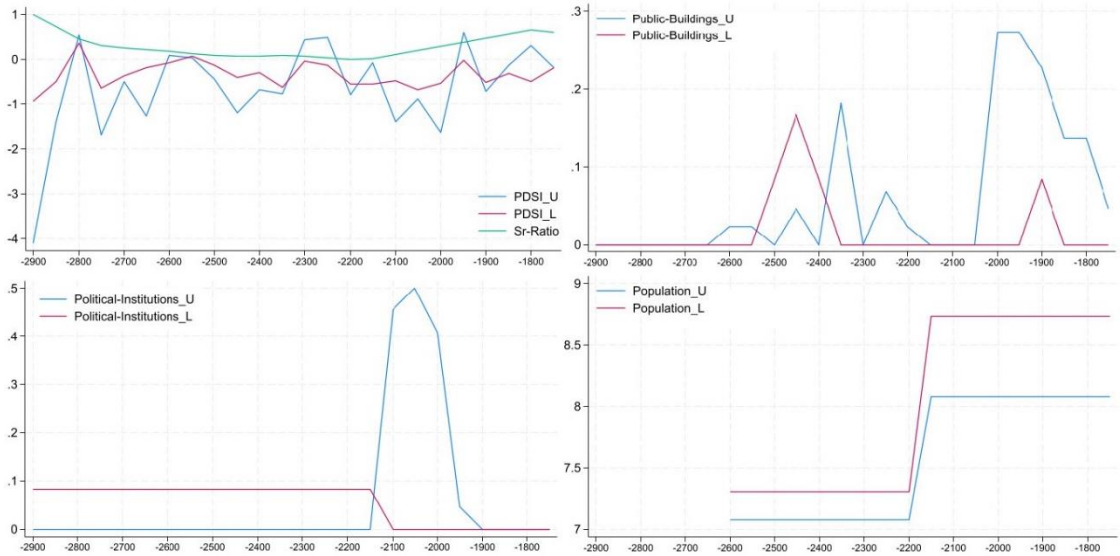
Second, we build on (73), and we calculate the Palmer drought severity index—PDSI—by mixing temperature, rainfall, latitude and available water storage capacity, all averaged over the previous half-century, i.e., *PDSI*. To elaborate, we collect the water storage capacity, which is defined as the mm/m 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. We get, instead, the climate data directly from (28), which simulate them for each month between 60,000 and 0 BP—i.e., 1950—and the northern hemisphere at a 0.5 degree spatial resolution.[7] The model underlying this 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). 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 (74). Then, the PDSI, like the abundance of the Nile inundation, is a key driver of both yield anomalies and the efficiency of harvest storage (59,74). Crucially, our empirical results are unaffected by considering also the rainfall and temperature levels (results available upon request). Three pieces of evidence support our choice of focusing on the *PDSI*. First, (28) validate the time series and spatial variation of their simulations by employing, respectively, coeval proxy data and present-day data. Second, we corroborate such conclusions by documenting that the correlation between *PDSI* and a proxy for the temperature of the rainfall, defined as the oxygen stable isotope ratios—i.e., δ18O—and extracted from Qunf and Soreq caves' speleothems (75-76), is, for these locations, positive—0.35—and significant at 1%, conditional on the temperature and rainfall proxies collected from (28) as well as the caves' coordinates. Crucially, albeit (13) proxy the climate through the records extracted from Qunf and Soreq caves, their correlation with the PDSI of the nearest capital in our sample is insignificant (24). Finally, (26) document, for the 44 major Mesopotamian polities observed for each half-century between 3050 and 1750 BCE, that the PDSI is significantly related to the coeval barley yields in liters per hectare reported by cuneiform administrative texts.

[5] Conditional on observable factors, the interaction of these two variables is statistically insignificant.

[6] Similarly, the correlation between the Nilometer data calculated at Rhoda island by (72) and the climate conditions at this location is significant at 5%, conditional on the coeval climate at Manzala Lagoon.

[7] We average data over the entire year since growing and harvest periods lasted from October to May (59).

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



Note: The upper-left graph depicts the PDSI averaged over the previous half-century and the capitals of either Upper or Lower Egypt as well as the 87Sr/86Sr ratio. While the capitals of Upper Egypt are labeled with a subscript U, those of Lower Egypt are tagged with a subscript L. Upper-right, bottom-left and bottom-right graphs portray, respectively, the number of forts and temples averaged over the previous half-century and the capitals of either Upper or Lower Egypt, the inclusiveness of political process averaged over 40 years around each date and the capitals of either Upper or Lower Egypt and the natural logarithm of the population averaged over the previous half-century and the capitals of either Upper or Lower Egypt. While table 1 reports the composition of each group of capitals, table 2 details definition and sources of each variable.

3.2 Basic Empirical Results

A glance at figure 2 reveals that the model predictions square with three patterns evident in our data. First, the combination of low Nile flows and intermediate droughts of the 2300-2000 BCE period pushed the Pharaohs to acquiesce to—if not favor—a larger fiscal autonomy of the some of the southern provinces, which were hit the hardest by climate shocks, and the relative governors to use the tax revenues at their disposal to provide local public goods (compare upper-left graph with upper-right and bottom-left graphs). Second, this discontinuity, which, in our model, sustains cooperation in farming investments, was associated to a more resilient settlement (see bottom-right graph). Finally, the milder climate and consequent fluctuating moderate Nile flow of the Middle Kingdom favored the reunification of the country under a centralized monarchic power.

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

	(1)	*(2)*	*(3)*
		The dependent variable is:	
	Political-Institutions	*Public-Buildings*	*Population*
Public-Buildings			0.057
			(0.116)
Political-Institutions		0.226	0.470
		(0.054)***	(0.193)**
PDSI	- 0.042	0.009	- 0.112
	(0.008)***	(0.012)	(0.078)
Sr-Ratio	- 0.110	0.048	1.972
	(0.028)***	(0.043)	(0.228)***
Estimation		OLS	
Observations	816	816	369
R^2	0.04	0.02	0.20

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

These dynamics are confirmed by the capital 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 vary across capitals. We document, however, in the SM appendix that the message of our analysis is similar when we either cluster the standard errors at the capital

level, correct them for generic spatial dependence or both exclude *Sr-Ratio* and consider time fixed effects. The estimates in table 3 reveal three key regularities in our data. First, both a lower supply of soil moisture and a lower Nile flow are positively and significantly—at 1%—related to a nome's fiscal autonomy (see column (1)). As revealed by the average semi-elasticities of the conditional probability of a reform reported in the SM appendix, a one-standard deviation fall in *PDSI* leads to a 77% increase in the conditional probability of a switch towards fiscal autonomy, whereas a one-standard deviation decrease in *Sr-Ratio* entails a 90% rise in the same probability. Second, these reforms are significantly—at 1%—linked to larger provision of forts and temples (see column (2)). Finally, worsened climate conditions and, notably, a lower Nile flow have both the direct and negative impact of decreasing the population and the indirect and positive effect of increasing the inclusiveness of the political process, which, in turn, is associated to a stronger societal resilience (see column (3)). Crucially, a simple back-of-the-envelope calculation suggests that the magnitude of the second effect is roughly half of the magnitude of the first one.[8] Furthermore, consistent with our model, reforms towards a more inclusive political process are a sufficient statistics for more intense cooperation and, thus, completely trump the effect of larger public good provision.

3.3 Gaining More Insights About Causality

Even if our OLS estimates are consistent with our model predictions, they may be capturing reverse causality, they might be attenuated by measurement errors and/or they may be driven by omitted variables. In the SM appendix, we evaluate these issues reaching three conclusions.

First, the independence of the proxies for the return on farming from human decisions excludes reverse causation from institutions to environmental conditions. Furthermore, the fact that the provision of the public goods preferred by the non-elites is not positively related to future values of the inclusiveness of the political process is inconsistent with the average number of forts and temples driving the inclusiveness of the political process given the lag with which institutions adjust. Second, our conclusions remain unchanged when we deal with measurement error by considering either alternative proxies for fiscal autonomy or an alternative measure of the provision of the public goods preferred by the non-elites crudely obtained by subtracting the average number of forts and temples to that of mastabas and pyramids. As illustrated in the SM appendix, starting with the Sixth Dynasty, the Kingdom's shrinking resources were shifted from the construction of huge pyramids magnifying the Pharaoh to the provision of local public goods (see figure S1). Finally, we follow a two-step strategy to evaluate unobserved heterogeneity. First, we document that our results are robust to considering the degree of climate volatility, the degree of environmental circumscription and the severity of conflicts.[9] While we capture the first factor with the standard deviation of the PDSI over the previous half-century, we inversely pick the second one with the normalized average over the previous half-century of the ratio of a dummy for the yearly PDSI lying between – 4 and 0 to a similar dummy averaged over the other capitals and weighted by their inverse distance.[10] Finally, we proxy internal and external conflicts with the share of previous half-century over which a nome witnessed either of the two (77). Contrary to the claims of the related literature (31-34), the degree of environmental circumscription has no impact on state-building and/or societal resilience. Second, we calculate how much greater the influence of unobservable factors, relative to the influence of the degree of climate volatility, the degree of environmental circumscription and the severity of conflicts, would need to be to explain away the main estimates. We find that it would have to be on average almost 22 times greater, which seems quite unlikely.

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

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[8] For the sample for which *Population* is observed and the fixed effect Logit with dependent variable *Political-Institutions* can be run, the direct effect of a one-standard deviation fall in *Sr-Ratio* was to reduce the population of 43% whereas its indirect effect was to raise it of 20%. We obtain similar figures via a mediation analysis.

[9] Albeit the explicit inclusion of climate factors takes cares of the omitted variable bias, we do not consider the impact of the inclusiveness of the political process on the population as causal since *Political-Institutions* and *Population* are both jointly determined by the climate shocks (see 47-48 and the SM appendix).

[10] Intermediate and negative values pick adverse, but not unbearable shocks favoring state-building (26).

4. Conclusions

Building on the first provincial data set on the climate, institutional evolution and population of Bronze Age Egypt, we document that an enduring period of low Nile floods and droughts pushed the Pharaohs of the late Old Kingdom and First Intermediate Period to acquiesce to—if not favor—a larger fiscal autonomy of the provinces hit the hardest by climate shocks. This discontinuity allowed locally-selected governors to provide the public goods preferred by provincial non-elites. Crucially, the stronger provincial non-elites' control over fiscal policies, which, in our model, sustains cooperation in farming investments, was associated to a more resilient settlement. Ultimately, and contrary to the conjecture of the collapse archeology literature, the 4.2 ka BP megadrought did not provoke Egypt's societal breakdown, but shaped these ancient societies both directly via the deteriorated production conditions and 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 (26). First, any such project should build on game theoretical models clarifying the incentives that link exogenous environmental 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 the heterogenous quality of archaeological data and their aggregation process. This last recommendation is particularly relevant to shed light on the pre-colonial institutional causes of the present-day underdevelopment of Africa. The main insight about this link comes from the correlations between the pre-colonial institutional data reported in (78) and present-day economic outcomes (79). Over and above the lack of a robust theoretical 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 the archaeological and anthropological literature.

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This file includes: Main text, tables 1 to 3 and figures 1 to 2.

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Supplementary Materials for

Climate Change, State-Building

and Societal Resilience in Ancient Egypt.

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Supplementary Materials for this manuscript include:

Historical Evidence
A Time Inconsistency Model of State-Building
Errors in the Measurement of Archaeological Variables
Empirical Methodology
Figure S1 and Tables S1 to S6
SM References

I. Historical Evidence

Late Neolithic and Predynastic periods (8000-2901 BCE).—The fertile Nile valley favored since 8000 BCE the development of regionally fragmented agricultural economies (1). To elaborate, during the flood, "settlements were almost cut off from the outside world. And when the Nile receded, the peasantry had to till the fields. [This dynamics implied] a relatively immobile population [and that] irrigation […] did not operate based on feeder canals parallel to the Nile, but on canals more or less perpendicular to the river. [Intuitively, making] use of natural elevations and dykes, artificial basins were created on higher land to prevent all the water from flowing away to lower areas [faraway from the levees on active or abandoned river banks]. [Within] local units a degree of cooperation must have existed to make the system work, and where chains of basins are involved, fairly large groups of persons are likely to have been involved" (2). As the climate grew arid, the population concentrated along the river (3) and, by the onset of the 4th millennium BCE, Upper Egypt was under chiefdoms, such as those ruling Abydos, Naqada, and Hierakonpolis, whereas Lower Egypt was characterized by a lower social differentiation (3). Against this background, fierce inter-polity competition ended up favoring by 3500 BCE the creation by the Naqada culture of a unified proto-kingdom revolving around a capital, i.e., Hierakonpolis, first, and Abydos, later (1). The 3300 BCE advent of written records, moreover, allowed these rulers to label and keep track of goods, leading to an incipient bureaucracy and a centralized government (3).

Early-dynastic period (2900-2593 BCE).—The monarchs of the First Dynasty emerged from this experience. To elaborate, king Narmer of Upper Egypt strengthened his control over Lower Egypt and established the capital at Memphis (4), thereby unifying the country. From here, he could organize both the labor force necessary to support farming in the fertile delta region and the lucrative exchanges reaching the Levant (4). Even if the bureaucratic machinery had not yet attained full maturity, the centralized state soon stretched from Elephantine to the Mediterranean (4). To control this vast area, the royal household relied on the *šmsw ḥr.w*, i.e., “followers of Horus” (5). This biennial inspection of the reign aimed to oversee tax collection and the administration of justice (5). Another innovation, the *ḥw.t* centers—i.e., “enclosures”—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 managing the labor force, production processes, food storage, and tax collection (4). The cities, instead, covered apparently no crucial role within the royal administration. This organizational structure started to change during the Old Kingdom.

Old Kingdom (2592-2120 BCE).—A first phase witnessed the construction of the first pyramids symbolizing the Pharaohs' dominance, the rise of religious practices exalting the sun god Ra, intensified foreign expeditions, and the centralization of administrative offices under and around the royal household (4,6). This bureaucracy, who was initially based in the capital *Inbu-hedj*—later known as Memphis, carried the *imy-rꜣ*—i.e., "overseer"—and *ḥqꜣ*—i.e., "governor"—title and managed the state affairs via the *ḥw.t* centers and temples (6). Only with the Fourth Dynasty, production and taxation were entrusted to a vizier usually selected among the Pharaoh's sons and the temples strengthened their role of guardians of the Pharaoh's power (6). A second phase, beginning with the Fifth Dynasty, was, instead, characterized by the rise of provincial elites promoting their own cults and independence (4). To counteract such centrifugal forces, the Pharaohs shifted their effort from the construction of huge pyramids to the organization of marriages between their household and non-royal elites, the erection of new sun temples, and the empowerment, especially in Upper Egypt, of the provincial capitals (6). Moreover, during Djedkara's reign, the provinces—i.e., nomes, which were denominated according to their protective deity, gained relevance, and their governors, the *ḥrj-tp ʿꜣ*—i.e., Nomarchs, "great chief" or "overseer", started to collect taxes and manage the construction of public buildings on behalf of the Pharaoh (6,7). Despite these centralization attempts, during the 23rd and 22nd centuries BCE period of low Nile floods and droughts (8), non-royal households acquired an elite status, which they showcased by shoring up their displays of personal piety to the afterlife cult of Osiris and erecting tombs in their own provinces (6). More importantly, while the Nomarchs of the delta region and the northern part of Upper Egypt continued to govern their provinces from the royal palace, those of the southern nomes acquired the fiscal autonomy of keeping part of the tax revenues and employing them to finance the provision of local public goods (6,9). With time, the Upper Egyptian Nomarchs started to pass down their *ḥrj-tp ʿꜣ* title in hereditary fashion, build their own tombs without royal oversight, and donate land to the provincial temples to earn the favor of the local gods (6,9). To preserve their power, the Pharaohs also distributed lands to the temples and established seats of the vizier in Edfu, first, and Abydos, later (6). Yet, the centrifugal forces prevailed and, first, 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 nomes (6), and, then, Pepi I and Pepi II became the first Pharaohs to marry the daughters of Southern Nomarchs and eventually lose their unitary political power. As a result of this institutional dynamics, the Seventh and Eight Dynasties were only able to rule for a very brief period of time without de facto political control over the southern nomes (6).

First Intermediate Period (2119-1980 BCE).—In conjunction with a new period of harsh climate, Egypt split into a northern Heracleopolitan kingdom ruled by the Ninth Dynasty and a southern Theban reign revolving around the household of the local Nomarchs (4). Crucially, these governors, together with those of the other southern provinces, started to be an expression of local households rather than the royal administration (2). The territorial antagonism between the Heracleopolitan kingdom and the Theban reign endured for approximately a century and culminated with the military triumph of the latter and the consequent reunification of Egypt (4). Meanwhile, the southern capitals thrived and local trade expanded (4,10,11). Crucially, the resilience of Upper Egypt rested on the Pharaoh's need of reaching a new social contract with local farmers by acquiescing to—if not favoring—their fiscal autonomy, which, in turn, eased the provision by the local Nomarchs of the regional non-elites' preferred public goods, i.e., irrigation projects,[11] defensive walls and temples (2,4,11). The temples, in turn, "took on some of the managerial activities hitherto restricted to the crown" (4) such as the administration of justice as well as key risk-sharing activities, like grain storage and local market organization (4,6,11). To finance these activities, the temples relied on the resources obtained from the exploitation of land and mines donated by the Pharaohs first and local elites later (4). Crucially, "access to priesthood was fiercely controlled by local associations of priests" (4). Lower Egypt, instead, remained under the relatively loose control of Heracleopolis (4).

[11] The Nomarchs also settled conflicts between neighboring capitals about rights over water (2).

Middle Kingdom (1979-1630 BCE).—Characterized by milder climate and fluctuating moderate Nile flow (7), the Middle Kingdom opened with the reunification of the reign by the Theban kings of the Eleventh Dynasty**,** the relocation of the capital to Thebes and a northward expansion (12). To illustrate, the Theban kings' victory at Asyut prompted several nomes, who had supported before the Heracleopolitan kings, to switch side (12). While many of these provinces lost autonomy, the southernmost Aswan nome was even reinstated in response to the burgeoning influence of the emerging Nubian Kingdom of Kush (12). The tension between the central government and the nomes, however, continued until the late Twelfth Dynasty, when Amenemhat III was finally able to subdue the provincial system (12). This success gave rise to a novel administrative system characterized by offices strictly linked to the royal palace (12). Local administrators assumed the title of *ḥꜣtj-ʿ*—i.e., "town mayors"—and actively helped enforce the royal authority over the provinces and their capitals (12). Moreover, at the intermediate level, a *ḥry-tp šmʿ*—"Head of the South"—figure linking Upper Egypt to the capital of the kingdom was established (12).

Constructing the proxies for inclusive political institutions.—We identify the provinces whose Nomarchs held the *ḥrj-tp ʿꜣ* title through (13-17), and we assign to these nomes a value of *Political-Institutions* equal to 1 for the period during which they were fiscally independent. The latter happened for one or more half-centuries between the Seventh Dynasty and the 1950 BCE reunification. By the onset of the Middle Kingdom, all nomes had gradually lost fiscal autonomy. Similarly, *Political-Institutions-O* equals 3 whenever *Political-Institutions* equals 1, 2 if the nome was administered by a Nomarch gathering taxes on behalf of the Crown and 1 otherwise.

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 are zero.[12]

The non-elite's utility under 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 transformation and transfer rights to the input, leaving to the non-elite only the use rights. Accordingly, she appropriates the entire untaxed output (18-19).[13] Second, we assume that the elite lacks the ability to commit to direct transfers to the non-elite (20-24), because, for instance, contracts tended to be enforced by courts controlled by the same members of the elite promising not to renege on transfers (25). While the first assumption squares with the fact that land ownership steadily represented the crucial divide between elite and non-elite (26), the second hypothesis is consistent with the idea that, only starting with the First Intermediate Period, the administration of justice was gradually transferred from royal courts to provincial judicial bodies populated by representatives of the non-elite (27). Crucially, both assumptions can be easily relaxed as clarified below (see also footnote 14).

The elite can incentivize the non-elite by enacting an inclusive political institution $r = I$, which allows the non-elite to pick fiscal policies. 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 and βg_r to its partner. 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,

[12](18) also allow for positive elite's and non-elite's outside options. Since there is no uncertainty over V, the equilibrium will be the same should agents be risk-averse. Should V capture, instead, the expected output value, the non-elite will require a strictly positive expected utility to participate but our conclusions will stand.
[13] We refer to the elite as "she," to the non-elite as "he" and to a generic party as "it."

the elite liked better (was better at) constructing colossal pyramid tombs than providing public projects such as irrigation works, defensive walls, and temples, and 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.

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.

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, he optimizes his payoff by maximizing the share of output contributing to public good provision, i.e., by selecting $\delta_I = 1$. This choice does not discourage the elite from participating being $\beta V > 0$. Ultimately, for $r = I$ and $V \geq \gamma/\rho \equiv \widehat{\Omega}$, $\delta_I^* = 1$ 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 invests but $V < \gamma/\beta \equiv \overline{\Omega}$ with $\widehat{\Omega} < \overline{\Omega}$. For $V \geq \overline{\Omega}$ instead, it can be satisfied when he cooperates and $\delta_A^* = \gamma/(\beta V) \leq 1$. 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. Ultimately, for $V \geq \overline{\Omega}$, the elite gains $\pi_A = (1-\delta_A^*)V + \rho\delta_A^* V > \beta V = \pi_I$ and autocracy prevails.

While production is unfeasible under any regime for $V < \widehat{\Omega}$, granting the inclusive political institution is the only way of garnering the non-elite's cooperation for $\widehat{\Omega} \leq \mathrm{V} < \overline{\Omega}$. 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 $\pi_A > \pi_I$. Crucially, the larger γ is, the more difficult is to support production and, thus, the larger is the ability of the inclusive political regime to elicit cooperation when autocracy cannot, i.e., the larger $\overline{\Omega} - \widehat{\Omega} = \gamma(\rho-\beta)/\rho\beta$ is. The following proposition summarizes our analysis:

Proposition: *For* $0 < \beta < \rho < 1$*: 1. If* $V < \gamma/\rho$*, production is unfeasible; 2. If* $\gamma/\rho \leq V < \gamma/\beta$*, the elite grants the inclusive political regime, whereas the non-elite picks the maximum tax rate* $\delta_I^* = 1$*, invests and obtains a weakly positive utility from cooperating; 3. If* $V \geq \gamma/\beta$*, the elite selects the autocratic regime and* $\delta_A^* = \gamma\ /\ (\beta V) \leq 1$*, and the non-elite invests and obtains a zero utility*.

In a world of inefficient public good provision, reforms towards inclusive political institutions make possible for $\widehat{\Omega} \leq \mathrm{V} < \overline{\Omega}$ a cooperation otherwise unattainable given the elite's time inconsistency issues. When these institutional arrangements are unavailable, the elite can elicit cooperation for $\gamma/\zeta \leq V < \gamma/\beta$ and $\zeta > \beta$ only if able to credibly offer ζV to the non-elite as either a direct transfer or an high-powered contract.[14] When, finally, the output value is sufficiently large—i.e., $V \geq \overline{\Omega}$, the elite prefers to direct fiscal policies and decrease taxation as the output rises.

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 (28). Similarly, it can be shown that, in dynamic versions of the model allowing the elite to regain the power to select fiscal policies after unforeseen favorable shocks, our conclusions survive (29,30). This remark justifies our dynamic interpretation of the equilibrium. Second, our results will be similar should we allow the decision-maker to explicitly select the type of public good (29). Third, we maintain that the group in power can always commit to a tax policy. While this assumption is without loss of generality in the case of the inclusive political regime since the non-elite would never deviate from his preferred

[14] Should this payment be always possible, the elite will rely on it only for $\gamma/\zeta \leq V \leq \gamma/\rho$ and $\zeta > \rho$. Intuitively, since the elite values public good, she also prefers it over direct transfers.

full-taxation level, it can be justified in the case of autocracy by foreseeing that the non-elite can impose a sufficiently large punishment on an elite reneging on the promised fiscal policies via either violence or by refusing to protect the output from looters (25,29). More generally, our conclusions will be the same 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 high-powered contracts (see footnote 14). This last observation confirms that our assumptions on the asymmetry in the preferences, ability and property rights of the two groups are mild. Fourth, the message of the model is the same when the elite can also try to incentivize the non-elite by punishing him (31), since she would be unable to do it because the non-elite cannot be always enticed under time-inconsistency (32). Nevertheless, punishment can arise in equilibrium whenever it sufficiently strengthens the elite's use rights for very valuable and observable investments (32). Since however the Nile flooding was difficult to foresee, this is a less relevant empirical scenario (1-5). Finally, the gist of our analysis will be the same should we assume that either the elite or the non-elite must assure, when designing fiscal policies, a reservation utility $\tau > 0$ to an agent—i.e., the Nomarch—gathering the tax revenues and gaining a sub-utility from public good consumption equal to αg_r, with $\alpha < 1$. When acting as an agent of the non-elite under regime $r = I$, the Nomarch cooperates if $\alpha V > \tau$. A Nomarch acting as an agent of the elite under regime $r = A$, instead, cooperates if $(1 - \delta_A^*)V + \alpha\delta_A^* V > \tau$ when the elite can commit to transfers and if $\alpha\delta_A^* V > \tau$ otherwise. A third scenario arose during the First Intermediate Period when the Pharaoh transferred to some of the independent Nomarchs the residual rights to land in exchange for a transfer $\varphi > 0$. In this last scenario, the Nomarch participates whenever $(1 - \delta_A^*)V + \alpha\delta_A^* V > \tau + \varphi$.

III. Errors in the Measurement of Archaeological Variables

Besides the chronological errors described in footnote 4, three are the sources of measurement errors created by the low and/or asymmetric quality of some of our archaeological data.

First, observations on the beginning of the 3rd millennium are obtained from deep stratigraphic soundings and not from the more reliable extensive excavations and modern surveys used for more recent observations (33). The fact, however, that this asymmetry uniformly affects the nomes part of the sample greatly limits its impact since, conditional on half-century fixed effects, measurement errors assume a “classical" form, i.e., they are independent of true variables. This remark has two effects (34). First, errors in the measurement of the dependent variable do not affect the magnitude of the coefficients attached to the independent variables but just inflate their standard errors lowering their significance. Second, measurement errors in the independent variables decrease the absolute value of the relative coefficients making our estimates a lower bound of the true impact of environmental conditions. Together, these issues should not affect the message of our analysis.

Second, the methods adopted for each archaeological site might vary. Yet, “several studies have shown broad agreement in the demographic trends produced by the SPD of radiocarbon dates and other archaeological indices" (35). Similarly, the southern nomes have comparatively better levels of preservation because they experienced only limited Nile’s avulsion, while floodings and fluvial movements were much more extreme in Lower Egypt (36). Accordingly, the southern capital of Thebes is widely considered the country’s most intact ancient site, whereas the northern capital of Memphis now consists only of disarticulated archaeological remains further degraded by modern agricultural and residential development, as well as a rising water table (36). Yet, again, conditional on capital fixed effects, these capital-specific measurement errors assume a classical form and, given the cautions discussed before, they should not change our key conclusions.

Finally, our proxy for each nome’s fiscal autonomy aggregates information on its institutional structure taken from inscriptions and secondary sources and is, thus, independent from precisely measuring each Nomarch’s status, wealth and functions as reflected by his titles. Such dimensions varied widely in both Old and Middle Kingdoms (16,17). Factoring in local trends as much as would ideally be desirable from an archaeological perspective is an avenue open to future research.

IV. Empirical Methodology

Basic models.—To test our model predictions, we run by OLS panel models of the type:

$$Y_{c,t} = \alpha_c + \gamma' \boldsymbol{X}_{c,t} + \delta' \boldsymbol{Z}_{c,t} + \varepsilon_{c,t}, \quad (1)$$

where $Y_{c,t}$ is either *Political-Institutions*, *Public-Buildings* or *Population* for capital *c* in half-century *t*

and α_c picks capital fixed effects controlling for time-independent determinants of $Y_{c,t}$. These are geographic traits, like land suitability for agriculture and pasture and the degree of land use (37,38), and predetermined shocks, such as the out of Africa exodus of humankind and the agricultural revolution (39,40). $\boldsymbol{X}_{c,t}$ gathers *S-Ratio* and *PDSI* and, if $Y_{c,t}$ is either *Public-Buildings* or *Population*, it also includes, respectively, *Political-Institutions* and both *Political-Institutions* and *Public-Buildings* since we do not observe all the determinants of the return on farming and state-building. Finally, $\boldsymbol{Z}_{c,t}$ possibly collects the standard deviation of PDSI over the previous half-century—i.e., *PDSI-SD*, *Low-Circumscription*, which is the normalized—to range between 0 and 1—average over the previous half-century of the ratio of a dummy for a capital's yearly PDSI lying between – 4 and 0 to the average of a similar dummy over the remaining capitals and weighted by their inverse distance, and both *Internal-Conflicts* and *External-Conflicts*, which represent the share of previous half-century over which the nome witnessed, respectively, internal and external conflicts (see table S1 for definition and sources of each of the variables that we employ in the SM appendix).

We do not consider time fixed effects since *Sr-Ratio* does not vary across capitals. Yet, we document in table S3 that the message of our analysis is similar when we either tackle within-capital correlation by clustering the standard errors at the capital level (see columns (1) to (3)), switch to the wild bootstrapped standard errors proposed by (41) to deal with a possible bias driven by the small number of clusters (see columns (4) to (6)) or correct standard errors for generic spatial dependence possibly created by regional climatic patterns (see columns (7) to (9)), as proposed by (42).[15] Results available upon request also clarify that the estimates of the coefficients on *PDSI* and *Political-Institutions* in columns (1) and (2) of table 3 are similar if we consider time fixed effects.

Our regression analysis returns two crucial pieces of information: an estimated coefficient and the relative *p*-value. The coefficient measures the effect of each explanatory variable on the dependent variable $Y_{c,t}$. While the sign of the coefficient indicates if a rise in the relevant explanatory variable is related to either an increase or a fall in the dependent variable, its magnitude clarifies how much $Y_{c,t}$ changes because of a unitary change in the independent variable. Crucially, in a large dataset, variables could be related to each other by chance. Accordingly, the information coming from the *p*-value is key. This figure represents the probability of observing a distribution of data producing a coefficient even more different from zero. If this probability is lower than the confidence level 1%, which is indicated with three asterisks in our tables, there is low chance, according to the social sciences standards, that a coefficient equal to zero has produced the observed variation. Hence, our reduction ad absurdum allows us to reject at the confidence level of 1% that the coefficient is null and, in turn, that its estimate is due to chance. We label with two and one asterisks, respectively, the two less stringent confidence levels of 5% and 10%. In section 3.2 of the main text, we discuss the coefficients estimated through the basic capital fixed effects models not considering any control variable in the vector $\boldsymbol{Z}_{c,t}$. Even if consistent with our model predictions, these estimates may be capturing reverse causality, measurement errors and/or the omission of relevant variables. Next, we discuss in details the impact of these endogeneity issues.

Evaluating causality.—First, the independence of the proxies for the farming return from human decisions excludes reverse causation from institutions to environmental conditions. To test, instead, whether it is public good provision to determine the inclusiveness of the political process and not the other way around, we follow (34) and we add to the set of variables explaining *Public-Buildings* also *Political-Institutions* lead one period. The fact that this last regressor is not positively and significantly related to the provision of the public goods preferred by the non-elite is inconsistent with the average number of forts and temples driving the inclusiveness of the political process given the plausible lag with which institutions adjust (see column (1) of panel A of table S4). By the same token, the estimates in column (2) of the same panel of table S4 suggest that *Political-Institutions* and *Population* are both jointly determined by climate shocks (see footnote 9).

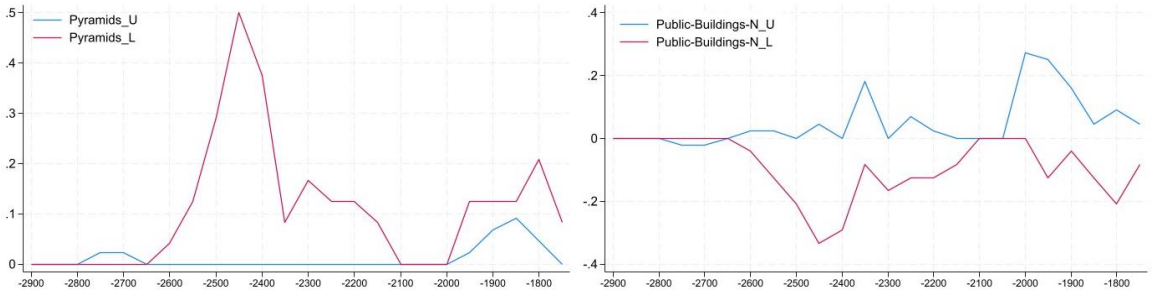
[15] Standard errors à la (41) with Bartlett kernel are constructed for a threshold beyond which the correlation between error terms is assumed to be 0 of 23.8 km, which is the average distance among the sample capitals.

Second, our conclusions remain unchanged when we deal with measurement errors by evaluating: 1. an alternative proxy for the nome's fiscal autonomy constructed by considering that the capital of the kingdom between 1950 and 1750 BCE was Itjtawy, in the vicinity of Memphis, and, thus, assigning to Memphis a value of 1 for this period (see columns (3) to (5) of panel A of table S4), i.e., *Political-Institutions-A*; 2. an alternative proxy for the public goods preferred by the non-elites crudely obtained by subtracting the average number of forts and temples to that of mastabas and pyramid tombs (see figures S1 and columns (1) and (2) of panel B of table S4), i.e., *Public-Buildings-N*; 3. the indicator *Political-Institutions-O*, which takes value three if the nome was fiscally autonomous, two if it was administered by a Nomarch gathering taxes on behalf of the Crown and one otherwise. To elaborate on the last point, we show that the conclusions of our analysis are similar not only when we run a capital fixed effect ordered Logit with dependent variable *Political-Institutions-O*, but also when we switch to a capital fixed effects Logit to study the impact of environmental shocks on *Political-Institutions* (see table S5).

Finally, we follow a two-step strategy to assess the role of unobserved heterogeneity. First, we document that our estimates are very similar when we consider degree of climate volatility, inverse proxy for the degree of environmental circumscription and severity of conflicts (see columns (3) to (5) of panel B of table S4). Second, we calculate how much greater the influence of factors that are unobservable, relative to the impact of our two observables, would need to be to explain away the estimates (43). To see how the index is calculated, consider a regression with a restricted set of controls and one with a full set of controls. Next, denote the estimate of the coefficient attached to the variable of interest from the first regression λ^R, where R stands for "restricted," and that from the second regression λ^F, where F stands for "full." Then, the index is the absolute value of $\lambda^F/(\lambda^R - \lambda^F)$. The intuition behind the formula is as follows. The lower the absolute value of $(\lambda^R - \lambda^F)$ is, the less the estimate of the coefficient attached to the variable of interest is affected by selection on observables, and the stronger selection on unobservable factors needs to be to explain away the entire coefficient. Similarly, the higher the absolute value of λ^F is, the greater is the effect that needs to be explained away by selection on unobservable factors. We consider the specifications without controls of table 3 as the restricted regressions and those incorporating all controls in columns (3) to (5) of panel B of table S4 as the full regressions. We report the indexes calculated from the regressions with dependent variable *Political-Institutions*, *Public-Buildings* and *Population* in columns (1) to (3) of table S6, respectively. The key observation is that the median (average) of these indexes is 9.5 (21.7). Therefore, to attribute the entire estimates to selection effects, selection on unobservable factors would have to be on average almost 22 times greater than selection on all the observable variables that we consider, which seems quite unlikely.

V. Supplementary Figure and Tables

Figure S1. Public Good Provision in Ancient Egypt



Note: The left and right graphs portray, respectively, the number of mastabas and pyramids averaged over the previous half-century and the capitals of either Upper or Lower Egypt and the difference between the number of forts and temples and the number of mastabas and pyramids, both averaged over the previous half-century and the capitals of either Upper or Lower Egypt. While the capitals of Upper Egypt are labeled with a subscript U, those of Lower Egypt are tagged with a subscript L. While table 1 reports the composition of each group, table S1 details definition and sources of each variable.

Table S1. Summary of Extra Variables

	Variable	Definition and Sources	Statistics
State-building:	*Political-Institutions-A*	*Political-Institutions* constructed considering that the reign capital between 1950 and 1750 BCE was Itjtawy, nearby Memphis. Sources: (13-17).	0.063 (0.242)
	Political-Institutions-O	3 if, in a 40-year window around each date, *Political-Institutions* = 1, 2 if it the Nomarch just gathered taxes on behalf of the Crown, 1 otherwise. Sources: (13-17).	1.163 (0.502)
	Pyramids	Average number of mastabas and pyramid tombs built over the previous 50 years. Sources: (46-46).	0.045 (0.352)
	Public-Buildings-N	Average number of forts and temples less average number of mastabas and pyramid tombs built over the previous 50 years. Sources: (44-46).	0 (0.408)
Control variables:	*PDSI-SD*	Standard deviation of PDSI over the previous 50 years. Sources: (47) and HWSD dataset, available at https://www.fao.org/soils-portal	2.584 (0.641)
	Low-Circumscription	Average over the previous 50 years of the ratio of a dummy for the capital's yearly PDSI lying between – 4 and 0 to the average of a similar dummy over the other capitals and weighted by their inverse distance. Sources: (47) and HWSD dataset.	0.538 (0.124)
	Internal-Conflicts	Share of previous 50 years during which the nome witnessed an internal conflict. Sources: (48-50).	0.0001 (0.001)
	External-Conflicts	Share of previous 50 years during which the nome participated in an external conflict. Sources: (48-50).	0.004 (0.036)

Note: The last column lists mean and, in parentheses, standard deviation, calculated for the samples used in tables S3-S6.

Table S2. Extended Sample and Alternative Chronology

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	The dependent variable is:					
	Political-Institutions	*Public-Buildings*	*Population*	*Political-Institutions*	*Public-Buildings*	*Population*
Public-Buildings			0.057 (0.116)			0.018 (0.090)
Political-Institutions		0.227 (0.050)***	0.470 (0.193)**		0.207 (0.062)***	0.705 (0.180)***
PDSI	- 0.039 (0.007)***	0.010 (0.011)	- 0.112 (0.078)	- 0.013 (0.007)*	- 0.020 (0.013)	- 0.142 (0.073)*
Sr-Ratio	- 0.089 (0.023)***	0.057 (0.036)	1.972 (0.228)***	- 0.085 (0.023)***	- 0.002 (0.041)	2.363 (0.255)***
Estimation	OLS					
Observations	1,008	1,008	369	884	884	369
R^2	0.04	0.02	0.20	0.02	0.02	0.22

Notes: 1. Columns (1) to (3) consider also the eight mostly unpopulated capitals listed in figure 1, whereas the variables *Political-Institutions* and *Public-Buildings* are constructed building on the "high" chronology in columns (4) to (6).
2. Standard errors in parentheses; *** denotes significant at the 1% confidence level; **, 5%; *, 10%.
3. All specifications include capital fixed effects.

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			0.057 (0.056)			0.057 (1.01)			0.057 (0.048)
Political-Institutions		0.226 (0.213)	0.470 (0.150)***		0.226 (1.06)	0.470 (3.15)**		0.226 (0.170)	0.470 (0.085)***
PDSI	- 0.042 (0.008)***	0.009 (0.014)	- 0.112 (0.073)	- 0.042 (- 5.24)***	0.009 (0.62)	- 0.112 (- 1.52)*	- 0.042 (0.010)***	0.009 (0.016)	- 0.112 (0.047)**
Sr-Ratio	- 0.110 (0.028)***	0.048 (0.060)	1.972 (0.603)***	- 0.110 (- 4.05)***	0.048 (0.81)	1.972 (3.28)***	- 0.110 (0.024)***	0.048 (0.043)	1.972 (0.206)***
Estimation	OLS								
Observations	816	816	369	816	816	369	816	816	369
R^2	0.04	0.02	0.20	0.04	0.02	0.20	0.29	0.21	0.71

Notes: 1. Standard (T-test obtained from wild bootstrapped standard) errors clustered at the capital level in the parentheses of columns (1) to (3) ((4) to (6)) and Conley's (1999) standard errors with Bartlett kernel in the parentheses of columns (7) to (9). The distance beyond which the correlation between error terms is assumed to be 0 is 23.8 km.
2. *** denotes significant at the 1% confidence level; **, 5%; *, 10%. All specifications include capital 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		0.046 (0.129)			0.066 (0.116)
Public-Buildings(+1)		0.085 (0.130)			
Political-Institutions	0.319 (0.068)***	0.009 (0.241)			
Political-Institutions(+1)	- 0.151 (0.067)**	0.679 (0.226)***			
Political-Institutions-A				0.243 (0.055)***	0.407 (0.199)**
PDSI	0.010 (0.012)	- 0.140 (0.078)*	- 0.039 (0.008)***	0.009 (0.012)	- 0.121 (0.079)
Sr-Ratio	0.038 (0.043)	2.093 (0.230)***	- 0.086 (0.027)***	0.045 (0.043)	1.931 (0.228)***
Estimation			OLS		
Observations	816	369	816	816	369
R^2	0.03	0.22	0.03	0.02	0.19
			Panel B. The dependent variable is:		
	Public-Buildings-N	*Population*	*Political-Institutions*	*Public-Buildings*	*Population*
Public-Buildings					0.047 (0.129)
Public-Buildings-N		0.097 (0.106)			
Political-Institutions	0.154 (0.061)**	0.484 (0.191)**		0.068 (0.051)	0.456 (0.202)**
PDSI	0.003 (0.014)	- 0.108 (0.079)	- 0.044 (0.008)***	0.009 (0.012)	- 0.099 (0.083)
Sr-Ratio	0.070 (0.049)	1.966 (0.227)***	- 0.123 (0.028)***	0.001 (0.040)	1.946 (0.234)***
PDSI-SD			0.002 (0.017)	- 0.023 (0.024)	- 0.127 (0.175)
Low-Circumscription			0.105 (0.075)	- 0.073 (0.105)	- 0.536 (0.660)
Internal-Conflicts			- 7.546 (7.183)	17.851 (10.137)*	- 11.845 (34.548)
External-Conflicts			1.426 (0.199)***	3.730 (0.290)***	0.229 (1.101)
Estimation			OLS		
Observations	816	369	816	816	369
R^2	0.01	0.20	0.10	0.20	0.20

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

Table S5. 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				0.058 (0.116)
Political-Institutions-O			0.093 (0.025)***	0.241 (0.090)***
PDSI	- 0.834 (0.189)***	- 0.400 (0.108)***	0.005 (0.012)	- 0.126 (0.076)*
Sr-Ratio	- 3.443 (0.890)***	- 2.649 (0.548)***	0.048 (0.043)	1.997 (0.229)***
Estimation	Logit	Ordered Logit	OLS	OLS
Observations	312	720	816	369
Pseudo R^2		0.07		
R^2			0.02	0.20

Notes: 1. The coefficients in column (1) are average semi-elasticities of $P(Y_{c,t} = 1 | \boldsymbol{X}_{c,t}, \alpha_c)$.
2. Standard errors in parentheses; *** denotes significant at the 1% confidence level; **, 5%; *, 10%.
3. All specifications include capital fixed effects.

Table S6. 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			4.7
Political-Institutions		0.43	32.57
PDSI	22		7.62
Sr-Ratio	9.46		74.85

Note: Each index is calculated as explained in section IV. 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 (3) to (5) of panel B of table S4. The sample sizes are respectively 816, 816 and 369.

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