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 shocks, state institutions and population dynamics of Bronze Age Egypt to shed light on the alleged societal breakdown that followed the 4.2 ka BP megadrought. We document two key patterns. First, the 2300-2100 BCE string of droughts and low Nile floods pushed the Pharaohs of the late Old Kingdom and First Intermediate Period to acquiesce to a larger fiscal autonomy of the provinces hit the hardest by climate shocks. This discontinuity allowed locally-selected governors to shift the allocation of tax revenues towards the provision of the public goods preferred by the provincial non-elites, i.e., irrigation projects, defensive walls and risk-sharing instead of pyramids. Second, these reforms, which, in our model, sustain cooperation between the provincial non-elites and time-inconsistent elites, were related to a more resilient settlement. Our conclusions hold across identification strategies and are consonant with the idea that climate change shaped ancient Egypt directly via worse production conditions and indirectly via institutional resilience. *Keywords*: climate change; state-building; time inconsistency; collapse. *JEL classification*: D72; H10; O13; P00.

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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 states during the Neolithic Revolution (Brooke, 2014; Roberts et al., 2018), a pioneering archaeological literature has correlated the severity of climate change to state formation and evolution, i.e., state-building (Haldon et al., 2018; Dow and Reed, 2023). This evidence suggests that persistent droughts—"cold and dry spans" (Weiss, 2017)—invariably triggered economic crises and state dissolution (Kennett et al., 2012; Wei et al., 2015; Sinha et al., 2019; Fleitmann, et al., 2022; Manning et al. 2017, 2023; Chaney, 2013). These dynamics would, for instance, explain the weakening of the Pharaohs' power and the alleged collapse of the Egyptian society in the aftermath of the 4.2 ka BP megadrought (Mayoral and Olsson, 2024).[1]

The credibility of the conclusions of this "collapse archaeology" literature is, however, undermined by three limitations. First, this strand of research lacks a formal theoretical foundation identifying the strategic determinants of state-building and societal resilience and thus, helping select the functional form of the equations linking these variables (McAnany and Yoffee, 2009; Butzer, 2012; Guedes et al., 2016; Arponen et al., 2019; Degroot et al., 2021). Second, it relies on proxies whose measurement is not theoretically informed and is, thus, prone to large errors (Butzer and Endfield, 2012). 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. 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" (Burgess, 2022), 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 (Benati and Guerriero, 2021; Bárta, 2022). To make matters worse, the collapse archaeology literature gauges

[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."

climate change through the still limited coeval hydro-climatic records (Kennett et al., 2012; Wei et al., 2015; Manning et al., 2017; 2023; Sinha et al., 2019; Fleitmann et al., 2022; Mayoral and Olsson, 2024), which are only poor proxies for the climate conditions prevailing in distant polities (Benati et al., 2022; Benati and Guerriero, 2024a,b). Finally, this literature focuses on the single impact of environmental shocks on state-building overlooking their combined and indirect effects (Zhao et al., 2017; Benati and Guerriero, 2023; 2024c).

We tackle these issues by blending the "time inconsistency" theory of the state (Benati et al., 2022), novel proxies informed by this formal model and highly granular climate data to study the impact of the 4.2 ka BP megadrought on state-building and societal 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 OLS reveal two patterns inconsistent with the collapse archaeology literature mantra. First, the 2300-2100 BCE string of droughts and low Nile floods 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 (Bunbury, 2019; Moeller, 2005). This discontinuity allowed locally-selected governors to shift the allocation of tax revenues towards the provision of the public goods preferred by the provincial non-elites, i.e., irrigation projects, defensive walls and risk-sharing instead of pyramids. Second, the stronger control over fiscal policies, which, in our theoretical model, convinces the provincial non-elites that they will enjoy a sufficient part of the returns on investing in farming innovations with the time-inconsistent elites, was related to expanded cooperation and in turn, a more resilient settlement. We do not consider this link as causal since state-building and societal resilience are jointly determined by climate shocks.

While our baseline estimates are consistent with the model predictions, they may be capturing reverse causality, measurement error and/or unobserved heterogeneity. We evaluate these three issues in turn. First, the independence from human decisions of our proxies for climate shocks excludes reverse causation in our analysis of the environmental determinants of state-building. Moreover, the fact that public good provision is unrelated to future values of the inclusiveness of the political process is inconsistent with the former driving the latter 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. Finally, we follow a two-step strategy to evaluate unobserved heterogeneity. To begin with, we document that our empirical results are robust to considering the key factors discussed by the extant literature on state-building and societal resilience in ancient societies and notably, the degree of environmental circumscription (Carneiro, 1970; Allen, 1997; Schönholzer, 2024; Ahmed and Stasavage, 2020), the severity of internal and external conflicts (Acemoglu and Robinson, 2000; Besley and Persson, 2009) and the potential for trade, epidemics and immigration waves (Inglehart and Welzel, 2005; Voigtländer and Voth, 2009; Alesina and Tabellini, 2024). The fact that high Nile floods, reducing output observability, were positively linked to jurisdictional hierarchy is, moreover, 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 (Mayshar et al., 2017). Next, we build on both our baseline results and those controlling for the aforementioned three sets of observables and we calculate that the influence of unobservables, relative to the influence of observables, would need to be on average more than 43 times greater to completely explain away the baseline estimates. This seems unlikely. Together, these tests make it difficult to envision that our results are driven by mechanisms different from those we model and thus, we take them as consistent with causality running from climate shocks to state-building and from state-building to public good provision.

The paper proceeds as follows. In section 2, we discuss four stylized facts about Bronze Age Egypt consonant with the two key implications of the model that we illustrate in section 3. Next, we illustrate the test of these predictions in section 4. Finally, we conclude in section 5, and we report figures, tables and further historical details in the appendixes.

2 State-Building in Bronze Age Egypt

While we analyze in detail the economic and institutional evolution of Bronze Age Egypt over our sample in the Internet appendix, we illustrate in this section four stylized facts consistent with the two key implications of our model and our main empirical results.

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 violence

of the flooding, could not be organized around centrally-planned feeder canals parallel to the river but necessitated the cooperation of groups of farmers in the management of local irrigation systems (Krom et al., 2002; Willems, 2013). 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 (Shaw, 2003; Köhler, 2020). Against this background, inter-polity competition raged until the creation by the Naqada culture of a unified kingdom (Shaw, 2003; Köhler, 2020). 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 trade reaching the Levant (Shaw, 2003).

Second, this structure continued to characterize the first phase of the Old Kingdom (2592-2120 BCE) until the extended strand of low Nile floods and droughts of the 23rd and 22nd centuries BCE forced the Pharaohs to shift their effort from the construction of huge pyramids to pandering to rising local landowners promoting their cults (Bárta, 2020). 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 (Armstrong et al., 2019), acquired the fiscal autonomy of keeping part of the tax revenues and employing them to provide local public goods (Lloyd, 2014; Moreno García, 2020a; Bárta, 2020).

Third, in conjunction with the new series of droughts of the First Intermediate Period (2119-1980 BCE), Egypt first split into 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 (Moreno García, 2020b). Contrary to the conjecture of the collapse archaeology literature, the southern capitals, which started to be governed by representatives of local landowners, thrived and witnessed expanding local trade (Moreno García, 2013; 2020a,b). 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 (Favry, 2004; Martinet, 2019; Moreno García, 2020a). The temples, in turn, provided justice as well as key risk-sharing activities,

like grain storage and market organization (Favry, 2004; Moreno García, 2013; 2020a).

Finally, the milder climate of the Middle Kingdom (1979-1630 BCE) favored the re-unification of Egypt, a northward expansion and an increasing fiscal centralization (Shaw, 2003; Willems, 2013). With Amenemhat III's reign indeed, a novel administrative system characterized by local offices closely linked to the royal palace prevailed (Willems, 2013).

3 A Time Inconsistency Theory of State-Building

Our model is a simplified version of Benati et al.'s (2022) and Guerriero and Righi's (2024) theoretical frameworks. As these studies, we analyze the possible cooperation between elites and non-elites in a joint investment, e.g., farming. While the elites gather the agents with control over scarce resources and institutional design, the non-elites assemble the initially rightless agents (Benati and Guerriero, 2022).[2] In our historical case, the Pharaoh, his family and the royal administration represent the former, whereas each nome stands for the latter.

The economy.—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.[3] 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—i.e., π_r—equals the sum of the untaxed output and the payoff from public good consumption.

The elite lacks the commitment to write either non-contingent or state-contingent contracts, but she can incentivize the non-elite by enacting an inclusive political institution $r = I$, which allows him to select the tax rate and his preferred between two inefficiently-produced public goods. 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 public good provision of g_r delivers a sub-utility ρg_r to the group designing fiscal policies and βg_r to its partner, with $0 < \beta < \rho < 1$. In words, $\rho < 1$ implies that all prefer 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 option preferred by its partner. In

[2]We refer to the elite as "she", to the non-elite as "he" and to a generic party as "it."

[3]The equilibrium will be the same should agents be risk-averse. Should V capture the expected output value, the non-elite will require a positive expected utility to participate but our conclusions will stand.

our sample, the elite preferred (was better at) constructing pyramids than providing public projects such as irrigation works, defensive walls, and risk-sharing, and the non-elite had opposite preferences (abilities). Public good provision is linear in the tax revenues $V\delta_r$.

Timing of events.—At time t_0, the elite picks r. At time t_1, 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 realized.

Discussion.—In evaluating our setup, several remarks should be heeded.

First, the interaction between the elite and the non-elite should be envisioned between any two consecutive and unforeseen shocks, each endowing the non-elite with a more efficient technology and the elite with the initial control over resources and institutional design (Benati and Guerriero, 2022). Similarly, our conclusions survive when the elite can regain power over fiscal policies after democratization and unforeseen shocks (Boranbay and Guerriero, 2019). This remark justifies our dynamic interpretation of the equilibrium of the basic setup.

Second, we maintain that the elite keeps control and transfer rights to the input, leaving to the non-elite only the use rights (Guerriero, 2016; 2023). Therefore, she retains the untaxed output. This assumption captures the fact that, over the sample, land ownership steadily represented the crucial divide between elite and non-elite groups (Bussmann, 2020).

Third, our results will be similar should we allow the party with control over fiscal policies to explicitly select the type of public good (Boranbay and Guerriero, 2019).

Fourth, the hypothesis that the elite lacks the commitment to write contracts with the non-elite builds on a long literature on the time inconsistency issues inherent to politics (North and Weingast, 1989; Barzel and Kiser, 1991; Fleck and Hanssen, 2006; Myerson, 2008), and it is justified in our case by the fact that contractual agreements were enforced by courts controlled by the same elite promising not to renege on future transfers (Acemoglu, 2003). To elaborate, 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 (Loktionov, 2020). We assume, instead, that the group with the power of designing fiscal policies can always commit to a tax policy. While this assumption is irrelevant in the case of the inclusive political regime since the non-elite would never deviate from full-taxation, it can be justified in the case of autocracy by foreseeing

that the non-elite can impose a large punishment ζ on an elite deviating to her preferred zero tax level by rising up and/or refusing to fight against external enemies (Acemoglu, 2003).[4] 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 or should we let the elite commit to contracts (see footnote 5). This observation confirms that our assumptions on the asymmetry in the preferences, ability and property rights of the two groups are mild.

Fifth, our conclusions are the same when the elite can also try to incentivize the non-elite by punishing him (Mayshar et al., 2017), since she would be unable to do it because her time-inconsistency entails that the non-elite cannot be always enticed (Benati et al., 2022). Yet, punishment can arise in equilibrium when it sufficiently strengthens the elite's use rights for very valuable and observable investments (Benati et al., 2022). Since however the Nile flooding was difficult to foresee, this is a less relevant scenario (Shaw, 2003).

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 $\varphi > 0$ (Engel, 2013; Moreno García, 2020a,b). In this last scenario, the Nomarch participates whenever $(1 - \delta_A^*) V + \alpha \delta_A^* V > \tau + \varphi$.

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

[4] A $\zeta > V - \pi_A$ will suffice. Similarly, the elite could also renege on her time t_1's regime choice. If she reinstated autocracy at time t_2, the non-elite would then become uncooperative. If, instead, the elite could take her power back at time t_3, the non-elite could discourage this move by imposing a punishment $\zeta > V - \pi_I$.

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 $\beta V > 0$ and maximizes the non-elite's fitness and, in turn, society's resilience to adverse production shocks.

Once the elite has picked $r = A$, she selects the δ_A solving the linear problem

$$\max_{\delta_A \in [0,1]} \quad (1-\delta_A)V + \rho\delta_A V,$$

subject to satisfying all individual rationality constraints. While the elite's individual rationality constraint $\pi_A \geq 0$ is always met, the non-elite's individual rationality constraint $U_A \geq 0$ fails when he does not invest or when he does and $V < \frac{\gamma}{\beta} \equiv \overline{\Omega}$ with $\hat{\Omega} < \overline{\Omega}$. For $V \geq \overline{\Omega}$ instead, it can be satisfied when he cooperates and $\delta_A^* = \frac{\gamma}{\beta V} \leq 1$. This is the lowest possible tax rate such that $U_A = \beta\delta_A^* V - \gamma \geq 0$ 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 $V < \hat{\Omega}$, granting the inclusive political institution is the only way of garnering the non-elite's cooperation for $\hat{\Omega} \leq V < \overline{\Omega}$. 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, as seen before, $\pi_A > \pi_I$. More important, the larger γ is, the more difficult is to support production and thus, the larger will be the ability of the inclusive political regime to elicit cooperation when autocracy cannot, i.e., the larger $\overline{\Omega} - \hat{\Omega} = \frac{\gamma(\rho-\beta)}{\rho\beta}$ is. The following proposition summarizes our analysis for $0 < \beta < \rho < 1$:

Proposition: *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 tax rate $\delta_I^* = 1$, invests and obtains a weakly positive utility from cooperating; 3. If $V \geq \frac{\gamma}{\beta}$, the elite selects the autocratic regime and $\delta_A^* = \frac{\gamma}{\beta V} \leq 1$, and the non-elite invests and obtains a zero utility.*

In a world of inefficient public good provision, the adoption of an inclusive political order makes possible for $\hat{\Omega} \leq V < \overline{\Omega}$ a cooperation otherwise unattainable given the elite's time inconsistency issues (Blanton and Fargher, 2008; 2016). When these reforms are unfeasible, the elite can elicit production for $\frac{\gamma}{\zeta} < V \leq \overline{\Omega}$ and $\zeta > \beta$ only if able to credibly offer ζV,[5] as

[5]Should this payment be always possible, the elite will rely on it only for $\frac{\gamma}{\zeta} < V \leq \hat{\Omega}$, $\zeta > \rho$ and no taxation.

either a direct transfer or a contract. When, finally, the output value is large—i.e., $V > \overline{\Omega}$, the elite prefers to direct fiscal policies and decrease taxation as the output rises.

In the case of an economy, like the one characterizing our sample, for which the production conditions were never too adverse (Nicholson and Shaw, 2000), our model entails that:

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

4 Evidence

To evaluate the testable predictions, we need proxies for the independent and dependent variables and a suitable empirical strategy. To select them, we build on section 2.

4.1 Sample Construction

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 (Nielsen, 2024). 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 (Pennington et al., 2017).[6] Crucially, our results are qualitatively similar when we include the information available for these capitals (see the Internet appendix). 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 (Shaw, 2003). By employing instead the "low" chronology,[7] which has been proposed by Hornung et al. (2019) and

Intuitively, since she values public good, she also prefers it over wasteful transfers.

[6] An Heckman model run on data on all 42 nomes suggests the residuals of regression and selection equations are unrelated. To identify the latter, we exploit the fact that selection is negatively linked to latitude, longitude and distance to Nile since the excluded polities lie in north-east Egypt (Pennington et al., 2017).

[7] Since our institutional proxies are based on the 40 years around each date, the impact of the dating errors

combines king lists with Carbon-14 evidence, it is, instead, possible to quite accurately link historical with archaeological data and therefore, minimize measurement errors.

4.2 Measurement

4.2.1 Societal Resilience

In Malthusian economies, like those part of our sample, technological innovations only produce population growth (Clark, 2005). 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 (Benati and Guerriero, 2021). Building on this remark, we elect as proxy for the degree of societal resilience the natural logarithm of the population of each capital averaged over the previous half-century and estimated by Nielsen (2024) (see table 2 and table I of the Internet appendix for definition and sources of each variable), i.e., *Population*. To illustrate, Nielsen (2024) provides an assessment of the average population of some of our capitals over the Old Kingdom as well as the 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 capacity of the Nile Delta to sustain settlement.

4.2.2 State-Building

Turning to the provision of the public goods preferred by the non-elites, we follow Benati et al. (2022), and we rely on the average number of forts and temples built over the previous half-century (Bard, 1999; Wilkinson, 2000; Arnold, 2005), i.e., *Public-Buildings*. While the royal elites preferred building huge pyramids, 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 market organization (Lloyd, 2014; Moreno García, 2013; 2020a,b; Bárta, 2020; Wilkinson, 2000). As the proxies for the non-elites' political rights, these variables are based on analyses of the single periods and capital-specific secondary sources informed by archaeological data (Bard, 1999; Wilkinson, 2000; Arnold, 2005).

of the low chronology, which range between 12 and 25 years (Hornung et al., 2019), is limited. Crucially, the "high" chronology produces qualitatively similar results (see table II of the Internet appendix), but it displays, instead, errors ranging between 20 and 200 years (Kitchen, 1991). Finally, results available upon request and based on data for the Old and Middle Kingdom are even more consistent with our model.

Regarding the inclusiveness of the political process, which, in our theoretical model, corresponds to fiscal autonomy, we again follow Benati et al. (2022), and we build on the events in a 40-year window around each period to construct a dummy for fiscally autonomous nomes, i.e., *Political-Institutions*. As detailed in the Internet 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 aA*, i.e., Great Chief of the nome. More generally, *Political-Institutions* can also be seen as a direct measure of political decentralization and/or an inverse proxy for jurisdictional hierarchy (Mayshar et al., 2017).

4.2.3 Return on Investment

Finally, to gauge the environmental factors key to the domestication of cereal grains, which were the most diffused crops (Shaw, 2003; Nicholson and Shaw, 2000), we build on broad botanical evidence showing 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, but the vast majority—i.e., 80%—of the anomalies in its yield are mainly explained by the combined effect of temperature and rainfall (Serna-Saldivar, 2010; Vogel, et al., 2019). Since present-day land suitability data are by construction unable to properly capture the historical soil capacity to retain and supply nutrients and water (Benati et al., 2022; Benati and Guerriero, 2024a,b), we then focus on the following two proxies.[8]

First, being the Egyptian agriculture primarily irrigated, 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 (Krom et al., 2002), 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 rely on the normalized—to range between 0 and 1—87Sr/86Sr ratio averaged over the previous half-century and collected from the Manzala Lagoon by Krom et al. (2002), i.e., *Sr-Ratio*. The following three remarks support this choice. First, Krom et al. (2002) 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

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

the delta freshwater obtained from pollen records collected from Sais by Zhao et al. (2020) is positive—0.24—and significant at 1%, conditional on a marker of drought severity also obtained by Zhao et al. (2020) and temperature and rainfall proxies simulated by Armstrong et al. (2019). 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 Armstrong et al. (2019) and evaluated at lake Tana and temperature, rainfall and inverse drought severity measures collected from Armstrong et al. (2019) and evaluated at Manzala Lagoon.[9]

Second, we build on Jacobi et al. (2013), 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*. Operationally, we collect the water storage capacity from the HWSD dataset developed by FAO at the 30 arc-second spatial resolution. This feature is defined as the mm/m of water available for use by plants that a soil can store and is a function of exogenous dimensions such as soil texture and crop rooting depth (Kassam, 1991). We get, instead, the climate data directly from Armstrong et al. (2019), 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.[10] 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 (Armstrong et al., 2019). 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 (Redmond, 2002). Then, the PDSI, like the abundance of the Nile inundation, is a key driver of both yield anomalies and the efficiency of harvest storage (Nicholson and Shaw, 2000; Redmond, 2002). Crucially, our conclusions remain substantially unaffected when we also include in our specifications the temperature and rainfall levels (results available upon request).

Three extra pieces of empirical evidence support our choice of focusing on the PDSI.

[9]The correlation between the Nilometer data calculated at Rhoda Island by Popper (1951) and the climate conditions at this location is positive and significant at 5%, conditional on the climate at Manzala Lagoon.
[10]We average data over the full year since growing and harvest months spanned October to May (Shaw, 2003).

First, Armstrong et al. (2019) 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 the PDSI and a hydro-climatic proxy for the temperature of the rainfall extracted from the speleothems discovered at the Qunf and Soreq caves is, for these locations, positive—0.35—and significant at 1%, conditional on the temperature and rainfall proxies collected from Armstrong et al. (2019) as well as the caves' coordinates.[11] It is worth to notice that Mayoral and Olsson (2024) proxy the climate through the very same hydro-climatic records extracted from Qunf and Soreq caves, even if their correlation with the PDSI of the nearest capital in our sample is insignificant (Benati and Guerriero, 2024a). Finally, Benati and Guerriero (2023) document, for the sample of 44 major Mesopotamian polities observed for each half-century between 3050 and 1750 BCE, that the PDSI is significantly correlated with the coeval barley yields in liters per hectare reported by cuneiform administrative texts.

4.3 Identification Strategy

Albeit figure 2 reveals that the mix of low Nile flows and intermediate droughts of the 2300-2100 BCE period hit more heavily Upper Egypt and was followed here by a rise in fiscal autonomy, provision of the public goods preferred by the non-elites and population, we rely on OLS capital fixed effects to construct a formal test of our model. We estimate:

$$Y_{c,t} = \alpha_c + \gamma' \mathbf{X}_{c,t} + \delta' \mathbf{Z}_{c,t} + \varepsilon_{c,t}, \tag{1}$$

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 (Guerriero, 2020; Litina, 2016), and predetermined shocks, such as the out of Africa exodus of humankind and the agricultural revolution (Ashraf and Galor, 2013; Olsson and Paik, 2016). $\mathbf{X}_{c,t}$ gathers, instead, *Sr-Ratio* and *PDSI* and, if the dependent variable is either *Public-Buildings* or *Population*, *Political-Institutions* and both *Political-Institutions* and *Public-Buildings*, respectively. This choice allows us to control for unobserved determi-

[11] Such a proxy is the δ18O, i.e., oxygen stable isotope ratios (Fleitmann et al., 2007; Grant et al., 2012).

nants of the return on farming and state-building. Finally, $\mathbf{Z}_{c,t}$ possibly collects the extra control variables discussed in section 4.5. We do not consider, instead, time fixed effects since the variable *Sr-Ratio* does not vary across nome capitals.

We document, however, that the message of our analysis is similar when we either tackle within-capital correlation by clustering the standard errors at the capital level, switch to the wild bootstrapped standard errors proposed by Cameron et al. (2008) to deal with the small number of clusters or employ Conley's (1999) standard errors to account for the generic spatial dependence possibly created by regional climatic patterns (see table III of the Internet appendix).[12] Results available upon request also clarify that the estimates of the coefficients on *PDSI* and *Political-Institutions* are similar if we consider time fixed effects.

4.4 Basic Empirical Results

The estimates in table 3 reveal three key patterns. 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 Internet appendix, a one-standard deviation fall in *PDSI* leads to a 99% 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)), and they significantly curb the provision of mastabas and pyramids (see the Internet appendix). 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 and expanding the provision of the public goods preferred by the non-elites, which are, in turn, associated with a stronger societal resilience (see column (3)). A back-of-the-envelope calculation suggests that the magnitude of the indirect effect is roughly half of the magnitude of the direct impact.[13] Albeit the explicit inclusion of climate factors takes care of the omit-

[12] Standard errors à la Cameron et al. (2008) are constructed for a threshold of 23.8 km, which is the average distance among capitals, beyond which the correlation between error terms is assumed to be 0.

[13] For the sample for which 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 by 35% whereas its indirect effect was to raise it by 18%. We obtain similar figures via a mediation analysis.

ted variable bias, we do not consider the impact of both the inclusiveness of the political process and public good provision on the population as causal since *Political-Institutions*, *Public-Buildings* and *Population* are all jointly determined by climate shocks.

4.5 Gaining More Insights About Causality

Even if OLS estimates are consistent with our theoretical model, they may be picking reverse causality, they might be attenuated by measurement error and/or they may be driven by omitted variables. We evaluate these three issues in turn as follows.

4.5.1 Evaluating the Impact of Reverse Causality

The independence of the proxies for the farming return from human decisions excludes reverse causation from state-building 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 Angrist and Pischke (2009) and we add to the set of variables explaining *Public-Buildings* also the indicator *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-elites is inconsistent with the average number of forts and temples driving the inclusiveness of the political process given the plausible lag with which institutions should adjust (see column (1) of panel A of table 4).

4.5.2 Evaluating the Impact of Measurement Error

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, i.e., *Political-Institutions-A* (see columns (2) to (4) of panel A of table 4); 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, i.e., *Public-Buildings-A* (see columns (5) and (6) of panel A of table 4); 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 the indicator *Political-Institutions* (see table IV of the Internet appendix).

4.5.3 Evaluating the Impact of Unobserved Heterogeneity

We follow a two-step strategy to evaluate unobserved heterogeneity. First, we document that our conclusions are robust to considering the key forces identified by the extant literature on state-building and societal resilience in ancient societies. Second, we build on these estimates to calculate how much the influence of unobservables, relative to the influence of observables, would need to be to completely explain away the baseline estimates.

Controlling for observables.—Over and above the aforementioned "appropriability" theory of state-building, three are the key models of state-building and societal resilience in ancient societies. First, a growing body of research focuses on the 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 (Carneiro, 1970; Allen, 1997; Schönholzer, 2024; Ahmed and Stasavage, 2020). To inversely capture these institutional dynamics, we evaluate the normalized average over the previous half-century of the ratio of a dummy for the yearly PDSI lying between - 4 and 0 to the average over the other capitals of a similar dummy weighted by their inverse distance, i.e.,[14] *Low-Circumscription*. Second, a well-known literature suggests that the severity of internal and external conflicts reinforces the elites' need to share their power with the non-elites to, respectively, avoid expropriation and encourage them to fight invaders (Acemoglu and Robinson, 2000; Besley and Persson, 2009). Accordingly, we include in $\mathbf{Z}_{c,t}$ the share of previous half-century over which a nome witnessed either internal and external conflicts (Morkot, 2003), i.e., *Internal-Conflicts* and *External-Conflicts*. Finally, a long economic development tradition stresses that economic success, as driven by a large trade potential, a lower pathogen load and more limited immigration flows, favors societal modernization and resilience (Inglehart and Welzel, 2005).[15] As further discussed in the Internet appendix, the

[14] This range picks adverse, but not unbearable shocks favoring state-building (Benati and Guerriero, 2023).

[15] While Voigtländer and Voth (2009) suggest that epidemics modulate the incentives to escape the Malthusian trap, Alesina and Tabellini (2024) report correlations consistent with the idea that immigration waves are bound to trigger backlash and weaken preferences for redistribution and inter-group cooperation.

available evidence suggests that migration into Egypt, long-distance trade and pandemics were closely related to the density of urban areas because of either the availability of administrative and logistical infrastructures or the significantly larger frequency and intensity of human interactions. Ultimately, we consider a measure of urban potential first proposed by de Vries (1984) and defined as the distance-weighted sum of the inhabitants of all the settlements around each nome and for which data are available from Nielsen (2024).[16]

The estimates listed in panel B of table 4 entail four key observations. First, conditional on our main observable factors, our conclusions remain the same. Second, and consistent with Benati et al. (2022) and Benati and Guerriero (2024), the degree of circumscription has no institutional role. Third, and consonant with Besley and Persson (2009), providing public goods as defense from external enemies favors democratization. Finally, the potential for trade, epidemics and immigration waves encourages reforms towards a more inclusive political process as implied by the modernization theory (Inglehart and Welzel, 2005).[17]

Selection on observables.—To calculate how much greater the influence of factors that are unobservable, relative to the impact of the aforementioned observable factors, would need to be to completely explain away the estimates, we calculate the index proposed by Bellows and Miguel (2009). To see how this measure is calculated, we first consider a regression with a restricted set of controls and one with a full set of controls. Next, we 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, we define the index as the absolute value of $\lambda^F / \left(\lambda^R - \lambda^F\right)$. The intuition behind the formula is as follows. The smaller the absolute value of $\left(\lambda^R - \lambda^F\right)$ 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 larger 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

[16] We substitute missing observations with the average population of the towns displaying similar size according to Butzer (1976). This approximation does not drive our conclusions (results available upon request).

[17] Consonant with this pattern, there is no evidence of migration from Lower Egypt and/or the outskirts of Upper Egypt towards the southern capitals between 2300 and 2100 BCE (figure II in the Internet appendix).

those incorporating all controls in panel B of table 4 as the full regressions, and we report the indexes calculated from the regressions in columns (1) to (6) of panel B of table 4 in columns (1) to (6) of table 5, respectively. The key observation is that the median (average) of these indexes is 10.9 (43.7). Therefore, to attribute the entire estimates to selection effects, selection on unobservable factors would have to be on average more than 43 times greater than selection on the observable variables that we consider, which seems unlikely.

5 Conclusions

Rather than reviewing our results, we close by illustrating a general three-step strategy for future research on the interplay among climate change, state-building and societal collapse implied by our approach. First, any such project should build on game theories 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 to minimize the errors introduced by the heterogeneous 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 African underdevelopment. The main insights about this link come from the correlations between the pre-colonial institutions measured by Murdock (1967) and present-day economic outcomes (Michalopoulos and Papaioannou, 2013). Over and above the lack of a robust theory of these links, 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 records, rather than the archaeological literature (Amin et al., 2024).

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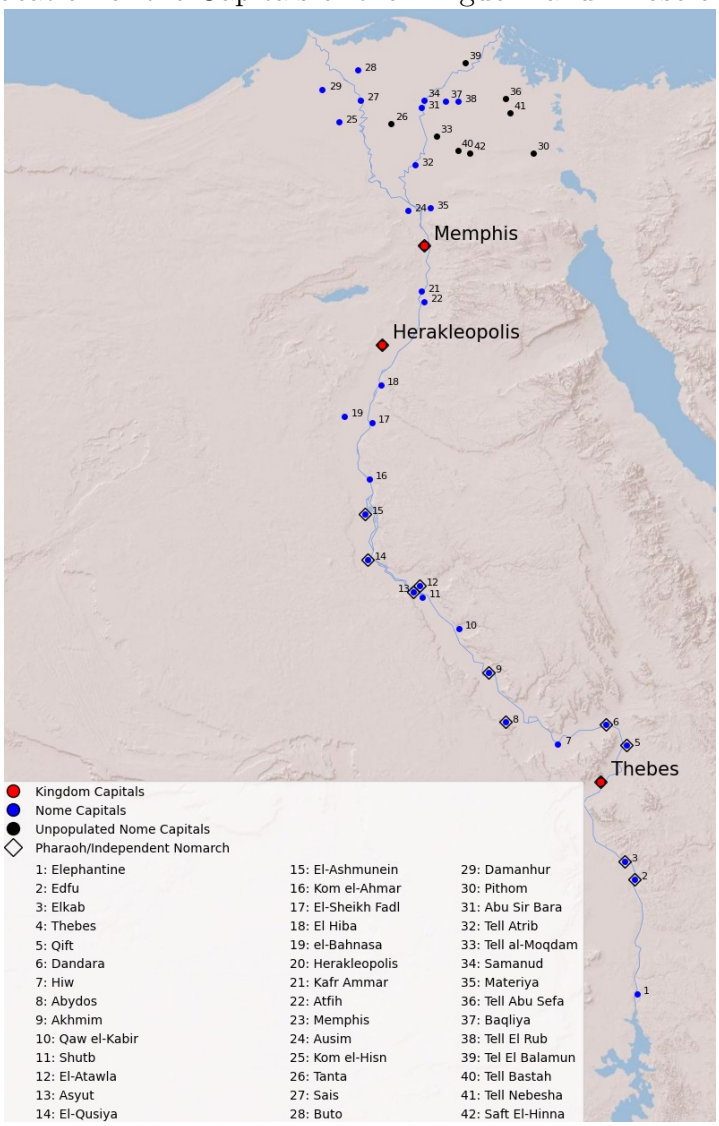
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Appendix

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



Note: 1. The figure depicts the locations of the capitals of the kingdom, nomes included and those excluded from the sample.

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*).

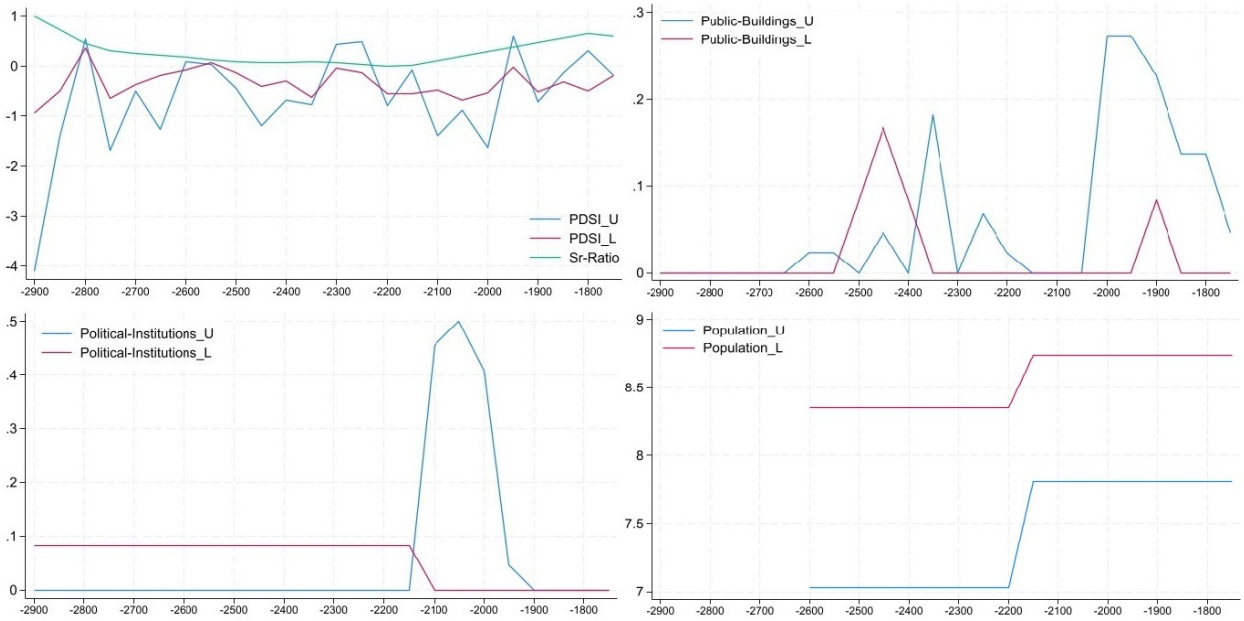
Note: 1. The names of the present-day archaeological sites are in regular lowercase type, whereas the corresponding names of the capitals of the nomes, which constitute the cross-section identifiers of our analysis, are in Italic lowercase font.

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 Internet appendix.	0.058 (0.233)
	Public-Buildings:	Average number of forts and temples built over the previous 50 years. Sources: Bard (1999), Wilkinson (2000), and Arnold (2005).	0.045 (0.331)
Societal resilience:	*Population*:	Natural logarithm of the population of the capital averaged over the previous 50 years. Sources: Nielsen (2024).	7.972 (1.093)
Climate change:	*PDSI*:	PDSI averaged over the previous 50 years. Sources: Armstrong et al. (2019) 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: Krom et al. (2002).	0.290 (0.260)
Control variables:	*Low-Circumscription*:	Average over the previous 50 years of the ratio of a dummy for the yearly PDSI lying between - 4 and 0 to the average of a similar dummy over the other capitals weighted by their inverse distance. Sources: Armstrong et al. (2019) and HWSD dataset.	0.538 (0.124)
	Internal-Conflicts:	Share of previous 50 years during which the nome witnessed an internal conflict. Sources: Vandier (1950); Altenmüller and Moussa (1991); Morkot (2003).	0.0001 (0.001)
	External-Conflicts:	Share of previous 50 years during which the nome participated in an external conflict. Sources: Vandier (1950); Altenmüller and Moussa (1991); Morkot (2003).	0.004 (0.036)
	Urban-Potential:	Urban potential. Sources: Butzer (1976) and Nielsen (2024).	6.751 (0.577)

Note: 1. The last column lists mean and, in parentheses, standard deviation, all calculated for the samples used in tables 3 to 5.

Figure 2: Climate Change, State-Building and Societal Resilience in Bronze Age Egypt



Note: 1. 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.

Table 3: Climate Change, State-building and Societal Resilience in Bronze Age Egypt

	(1)	(2)	(3)
		The dependent variable is:	
	Political-Institutions	*Public-Buildings*	*Population*
Public-Buildings			0.101 (0.054)*
Political-Institutions		0.226 (0.054)***	0.477 (0.089)***
PDSI	- 0.042 (0.008)***	0.009 (0.012)	- 0.048 (0.036)
Sr-Ratio	- 0.110 (0.028)***	0.048 (0.043)	1.379 (0.107)***
Estimation		OLS	
Within R^2	0.04	0.02	0.39
Number of observations	816	816	360

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

Table 4: Gaining More Insights About Causality

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A. The dependent variable is:			
	Public-Buildings	*Political-Institutions-A*	*Public-Buildings*	*Population*	*Public-Buildings-A*	*Population*
Public-Buildings				0.107 (0.054)**		
Public-Buildings-A						0.130 (0.049)***
Political-Institutions	0.319 (0.068)***				0.154 (0.061)**	
Political-Institutions(t+1)	- 0.151 (0.067)**					
Political-Institutions-A			0.243 (0.055)***	0.454 (0.092)***		0.502 (0.088)***
PDSI	0.010 (0.012)	- 0.039 (0.008)***	0.009 (0.012)	- 0.050 (0.037)	0.003 (0.014)	- 0.043 (0.036)
Sr-Ratio	0.038 (0.043)	- 0.086 (0.027)***	0.045 (0.043)	1.336 (0.107)***	0.070 (0.049)	1.378 (0.105)***
Estimation				OLS		
Within R^2	0.03	0.03	0.02	0.38	0.01	0.39
Number of observations	816	816	816	360	816	360
			Panel B. The dependent variable is:			
	Political-Institutions	*Public-Buildings*	*Political-Institutions*	*Public-Buildings*	*Political-Institutions*	*Public-Buildings*
Political-Institutions		0.227 (0.054)***		0.067 (0.051)		0.228 (0.066)***
PDSI	- 0.046 (0.008)***	0.010 (0.013)	- 0.040 (0.008)***	0.006 (0.011)	- 0.090 (0.014)***	- 0.017 (0.023)
Sr-Ratio	- 0.110 (0.028)***	0.048 (0.043)	- 0.123 (0.027)***	- 0.005 (0.039)	- 0.276 (0.056)***	0.240 (0.091)***
Low-Circumscription	0.102 (0.064)	- 0.034 (0.097)				
Internal-Conflicts			- 7.791 (7.177)	18.339 (10.118)*		
External-Conflicts			1.426 (0.199)***	3.736 (0.290)***		
Urban-Potential					0.186 (0.030)***	- 0.062 (0.049)
Estimation				OLS		
Within R^2	0.04	0.02	0.10	0.20	0.17	0.03
Number of observations	816	816	816	816	612	612

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

Table 5: Using Selection on Observables to Assess the Bias from Unobservables

	(1)	(2)	(3)	(4)	(5)	(6)
			The dependent variable is			
	Political-Institutions	*Public-Buildings*	*Political-Institutions*	*Public-Buildings*	*Political-Institutions*	*Public-Buildings*
The index is calculated for *Political-Institutions*		227		0.4		10.9
PDSI	11.5		20		3.6	
Sr-Ratio	109		9.5		1.1	

Note: 1. The "restricted set" of controls includes capital fixed effects, whereas the "full set" of covariates gathers those considered in columns (1) to (6) of panel B of table 4, respectively. The sample size is 816 except in columns (5) and (6) where it is 612.

Appendix (For Online Publication)

State-Building in Bronze Age Egypt: Details

Late Neolithic and Predynastic periods (8000-2901 BCE).—The fertile Nile valley favored since 8000 BCE the development of regionally fragmented agricultural economies (Shaw, 2003). 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. [These 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. 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 [were] involved" (Willems, 2013). As the climate grew arid, the population concentrated along the river (Köhler, 2020) 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 (Köhler, 2020). Against this background, fierce inter-polity competition favored 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 (Shaw, 2003). 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 (Köhler, 2020).

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 (Moreno García, 2020b), 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 (Moreno García, 2020b). Even if the bureaucratic machinery had not yet attained full maturity, the centralized state soon stretched from Elephantine to the Mediterranean (Moreno García, 2020b). To control this area, the royal household relied on the *šms.w Ḥr.w*, i.e., "followers of Horus" (Engel, 2013). This biennial inspection of the reign aimed to oversee tax collection and the administration of justice (Engel, 2013). 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 (Moreno García, 2020b). 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 (Moreno García, 2020b; Bárta, 2020). This bureaucracy, who was initially based in the capital Inbu-hedj—later known as Memphis, carried the *imy-rA*—i.e., "overseer"—and *ḥqA*—i.e., "governor"—title and managed the state affairs via the *ḥw.t* centers and temples (Bárta, 2020). 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 (Bárta, 2020). A second phase, beginning with the Fifth Dynasty, was, instead, characterized by the rise of provincial landowners promoting their own cults and independence (Moreno García, 2020b). 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 (Bárta, 2020). 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 aA*—i.e., Nomarchs, "great chief" or "overseer", started to collect taxes and manage the construction of public buildings on behalf of the Pharaoh (Bárta, 2020; Cooper, 2009). Despite these centralization attempts, during the 23rd and 22nd centuries BCE period of low Nile floods and droughts (Krom et al., 2002), non-royal households acquired a rising power, which they showcased by shoring up their displays of personal piety to the afterlife cult of Osiris and erecting tombs in their own provinces (Bárta, 2020). 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, the remainder acquired the fiscal autonomy of keeping part of the tax revenues and employing them to finance the provision of local public goods (Bárta, 2020; Lloyd, 2014). With time, the Upper Egyptian Nomarchs started to pass down their *ḥrj-tp aA* 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 (Bárta, 2020; Lloyd, 2014). To preserve their power, the Pharaohs also distributed lands to the temples and established seats of the vizier in Edfu, first, and Abydos, later (Bárta, 2020). Yet, the centrifugal forces prevailed. 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 (Bárta, 2020). Next, 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 these dynamics, the Seventh and Eight Dynasties were only able to rule for a brief period of time without de facto political control over the South (Bárta, 2020).

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 (Moreno García, 2020b). Crucially, these governors, together with those of the other southern provinces, started to be an expression of local households rather than the royal administration (Willems, 2013). 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 (Moreno García, 2020b). Meanwhile, the southern capitals thrived and local trade expanded (Moreno García, 2013; 2020a,b). 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,[18] defensive walls and temples (Willems, 2013; Moreno García, 2013; 2020b). The temples, in turn, "took on some of the managerial activities hitherto restricted to the crown" (Moreno García, 2020b) such as the administration of justice as well as key risk-sharing activities, like grain storage and local market organization (Moreno García, 2013; 2020b; Bárta, 2020). 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 landowners later (Moreno García, 2020b). Crucially, "access to priesthood was fiercely controlled by local associations of priests" (Moreno García, 2020b). Lower Egypt, instead, remained under the relatively loose control of Heracleopolis (Moreno García, 2020b).

Middle Kingdom (1979-1630 BCE).—Characterized by milder climate and fluctuating

[18]The Nomarchs also settled conflicts between neighboring capitals about rights over water (Willems, 2013).

moderate Nile flow (Krom et al., 2002), 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 (Willems, 2022). To illustrate, the Theban kings' victory at Asyut prompted several nomes, who had supported before the Heracleopolitan kings, to switch side (Willems, 2022). 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 (Willems, 2022). 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 (Willems, 2022). This success gave rise to a novel administrative system characterized by offices strictly linked to the royal palace (Willems, 2022). Local administrators assumed the title of *ḥAtj-a*—i.e., "town mayors"—and actively helped enforce the royal authority over the provinces and their capitals (Willems, 2022). Moreover, at the intermediate level, a *ḥry-tp šma*—"Head of the South"—figure linking Upper Egypt to the capital of the kingdom was established (Willems, 2022).

Constructing the proxies for inclusive political institutions.—We identify the provinces whose Nomarchs held the *ḥrj-tp aA* title through (Helck, 1975; Ward, 1982; Jones, 2000; Favry, 2004; Martinet, 2019), 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 (see table I for definition and sources of the variables that we employ in this appendix).

Errors in the Measurement of Archaeological Variables

Besides the miscalculations discussed in footnote 7 of the main text, three are the sources of measurement errors created by the low and/or asymmetric quality of some of our 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 (Banning, 2002). 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 inde-

pendent of true variables. Two are the key effects (Angrist and Pischke, 2009). 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 our conclusions.

Second, the methods of excavation and preservation adopted for each archaeological site might vary. Nevertheless, "several studies have shown broad agreement in the demographic trends produced by the SPD of radiocarbon dates and other archaeological indices" (Palmisano et al., 2021). Similarly, the southern nomes have comparatively better levels of preservation because they experienced only limited Nile's avulsion, while flooding and fluvial movements were much more extreme in Lower Egypt (Smith and Jeffreys, 1986). 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 (Smith and Jeffreys, 1986). 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 the message of our empirical analysis.

Finally, our proxy for fiscal autonomy aggregates institutional information taken from inscriptions and secondary sources and is, thus, independent of precisely measuring each Nomarch's status, wealth and functions as reflected by his titles. Such dimensions varied over our sample (Jones, 2000; Ward, 1982), and factoring in local trends as much as would be desirable from an archaeological perspective is an avenue for future research.

Trade, Epidemics and Immigration Waves in Bronze Age Egypt

Concerning long-distance trades, there is large evidence of its connection with urbanization and the centralization of the administrative and logistical apparatus needed for shipping (Castle, 1992; Bietak, 2017). Turning to disease spread, New Kingdom textual and archaeological evidence for the plague impact in the 14th century BCE shows that it was closely associated with higher population density, as well as greater exposure to international contacts (Panagiotakopulu, 2004; Norrie, 2016). While there are no comparable studies for the spread of pathogens in the earlier periods part of our sample, it seems likely that here too

the same trends would prevail. Finally, the existing evidence on the patterns of migration into Egypt points to its link with heavily urbanized sites, as typified for instance by the cases of Tell el-Dab'a (Bader, 2011; Priglinger, 2019) and Naukratis (Demetriou, 2012; Knight, 2019). While examples such as these date to periods subsequent to our sample, it is logical to assume that earlier migration trends would have followed a similar pattern. Ultimately, periods of higher urbanization witnessed greater state centralization and in turn, an expansion of long-distance trade, epidemic outbreaks and immigration waves.

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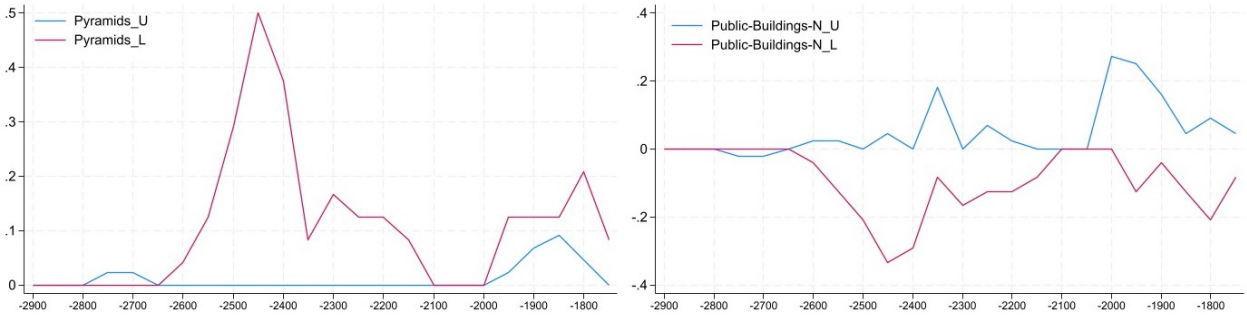
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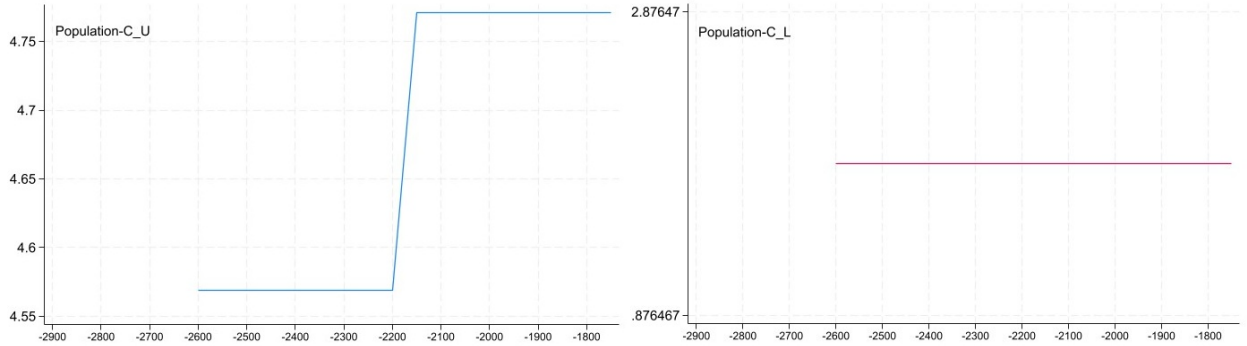
Supplementary Tables and Figures

Figure I: Public Good Provision in Bronze Age Egypt



Note: 1. 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 I details definition and sources of each variable.

Figure II: Nome's Population Outside the Capital



Note: 1. The left and right graphs portray the natural logarithm of the population of the countryside of each Nome averaged over the previous half-century and, respectively, Upper and 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 I details definition and sources of each variable.

Table I: Summary of 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: Martinet (2019); Favry (2004); Helck et al. (1975); Jones (2000); Ward (1982).	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: Martinet (2019); Helck et al. (1975); Jones (2000); Ward (1982).	1.163 (0.502)
	Pyramids:	Average number of mastabas and pyramid tombs built over the previous 50 years. Sources: Bard (1999), Wilkinson (2000), and Arnold (2005).	0.045 (0.352)
	Public-Buildings-N:	Average number of forts and temples less that of mastabas and pyramid tombs built over the previous 50 years. Sources: Bard (1999), Wilkinson (2000), and Arnold (2005).	0 (0.408)

Note: 1. The last column lists mean and, in parentheses, standard deviation, calculated for the samples used in tables II to IV.

Table II: Extended Sample and Alternative Chronology

	(1)	(2)	(3)	(4)
	The dependent variable is:			
	Political-Institutions	*Public-Buildings*	*Political-Institutions*	*Public-Buildings*
Public-Buildings				
Political-Institutions		0.227 (0.050)***		0.207 (0.062)***
PDSI	- 0.039 (0.007)***	0.010 (0.011)	- 0.013 (0.007)*	- 0.020 (0.013)
Sr-Ratio	- 0.089 (0.023)***	0.057 (0.036)	- 0.085 (0.023)***	- 0.002 (0.041)
	OLS			
Within R^2	0.04	0.02	0.02	0.02
Number of observations	1008	1008	884	884

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

Table III: Clustered, Wild Bootstrapped and Spatially-corrected Standard Errors

	(1)	(2)	(3)	(4)	(5)	(6)
	The dependent variable is:					
	Political-Institutions	*Public-Buildings*	*Political-Institutions*	*Public-Buildings*	*Political-Institutions*	*Public-Buildings*
Political-Institutions		0.226 (0.213)		0.226 (1.06)		0.226 (0.170)
PDSI	- 0.042 (0.008)***	0.009 (0.014)	- 0.042 (- 5.24)***	0.009 (0.62)	- 0.042 (0.010)***	0.009 (0.016)
Sr-Ratio	- 0.110 (0.028)***	0.048 (0.060)	- 0.110 (- 4.05)***	0.048 (0.81)	- 0.110 (0.024)***	0.048 (0.043)
	OLS					
Within R^2	0.04	0.02	0.04	0.02	0.29	0.21
Number of observations	816	816	816	816	816	816

Notes: 1. Standard (T-test obtained from wild bootstrapped standard) errors clustered at the capital level in the parentheses of columns (1) and (2) ((3) and (4)) and Conley's (1999) standard errors with Bartlett kernel in the parentheses of columns (5) and (6). The distance beyond which the correlation between error terms is assumed to be 0 is 23.8 km.
2. Standard errors in parentheses; *** denotes significant at the 1% confidence level; **, 5%; *, 10%.
3. All specifications include capital fixed effects.

Table IV: Ordinal Measures of the Inclusiveness of the Political Process

	(1)	(2)	(3)
	The dependent variable is:		
	Political-Institutions	*Political-Institutions-O*	*Public-Buildings*
Public-Buildings			
Political-Institutions-O			0.093 (0.025)***
PDSI	- 0.834 (0.189)***	- 0.400 (0.108)***	0.005 (0.012)
Sr-Ratio	- 3.443 (0.890)***	- 2.649 (0.548)***	0.048 (0.043)
		Logit	
Pseudo R^2		0.07	
Within R^2			0.02
Number of observations	312	720	816

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