Property Rights and Civilizational Development at the Dawn of History

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Abstract

We examine the hypothesis that institutional development, in the form of property rights, played a key role in facilitating agricultural capital accumulation, thereby promoting the emergence of ancient civilizations. We develop a model that rationalizes how different property rights regimes endogenously emerge due to geographical differences, before eventually giving rise to civilizations. We subject our arguments to the data in two ways. First, we verify our theoretical propositions using data from more than 400 historical polities between 9600 BCE and 1900 CE. Second, we examine textual, artifactual, and archeological evidence, drawn from Neolithic settlements located in riverine environments along ancient trade routes between between 4500 and 1600 BCE, to identify the causal effect of property rights on civilizational development. This falsification approach allows us to rule out geography and trade as sufficient factors for civilizational formation.

KEYWORDS: Fundamental determinants of growth; property rights; capital accumulation; civilizational formation

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> It would seem that no advanced civilization has yet developed without a government which saw its chief aim in the protection of private property.
>
> Friedrich Hayek (1991, p. 32)

1 Introduction

The question of what gives rise to persistent cross-country differences in incomes is one of the central preoccupations of economics. Since the seminal work of Solow (1956), the profession has recognized that capital accumulation plays a key role in conditioning economic growth. But increased inputs of capital (along with labor) are only regarded as proximate factors associated with output expansion. Research has since identified more fundamental drivers as the basis for diverging economic performance, such as the geographical environment (Davis & Weinstein 2002; Diamond 1997; Gallup, Sachs & Mellinger 1999), integration through trade relations (Dollar & Kraay 2003; Frankel & Romer 1999), and the nature of political-economic institutions (Acemoğlu, Johnson & Robinson 2001; North, Wallis & Weingast 2009).

If these determinants of growth are indeed fundamental for economic advancement, then they should also matter over the long span of human history: geography, trade, and institutions must have played a role in shaping the initial emergence of civilizations, at its dawn. Specifically, these factors would have impacted the accumulation of capital—especially in terms of agricultural tools and techniques used for irrigation and drainage—which then enabled early sedentary human settlements to generate the food surpluses necessary to support economic specialization and development beyond the subsistence level.

In this paper, we assess the relative contributions of geography, trade, and institutions to agricultural capital accumulation and civilizational emergence. We develop a model where property rights affect agricultural investment, which in turn gives rise to food surpluses that increase the likelihood of civilizational formation. But we also endogenize the form of institutional arrangement that emerges; the strength of property rights regimes depends on the geographic preconditions that shape initial (agricultural) capital needs. Our argument stresses how rights institutions are central to growth dynamics, and this emphasis—relative to contracting institutions—is consistent with the empirical evidence when the two are unbundled (Acemoğlu & Johnson 2005). Our separation into weaker and stronger regimes may also be seen as analogous to the distinction, made by others, of informal versus formal institutions (Williamson & Kerekes 2011).

We also test our theory against the data. We first evaluate our theoretical propositions using a deep historical database of up to more than 400 historical polities, from 9600 BCE through 1900 CE. While we find broad support for our propositions, we recognize that these results do not withstand a causal interpretation. We therefore proceed with a systematic comparison of the institutional environment in four ancient river valley societies—Mesopotamian, Egyptian, Harappan, and Sinic[1]—to other large Neolithic settlements located in geographically-similar riverine valley regions on major ancient trade routes. This falsificaton-based analytical narrative allows us to isolate the causal effect of how property rights institutions influenced the evolution of disparate settlements into nascent civilizations.

The two interrelated aspects of our argument—that property rights induce capital accumulation and growth, and that resultant growth generates surpluses necessary for civilizational emergence—are, admittedly, not entirely novel. Our contribution, instead, rests on two separate pillars.

First, we marshal evidence from a mix of quantitative and qualitative sources to highlight the importance of institutions as a fundamental driver of growth in a unique economic setting. We are able to draw inferences over key initial conditions favoring civilizational emergence at the dawn of history, before the rise of nation-states, escape from the Malthusian trap, and the imperial and industrial eras. Since the complicating effects of certain confounding factors—such as human (Galor & Moav 2004; Glaeser, La Porta, López-de Silanes & Shleifer 2004) and social (Knack & Keefer 1997; Tabellini 2008)

[1]Together with the Mesoamerican and Andean civilizations in the Americas, these are commonly referred to as the "pristine" civilizations, having arisen independently from each other.

capital—would only come into play under later, more advanced settings, fundamental factors can be more cleanly analyzed under our research design.[2]

Second, notwithstanding our claim that institutions dominate geography, our model nevertheless captures the endogeneity of institutional strength vis-à-vis the geographical setting. While there has long been recognition of the need to endogenize institutional formation (Aoki 2007), specific applications to understand long-run growth dynamics have less forthcoming. In a series of papers, Acemoğlu, Johnson & Robinson (2002, 2005b) consider the joint role of trade, institutions, and geography in determining the modern world income distribution, but these papers do not provide a formalization of how these forces interact.[3] The work of Elis, Haber & Horrillo (2017) and Stasavage (2010) also underscore the importance of geography, but focus more on how it can alter the form of economic and/or political institutions (and, in turn, state development) rather than the nature of property rights. In contrast, other papers that examine how institutions may be endogenous to other factors—such as state capacity (Besley & Persson 2009; Frye 2004) or cultural norms (Greif 1994; Salter 2015)—do not explicitly enfold geography into the story.

1.1 Related literature

We speak to existing work in several distinct literatures. We clearly fall in line with papers that have sought to empirically disentangle the fundamental determinants of growth (Acemoğlu, Johnson & Robinson 2005a; Ashraf & Galor 2013; Decker & Lim 2008; Galor & Moav 2002; Glaeser *et al.* 2004; Rodrik, Subramanian & Trebbi 2004). However,

[2]It is also important to understand that our work here does not deny the importance of other contributing variables. Rather, our argument is that such factors exhibited much less cross-regional variation in ancient times, or are effectively time-invariant for the time period considered. For example, with subsistence consumption as the binding constraint during the the pre-Malthusian epoch (Galor & Moav 2002), the effect of human capital accumulation is unlikely to be a dominant differentiating factor between ancient settlements. Similarly, the comparatively small amounts of inter-societal migration in ancient times suggests that the sort of genetic or ethnolinguistic diversity characterized by migratory distances (Ashraf & Galor 2013) is more likely to hold for our time frame (relative to contemporaneous ones).

[3]Acemoğlu (2005) *does* offer such a model, but it is concerned with the question of the extent of development of state capacity, rather than economic development.

empirical explorations undertaken by this body of work relies on econometric analysis of cross-country data from 20th-century economic history, or patchy data from the middle ages onward. In contrast, we focus our lens on a much earlier time period beginning in the 5th millennia BCE, a period that remains understudied.

A number of papers also examine economic growth over the very long run, adopting perspectives that are either of a primarily empirical (Ashraf & Galor 2011; Kremer 1993; Rodrik *et al.* 2004) or theoretical (Acemoğlu & Zilibotti 1997; Galor & Weil 2000; Hansen & Prescott 2002; Jones 2001) nature. Our approach is consistent with some of the central findings—in particular, the stress on property rights (Jones 2001) and the important role of technology adoption in exiting Malthusian stagnation (Galor & Weil 2000; Hansen & Prescott 2002)—but we document the significance of such rights for capital accumulation since ancient times, not just after takeoff from the Malthusian trap (Galiani & Schargrodsky 2011), or in instigating the takeoff itself (Bogart & Richardson 2011).

The literature closest to our concerns here are those by Benati & Guerriero (2022), Bowles & Choi (2019), Dal Bó, Hernández-Lagos & Mazzuca (2022), Eswaran & Neary (2014), and the pair of papers by Mayshar, Moav & Neeman (2017) and Mayshar, Moav & Pascali (2022), all of which consider, as we do, the emergence of endogenous property rights at the dawn of history. However, each bring to bear distinct mechanisms. The first paper stresses skills complementarity that promotes cooperation. The next two focus on security—specifically, the tradeoff between surplus production and protection needs, or the relative ease of defense of cultivated crops and domesticated animals—while the fourth attributes rights emergence to innate behavioral (specifically, evolutionary) preferences. The final two papers turn the spotlight on appropriation, either in terms of the technology available for doing so, or informational asymmetries that inhibit the process. In contrast, our approach leans heavily on the *interaction* between environmental endowments and agricultural capital accumulation (and appropriation), all aspects of the qualitative evidence we bring to bear in our study.[4]

[4]We acknowledge that our work abstracts from the roles that religion, slavery, and warfare played in the development of ancient societies.

2 A Model of Civilizational Emergence and Property Rights

Our model places property rights institutions at the center of the capital accumulation process. More specifically, property rights increase the production and investment incentives of agricultural households. The setting is a two-stage game. In the first stage, a ruling elite chooses the revenue-maximizing level of property rights, before the citizens—taking the rights regime as given—optimally choose the effort they devote to production, as well as to investing in drainage, irrigation, or other water-management capital. To the extent that geographic features matter, it does so by conditioning the relative strength of these rights in shaping incentives for capital accumulation.[5]

Consider a society populated by $P > 0$ yeoman agricultural producers, each faced with the possibility of investing in capital for farming purposes.

Definition 1 (Capital)**.** Ancient agricultural *capital*, $k \geq 0$, are the structures, tools, and machinery employed for the purposes of controlling natural water supply systems and effecting either small- or large-scale irrigation and drainage associated with the growth of food crops.

Note that our definition of agricultural capital is somewhat narrower than that which is conventionally regarded as physical capital in contemporary terms (which treats capital as heavily substitutable), but is broader in the sense that our definition embodies existing hydraulic engineering knowledge and technology embedded in capital. Thus, Nubian *sakias* as well as *norias* (different forms of irrigation waterwheels) fall within our definition of agricultural capital, as do the Chinese *sanguoche* and *longguche* (distinct types of chain irrigation pumps).

[5]We do not formally model trade, under the assumption that there are equal opportunities for exchange among all societies. We also rule out the direct transfer of agricultural capital via trade, the evidence for which we provide in Section A.6.

Period optimization involves maximizing their respective utility functions given by

$$\begin{aligned} v &= \theta \left[af\left(k,n,l\right)\right] - e\left(i+n\right) \\ &= \theta \left[af\left(k_0+i,n,l\right)\right] - e\left(i+n\right), \end{aligned} \tag{1}$$

where output is the result of (disembodied) technology a used in production $f(\cdot)$, which relies on agricultural capital k, labor n, and land l as inputs, and $e(i+n)$ is the effort cost of devoting i labor units to expanding the irrigation system to size $k = k_0 + i$, and an additional n labor units to production. k_0 is the initial hydraulic capital stock, exogenously determined by the natural environment, and hence beyond the control of agents. $\theta \in (0,1)$ represents the share that is retained from production income following appropriation (which the producer takes as given). We assume that $e'_i, e'_n > 0$, $e''_{ii}, e''_{nn}, e''_{in} > 0$, where for ease of notation, partial derivatives are denoted with a prime superscript (with arguments in subscript).

The broad level of technology given by a includes knowledge generated within the agent's community or settlement, that learned from other settlements (for example via exchanges due to trade), and geographical determinants of productivity. Institutional determinants of income, however, are distinct and captured with the parameter θ, which we interpret as a measure of the security of property rights.

Definition 2 (Property rights)**.** A regime of *property rights* is a *de jure* or *de facto* system of rules or laws delineating the ability of an individual (or small group of close-knit individuals) to appropriate gains from the ownership and use of a given (agricultural) resource, the strength of which is measured by a parameter $\theta \in (0,1)$.

The definition encompasses, for example, the right to exclude (North 1981), and conveys the ability to benefit from such rights (Demsetz 1967). Given the historical context, however, the definition does not insist on such rights being bound by a formal legal code,[6] although we *do* require that the recognition of property rights is of a sys-

[6]This is because the rule of law is a distinct institutional concept, and legal codes may or may not have been established in the societies in question during the periods considered.

tematic nature; in other words, property rights should be either formally or informally recognized as institutions.[7] This approach is also consistent with more archeologically or anthropologically-centered perspectives (Castillo Butters, DeMarrais & Earle 1996; Earle 2000).[8] For analogous reasons, our definition blurs the distinction between institutional and private property that is occasionally made by some authors (Hunt & Gilman 1998).

It has long been accepted that a nominal recognition of land tenure can help promote greater investment in agricultural capital and technology. Indeed, Coase (1960) framed his seminal "problem of social cost" in the context of rights over agricultural use of land, and development economists have elaborated on the various channels, such as security-induced investment demand and collateral availability, by which more secure property rights over land can accelerate the adoption of farming technology and improve agricultural productivity (see Galiani & Schargrodsky (2011) for a recent survey).

The security of property rights captured by θ, while exogenous for agricultural producers, is in fact chosen by elites, who possess objective functions given by

$$w = (1 - \theta)\left[af\left(k_0 + i, n, l\right)\right]. \tag{2}$$

A settlement's food surplus, S, aggregates output net of consumption c_0 of all P agricultural producers:

$$S \equiv P \cdot \left[af\left(k_0 + i, n, l\right) - c_0\right]. \tag{3}$$

Our definition of a civilization follows the textbook definition of societal emergence due to agricultural surplus (Johnson & Earle 2000), albeit only at a sufficiently high level of development.[9]

[7]By this somewhat more expansive definition—where codification *per se* is unnecessary—property rights to land may even be traced back even further, to prehistory of around 8000 BCE (Earle 2000), and may have marked the transition between hunter-gatherer societies and sedentary agricultural settlements, starting with the Natufians (Pringle 2014). Although consistent with our main argument, our refinement to institutionalized property rights excludes cases where such rights may have existed but were of a more tenuous nature, enforced perhaps only by violent protection.

[8]The difficulty of a sole reliance on archeological definitions alone is that one is led almost to a tautological notion of property: if property rights can be inferred by labor investment, warfare, and patterns of migration and settlement, without regard to some nominal degree of institutionalization, then it becomes difficult to identify the cases where property rights might be deemed not to exist.

[9]Depending on the discipline, the term "civilization" is itself occasionally contentious. Historians

Definition 3 (Civilization)**.** A *civilization* is a sedentary human culture or society that has attained a high relative level of technological advancement and capital stock, exhibits broad-based specialization in intra-civilizational production and is hence capable of generating a food surplus, thereby enabling concentrated (typically urban) settlement patterns, and possessing institutions of political organization.

The emphasis on specialization, urbanization, and technology is fairly typical; Krejči (2004, p. 9), for example, characterizes civilizations as demonstrating "division of labor, city life, [and] some knowledge of how to make metal tools," while agricultural capital is central for Melko (1969, p. 8), who distinguished civilizations from simpler cultures by their "greater control of environment, including the practice of agriculture on a large scale and the domestication of animals." Some authors do go further in stressing the importance of technology for knowledge transmission, a feature that Bosworth (2003, p. 9) terms a "cultural infrastructure of information and knowledge," although it is often the communication aspects of technology that is emphasized (Targowski 2004), and how information technologies ultimately facilitate large-scale political organization (McGaughey 2000).

The probability that a civilization emerges, μ, as thus an increasing function of per capita food surplus, since this allows greater division of labor, specialization, and urbanization; that is,

$$\mu \equiv h\left[af\left(k_0 + i, n, l\right)\right],$$

with $h' > 0$. We make some additional assumptions over the functional form: $f'_k, f'_n, f'_l > 0$, $f''_{kk}, f''_{nn} < 0$, $f''_{kn} = f''_{nk} > 0$.

Civilizational emergence is the result of a simple two-stage game, where elites first establish the property rights regime by selecting θ, followed by producers making their effort and agricultural capital accumulation decisions. The formal definition of equilibrium

are comfortable with the use of civilization, while economic anthropologists often prefer referring to (regional) polities (Johnson & Earle 2000), whereas political scientists often adopt (premodern/primary) state as their favored nomenclature (Tilly 1992). Since we are referring specifically to large states/polities at the dawn of history, we use of the term civilization to refer to polities and states that have attained a sufficiently advanced level of development.

in this game follows.

Definition 4 (Civilizational emergence equilibrium)**.** The (pure strategy) subgame perfect Nash equilibrium in the civilizational emergence game is a triple $\{\theta^*, i^*, n^*\}$ such that: (a) $\nexists\ \tilde{\theta} \neq \theta^*$ such that $w(\theta^*) \leq w\left(\tilde{\theta}\right)$; (b) $\nexists\ \tilde{i} \neq i^*$ and $\tilde{n} \neq n^*$ such that $v(i^*, n^*) \leq v\left(\tilde{i}, n^*\right)$.

We focus on interior equilibria and solve the game by backward induction. Our first proposition obtains from optimizing (1) in the second stage, and states that after taking into account the overall technological level, more secure property rights promote greater investment in irrigation capital (along with labor supply).

Proposition 1 (Property rights promote capital investment)**.** *In any interior subgame perfect Nash equilibrium, more secure property rights promotes greater investment in agricultural capital, as well as greater labor input. That is,* $\frac{di}{d\theta} > 0$ *and* $\frac{dn}{d\theta} > 0$.

Proof. See appendix. □

This result, although straightforward, is important: it states that stronger property rights increase inputs to production, namely capital investment and the labor supply. This increase, in turn, results from the fact that optimality requires yeoman farmers to balance the marginal benefit of higher output from greater deployment of agricultural capital, against the marginal (effort) cost of allocating labor toward accumulating such capital. This will only be the case if the relationship between changes in irrigation-directed labor vis-à-vis changes in the security of property rights is positive (rather than, as may initially appear, the relationship between *output* and property rights). Ultimately, as detailed in the proof, this condition is satisfied because of the diminishing marginal product of labor and the (partial) complementarity of capital and labor. Proposition 1 offers a simple framework for rationalizing the empirical relationship between improved property rights and heightened agricultural investment (Anderson & Lueck 1992; Galiani & Schargrodsky 2011).

Like others in the literature, we assume that any surplus generated is appropriable, and that stronger property rights aligns incentives toward expanding this surplus (and hence growth). However, the degree of appropriation in our case does not stem from either informational asymmetries regarding farmer effort, as in Mayshar *et al.* (2017), or the type of crops planted, as Mayshar *et al.* (2022) have argued. Nor do we rely on the necessity of complementary skills to foster a culture of cooperation, as Benati & Guerriero (2022) require (although our framework does not explicitly rule out such Pareto-improving possibilities). Rather, we work with very standard incentives involving a tradeoff between effort and payoff. Yet, as we will see below, even such a simple incentive structure can yield significant insight when paired with political-economic decisionmaking in response to environmental constraints.

Moreover, in our setup the rise of elites are largely secondary to the story. In both Mayshar *et al.* (2022) and Dal Bó *et al.* (2022), elites exist to provide security. We instead allow the presence of elites,[10] but rather than provide a service, they instead face incentives regarding the extension of greater or lesser rights.[11] This shifts the focus to how elite choices are made, to which we now turn.

In Proposition 2, we ask how the variation in the environmentally-determined initial stock of irrigation capital (k_0) affects the equilibrium level of property rights, that is, rent-extraction. In practice, both the variation in the appropriability of different crop types and the variation in the availability of natural irrigation capital may have affected the historical evolution of property rights regimes.

We optimize (2) in the first stage, taking optimal investment in the second stage as given, to obtain the following proposition on how differences in initial agricultural capital needs might give rise to variations in the security of property rights chosen.

Proposition 2 (Greater initial capital needs weakens property rights regimes)**.** *For marginal costs that accelerate slower than a certain threshold, differences in geographic conditions requiring more initial capital provision leads to weaker property rights regimes.*

[10] While we abstract from how the elite arose, we note that as long as there exists an appropriable food surplus, some agent(s) will have an incentive to appropriate it and become the elite.

[11] From a purely technical perspective, we also differ in our solution strategy. Our analysis is built around subgame perfection solved via constrained optimization, rather than Bayesian perfection due to informational asymmetry (such as in Mayshar *et al.* (2017)), or Markov perfection with uncertainty (à la Acemoğlu (2005)).

For Cobb-Douglas production and quadratic effort costs, $\frac{d\theta}{dk_0} < 0$. *More generally,* $\frac{d\theta}{dk_0} < 0$ *if*

$$e'''_{nnn} < \delta, \qquad -\infty < \delta < \infty,$$

where δ *defines a given threshold. Otherwise, it strengthens property rights.*

Proof. See appendix. □

Proposition 2 implies that, owing to natural endowment differences, greater initial capital needs gives rise to weaker property rights. Whether this divergence in regimes occurs depends on the asymmetry of costs with respect to labor, or more precisely, the extent of inflection of the cost function. As long as this asymmetry is small enough, the third derivative of costs with respect to labor will be small, and fall below our required threshold δ.

The intuition behind the proposition is that the larger the natural capital stock k_0, the higher will be final agricultural output, *ceteris paribus*. Because z output units are not subject to appropriation, the effective "tax base" is small and more elastic in response to appropriation (tax) changes when k_0 and production are low. Conversely, the larger is k_0, the larger and less elastic is the tax base. As a result the ruler, whose optimality condition sets the elasticity of the tax base to unity, prefers a higher tax rate (weaker property rights), given by $(1-\theta)$.[12]

Now, if $\frac{d\theta}{dk_0} < 0$, then a large initial capital stock encourages appropriation and weaker property rights, crowding out future capital accumulation (that is, decreasing i). This would be a kind of natural resource curse, operating via appropriation incentives. In this sense, we can view the relationship as a form of *dynamic crowding out*, operating through the channel of institutions.

We are now in a position to link these propositions to civilizational emergence.

Proposition 3 (Property rights support civilizational emergence)**.** *In any interior optimum, more secure property rights increases investment in agricultural capital and labor*

[12] More formally, $\arg\max_\theta w = (1-\theta)\left[af\left(k\left(k_0+i\right),l\right)-z\right] \Rightarrow \frac{(1-\theta)\partial(af(i,l))/\partial\theta}{af(k(i),l)-z}$.

input, resulting in greater food production and surplus, and enhances the likelihood of civilizational emergence. That is, $\frac{d\mu}{d\theta} > 0$.

Proof. The relationship of the surplus to property rights is given by

$$\frac{dS}{d\theta} = \frac{d\{P[af(k_0 + i, n, l)]\}}{d\theta} = Pa\left(\frac{di}{d\theta} + \frac{dn}{d\theta}\right).$$

which is positive in an interior optimum by Proposition 1. Then the likelihood of civilization arising increases since

$$\frac{d\mu}{d\theta} = h'\left(\frac{dS}{d\theta}\right) > 0.$$

□

These results are related to a number of explanations offered in the literature that tie agricultural circumstances to the emergence of societal hierarchies and collectivist norms. Mayshar *et al.* (2022), for example, argue that the appropriability of certain crops (cereals, as opposed to roots or tubers) influence the tendency for a hierarchical state to form, while Zhou, Alysandratos & Naef (2023) provide evidence that wetland rice farming promotes cooperative behavior. Olsson & Paik (2016) add that regions that adopted agriculture first are more likely to develop societal traits associated with collectivism (such as greater obedience and weaker sense of independent control), an argument that is expanded on by Allen, Bertazzini & Heldring (2023), who find that geographic circumstances (specifically access to water) drove collectivism and hence state formation.[13] While the results presented above stress the importance of Neolithic agricultural conditions, our explanation differs in that we stress the importance of property rights over crop type or irrigation needs as the central mechanism for prompting agricultural investment and hence civilizational emergence (Proposition 1). For us, environmental conditions only come into play secondarily—via its *mediating effect* on the property rights regime (Proposition 2)—rather than as a sociocultural norm that is biased toward collectivist

[13]Moreover, Allen *et al.* (2023) focus on the degree of centralization for settlements around Southern Iraq, whereas we regard these as comprising Mesopotamian civilization as a whole.

values.[14]

Admittedly, our claim for civilizational emergence in Proposition 3 is a *probabilistic* one, and abstracts from whether civilizations *must* necessarily develop. Importantly, we do not incorporate Malthusian limitations (Galor & Weil 2000; Hansen & Prescott 2002), which may well inhibit the emergence of civilizations in practice. We do not regard this as a major shortcoming in our setup, since our theoretical emphasis is on the property rights-investment tradeoff, and the conditioning role of geography (but not trade) for the strength of these property rights. Introducing additional elements would complicate the model and dilute our central argument.

3 Correlational Evidence: Institutions, Geographic Needs, and Civilizational Development

In this section, we report regressions for each of the three propositions in Section 2, before providing a comparative analysis of property rights institutions vis-à-vis trade linkages and geographic conditions.

3.1 Data and methodology

We rely on the *Seshat Global History Databank*, which documents characteristic of 414 societies in 30 distinct regions, from the Neolithic (circa 10000 BCE) through till the end of the 19th century (Turchin *et al.* 2015). We extract features that correspond to the variables of interest in Section 2: property rights institutions (for example, the existence of a legal code as well as nonwritten records), agricultural capital (e.g. the presence of irrigation systems and food storage facilities), initial agricultural needs (e.g. how responsive crops are to irrigation or fertilization), and civilizational development (e.g.

[14] Other studies have highlighted similar mechanisms using data from later periods. Buggle (2017), for instance, documents how the joint practice of irrigation culture in pre-industrial societies exhibit stronger contemporaneous collective norms, similar to Mayshar *et al.* (2022), and complementary to our own justification. Someone closer to our view, Goldstein & Udry (2008) find that property rights over agricultural plots in Ghana encourage more intensive investment, with an individual's position in the political hierarchy influencing their security of land tenure.

the hierarchy of the settlement, or simply population size). We complement these with additional variables related to the strength of trading relationships (e.g. whether there are ports or foreign coinage), and geographical characteristics (e.g. the distance to the equator).

In most instances, we are able to construct variables that are more narrowly-defined—for instance, limiting our metric for property rights to simply a combination of the legal code, nonwritten records, and the existence of a script)—or a broader definition that incorporates complementary measures (such as including, in this metric, written records, or allied legal institutions such as the presence of lawyers and courts), at risk of overidentifying the construct. Additional details on variable choice and construction are documented in detail in the data appendix.

3.2 Evaluating the relationship between property rights, agricultural capital, and civilizational emergence

We perform regressions corresponding to Proposition 1 (top panel of Table 1), Proposition 2 (middle panel), and Proposition 3 (bottom panel).[15]

Our first proposition implies that stronger property rights give rise to greater agricultural capital accumulaton. The estimates in the top panel strongly support this result, regardless of whether a more limited or more expansive definition of property rights and/or agricultural capital is deployed. While data limitations preclude being able to directly control for labor inputs or effort (as alluded to in Mayshar *et al.* 2017), we are able to include crop type (Mayshar *et al.* 2022) as an independent covariate.[16] However, doing so does not diminish the strong statistical significance of the property rights effect.

Proposition 2 suggests that when geographic conditions call for greater initial agricultural capital needs, property rights regimes could end up weaker.[17] The results in

[15]A full documentation of the empirical methodology, along with justifications for the variations for each specification, may be found in the appendix.

[16]These typically did enter with a significant coefficient. Details are available on request.

[17]We also consider, in the appendix, a more involved specification where property rights depends on not just initial agricultural needs but also, conditionally, on agricultural capital investment.

Table 1: Regression results for main theoretical propositions[†]

	Proposition 1					
	Dependent: Ag. capital (narrow)			*Dependent: Ag. capital (broad)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.568 (0.044)***			1.470 (0.090)***		
Prop. rights (incl. leg. inst.)		0.290 (0.022)***			0.809 (0.041)***	
Prop. rights (incl. writ. rec.)			0.389 (0.036)***			1.089 (0.072)***
Crop type?	No	Yes	Yes	No	Yes	Yes
R^2 (adj.)	0.326	0.519	0.472	0.422	0.574	0.512
N	386	312	313	403	329	330
	Proposition 2					
	Dependent: Prop. rights		*Dependent: Prop. rights (incl. leg. inst)*		*Dependent: Prop. rights (incl. writ. rec.)*	
	(7)	(8)	(9)	(10)	(11)	(12)
Initial ag. needs (narrow)	0.520 (0.395)		-3.176 (1.435)**		-1.470 (0.800)*	
Initial ag. needs (broad)		-0.749 (0.282)***		-1.623 (0.649)**		-0.774 (0.422)*
Add. needs?	No	No	Yes	No	Yes	No
Crop type?	No	No	Yes	Yes	Yes	Yes
R^2 (adj.)	0.003	0.027	0.201	0.150	0.185	0.166
N	225	205	205	205	206	206
	Proposition 3					
	Dependent: Prob. civilization			*Dependent: Settlement hierarchy*		
	(13)	(14)	(15)	(16)	(17)	(18)
Prop. rights	0.591 (0.094)***			1.031 (0.078)***		
Prop. rights (incl. leg. inst.)		0.351 (0.044)***			0.584 (0.037)***	
Prop. rights (incl. writ. rec.)			0.508 (0.074)***			0.813 (0.054)***
R^2 (adj.)				0.382	0.451	0.420
N	409	409	410	399	399	400

[†] Coefficients estimated via OLS and Probit, with the dependent variable listed in the top row of each panel. Crop type are indicators corresponding to one of 12 different crop types. Additional agricultural needs include the fertilizer and crop system coefficients. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

the middle panel corroborate this claim, at least insofar as the statisfically significant coefficients turn out to be negative.[18]

Our final proposition relates the probability of civilizational emergence to the strength of property rights. We also find evidence that this holds, whether via a probabilistic model, or in a specification where the level of development attained by settlements is directly regressed on property rights. More advanced civilizations are clearly associated with stronger property rights.

3.3 Comparing property rights institutions to other fundamental determinants

We move on to directly compare institutions—as embodied by property rights—against trade integration and geographical characteristics, the two other major fundamental determinants of development (Table 2). Even though trade and (certain aspects of) geography appear to matter for civilizational development, the effect of property rights always remains relevant. And while variations in measurement imply that these coefficients are not directly comparable, it is useful to observe that the coefficients on property rights institutions are always highly significant, which speaks to the strength of this relationship.

That said, the results captured in Tables 1 and 2 face one important drawback: they are essentially associations. While econometric techniques may be deployed to better determine the causal influence of institutions in modern applications (Acemoğlu *et al.* 2005a; Rodrik *et al.* 2004), data paucity at the dawn of history mean that these are not generally possible in our setting. Accordingly, we pursue a more qualitative approach in the next section, in an effort to better establish causality.

[18]To be clear, Proposition 2 also allows for the possibility of a *positive* coefficient, should the threshold condition not be satisfied (whether $e'''_{nnn} > \delta$, or if a Cobb-Douglas functional form for production and/or quadratic form for effort are inappropriate).

Table 2: Regression results comparing the effect of institutions against other fundamental determinants†

	Dependent: Civilization (hierarchy)			*Dependent: Civilization (population)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.607 (0.103)***			1.092 (0.277)***		
Prop. rights (incl. leg. inst.)		0.428 (0.064)***			0.622 (0.121)***	
Prop. rights (incl. writ. rec.)			0.541 (0.069)***			1.054 (0.207)***
Trade	0.613 (0.090)***	0.486 (0.118)***		1.142 (0.203)***	0.883 (0.200)***	
Trade (incl. sup. rels.)			0.475 (0.058)***			0.643 (0.119)***
Geography	0.002 (0.007)			0.029 (0.016)*		
Latitude		0.001 (0.006)	-0.001 (0.006)		0.021 (0.015)	0.019 (0.016)
Longitude		-0.003 (0.001)**	-0.004 (0.001)***		0.009 (0.003)***	0.008 (0.003)**
R^2 (adj.)	0.447	0.491	0.514	0.419	0.478	0.471
N	327	327	335	242	242	247

† Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

3.4 Robustness

In the appendix, we further evaluate the robustness of the findings presented in this section. We consider alternative computations of the variables of interest, different choices for clustering of standard errors, the inclusion of additional (but tangentially related) controls, alternative measures of civilizational development, and a restriction of our sample to only pre-Common Era polities. Our qualitative findings remain essentially unaltered in response to these sensitivity checks.

4 Causal Evidence: Institutions Influence Civilizational Emergence

In this section, we provide causal evidence on how institutions affect civilizational emergence. We do so via research design: we indirectly control for the effects of geography and trade by focusing on large Neolithic settlements located in geographically-similar riverine valley regions, sited along major ancient trade routes, and compare the institutional environment in non-civilizational societies to those that made the transition into civilizations. Our analysis draws on diverse sources of (primarily qualitative) evidence—textual, artifactual, and archeological—and considers how property rights supported the broad-based adoption of region-specific agricultural technology, as embodied in capital equipment.

4.1 River valley civilizations along trade routes that became civilizations

This subsection documents, by falsification, why geography and trade were not *sufficient* explanations for the early emergence of civilizations.[19] There is fair amount of consensus in both the historical and archaeological literature that independent civilizations first emerged during the Neolithic period in six distinct regions, all associated with river valleys: the Indus Valley (Harappan), Mesopotamia (Sumerian/Akkadian), Nile River Valley (Egyptian), Yellow River Valley (Sinic), the Norte Chico valley system (Andean), and the Coatzacoalcos River basin (Olmec/Mesoamerican).[20]

We concentrate on the four non-American civilizations situated in the Old World, since these are directly connected by land trade routes. Our historical scope thus encompasses the late Ubaid (4500–3800 BCE) and early Uruk (3800–3100 BCE) periods in Mesopotamia,

[19]Importantly, we do not claim that they were not *necessary*; indeed, some form of property rights would be required to effect economic exchange via trade, and geographic conditions shape the nature of institutions that emerge, along the lines of the model in Section 2. Just as important, our claim is not that these factors were not observed in stable human *settlements*; rather, that settlements without sufficiently-developed property rights failed to advance to civilizations.

[20]We have deliberately chosen to exclude nascent Aegean society—which some authors classify as a civilization—from this list, for several reasons. First, unlike the other major civilizations we consider, Minoan and early Mycenaen society did not blossom into large, complex societies until its evolution into ancient Greek Civilization during the Hellenic Age, around 800 BCE. Second, these societies were geographically confined to the island of Crete and the Peloponnesian peninsula, which meant that Aegean culture, for all its achievements in art and architecture, remained somewhat more limited in scope and influence. By a similar token, while farming was not unknown in Aegean society at the time, the economy was heavily dependent on seafaring activity, rather than sedentary forms of agriculture, which was a common thread among the other six civilizations listed here. Third, and most controversially, the independent origins of Aegean civilization has recently come into question (Bernal 1987).

the proto and early Dynastic (3200–2686 BCE) and Old Kingdom (2686–2181 BCE) of ancient Egypt, the early Harappan (3300–2600 BCE) phase in ancient India, and the late Xia[21] (2000–1600 BCE) and early Shang (1600–1400 BCE) dynasties in ancient China.[22]

We further limit the discussion of non-civilizational societies to larger Neolithic settlements that were established during this period along ancient trade routes, and displaying geographic features—principally a riverine environment[23]—that were comparable to those of our ancient civilizations of interest. These routes are illustrated in Figure 1. We consider overland routes from three distinct periods, of which there is substantial overlap: ancient urban supply routes existing around 3000 BCE; the loose network of intra- and inter-civilization transit routes—such as India's Grand Trunk Road, the Persian Royal Road, and China's Yellow River system—that existed around 500 BCE; and the interconnections between ancient Silk Routes that were first established around 206 BCE and reached its height around the turn of the millennium. The first period considered highlights the fact that interconnections between Egypt, Mesopotamia, and Harappa were already established at the dawn of these respective civilizations; the second illustrates these expanding linkages, especially within civilizational units; and the third is demonstrates fullest articulation of trading linkages between civilizations during the pre-Classical era.[24]

There is substantial historical evidence that non-civilizational societies existed along

[21] There has been, to date, no archeological evidence attesting to the existence of this dynasty. Here, we will accept the veracity of Chinese tradition that maintains the historicity of the Xia, although much of the argument that follows will continue to hold as long as the record from the early Shang period is broadly reflective of late Xia developments as well.

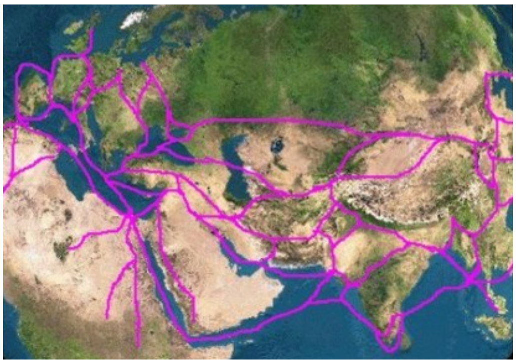
[22] Although the focus is on the respective founding periods of these civilizations, we will occasionally bring to bear evidence from later periods if the subsequent historical record is superior, so long as there is sufficient reason to believe that the evidence presented in these later sources apply to the preceding period as well.

[23] Of course, climatic changes since the ancient period means that geographic features in these regions today are potentially different—and in some cases, such as for the Indus Valley or Bactria-Margiana complex—substantially so. What mattered, however, were contemporaneous conditions. Moreover, the very existence of settlements and, more crucially, the emergence of extensive urbanization in these areas in later periods together suggest that geography was, at best, a mild constraint to the development of ancient civilizations in these regions.

[24] Although it may appear somewhat discordant that we choose to incorporate into the analysis trade routes that were established well after the formation of these civilizations, this approach actually affords two significant advantages: first, it ensures that our sample does not place the onus of proving causality on the nonexistence of a route, since our knowledge of ancient routes may be imperfect; second—and related to the first—by overidentifying potential locations for civilizational formation, the falsification exercise is more robust, given this imperfect knowledge.

(a) Urban supply routes, 3000 BCE

(b) Urban supply routes, 500 BCE



(c) Urban supply routes, 0 CE

Figure 1: Major trading routes between Sinic, Harappan, Mesopotamian, and Egyptian civilizations, 3000 BCE to 0 CE. These urban supply routes connected major civilizations, and expanded considerably between 500 and 250 BCE. Goods trade was typically inter-industry in nature, with imports of finished products and intermediates not found in the importing economy. Source: Sherratt (2004).

these trade routes, sometimes contemporaneously, during the period that our civilizations of interest became established. However, despite similar geographical conditions—approximated by river valley environments and fertile plains—these cultures did not resolve into more advanced civilizations.

Consider first the route between Mesopotamia and the Indus Valley. Settlements along this route have existed in the northern foothill oases of the Kopet Dag (near Mesopotamia) and Mehrgarh (near the Indus) since the Neolithic period, around 6000 BCE. By the Eneolithic, there was substantial population growth, with evidence of farming of wheat and barley, and animal husbandry with domesticated pigs, sheep, and goats. Geographical conditions in Mehrgarh were exceedingly similar to those of the Indus valley; indeed, there is speculation that wild wheat varieties, subsequently cultivated in the Indus Valley, may have originated there (Costantini & Biasini 1985). But settlements in Mehrgarh remained largely confined to the Kachi plain (modern-day Balochistan), and ultimately became absorbed into greater Harappan civilization (Kenoyer & Heuston 2005). And although settlements at Kopet Dag did expand further—into the Murghab valley delta (modern-day Afghanistan) and the Zerafshan Valley in Transoxonia (modern-day Tajikistan), before coalescing into the Oxus culture—these societies never developed much beyond proto-urban organization, even at the peak of its development in the Bronze age around 2300 BCE. Excavations in the Bactria-Margiana archeological complex, corresponding to level V at Namazga-Depe, attests to settlements that practiced some basic irrigation agriculture (Masson 1992), but little evidence of more advanced hydraulic methods or large-scale irrigation networks.

Similarly, specialization into professions appears to have been limited to sedentary farming, livestock breeding, and craftsmanship, with no evidence of more sophisticated social and political organization, such as specialization into administrative bureaucracies or more service-oriented professions like teachers or scribes (although differentiation into social classes undoubtedly existed).[25] Even the discovery of the Anau seal, which hints at the possibility that a system of writing existed in the Oxus culture, has largely been regarded as anomalous, and when placed in context it may potentially be of Chinese origin, comparable to a seal unearthed in Niyä, a relic of the Western Han dynasty (Colarusso 2002).

Trade routes in the second millennium BCE between Mesopotamia and the Indus also included maritime trade between societies in the central Gulf (Barbar culture, in modern-day Bahrain) and southeastern Arabia (Makkan culture, modern-day Oman). Although relatively little is known of these settlements, the available evidence suggests that trade was definitely not fundamentally transformational for the social structures of these societies (Edens 1992). For example, scattered oasis settlements in the interior and on the coastal regions of southeast Arabia—notably the Bronze-Age cultures at Hafi, Hili,

[25] This has been verified by historical linguistics, which offers no indication that words associated with professional specialization existed (Witzel 2005).

Umm al-Nar, and Wadi Suq—indicate that agricultural activity involved rudimentary water management and double cropping, but techniques did not progress far beyond that (Berthoud & Cleuziou 1983). Specialization was also limited, with evidence of earthenware and weapons production, but none with regard to tertiary (service) activities (Frifelt 1985). Moreover, political organization was fairly loose, with semi-autonomous polities weakly centralized along kinship groups, but little suggestion of more advanced structures. Polities in the region that eventually emerged as major centers—notably Dilmun, in Eastern Arabia—only became prosperous much later, between 2000 through 1700 BCE, and were much more a *consequence* of Indus-Mesopotamian emergence, rather than an alternative to it (Crawford 1998),

Perhaps the most puzzling example of the absence of civilizational evolution in South Asia is along the Grand Trunk Road, along which lies the Ganges river delta. This is peculiar, especially given the centrality of the river in subsequent agricultural advancement in the Ganges-Yamuna Doab and Ganges valley, and the fertility of the alluvial plains for agriculture in general. But it is clear from the historical record that the area only developed in the mature Harappan period, starting in 2500 BCE, and excavations of copper artifacts suggest that interactions between the Indus and Ganges valleys most likely occurred in the direction of the former to the latter, rather than the other way round (Allchin & Allchin 1982).

Along Mediterranean trade routes, there is no indication that the ancient Aegean settlements—notably the Minoan and early Mycenaean societies, but also the relatively less developed Cycladic and Helladic ones—blossomed into large, complex societies until its displacement by ancient Greek Civilization during the Hellenic Age, around 800 BCE, significantly after the emergence of Mesopotamia and Egypt (Aegean culture is generally accepted as discontinuous from Greek civilization). Unique Aegean achievements were primarily limited to art and architecture. Early Minoan culture appears to have imported elements of agricultural practices from the Fertile Crescent (Zeder 2008) and (hieroglyphic) writing appears to have diffused from Egypt, rather than developing independently (Bengtson 2002). In Minoan society, specialization in production was fairly limited; even among the elite, consumption was distinguished more by quantity than quality or variety (Schoep 2010). And for all their artistic and architectural achievements, including a clear aristocratic class, Mycenaean societies appear to have lacked a highly-educated or hierarchically-complex bureaucracy (Steele 2009),[26] an important precondition for the more advanced political institutions associated with complex civilizations. Moreover, these early Aegean societies were mostly geographically confined to the islands of the Cyclades, Crete, and the Peloponnesian peninsula, which meant that they remained mostly limited in scope and influence, and were more likely to be technological recipients rather than innovators. Finally (and most controversially), the independent origins of Aegean civilization have also been questioned, with claims that Aegean cultures were Egyptian derivatives (Bernal 1987).

A number of settlements between Egypt and Mesopotamia, notably those within the Fertile Crescent, also failed to coalesce into full-fledged civilizations. Ain Ghazal and Jericho, for instance, were relatively small farming communities of limited size. Although both settlements predated Sumer, they remained comparatively small. Jericho, for instance, had a wall and tower circa 8000–7000 BCE, but was abandoned within a few centuries for reasons unknown. A second settlement was established around 6800 BCE, but this too was abandoned, and the city only rose to prominence again around the 16th century BCE, far after the rise of Mesopotamia and Egypt. More generally, Phoenician (or Canaanite) civilization only became a credible force much later, beginning around 1500 BCE. Key coastal settlements, such as Berytus (Beirut) and Gubla (Byblos), served as trading centers, but were not distinguished entities in their own right; indeed, many Eastern Mediterranean cities may have operated as colonies of Egypt.

There were also many Neolithic settlements scattered on the Crescent across Asia Minor (Anatolia, in modern-day Turkey) that likewise did not advance. Çatalhöyük—among the oldest (dating circa 7,500 BCE), and certainly the largest and most advanced—

[26] This was certainly the case when compared to bureaucracies in the Near East; for example, bureaucratic records in Near Eastern civilizations employed "bilateral" documentation (records that provide legal evidence of liability for transactions), which are absent in Mycenaean Linear B archives (Steele 2009).

is the most credible candidate site for independent civilizational emergence. Yet despite evidence of "craft specialization" that supported "intensive agriculture" and a large population (Goody 1976, p. 24)—largely owing to its equal gender treatment, where men and women received comparable nutrition (Maynes & Waltner 2012) and could therefore contribute equally to production—the proto-city never took the next step to become a full-fledged civilization. One plausible reason is that the very egalitarianism that served them so well in the initial takeoff stage also meant common ownership of land and agricultural equipment,[27] coupled with prohibitions on intertemporal transfers of personal property (inheritance) (Wright 2014), such restrictions on private property utilization likely proved detrimental to accumulation and civilizational emergence.

Routes connecting ancient China to other civilizations similarly point to the absence of civilizations emerging in the southern parts of China and Central Asia. The archeological record indicates that settlements in the Xia era (around 3000 BCE) were not limited to the (Northern) Ordos bulge region of the Yellow River, but also included proto-states along the Middle and Lower Yangtze (at Qujialing and Liangzhu, respectively) (Lin & Cao 2010; Liu 2009). But these settlements never coalesced sufficiently, either economically or politically, into civilizations. This is in spite of geographical conditions that were very favorable to population expansion and economic development. After all, cultivable rice—which very quickly established itself as the primary agricultural staple across China—likely originated in Southern China around the Yangtze valley (Zhang & Hung 2013), and the geography of southeastern China on the banks of the Yangtze was conducive for large-scale rice cultivation (Murphey 1973). Indeed, many such riverine environments could be found along the Southern Silk Road (Wilkinson 1998). Yet the South only became integrated into greater Sinic civilization in the late Shang and Zhou periods, and it was only thence that there was significant expansion of settlements beyond the immediate proximity of the Yangtze (Chang 1973).

Similarly, more complicated agricultural tools and techniques appear to have been

[27]Households did possess limited private property ownership pertaining to portable stone tools, but larger agricultural pieces were almost certainly shared.

deployed in the south only after assimilation into Sinic civilization. The *Tribute to Yü* in the *Shangshu* documents that significant large-scale damming and irrigation projects beyond the Yangtze and other river systems only began during that period (Chen & Williams 1977).

Finally, consider the southern and eastern routes that originate, respectively, from the agriculturally-productive Nubian region of the upper Nile, along with the so-called land of Punt.[28] Egyptian civilization was founded following the unification of upper and lower Egypt by the Pharaoh Narmer (Menes), and based in the middle and lower Nile. But this region was not any more geographically favorable than that of the Nubian region—situated at the confluence of the Blue Nile, White Nile, and River Atbara—for flood irrigation-based crop cultivation; if anything, archeological evidence points to successful farming colonies on both the middle and upper Nile since Neolithic times (Krzyżaniak 1991).

Available historical evidence also reveals that the independent Kush (or Nubian) kingdom only emerged in Middle Nile in 10th century BCE, following the disintegration of the New Kingdom in Egypt. Significantly, this occurred only after Egyptian civilization had formed and consolidated (Török 1997). Moreover, Kushian political organization was fairly simple and small in scale (O'Connor 1993). Even after the kingdom eventually established a sophisticated mode of political organization, this was primarily modeled on existing Egyptian structures. Writing also did not develop independently in the kingdom, and the Meroïtic writing system, although applied to a language unrelated to ancient Egyptian, was likely derivative from the Semitic or Greek alphabet, together with Egyptian scripts (Houston, Baines & Cooper 2003; Leclant 2000).[29] Thus, while the kingdom did subsequently attain dynastic status in Greater Egypt—following a series of successful conquests beginning in 760 BCE—this was already the 25th dynasty of Egypt, long after

[28] Current archeology has not established the definitive location (or existence) of Punt, and the culture is almost entirely known to us only through Egyptian records from the Old Kingdom through Second Intermediate period (2498–1549 BCE). However, scholars have generally placed the region within the Horn of Africa, around modern-day Eritrea and Ethiopia, southeast of Egypt.

[29] Meroïtic script comprised an administrative and everyday form, which was alphabetic and inspired by Semitic or Greek alphabets, and a monumental script, which was modeled on either Egyptian hieroglyphs or hieratic script.

the initial founding of the civilization.

Even taking the existence of Punt as given, the evidence shows that the culture did not evolve into a complex society. Traded goods from Punt were fairly simple primary products, such as precious metals, ebony, incense, and wild animals (although these were undeniably exotic, and desirable, from the point of view of the ancient Egyptians) (Bradbury 1996). Puntites were described as "'cattle-herding pastoralists'... [who lived in] round hut 'pile-dwellings' woven as basketwork" (Phillips 1997, pp. 430–431). There is no evidence of more organized political frameworks developing, and even in later periods (1st millennium BCE)—when the D'MT kingdom emerged in the proximate geographic area of Punt—the society did not exhibit much of a complex production structure or sophisticated political organization, other than being in likely possession of a written language (Phillips 1997).

4.2 Property rights regimes in ancient civilizations

The insufficiency of economic integration and geographic conditions by themselves to ensure the widespread adoption of agricultural tools and technologies suggests that institutional factors—in particular, either a *de jure* or *de facto* respect for property rights—may have played a crucial role in supporting the emergence of civilizations. This subsection documents the textual, artifactual, and archeological evidence of the existence such rights, especially among the pristine civilizations.

The historical evidence is probably strongest for Mesopotamian civilization. The *Code of Hammurabi* includes a section that explicitly spells out the rights accruing to agricultural land ownership (albeit applying primarily to fiefs and nobility), including rights of ownership and transfer, along with contractual gains from ownership (Harper 1904, §27, §39, §46):

> If an officer or constable... be captured, and afterward they give his field and garden to another... if the former return[s]... they shall restore to him his field and garden.... He may deed to his wife or daughter the field, garden or

> house which he has purchased and (hence) possesses, or he may assign them for debt. . . . [If an owner has] rented the field. . . the tenant and the owner of the field shall divide the grain which is in the field according to agreement.

The *Code* goes on further to expound on obligations regarding irrigation practices, and how these were governed by the prevailing regime of property rights. For example, the law waives contractual interest for a farmer if weather conditions (attributed to the god of storms, Adad) lead to the "inundat[ion of] his field. . . or, through lack of water, grain have not grown in the field" (Harper 1904, §48), and also stipulates that "if a man open [sic] his canal for irrigation and neglect [sic] it. . . and the water carry [sic] away improvements of an adjacent field, he shall measure out [compensation]" (Harper 1904, §55–57).

Legal recognition of property was not confined to the Hammurabic code; similar, albeit less comprehensive, collections of Mesopotamian laws include those of Eshunna, Ur-Nammu, and Lipit-Ishtar, and Sumerian tablets etched with maps and plans clearly delineate ownership rights (Figure 2). Personal seals, known as cylinder seals, date back even earlier—to around 3500 BCE—and were used to denote property ownership, in addition to serving as official "signatures." And court memoranda and testimony in these regions also document property rights transfer via inheritence (Roth 1995).

The ubiquitous recognition of private property, and prevalence of respect for it, was thus a feature of the social and religious fabric long before its formal codification (Speiser 1953). This latter point is further underscored by the fact that the binding nature of contracts was not limited to written form in ancient Mesopotamia, where oral contracts were often recognized as equally valid (Charpin 2010).[30]

Other agricultural practices also reflected the importance of property rights in the civilization. While specific farming arrangements differed, especially between the northern rain-fed hills and the southern dry plains,[31] hydrologic engineering was important for

[30]Oral traditions have typically preceded written records in history, and the pervasiveness of oral contracts in ancient Mesopotamia lends credence to the notion that such regimes were in existence before the Akkadian period.

[31]In the north, violent surges in the flow of the Tigris and Euphrates due to snowmelt in the spring

Figure 2: A Sumerian clay tablet with a map of Nippur and its environs, with distinct property boundaries and ownership rights (marked in cuneiform), 14th–13th century BCE. These properties were owned by royalty and temple households, and corresponded to cultivated land. The map also marks irrigation canals (the narrow parallel bars), as well as unassigned property (the broad parallel bar at bottom left). Source: University of Pennsylvania Museum of Archeology and Anthropology.

agricultural productivity. The adoption of irrigation, in turn, was closely tied to property rights over agricultural land (Gruber 1948). Yields were often highest in the large holdings of irrigated arable land owned by temple households and the palace (Postgate 1984), where property rights were especially well demarcated.[32] Other land with assigned tenure—either as grants to important officials, held by small kinship collectives, or rented on a commercial basis to tenant farmers via sharecropping—also appear to have benefited from the autonomous adoption of irrigation tools and technology (Steinkeller 1981). It was the buffer land between settled enclaves—unassigned land known as the *edin*—that typically lay unirrigated (Crawford 2004).[33]

Because of the cyclical inundations of the Indus river, agriculturalists in the Indus

meant the need for damming or diversion to protect the ripening harvest; in the south, the challenge was one of adequate irrigation, both in the autumn where softened land facilitated plowing, and in the summer to supplement the meager rainfall.

[32]There is the possibility that priests and royalty simply chose the most productive land, and that higher productivity reflects a selection effect, rather than superior agricultural techniques. Given the proximity of the landholdings, and the state of pedology at the time, it is unlikely that this outperformance would be due primarily to selection.

[33]Incidentally, the property rights argument lends an additional reason to believe why sharecropping may be an optimal institutional arrangement, no only because of efficient risk-sharing contract (Stiglitz 1974), but also as a means of encouraging capital accumulation.

valley had little need for large-scale canal irrigation of the rich alluvial land. However, the more decentralized, small-plot agricultural practices of Harappan farmers (Possehl 2002) meant that they were freed from the need to maintain the more sophisticated basin irrigation techniques of the Egyptians (who also enjoyed regular flood cycles) (Singer, Hall & Holmyard 1954).[34] The absence of any systematic regulation of irrigation, in turn, encouraged individual land ownership.[35] In addition, private property ownership is also implied by the overall design of Harappan cities: urban layouts would follow a net/grid plan, with individual dwellings either oriented toward central common spaces, or constituting part of a complex, with a large house surrounded by smaller habitation units that served the central house. Habitations in such neighborhoods were often associated with restricted-access wells, suggesting private ownership, and stood in contrast to public architectural developments, which were characterized by large open courtyards and large-scale structures (such as baths and granaries) (Kenoyer 1991).

Furthermore, the pervasiveness of small stone seals (Figure 3), and substantial stylistic variation in discovered pieces across Harappan archeological sites, also speaks to the likelihood that respect for property rights was reasonably broad-based in Harappan society (McIntosh 2008).[36] Such inscriptions were likely used in commerce and trade to connote ownership and access rights; this probable use is corroborated by how some inscribed objects were maintained whole within merchant and elite homes, even as the majority of other items were intentionally broken and discarded with trash (Kenoyer 2006). Textual analysis of the Indus inscriptions[37] further suggests that agricultural output likely

[34] Although such flood cycles were central for enhancing soil fertility and raising agricultural productivity, ancient Egyptian farmers faced a different challenge: water management due to *excess* inundation (Noaman & El Quosy 2017). This would ultimately condition their reliance on the state for the provision of capital-intensive hydrology projects (especially dams), as suggested by Proposition 2.

[35] Ironically, this decision may have been at least partially responsible for the decline and ultimate collapse of Harappan civilization. Recent research has speculated that climatic changes between 1800 and 1700 BCE disrupted the regularity of the monsoon; without control over its agricultural landscape, these changes eventually eroded the agricultural surpluses necessary for supporting the civilization's predominantly urban civilization (Giosan, Clift, Macklin, Fuller, Constantinescu, Durcan, Stevens, Duller, Tabrez, Gangal, Adhikari, Alizai, Filip, VanLaningham & Syvitski 2012).

[36] Although the majority of seals date to the mature Harappan (Periods 3B and 3C), a number of seals date back to the Early Harappan phase.

[37] Harappan inscriptions remain undeciphered, and while some have questioned whether these markings constitute an actual writing system (Farmer, Witzel & Sproat 2004), the preponderance of Indologists are of the view that Harappan inscriptions can be regarded as proper (logographical) script (Parpola,

Figure 3: A Harappan steatite seal discovered during initial excavations at Mohenjo-Daro (modern-day Pakistan), dated approximately 20th century BCE. The seal displays the classic features of such seals: an icon, usually of an animal (in this case, a unicorn), often interpreted as representing either a city or social group, and pictographic inscriptions that may have been related to the owner of the seal. Such seals, when used to create sealings, could have marked the ownership of goods or materials. Source: Department of Archaeology and Museums, Government of Pakistan.

accrued, in part at least, to owners of land: diacritic modifiers (the "upper," denoted by ⋏) to the likely symbol for crops (ψ, for the compound symbol ψ̂) can be interpreted to mean "the 'upper share of the produce (due to the landlord)'... suggested by the Tamil literary and inscriptional usage" (Mahadevan 2006, p. 70). Other compound signs, with a harrow modifier (ɯɯ), may have indicated the equivalent share of the crop belonging to the tenant-farmer (Mahadevan 2006). Given the relative abundance of water, the key form of agricultural capital would have taken the form of proper drainage systems, rather than irrigation mechanisms. While there is little surviving evidence of agricultural drainage systems—the repeated flooding inherent to the region would have obliterated such archeological evidence—there is extensive evidence of complex drainage systems in urban areas (Meadow & Kenoyer 1997, 2005). To the extent that such urban systems are reflective of the general level of technological advancement in hydraulic engineering, we would expect a certain level of innovativeness for rural agricultural drainage systems as well. Taken together, the textual, artifactual, and archeological evidence lends sup-

Pande, Koskikallio, Meadow & Kenoyer 2010; Rao, Yadav, Vahia, Joglekar, Adhikari & Mahadevan 2009). In any case, even *if* the inscriptions were simply nonlinguistic symbols or emblems, they were almost certainly used as personal or official identifiers to denote property, consistent with seal usage in Mesopotamia.

ports the notion that property was important for agricultural capital accumulation in Harappan civilization.

In *principle*, all property in ancient Egypt and China was centralized and belonged to the pharaoh and emperor,[38] respectively. However, in practice, property rights were nevertheless fairly well-allocated to specialized groups or individuals.[39]

In Egyptian civilization, respect for property rights was most prominent in the domain of land. Land transfers from pharaonic holdings to temples were routinely recorded in documents and inscriptions (Johnson 1978), and there is both textual and archeological evidence dating to 2600 BCE from the pyramid at Meidum that indicates the ability of elites to independently hold property and render inheritance (Romer 2012). Nor was property limited to elites; by around 2400 BCE, commoners also did, as noted in *The Offering of Uha* (Dunham 1937, p. 102):

> I was a commoner of repute, who lived on his own property, plowed with his own span of oxen, and sailed in his own ship, and not through that which I had found in the possession of my father, honored Uha.

Essentially, the practice of usufruct—the legal right to utilize land whose title may vest to another—was widespread in ancient Egypt (Ellickson & Thorland 1995).[40] Such property was also transferable, which would have facilitated economic exchange. A fragmentary text on a slab uncovered at the necropolis of Saqqara, dated to the 5th or 6th

[38]This was likely the case even in the predynastic periods that is the focal point of our paper. For example, the first Chinese king to declare himself as emperor was *Shihuangdi*, during the Qin dynasty; however, property rights in the pre-Qin period were already formally assigned to regional kings, as representatives of the deity (*shangdi*). Similarly, ancient Egyptian rulers were living manifestations of Horus, and thereby titular landowner by virtue of divinity. Land ownership rights in these two civilizations were therefore more centralized, relative to ancient Harappa and Mesopotamia.

[39]This is not to say that the notional sense of property rights granted by the centralized systems of ancient China and Egypt were particularly supportive of growth. Indeed, if anything, centralization may have inhibited more rapid technological innovation and capital adoption in agriculture. In Egypt, the *shaduf* only arrived in the New Kingdom period—more than six centuries after the end of the Old Kingdom—and this was not a native innovation but a technological adaptation from Mesopotamia (Stroubal 1992). In China, the taming of the middle Yangtze with flood control projects only began a half-century later during the Western Zhou era, and control of Yangtze riverland during the Xia dynasty was far more limited (Chen & Williams 1977).

[40]Usufruct generally includes rights to possess and occupy, to exclude others, the entitlement to all the profits, use and benefit of the land.

Dynasty (c. 2494–2181 BCE), describes the sale of a burial plot "bought from the maker of sweet things Perhernefert. . . the price [was to be] paid by [the purchaser's] daughter" (Strudwick 2005, p. 204). Textual evidence attesting to land conveyancing from the later Ptolemaic period in Egypt (332–30 BCE) also strongly suggest that the use of Demotic contracts was merely a continuation of similar ancient land tenure practices, involving the rental of temple land from priests for the purposes of share-cropping (Manning 2004). Importantly, this temple-based landholding system was not closed. Indeed, share-cropping arrangements were widely available in Pharaonic Egypt, and was in fact a crucial mechanism for development (Eyre 1997, pp. 368–369, 379, *emphasis* added):

> Modernisation. . . has arisen from changes to the water regime and associated farming technology, *mediated by traditional patterns of land tenure*, and commercial imperative. . . . The development of tracts of "new" land was a normal feature of the ancient regime, in reaction to local fluctuation in the valley profile and in the flood patterns.. . . Such development came in cycles. . . [but] it is likely that internal colonisation in the Old Kingdom at least was characterised by extension of flood-basin control to new areas. . . . [These] holdings and estates in Egypt were essentially management structures, not single enterprises: managing individuals running small-to-medium farms *on a share-cropping basis*.

It is thus clear that the extension of nominal property rights was not accidental, but rather a conscious strategy to encourage the adoption of agricultural capital by peasant labor. The actual mechanism employed was typically an agreement by the "tenant" to purchase crop in advance at an agreed (low) price, which would then free him or her to exploit irrigation and other agricultural productivity techniques to maximize the yield from the land (Eyre 1997). While, unlike Mesopotamia, there was no explicit complementary institution in the rule of law, this was not an intractable problem; the prevalence of a strong social customs and adherence to precedent (Brewer & Teeter 2007) meant that the indiscriminate expropriation of property was unlikely, even with the absence of contract. Subsequent developments also attest to the fact that *de facto* property rights were prevalent in Egypt: given the gradual diminution of Pharaoh's landholdings over time, with traditionally-ceded titles upheld in courts, the Pharaonic state eventually resorted to levying taxation as a means to extract some surplus from former royal landholdings (Brier & Hobbs 1999), which began as early as the 1st dynasty of the Early Dynastic period (between 3000–2800 BCE).

In much the same manner, there was a clear sense of private property rights—especially regarding land ownership—in ancient Sinic civilization. In spite of theoretical ownership by the king (or emperor), land holdings accrued, *de facto*, to the vassal (Hou 1973). The *Chijangkou* ("Song of Mud Balls"), which, according to tradition, dates back to ancient times, exemplifies this individualism in farming practices: "I dig a well for my drink, I till the fields for my food. What has the power of the emperor to do with me?" (Wu 1977, p. 86). But while the textual record in favor of this argument is strongest for the Zhou period[41]—and we will thus draw heavily on this record—it should nevertheless be noted that up till at least 600 BCE, practices in the Zhou dynasty was essentially a continuation and propagation of its Shang precedent (Chang 1973). Moreover, an acceleration of agricultural productivity (and by extension economic growth), only really took hold in Sinic civilization during the Zhou (although there was undeniably substantial territorial expansion during the Shang).

Possibly the earliest (verifiable) textual evidence of individual property rights in this region comes to us from the *Daya* and the *Xiaoya* of the *Shijing* (Classics of Poetry).[42] In the fifth stanza of *Jianghan* (Poem 262), the king confers "hills and streams. . . in K'e-chow" to a loyal subject (Legge 1876, p. 344), a clear indication that ownership could indeed be held privately. Indeed, the *Datian* (Poem 212) not only explicitly distinguishes between public and private ownership in agricultural property, it also attributes a signif-

[41] It is well-known that the major challenge for documenting and analyzing pre-Zhou historical developments is that popular writing media—bamboo and silk—were highly perishable, and so much of that early record has been lost (Wilkinson 1998).

[42] Dobson (1964) relies on linguistic innovations to date the written form of the *Daya* and the *Xiaoya* to around the 10th and 9th century BCE, respectively, corresponding to the early Zhou period, although the poems may have passed on as oral traditions from earlier eras.

icant degree of agency in farming practices to peasants (Legge 1876, p. 258):

> Various are the toils which fields so large demand!
>
> We choose the seed; we take our tools in hand.
>
> . . .
>
> The clouds o'erspread the sky in masses dense,
>
> And gentle rain down to the earth dispense.
>
> First may the public fields the blessings get,
>
> And then with it our private fields we wet!

The well-field system (*jingtian zhidu*) that was prevalent in the 9th century BCE also clearly demarcated private ownership; the system involved eight outer sections that were privately cultivated (the *sitian*), with a center section held in common (the *gongtian*). Indeed, the Chinese character used to describe the system, "well" (*jing*), is similar in form to the # symbol and represents this form of land division (the center of the symbol corresponding to the public plot) (Fu 1981).

By the time of the Chunqiu (Spring and Autumn, 722–476 BCE) and Zhanguo (Warring States, 476-–221 BCE) eras of the late Zhou dynasty, *de facto* land ownership was widespread, and fostered substantial increases in agricultural productivity. Irrigation facilities were expanded considerably, as technological advances were enthusiastically adopted by the peasantry; indeed, the prosperity that followed large agricultural surpluses probably contributed to the eventual formal recognition of private land ownership in the 4th century BCE (Hou 1973). This was accompanied by the arrival of the rule of law late in the Zhou dynasty, around 536 BCE (Bodde 1963), although—similar to the case of Egypt—the prevalence of a strong social order likely limited indiscriminate expropriation of property in earlier periods, even in the absence of formal enforcement.

In summary, early Harappan and Mesopotamian civilizations exhibited more distinct individual property rights than the Egyptian or Sinic civilizations.[43] Weaker rights, in

[43]This does not preclude high levels of economic centralization within these civilizations. Indeed, Postgate (1992) and Kenoyer (1994) both make the case that city-states in Mesopotamia and Harappa, respectively, were organized as command economies.

turn, emerged due to the presence of greater initial natural (exogenous) capital stocks, as was prevalent in the Nile and Yellow River valleys.

4.3 Additional corroborative evidence

In this subsection, we discuss the robustness of our main mechanisms along two additional dimensions: how trade did not give rise to significant capital or technology transfer, and how the simultaneous emergence of writing facilitated the functioning of property rights institutions. We summarize our findings here, and leave a more comprehensive description of each to the appendix.

Secondary role of trade in agricultural capital transfer. In spite of the flourishing overseas trade between Harappa and Mesopotamia, this occurred mostly in the form of consumer goods exchange (Allchin & Allchin 1982), with little evidence of any transfer of capital goods. The main export to Mesopotamia via the Gulf was copper, a luxury good in the 3rd millennium BCE, and there is likewise no indication intra-industry trade (Edens 1992). Trade between Egypt and Mesopotamia was, similarly, not accompanied by broad-based capital transfer or technology, at least in the earlier periods (Rice 2003). Archeological evidence has only uncovered exchanges of ornamental stone tools (Hobbs 2002), rather than implements related hydraulic control. Moreover, irrigation techniques employed in Mesopotamia, which was channel-based, were anyway distinct from that of Harappa and Egypt, which relied on inundation flooding, thereby further limiting opportunities for technology transfer. Finally, the evidence of hydraulic engineering in the Shang and Zhou dynasties in China provides little reason to believe that engineering knowledge for large-scale projects were exchanged with other civilizations via movements of goods or factors in ancient times (Biswas 1970). The great hydraulic engineering projects of the ancient world were pursued independently, using the technologies available in their respective civilizations.

Complementary role of writing in reinforcing property rights. Among the civilizations considered, a script (or proto-script) dates back to the earliest stages of each civilization. Mesopotamian cuneiform was invented in the Uruk period, having built on proto-script in the Ubaid period (Pollock 1999). Archaic Chinese writing, as recorded on the oracle bones at Anyang, corresponds to the period of the early Shang dynasty (Creel 1937; Wilkinson 1998). Hieroglyphic symbols were already foreshadowed in predynastic Egypt, as civilization was only just taking hold in the Nile valley, and the indigenous invention of the hieroglyphic and hieratic scripts occurred in the Early Dynastic period (Baines 1983; Shaw 2003; Wilkinson 2010). And rudimentary symbols began to appear on pottery dating back to the early Harappan, with prototypical logographic inscriptions found on square stamp seals associated with the late Kot Diji Phase (2800–2600 BCE) level of a Harappan mound at Kunal (Khatri & Acharya 2005), before a more standardized script began to circulate across all major settlements by the mature Harappan phase (2600–1900 BCE) (Kenoyer 2006). In contrast, two other major groups of writing systems—Near Eastern protohistoric scripts (Proto-Elamite, Proto-Sinaitic, and Proto-Canaanite) and Cretan protohistoric writing (Cretan Hieroglyphic, Minoan Linear A, and Mycenaean Linear B)—probably emerged as an intermediate steps from Egyptian hieroglyphs (Hamilton 2006) or Sumerian cuneiform (Walker 1987), or developed with contemporary knowledge of the Mesopotamian or Egyptian systems (Olivier 1986), rather than as an independent creations.

5 Conclusion

We argue that institutional mechanisms—in particular, property rights—were central in prompting the evolution of ancient settlements into full-fledged civilizations. By examining other Neolithic settlements possessing riverine environments located along ancient trade routes, we show that purely geographic and trade-based explanations are inadequate, whereas *de jure* or *de facto* regimes of property rights over agricultural land were present in all the pristine civilizations on the Afro-Eurasian landmass. We also offer corroborative evidence, based on historical polities across several millennia, that supports a strong correlation between property rights and civilizational development. Our findings speak to the contemporary academic debate on the importance of institutions as a fundamental determinant of economic growth (Acemoğlu *et al.* 2005a), but we extend the evidence base to the dawn of history.

Although the issue of property rights emergence giving rise to early civilizations may seem far removed from the concern of modern economies, this is only true from a very limited perspective. In developing countries, property rights are typically fragile and frequently violated; policymakers seeking reform may wish to understand the crucial importance of this particular institution as they consider the large menu of reform priorities. Even in advanced economies, the growing importance of easy-to-replicate knowledge goods and services has meant a need to understand how rudimentary property rights regimes may yet be a crucial ingredient for long-run growth.

Future research in this vein can seek to further examine the relevance of distinct property rights regimes for economic outcomes. While some work in this area has already been undertaken (Acemoğlu & Johnson 2005; Williamson & Kerekes 2011), there is substantial scope for additional research, especially in the realm of economic history; greater insight into the relative importance of property rights mechanisms in high-income countries in the early stages of their development, vis-à-vis other institutional mechanisms, can be especially valuable for developing nations currently debating the relative merits of these distinct political-economic institutions.

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Online Appendix

Contents

A.1 Proofs of Theorems

Proof of Proposition 1. We first show that $\frac{dk}{dn} > 0$. We first optimize (1):

$$\max_{i,n} \{\theta [af(k_0 + i, n, l)] - e(i + n)\},$$

which yields the following first-order conditions for an interior optimum:

$$\theta a f'_k = e'_i, \tag{A.1a}$$

$$\theta a f'_n = e'_n, \tag{A.1b}$$

which implies $f'_k = f'_n$ since $c'_i = e'_n$ (due to our assumption that i and n are perfect substitutes). The two second-order conditions are:

$$\theta a f''_{kk} - e''_{ii} < 0, \tag{A.2a}$$

$$\begin{aligned} D \equiv & \begin{vmatrix} \theta a f''_{kk} - e''_{ii} & \theta a f''_{kn} - e''_{in} \\ \theta a f''_{nk} k'_i - e''_{ni} & \theta a f''_{nn} - e''_{nn} \end{vmatrix} \\ &= (\theta a f''_{kk} - e''_{ii})(\theta a f''_{nn} - e''_{nn}) - (\theta a f''_{kn} - e''_{in})^2 > 0, \end{aligned} \tag{A.2b}$$

where the conditions (A.2a) < 0 and (A.2b) exists as a negative definite Hessian matrix are satisfied due to the assumptions $f''_{kk}, f''_{nn} < -f''_{kn} < 0$ and $c''_{ii} = e''_{nn} > 0$.

To make further progress, it will be useful to rewrite (A.1) in a semi-reduced form where (1) depends only on labor inputs n. From (A.1), $f'_k = f'_n$ (the marginal products of capital and labor are equal), and so totally differentiating this relationship yields $f''_{kk}dk + f''_{kn}dn = f''_{nk}dk + f''_{nn}dn$, which implies

$$\frac{dk}{dn} = \frac{f''_{nn} - f''_{kn}}{f''_{kk}dk + f''_{kn}} > 0.$$

Since capital inputs increase monotonically with labor inputs, we can now rewrite

$$k = k_0 + i \equiv g(n), \tag{A.3}$$

with $g'_n = \frac{dk}{dn} > 0$. Output, in turn, can be rewritten as

$$af(k_0 + i, n, l) = af[g(n), n, l] \equiv a\tilde{f}(n, l).$$

For this expression, the partial derivatives with respect to labor can be signed:

$$\tilde{f}'_n = (1 + g'_n) f'_n > 0, \tag{A.4a}$$

$$\tilde{f}''_{nn} = g''_{nn} f'_n + (1 + g'_n)(f''_{nk} g'_n + f''_{nn}) < 0, \tag{A.4b}$$

where the sign of (A.4b) follows from the original problem's concavity (that is, our earlier assumptions that $f''_{kk}, f''_{nn} < -f''_{kn} < 0$), which is retained by the re-expression (A.3). Finally, we rewrite effort costs in terms of labor inputs with i set at the optimal level (according to the $i = g(n)$ mapping). This yields

$$c(i + n) = e[g(n) - k_0 + n] = \tilde{e}(n - k_0),$$

with the associated first and second partials given by

$$\tilde{e}'_n = (1 + g'_n)\, e'_n > 0, \tag{A.5a}$$

$$\tilde{e}''_{nn} = g''_{nn} e'_n + (1 + g'_n)^2\, e''_{nn}. \tag{A.5b}$$

Rewriting the problem in terms of these implicit functions, obtain

$$\max_n \tilde{v} = \left\{ \theta \left[a \tilde{f}(n, l) \right] - \tilde{e}(l - k_0) \right\}, \tag{A.6}$$

with the associated optimality conditions given by

$$\tilde{v}'_n = \theta a \tilde{f}'_n = \tilde{e}'_n, \tag{A.7a}$$

$$\tilde{v}''_{nn} = \theta a \tilde{f}''_{nn} - \tilde{e}''_{nn} < 0, \tag{A.7b}$$

where, as was the case in (A.3), the sign of (A.7b) follows from the concavity in the original formulation (we verify that the equations in (A.7) are equivalent to (A.1b) and (A.2) in Appendix A.2). The proof of Proposition 1 now follows from applying the implicit function to (A.7a):

$$\frac{dn}{d\theta} = -\frac{\frac{\partial \tilde{v}'_n}{\partial \theta}}{\frac{\partial \tilde{v}'_n}{\partial n}} = \frac{-a \tilde{f}'_n}{\tilde{v}''_{nn}} > 0, \tag{A.8}$$

which establishes the second part of the proposition. Since $k_0 + i \equiv g(n)$ with $g'_n > 0$, it also follows that

$$\frac{di}{d\theta} = g'_n \cdot \frac{dn}{d\theta} > 0,$$

which is the first part of the proposition. □

Proof of Proposition 2. The following lemma establishes a special case—where production takes the Cobb-Douglas form and costs are quadratic—when greater initial supply of irrigation capital unambiguously weakens private property rights. The rest of the proof then addresses the general case.

Lemma 1. Let production be $f(k_0 + i, n, l) = (k_0 + i)^\alpha n^\beta l^{1-\alpha-\beta}$, $0 \leq \alpha, \beta, (\alpha + \beta) \leq 1$, and effort by $c(i + n) = \frac{\sigma}{2}(i + n)^2$. Then greater initial capital investment diminishes property rights, or $\frac{d\theta}{dk_0} < 0$.

Proof of Lemma 1. Given the functional forms of the lemma, the first-order conditions (A.1) become

$$\theta a \alpha (k_0 + i)^{\alpha - 1} n^\beta l^{1-\alpha-\beta} = \sigma (i + n), \tag{A.1a$'$}$$

$$\theta a \beta (k_0 + i)^{\alpha} n^{\beta - 1} l^{1-\alpha-\beta} = \sigma (i + n) \tag{A.1b$'$}$$

Equating (A.1a′) to (A.1b′), obtain

$$k_0 + i = \frac{\alpha}{\beta} \cdot n \equiv g(n), \tag{A.3$'$}$$

which implies $g'_n = \frac{dk}{dn} = \frac{\alpha}{\beta} >= g''_{nn} = 0$. The producer thus solves

$$\begin{aligned}\max_n \tilde{v} &= \left\{\theta\left[a\tilde{f}(n,l)\right] - \tilde{e}(l-k_0)\right\}\\ &= \theta a\left(\frac{\alpha}{\beta}\right)^{\alpha} n^{\alpha+\beta} l^{1-\alpha-\beta} - \frac{\sigma}{2}\left[n\left(1+\frac{\alpha}{\beta}\right) - k_0\right]^2,\end{aligned}$$

which yields

$$\tilde{v}'_n = \theta a(\alpha+\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta} - \left(1+\frac{\alpha}{\beta}\right)\sigma\left[n\left(1+\frac{\alpha}{\beta}\right) - k_0\right] = 0, \quad (\text{A.7a}')$$

$$\tilde{v}''_{nn} = \theta a(\alpha+\beta)(\alpha+\beta-1)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n} - \sigma\left(1+\frac{\alpha}{\beta}\right)^2 < 0, \quad (\text{A.7b}')$$

Applying the implicit function theorem, we recover the derivative, consistent with Proposition 1, that

$$\frac{dn}{d\theta} = \frac{a(\alpha+\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}}{\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n} + \sigma\left(1+\frac{\alpha}{\beta}\right)^2} > 0. \quad (\text{A.8}')$$

In the prior stage of the game, the elite solves

$$\max_\theta w = (1-\theta)\left[a\left(\frac{\alpha}{\beta}\right)^{\alpha} n^{\alpha+\beta} l^{1-\alpha-\beta}\right],$$

which yields the interior first-order condition

$$\begin{aligned}w'_\theta &= a\left(\frac{\alpha}{\beta}\right)^{\alpha} n^{\alpha+\beta} l^{1-\alpha-\beta}\cdot\left[(1-\theta)(\alpha+\beta)\frac{n'_\theta}{n} - 1\right] = 0\\ \Leftrightarrow 1-\theta &= \frac{1}{(\alpha+\beta)\frac{n'_\theta}{n}}.\end{aligned} \quad (\text{A.11})$$

The second-order condition associated with (A.11) is

$$w''_{\theta\theta} = a(\alpha+\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\cdot\left\{-2n'_\theta + (1-\theta)\left[(\alpha+\beta-1)\frac{n'^2_\theta}{n} + n''_\theta\right]\right\} \quad (\text{A.12})$$

A sufficient condition for (A.12) to be negative is that $n''_{\theta\theta} < 0$. We verify that this is the case. From (A.8′), obtain

$$n''_{\theta\theta} = \frac{\begin{aligned}&(\alpha+\beta-1)\frac{n'_\theta}{n}\cdot\left[\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n} + \sigma\left(1+\frac{\alpha}{\beta}\right)^2\right]\\ &-\left[1+\theta(\alpha+\beta-2)\frac{n'_\theta}{n}\right]\cdot\left[a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}\right]\end{aligned}}{\left[\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n} + \sigma\left(1+\frac{\alpha}{\beta}\right)^2\right]^2}.$$

This expression is negative—the elite's second-order condition (A.12) is always satisfied—if and only if

$$\begin{aligned}
&(1-\alpha-\beta)\frac{n'_\theta}{n}\cdot\left[\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}+\sigma\left(1+\frac{\alpha}{\beta}\right)^{2}\right]> \\
&\left[\theta(2-\alpha-\beta)\frac{n'_\theta}{n}-1\right]\cdot\left[a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}\right] \\
&\Leftrightarrow \begin{array}{l}(1-\alpha-\beta)\frac{n'_\theta}{n}\cdot\left[\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}+\sigma\left(1+\frac{\alpha}{\beta}\right)^{2}\right]> \\ \left[\theta(2-\alpha-\beta)\frac{n'_\theta}{n}-1\right]\cdot\left[a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}\right]\end{array} \\
&\Leftrightarrow \theta(1-\alpha-\beta)\frac{n'_\theta}{n}>\theta(2-\alpha-\beta)\frac{n'_\theta}{n}-1 \\
&\Leftrightarrow \frac{\theta n'_\theta}{n}<1,
\end{aligned}$$

where the first line derives from the fact that the denominator is unambiguously positive, and the second line since $\sigma\left(1+\frac{\alpha}{\beta}\right)^2$ is also unambiguously positive. To verify that this final condition holds, substitute (A.8′) into the above to yield

$$\frac{\theta a(\alpha+\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}}{\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}+\sigma\left(1+\frac{\alpha}{\beta}\right)^{2}}<1.$$

Observe from (A.7a′) that $\theta a(\alpha+\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}=\left(1+\frac{\alpha}{\beta}\right)\sigma\left[n\left(1+\frac{\alpha}{\beta}\right)-k_0\right]$; hence the above is equivalent to

$$\begin{aligned}
&\frac{\left(1+\frac{\alpha}{\beta}\right)\sigma\left[\left(1+\frac{\alpha}{\beta}\right)-\frac{k_0}{n}\right]}{\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}+\sigma\left(1+\frac{\alpha}{\beta}\right)^{2}}<\frac{\left(1+\frac{\alpha}{\beta}\right)\sigma\left[\left(1+\frac{\alpha}{\beta}\right)-\frac{k_0}{n}\right]}{\sigma\left(1+\frac{\alpha}{\beta}\right)^{2}} \\
&<\frac{\left(1+\frac{\alpha}{\beta}\right)-\frac{k_0}{n}}{1+\frac{\alpha}{\beta}}<1.
\end{aligned}$$

Now, returning to (A.11) and again substituting (A.8′), obtain

$$1-\theta=\frac{\theta a(\alpha+\beta)(1-\alpha-\beta)\left(\frac{\alpha}{\beta}\right)^{\alpha}l^{1-\alpha-\beta}+\sigma\left(1+\frac{\alpha}{\beta}\right)^{2}n^{2-\alpha-\beta}}{a(\alpha+\beta)^{2}\left(\frac{\alpha}{\beta}\right)^{\alpha}l^{1-\alpha-\beta}}.$$

Solving for θ gives (after some rearrangement):

$$\theta \cdot a\left(\alpha+\beta\right)\left(\frac{\alpha}{\beta}\right)^{\alpha} l^{1-\alpha-\beta}\left[\left(1-\alpha-\beta+\alpha\right)+\left(\alpha+\beta\right)\right]=$$

$$a\left(\alpha+\beta\right)^{2}\left(\frac{\alpha}{\beta}\right)^{\alpha} l^{1-\alpha-\beta}-\sigma\left(1+\frac{\alpha}{\beta}\right)^{2} n^{2-\alpha-\beta}$$

$$\Rightarrow \theta = 1-\frac{\sigma\left(1+\frac{\alpha}{\beta}\right)^{2} n^{1-\alpha-\beta}}{a\left(\alpha+\beta\right)\left(\frac{\alpha}{\beta}\right)^{\alpha} l^{1-\alpha-\beta}\left[\left(\alpha+\beta\right)+\left(1-\alpha-\beta\right)\right]}.$$

Differentiating this expression with respect to k_0 gives

$$\frac{d\theta}{dk_0}=-\frac{\sigma\left(2-\alpha-\beta\right)\left(1+\frac{\alpha}{\beta}\right)^{2} n^{1-\alpha-\beta}}{a\left(\alpha+\beta\right)\left(\frac{\alpha}{\beta}\right)^{\alpha} l^{1-\alpha-\beta}\left[\left(\alpha+\beta\right)+\left(1-\alpha-\beta\right)\right]}\cdot\frac{dn}{dk_0},$$

which implies that $\operatorname{sgn}\left(\frac{d\theta}{dk_0}\right)=-\operatorname{sgn}\left(\frac{dn}{dk_0}\right)$. Applying again the implicit function theorem to (A.7a′) then yields

$$\frac{dn}{dk_0}=-\frac{\tilde{v}''_{n\theta}}{\tilde{v}''_{nn}}=\frac{-\sigma\left(1+\frac{\alpha}{\beta}\right)}{\theta a\left(\alpha+\beta\right)\left(1+\frac{\alpha}{\beta}\right)\left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{l}{n}\right)^{1-\alpha-\beta}\frac{1}{n}-\sigma\left(1+\frac{\alpha}{\beta}\right)^{2}}>0,$$

and hence $\frac{d\theta}{dk_0}<0$, as claimed. □

Lemma 1 allows us to demonstrate the important result that, as long as effort costs are quadratic, the effect of initial capital provision on property rights is unambiguously negative. It also serves to demonstrate the existence of an unambiguous solution to the more general version of the problem posed in Proposition 2, to which we now turn.

Using the definitions established in the proof for Proposition 1, the problem for the first stage is

$$\max_{\theta} w=\left(1-\theta\right)\left[af\left(k_0+i,n,l\right)\right]=\max_{\theta}\tilde{w}=\left(1-\theta\right)a\tilde{f}\left(n,l\right).$$

The interior optimality conditions are given by

$$\tilde{w}'_{\theta}=a\left[\left(1-\theta\right)\tilde{f}'_{n}n'_{\theta}-\tilde{f}\right]=0, \tag{A.13a}$$

$$\tilde{w}''_{\theta\theta}=a\left[\left(1-\theta\right)\left(\tilde{f}''_{nn}n'^{2}_{\theta}+\tilde{f}'_{n}n''_{\theta\theta}\right)-2\tilde{f}'_{n}n'_{\theta}\right]<0. \tag{A.13b}$$

Differentiating (A.8) with respect to θ, obtain

$$n''_{\theta\theta}=\frac{a}{\tilde{v}''^{2}_{nn}}\left[n'_{\theta}\left(\tilde{f}'_{n}\tilde{v}'''_{nnn}-\tilde{f}''_{nn}\tilde{v}''_{nn}\right)+a\tilde{f}'_{n}\tilde{f}''_{nn}\right]=\frac{a^{2}\tilde{f}'_{n}}{\tilde{v}''^{2}_{nn}}\left(2\tilde{f}''_{nn}+\tilde{v}'''_{nnn}n'_{\theta}\right), \tag{A.14}$$

where the second equality is obtained by substituting the result (A.8) and simplifying. Substituting (A.8) and (A.14) into (A.13b), and simplifying, results in

$$a\left[\left(1-\theta\right)n'^{2}_{\theta}\left(3\tilde{f}''_{nn}+\tilde{v}'''_{nnn}n'_{\theta}\right)-2\tilde{f}'_{n}n'_{\theta}\right].$$

For an interior solution, the above expression must be negative. This is the case if

$$(1-\theta)\, n_\theta'^2 \left(3\tilde{f}_{nn}'' + \tilde{v}_{nnn}''' n_\theta'\right) < 2\tilde{f}_n' n_\theta' \Leftarrow \tilde{v}_{nnn}''' < -\frac{3\tilde{f}_{nn}''}{n_\theta'}, \tag{A.15}$$

where, to obtain the second step, we drop the expression to the right of the inequality in the first step as it is unambiguously positive. The right-hand side of this second inequality is also unambiguously positive, so a sufficient condition for the interior solution is then simply that the third derivative of (A.6) given by

$$\tilde{v}_{nnn}''' = \theta a \tilde{f}_{nnn}''' - \tilde{e}_{nnn}''' \tag{A.7c}$$

is negative. Since we are seeking interior solutions, we will assume that this condition (A.7c) ≤ 0 holds.

We are now in a position to demonstrate that $\frac{d\theta}{dk_0} < 0$ if c''' falls below a threshold. First, differentiate (A.13a) implicitly with respect to k_0:

$$\frac{d\theta}{dk_0} = -\frac{\tilde{w}_{\theta k_0}''}{\tilde{w}_{\theta\theta}''} = \frac{a\left[(1-\theta)\left(\tilde{f}_{nn}'' n_\theta' n_{k_0}' + \tilde{f}_n' n_{\theta k_0}''\right) - \tilde{f}_n' n_{k_0}'\right]}{-w_{\theta\theta}''}.$$

The above is negative if and only if the numerator is negative:

$$(1-\theta)\left(\tilde{f}_{nn}'' n_\theta' n_{k_0}' + \tilde{f}_n' n_{\theta k_0}''\right) - \tilde{f}_n' n_{k_0}' < 0 \Leftrightarrow (1-\theta)\left(\frac{\tilde{f}_{nn}'' n_\theta'}{\tilde{f}_n'} + \frac{n_{\theta k_0}''}{n_{k_0}'}\right) < 1. \tag{A.16}$$

To make progress on signing (A.16), we again apply the implicit function theorem to (A.7a) to obtain

$$n_{k_0}' = -\frac{\tilde{v}_{nk_0}''}{\tilde{v}_{nn}''} = \frac{\tilde{e}_{nk_0}''}{\tilde{v}_{nn}''} > 0, \tag{A.17}$$

since the the denominator is negative by (A.7b), and the numerator is likewise negative since the cross-derivative of (A.5a) with respect to k_0 is

$$\tilde{e}_{nk_0}'' = -e_{nn}''\left(1 + g_n'\right) < 0. \tag{A.18}$$

The partial derivative of (A.5a) with respect to k_0 yields $\tilde{e}_{nk_0}'' = -c''\left(1+g'\right) < 0$, which implies that (A.17) is positive. Now take the partial derivative of this expression with respect to k_0:

$$\begin{aligned} n_{k_0\theta}'' = n_{\theta k_0}'' &= \frac{\tilde{v}_{nn}'' \tilde{e}_{k_0 nn}''' n_\theta' - \tilde{e}_{nk_0}''\left[a\tilde{f}_{nn}'' + n_\theta'\left(\theta a \tilde{f}_{nnn}''' - \tilde{e}_{nnn}'''\right)\right]}{\tilde{v}_{nn}''^2} \\ &= \frac{\tilde{v}_{nn}'' \tilde{e}_{k_0 nn}''' n_\theta' - \tilde{e}_{nk_0}''\left(a\tilde{f}_{nn}'' + \tilde{v}_{nnn}''' n_\theta'\right)}{\tilde{v}_{nn}''^2}. \end{aligned} \tag{A.19}$$

where the derivative $\frac{\partial \tilde{v}_{nn}''}{\partial\theta}$ in the first line relies on the definition (A.7b) and the second line substitutes the definition of the third derivative given by (A.7c).

These additional steps allow us to substitute (A.8), (A.17) and (A.19) into (A.16) so that

$$(1-\theta)\left\{\frac{\tilde{f}''_{nn}n'_\theta}{\tilde{f}'_n}+\frac{\left[\tilde{v}''_{nn}\tilde{e}'''_{k_0nn}n'_\theta-\tilde{e}''_{nk_0}\left(a\tilde{f}''_{nn}+\tilde{v}'''_{nnn}n'_\theta\right)\right]/\tilde{v}''_{nn}}{\tilde{e}''_{nk_0}}\right\}<1$$
$$\Rightarrow(1-\theta)\,n'_{k_0}\left[\frac{2\tilde{f}''_{nn}}{\tilde{f}'_n}+\frac{\tilde{e}'''_{k_0nn}}{\tilde{e}''_{k_0n}}-\frac{\tilde{v}'''_{nnn}}{\tilde{v}''_{nn}}\right]<1$$
$$\Rightarrow(1-\theta)\,n'_{k_0}\left[\frac{2\tilde{f}''_{nn}}{\tilde{f}'_n}-\frac{\theta a\tilde{f}'''_{nnn}}{\tilde{v}''_{nn}}+\frac{\tilde{e}'''_{nnn}}{\tilde{v}''_{nn}}+\frac{\tilde{e}'''_{k_0nn}}{\tilde{e}''_{k_0n}}\right]<1$$

where the second line results from the substitution of $\tilde{v}''_{nn}=\frac{-a\tilde{f}'_n}{n'_\theta}$ from (A.8), and the third line again uses the definition (A.7c).

To proceed, observe that the third derivatives of the original cost function only affect the final two terms:

$$\left(\frac{\tilde{e}'''_{nnn}}{\tilde{v}''_{nn}}+\frac{\tilde{e}'''_{k_0nn}}{\tilde{e}''_{k_0n}}\right).$$

From (A.5b), we can further derive:

$$\tilde{e}'''_{k_0nn}=-\left[e'''_{nnn}\left(1+g'_n\right)^2+e''_{nn}g''_{nn}\right],$$
$$\tilde{e}'''_{nnn}=e'''_{nnn}\left(1+g'_n\right)^3+3e''_{nn}\left(1+g'_n\right)g''_{nn}+e'_ng'''_{nnn},$$

which we use, together with (A.18), to further simplify the inequality (A.16):

$$\begin{aligned}(1-\theta)\,n'_{k_0}\cdot\Bigg[\frac{2\tilde{f}''_{nn}}{\tilde{f}'_n}-\frac{\theta a\tilde{f}'''_{nnn}}{\tilde{v}''_{nn}}+\frac{e'''_{nnn}\left(1+g'_n\right)^3+3e''_{nn}\left(1+g'_n\right)g''_{nn}+e'_ng'''_{nnn}}{\tilde{v}''_{nn}}&\\ +\frac{e'''_{nnn}\left(1+g'_n\right)^2+e''_{nn}g''_{nn}}{e''_{nn}\left(1+g'_n\right)}\Bigg]<1&\qquad\text{(A.20)}\\ \Rightarrow(1-\theta)\,n'_{k_0}\left[\frac{2\tilde{f}''_{nn}}{\tilde{f}'_n}-\frac{\theta a\tilde{f}'''_{nnn}}{\tilde{v}''_{nn}}+\Phi+\Psi e'''_{nnn}\right]<1,&\end{aligned}$$

where $\Phi\equiv\frac{3e''_{nn}(1+g'_n)g''_{nn}+e'_ng'''_{nnn}}{\tilde{v}''_{nn}}+\frac{g''_{nn}}{1+g'_n}$ and $\Psi\equiv\frac{(1+g'_n)^3}{v''_{nn}}+\frac{1+g'_n}{e''_{nn}}$.

We can sign Ψ by substituting (A.4) and (A.5), the third derivative of (A.4b) with respect to labor given by

$$\begin{aligned}\tilde{f}'''_{nnn}=g'''_{nnn}f'_n+2g''_{nn}\left(f''_{nk}g'_n+f''_{nn}\right)+\left(1+g'_n\right)\cdot&\\ \left(f''_{nk}g''_{nn}+f'''_{nkk}g'_ng'_n+2f'''_{nnk}g'_n+f'''_{nnn}\right),&\end{aligned}$$

and the fact that, from (A.3), we can derive

$$g'_n=\frac{f''_{nn}-f''_{kn}}{f''_{kk}-f''_{kn}},\qquad\text{(A.21)}$$

which altogether imply that $\Psi > 0$ if and only if

$$\begin{aligned}
& e''_{nn}\left(1+g'_n\right)^2 < -\tilde{v}''_{nn} = -\left(\theta a \tilde{f}''_{nn} - \tilde{e}''_{nn}\right) \\
& \Leftrightarrow e''_{nn}\left(1+g'_n\right)^2 < -\left\{\theta a\left[g''_{nn} f'_n + \left(1+g'_n\right)\left(f''_{nk} g' + f''_{nn}\right)\right] - e'_n g''_{nn} - e''_{nn}\left(1+g'_n\right)^2\right\} \\
& \Leftrightarrow 0 < -\left[g''_{nn}\left(\theta a f'_n - e'_n\right) + \left(1+g'_n\right)\theta a\left(f''_{nk} g'_n + f''_{nn}\right)\right], \\
& \Leftrightarrow f''_{nk} \cdot \frac{f''_{nn} - f''_{kn}}{f''_{kk} - f''_{kn}} + f''_{nn} < 0, \\
& \Leftrightarrow f''_{kk} f''_{nn} - f''^2_{kn} > 0,
\end{aligned}$$

where in the penultimate line we have used the result $\theta a f'_n - e'_n = 0$ from (A.1b). This final condition is always satisfied, on the basis of our regularity assumptions.

Since the sign of Ψ is unambiguous, and $n'_{k_0} > 0$ by (A.17), we can focus on the c'''_{nnn} term. From Lemma 1, the optimality conditions (A.7) and (A.13) hold, and $\frac{d\theta}{dk_0} < 0$. Conversely, as c'''_{nnn} becomes sufficiently large, the optimality conditions (A.7) and (A.13b) remain unchanged, but (A.13b) becomes

$$\tilde{v}'''_{nnn} = \theta a \tilde{f}'''_{nnn} - e'''_{nnn}\left(1+g'\right)^3 + 3\left(1+g'\right) e''_{nn} g''_{nn} + e'_n g'''_{nnn} < 0,$$

and so the simplified second-order condition (A.15) for the first stage likewise holds. Therefore, there must exist a threshold value $-\infty < \delta < \infty$ which reverses the inequality in (A.20). Hence $\frac{d\theta}{dk_0} < 0 \Leftrightarrow e'''_{nnn} < \delta$, and $\frac{d\theta}{dk_0} > 0$ otherwise, as claimed by the proposition. □

A.2 Proof of Equivalence of (A.7) with (A.1b) and (A.2)

In Appendix A.1, we rewrote the problem in terms of implicit functions, and derived equivalent optimality conditions. Here, we verify these conditions in (A.7) are indeed equivalent to (A.1b) and (A.2).

Proof of equivalence of (A.7) *to* (A.1b) *and* (A.2b). By substituting (A.4a) and (A.5a) into (A.7a), obtain

$$\begin{aligned}\tilde{v}'_n &= \theta a\left[\left(1+g'_n\right)f'_n\right] - \left(1+g'_n\right)e'_n\\ &= \theta a\left(1+g'_n\right)\left(\theta a f'_n - e'_n\right) = 0,\end{aligned}$$

which is equivalent to (A.1b). Substituting (A.4b) and (A.5b) into (A.7b) gives civilizational emergence

$$\begin{aligned}\tilde{v}''_{nn} &= g''_{nn}f'_n\left(\theta a - e'_n\right) + \left(1+g'_n\right)\left[\theta a\left(f''_{nk}g'_n + f''_{nn}\right) - \left(1+g'_n\right)e''_{nn}\right]\\ &= \left(1+g'_n\right)\left[\theta a\left(f''_{nk}\cdot\frac{f''_{nn}-f''_{kn}}{f''_{kk}-f''_{kn}} + f_{nn}\right) - \frac{f''_{kk}+f''_{nn}-2f''_{kn}}{f''_{kk}-f''_{kn}}\cdot e''_{nn}\right] < 0\\ &\Leftrightarrow \theta a\left(f''_{kk}f''_{nn} - f''^{2}_{nk}\right) - e''_{nn}\left(f''_{kk}+f''_{nn}-2f''_{nk}\right) > 0\\ &\Leftrightarrow \theta a\left[\left(f''_{kk}-e''_{nn}\right)\left(f''_{nn}-e''_{nn}\right) - \left(\theta a f''_{kn} - e''_{nn}\right)^2\right]/\theta a > 0,\end{aligned}$$

where the first line relies on the result from (A.1b) to eliminate the first term, and the second line substitutes (A.21). This final result is equivalent to (A.2b).

Notice as well that the expression (and thus the sign) of $\tilde{v}''_{nn}$ coincides with the expression (and sign) of $\theta a\tilde{f}''_{nn}$, if we set $c'' = 0$ in the claim above. Thus we have $\theta a\tilde{f}''_{nn} < 0$ if $\theta a f''_{kk} < 0$ and $\theta a\left(f''_{kk}f''_{nn} - f''^{2}_{nk}\right) > 0$, which follows from our regularity assumptions. □

A.3 Data Appendix

A.3.1 Data sources

The primry source of data is the *Seshat Global History Databank*, a compilation of quantitative characteristics for 414 human societies from 30 distinct geographical regions, spanning the past 10,000 years (Turchin *et al.* 2015). These features are classified along 9 dimensions, including social scale, economic organization, governance structures, and information systems. While these features are highly correlated—to the extent that one principal component captures three-quarters of observed variation—they are nevertheless distinct and, importantly, exhibit substantial cross-regional variability (Turchin *et al.* 2018). Although codifying historical (especially long historical) data is always a fraud enterprise, the project relies on a group of collaborating consultants and contributing experts to minimize subjectivity. To date, only Phase 1 of the databank has been completed and publicly released, and the majority of the variables are drawn from the *Equinox-2020* dataset. To supplement the main dataset, we also merged the *Equinox* dataset with snapshot data on agricultural productivity (Turchin *et al.* 2021) and adherence to the rule of law (Mullins *et al.* 2018).

In the data, civilizations are termed "polities," and these polities correspond to one of 30 natural geographical regions at any given point in time. Regions include locations such as Upper Egypt, Latium, the Middle Yellow River, the Deccan plateau, or Sogdiana, while polities (the primary ontological unit) are set within these regions and span different periods. For Egypt, for example, polities include rule by the First and Second Dynasties (during the Dynastic Period), the Ahmose and Ramesses Dynasties (New Kingdom), the Ptolemies, the Ayyubids, and the Mumluks, while the Cambodian Basin include the Early and Late Funan Kingdom, the Chenla Kingdom, and the Early/Middle/Late periods of the Khmer Empire.

A.3.2 Variable construction

Property rights. There are no variables that directly pertain to property rights in Phase 1 of the project (there are plans to code private property ownership of land and objects other than land in Phase 2, but efforts are ongoing and not publicly available). The three variables that bear the cloest relationship have to do with either the law or information systems. These are: formal legal code (which are usually written, but could be established by oral transmission), nonwritten records (non-script records that are more extensive than mnemonics, such as seals and stamps), and script (as indicated by, at the least, fragmentary inscriptions). When these are either present or inferred to be present, we coded them as unity; if absent or inferred absent, with zero. When unknown or suspected unknown, we coded the variable as missing. The baseline property rights measure is the sum total of all these three variables.

It is possible to construct a more comprehensive measure of property rights, at risk of including overidentifying information. There are several measures associated with the operation of the legal system that could plausibly be included: the presence (or not) of judges, specialized lawyers, and court buildings. These were coded as unity when present, and zero otherwise; our first alternative property rights measure thus incliudes these additional metrics, in addition to those in the baseline. There is also one additional measure related to writing, that is, written records (which are more than short and gragmentary inscriptions). If present, we code this as unity, and include this (but without the additional legal variables) as a second alternative property rights measure.

Agricultural capital investment. These are captured as specialized, utilitarian public buildings. Three variables closely correspond to the concept of agricultural capital: irrigation systems, food storage sites (such as granaries), and drinking water supply systems (such as acqueducts). When these are either present or inferred to be present, we coded them as unity; if absent or inferred absent, with zero. When unknown or suspected unknown, we coded the variable as missing. The baseline agricultural capital measure is the sum total of all these three variables.

It is possible to construct a more comprehensive measure of agricultural capital, using measures of transport infrastructure (they may thus also be regarded as infrastructural capital). These are, strictly speaking, used for purposes far beyond farming; nevertheless, they reflect allied capital that are almost certainly utilized for agricultural activity (especially following harvests) as well. These include: roads (these are defined as those that connect settlements, rather than merely streets and easements within settlements, or informal paths that emerge through repeated use), bridges, canals, and mines or quarries. Ports are deliberately excluded, owing to how this particular piece of infrastructure is far more likely to be associated with inter-regional trade (for instance, there is little evidence of ancient ports in the Egyptian delta, despite extensive intra-civilizational exchange).

Initial agricultural needs. This measure is not straightforward to establish. On one hand, we wish to capture the manner by which geography imposes a greater (or lesser) constraint on farming practices, which tends to be well-captured by agricultural productivity metrics. On the other, however, many such measures reflect outcomes that could embed constraints other than those imposed by geography. We settle on inputs related to, first, irrigation needs (the irrigation coefficient), along with those associated with the crop involved (the crop system coefficient), and the application of fertilizer (the fertilization coefficient). Irrigation and fertilization coefficients are inferred on the basis of crop type (which in turn is based on scientific estimates), while cropping coefficients are either computed (if data on length of cultivation and fallow are available), or estimated using a metastudy. As expected for an environmentally-determined variable, all coefficients apply at the level of the geographic area.

An irrigation coefficient of unity implies that irrigation has little effect, while numbers greater than unity point to how much yields rise with irrigation (hence higher values are associated with greater needs). Locations such as Latium and Sogdiana have irrigation coefficients of one—consistent with higher rainfall in these regions—while locations such as the Deccan, Kachi Plain, and Susiana have significantly higher coefficients.

A cropping coefficient of unity points to continuous cultivation; lower coefficients imply that fields are kept fallow at least some of the time (hence higher values are associated with greater needs). These are highest in Big Island Hawaii and the Yemeni Plains, and lowest in the Lena River Valley. A fertilization coefficient greater than one is the estimated improvement to yield after animal manure is used. Maize tends to respond the most to fertilization, while rice the least (wheat is in between). Hence the Cambodian Basin and Kansai Plain have low fertilization coefficients, while Cuzco and the Oaxaca Valley have high ones.

Given our theoretical model's focus on irrigation and drainage, our simplest measure of initial agricultural needs is restricted to the irrigation coefficient alone. However, we also consider including the cropping and fertilizer coefficient as additional independent proxies for other agricultural needs. We also create a combined measure that aggregates the three coefficients.

Civilizational emergence. The dataset provides an ideal measure of development, settlement hierarchy. This is a rich variable, which goes beyond simply size to also reflect complexity. Societal elements captured by this variable include aspects of economic, administrative, cultural, religious, and utilitarian development, as evidenced by the presence of markets, local government buildings, theaters, temples, and hospitals. This expansive definition is also consistent with our own definition of civilization, as societies that have attained (and are able to sustain) high levels of technological advancement and capital accumulation.

Settlement hierarchies are scored to range from 0 through 7, with higher values indicating more advanced development. Importantly, these assignments are not correlated with time, which would present econometric problems associated with temporal trends and possible cointegration. Hence, the early Roman Principate and Dominate, along with the early Tang and Song Dynasties, attain the highest score, while the Abbasid and peak Ottoman Empires fall just below (at six). In contrast, cultures in the pre-Harappan Kachi Plain and pre-Minoan Crete receive the most rudimentary score (of one).

We code the probability of civilizational emergence as unity for settlement hierarchies that score 5 or more, and zero otherwise. However, to take full advantage of the continuous nature of the settlement hierarchy variable, we also perform regressions using the measure directly.

As an alternative metric for development, we also rely on the (logarithm of) population size. There is a longstanding tradition in utilizing population as a crude metric of development in long-dated historical data, in lieu of per capita incomes. While the two measures are often correlated, one issue with this measure—and why we regard this measure as inferior—is that it changes drastically with territorial expansion resulting not just from growth but also conquest.

Trade. There is no direct measure of trade dating back to the time periods concerned. The closest indirect evidence is derived from markers of exchange: the presence of ports, markets, and foreign coinage. Ports are excavated facilities that are indicative of riverine and maritime trade (but also conflict and transportation, more generally). Markets need not be associated with international trade, but are nevertheless a forum whereby such exchanges occur. Foreign coins are one of several forms of monetary media, which includes indigenous coins and paper currency, but are almost invariably the result of trade. When any of these are either present or inferred to be present, we coded them as unity; if absent or inferred absent, with zero. When unknown or suspected unknown, we coded the variable as missing. The baseline trade measure is the sum total of all these three variables.

In a more comprehensive measure, we include two additional measures: evidence of political relations that exist beyond the boundaries of the polity, and the existence of supracultural links with another entity. The former ranges from alliances and nominal allegiances through to vassalage, and the latter is inferred from evidence of trade, religious exchange, technological transfer, migration, or elite marriage. These each take on unity if such relationships are evident. We add these two additional indicators to the basic trade measure.

Geography. For geography, we require a control that is orthogonal (or as distinct as possible) to that associated with constraints on farming practice, as captured by the initial agricultural needs variable. Our baseline is the distance from the equator (the absolute latitude), consistent with the large literature documenting the negative effects of the tropics on growth (Gallup *et al.* 1999). Alternatively, however, we consider more generally the latitude and longitude of the polity. These variables are all defined at the level of the geographic area.

The full list of data definitions and sources, along with summary statistics and a correlation matrix, is reported in Tables A.1–A.3.

Table A.1: Definitions and sources for main variables of interest

Variable	**Definition**	**Source**
	Proposition variables	
Property rights	Total of presence of formal legal code, nonwritten records, and script	Seshat Equinox 2020
Prop. rights (incl. leg. inst.)	As for property rights, but including presence of courts, lawyers, and judges	Seshat Equinox 2020
Prop. rights (incl. writ. rec.)	As for property rights, but including presence of written records	Seshat Equinox 2020
Ag. capital (narrow)	Total of presence of formal irrigation, food storage, and drinking water systems	Seshat Equinox 2020
Ag. capital (broad)	As for agricultural capital, but including presence of mines, roads, bridges, and canals	Seshat Equinox 2020
Initial ag. needs (narrow)	Irrigation coefficient	Seshat Ag. Prod.
Initial ag. needs (broad)	Total of irrigation coefficient, crop system coefficient, and fertilizer coefficient	Seshat Ag. Prod.
Settlement hierarchy	Level of administrative, economic, and sociocultural development	Seshat Equinox 2020
Population size	Estimated size of population of polity	Seshat Equinox 2020
	Additional controls	
Crop type	One of 12 different ctop types	Seshat Ag. Prod.
Trade	Total of presence of ports, markets, and foreign coins	Seshat Equinox 2020
Trade (incl. sup. rels.)	As for trade, but including supra-polity and supracultural relations	Seshat Equinox 2020
Geography	Distance of polity from the equator	Seshat Databank
Latitude	Latitude, based on historical capitals of polities	Seshat Databank
Longitude	Longitude, based on historical capitals of polities	Seshat Databank

Table A.2: Summary statistics for main variables of interest

	N	Mean	Std dev.	Min.	Max.
Prop. rights	409	1.86	1.07	0.00	3.00
Prop. rights (incl. leg. inst.)	409	2.95	2.05	0.00	6.00
Prop. rights (incl. writ. rec.)	410	2.58	1.42	0.00	4.00
Initial ag. needs (narrow)	232	1.32	0.18	1.00	1.48
Initial ag. needs (broad)	820	1.07	1.41	0.00	3.85
Ag. capital (narrow)	394	1.80	1.06	0.00	3.00
Ag. capital (broad)	413	3.95	2.41	0.00	7.00
Settlement hierarchy	417	3.55	1.82	0.00	7.00
Population	287	14.00	3.35	3.22	19.57
Trade	382	1.69	1.16	0.00	3.00
Trade (incl. sup. rels.)	395	2.91	1.62	0.00	5.00
Geography	372	31.06	11.73	0.77	64.13
Latitude	372	30.13	13.95	-13.48	64.13
Longitude	372	39.64	60.81	-155.92	151.60

Table A.3: Correlation matrix for main variables of interest

	P. rights	P. rights (l. inst)	P. rights (w. rec)	A. needs (narrow)	A. needs (broad)	A. cap. (narrow)	A. cap. (broad)	Sett. hier.	Pop	Trade	Trade (s. rel)	Geog.	Long.	Lat.
P. rights	1.00													
P. rights (leg. inst)	0.88	1.00												
P. rights (writ. rec)	0.98	0.87	1.00											
Ag. needs (narrow)	0.09	0.05	0.09	1.00										
Ag. needs (broad)	0.03	0.05	0.03	0.43	1.00									
Ag. capital (narrow)	0.57	0.64	0.60	0.04	0.14	1.00								
Ag. capital (broad)	0.65	0.72	0.68	-0.04	0.09	0.90	1.00							
S. hierarchy	0.62	0.67	0.65	-0.04	0.05	0.73	0.76	1.00						
Population	0.57	0.64	0.63	0.15	0.06	0.64	0.67	0.76	1.00					
Trade	0.63	0.70	0.68	0.04	0.02	0.72	0.76	0.61	0.61	1.00				
Trade (sup. rels)	0.56	0.64	0.61	-0.02	0.01	0.70	0.75	0.64	0.60	0.91	1.00			
Geography	0.06	0.04	0.07	-0.17	-0.23	0.02	0.04	0.06	0.07	0.03	0.01	1.00		
Latitude	0.09	0.07	0.11	-0.04	-0.21	0.03	0.05	0.05	0.07	0.07	0.05	0.95	1.00	
Longitude	0.28	0.24	0.28	0.27	0.04	0.11	0.15	0.07	0.29	0.23	0.22	0.05	0.09	1.00

A.4 Empirical Methodology

The three specifications—corresponding to each of the three theoretical propositions—are, for polity i in period t, given by:

$$k_{i,t} = \alpha + \beta_\theta \theta_{i,t} + \mathbf{X}^\top \mathbf{\Gamma}_{i,t} + \epsilon_{i,t}, \tag{A.22a}$$
$$\theta_{i,t} = \alpha' + \beta_k k_0 + \mathbf{Y}^\top \mathbf{\Gamma}'_{i,t} + \epsilon'_{i,t}, \tag{A.22b}$$
$$\mu_{i,t} = \alpha'' + \beta_\mu \theta_{i,t} + \epsilon''_{i,t}, \tag{A.22c}$$

where (following as much as possible the notation in the text) k_0 represents initial agricultural needs, θ property rights, and μ is the probability of civilizational emergence. $\mathbf{X}$ and $\mathbf{Y}$ are vector of additional controls not directly derived from the theoretical model (most notably, crop type), but could also include fixed effects (in specifications where this is permitted by the error clustering choice); coefficients for these are captured in $\mathbf{\Gamma}$s. The various αs a constant terms, and ϵs are i.i.d. error terms. $\boldsymbol{\beta} = [\beta_\theta \beta_k \; \beta_\mu]$ are coefficients of interest to be estimated.

We estimate the first two equations independently, via OLS, with standard errors clustered at the polity level (polities may stretch across more than one geographical area). For (A.22c), since $\mu \in [0,1]$, we estimate the probabilistic specification via Probit, but for the continuous settlement hierarchy variable, ν, we return to OLS.

We vary each of the specifications for (A.22), reported in Table 1, in several ways.

For Proposition 1, the dependent variable may take on a narrower (columns 1–3) or broader (columns 4–6) definition of agricultural capital. The main dependent variable, property rights, take on simpler (columns 1 and 4) or more comprehensive definitions; the latter may include legal institutions (columns 2 and 5) or written records (columns 3 and 6). For specifications where property rights take on wider definitions, we also further control for crop type.

For Proposition 2, the dependent variable can now take on simpler (columns 7–8) or more comprehensive definitions (columns 9–10 include legal institutions, while columns 11–12 include written records). Initial agricultural needs may be constructed from a narrower (odd-numbered columns) or broader (even-numbered columns) set of components. For the richer definitions, we not only control for crop type, but also include the excluded agricultural productivity coefficients (columns 9 and 11).

For Propostion 3, the dependent variable is either an indicator for the existence of a civilization or not (columns 1–3), or the actual measure of the settlement hierarchy (columns 4–6). Property rights then take on the simple (columns 13 and 16) or more comprehensive definitions (columns 14–15, and 17–18). For the first three columns, the estimation is performed via Probit (although a linear probability model yields similar results).

For the comparisons in Table 2, the empirical model is:

$$\mu_{i,t} = \alpha''' + \beta_0 \theta_{i,t} + \mathbf{Z}^\top \mathbf{\Gamma}''_{i,t} + \epsilon'''_{i,t}, \tag{A.23}$$

where $\mathbf{Z}$ is a vector of other fundamental determinants of growth (such as trade or geography), and the other symbols follow those defined above. The variable of interest in this case is β_0.

For regressions of (A.23), reported in Table 2, we include property rights using the simpler (columns 1 and 4) or more comprehensive (columns 2 and 5 when including legal institutions, columns 3 and 6 when including written records) definitions. The control for trade also consists of a standard (columns 1–2, and 4–5) or more comprehensive (columns 3 and 6) metric, while that for geography likewise uses a simple (columns 1 and 4) or detailed (columns 2–3, and 5–6) measures.

A.5 Additional Empirical Results

A.5.1 Alternative specification of Proposition 2

In the main text, our empirical specification for Proposition 2 introduced initial agricultural needs as the sole explanatory variable for the strength of property rights regimes. However, such needs could also plausibly depend on the *existing* amount of agricultural investment.* Endogeneity concerns—especially following from Proposition 1—also suggest the need to exclude contemporaneous agricultural capital from estimates of (A.22b).

Here, we evaluate an alternative specification where both expressions are included, along with an interaction term between the two. More precisely, we regress

$$\tilde{\theta}_{i,t} = \tilde{\alpha}' + \tilde{\beta}_k \tilde{k}_0 + \tilde{\beta}_\kappa k_{i,t} + \tilde{\beta}_\delta \tilde{k}_0 \times \tilde{k}_{i,t} + \tilde{\epsilon}'_{i,t}, \tag{A.24}$$

where k represents agricultural capital, and the rest of the variables are as defined in Section A.4.

We consider several variations of the main specification. In line with baseline in Table 1, the dependent variable is either a simpler (columns 7–8) or more comprehensive measure of property rights (columns 9–10 with legal institutions, columns 11–12 with written records). For independent variables, we use either the narrower (odd-numbered columns) of broader (even-numbered) definition of initial agricultural needs. We adopt the same approach for measure of agricultural capital (odd, narrow versus even, broad). For the more comprehensive property rights specifications (columns 9–12), we also control for crop type, and include the omitted agricultural productivity coefficients where possible (columns 9 and 11).

We find that agricultural needs are either directly associated with a decrease in property rights, and remain so even after we condition on outstanding agricultural capital (albeit almost always statistically insignificant). While we do not place excess stock on whether the negative coefficient on agricultural needs enters via an interacted or uninteracted form, although the total effects are always negative. In contrast, the coefficient on the contemporaneous agricultural capital stock is positive. These results suggest even if the manner by which agricultural needs affect property rights needs to be conditioned on the outstanding stock of agricultural capital, the effects are small, and the main findings from Table 1 continues to hold.

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* The reasoning is as follows. Observe how the final equation in the proof for Proposition 2 (or that for Lemma 1 for the special Cobb-Douglas case) depends, *inter alia*, on derivatives of the function $g(n)$, which in turn is defined by A.3′ as $k = k_0 + i$. Accordingly, the claim that property rights varies negatively vis-à-vis initial capital, k_0, could therefore also depend on the current stock of agricultural capital k.

Table A.4: Regression results for Proposition 2, with interaction specification[†]

	Proposition 2					
	Dependent: Prop. rights		*Dependent: Prop. rights (incl. leg. inst)*		*Dependent: Prop. rights (incl. writ. rec.)*	
	(7)	(8)	(9)	(10)	(11)	(12)
Initial ag. needs (narrow)	1.264		-2.742		-1.207	
	(0.781)		(2.045)		(1.535)	
Initial ag. needs (broad)		-0.543		-1.099		-0.608
		(0.382)		(0.650)*		(0.613)
Ag. needs × ag.		0.032		-0.031		-0.031
		(0.079)		(0.174)		(0.174)
Ag. capital	1.176	0.199	0.569	0.690	0.384	0.310
	(0.384)***	(0.262)	(1.070)	(0.559)	(0.784)	(0.375)
Add. needs?	No	No	Yes	No	Yes	No
Crop type?	No	No	Yes	Yes	Yes	Yes
R^2 (adj.)	0.332	0.460	0.491	0.574	0.425	0.498
N	212	204	192	204	193	205

[†] Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. The coefficients on agricultural capital and interaction effects correspond to the respective measures of agricultural capital and initial agricultural needs for that specification, as documented in the appendix. Crop type are indicators corresponding to one of 12 different crop types. Additional agricultural needs include the fertilizer and crop system coefficients. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

A.5.2 Variables as means instead of totals

The baseline chose to sum all related indicators for a given concept into an aggregate. While this is inherently reasonable—for instance, agricultural capital would generally be more developed in the complete presence of an irrigation system, food storage site, and drinking water supply system than if one were missing—but this introduces one difficulty: since our variables are compiled using multiple subcomponents, this approach may yield a total that is not as representative of the relative contributions of each metric, especially when the number of subcomponents used to construct measures differ. Accordingly, we convert our calculation of totals to means for all variables originally constructed as totals in the baseline, and report analogous results for Tables 1 and 2.

For agricultural needs, in particular, we compute the means in two alternative ways (since the irrigation coefficient is a single variable). The first computes the means of the three coefficients. The second restricts this average to only the two coefficients that are typically significant when the variables are regressed separately: the irrigation and crop system coefficients. Consequently, we drop the independent controls for additional agricultural needs that were included in baseline specifications (9) and (11).

As is clear from the results in Tables A.5 and A.6, the choice to construct our variables using totals, instead of means, do not make any appreciable difference to our results, and the conclusions described in the main text remain qualitatively unchanged.

Table A.5: Regression results for main propositions, variables calculated as means†

	Proposition 1					
	Dependent: Ag. capital (narrow)			*Dependent: Ag. capital (broad)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.620			0.614		
	(0.050)***			(0.043)***		
Prop. rights		0.527			0.551	
(incl. leg. inst.)		(0.061)***			(0.053)***	
Prop. rights			0.487			0.505
(incl. writ. rec.)			(0.073)***			(0.064)***
Crop type?	No	Yes	Yes	No	Yes	Yes
R^2 (adj.)	0.374	0.514	0.482	0.426	0.558	0.513
N	386	312	313	403	329	330

	Proposition 2					
	Dependent: Prop. rights		*Dependent: Prop. rights (incl. leg. inst)*		*Dependent: Prop. rights (incl. writ. rec.)*	
	(7)	(8)	(9)	(10)	(11)	(12)
Initial ag. needs	-2.248		-4.868		-2.322	
(all coeffs.)	(0.846)***		(1.946)**		(1.266)*	
Initial ag. needs		-0.570		-3.917		-1.582
(irrig. & crop)		(0.550)		(1.162)***		(0.819)*
Crop type?	No	No	Yes	Yes	Yes	Yes
R^2 (adj.)	0.027	0.000	0.150	0.147	0.166	0.142
N	205	225	205	225	206	226

	Proposition 3					
	Dependent: Prob. civilization			*Dependent: Settlement hierarchy*		
	(13)	(14)	(15)	(16)	(17)	(18)
Prop. rights	2.005			2.905		
	(0.315)***			(0.199)***		
Prop. rights		1.636			2.764	
(incl. leg. inst.)		(0.249)***			(0.200)***	
Prop. rights			2.140			2.920
(incl. writ. rec.)			(0.339)***			(0.193)***
R^2 (adj.)				0.355	0.343	0.369
N	409	409	410	399	399	400

† Coefficients estimated via OLS and Probit, with the dependent variable listed in the top row of each panel. Crop type are indicators corresponding to one of 12 different crop types. Agricultural needs are averaged across the fertilizer, irrigation, and crop system coefficients, or just the latter two. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table A.6: Regression results comparing the effect of institutions against other fundamental determinants, variables calculated as means†

	Dependent: Civilization (hierarchy)			*Dependent: Civilization (population)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	1.896			3.771		
	(0.285)***			(0.898)***		
Prop. rights		2.036			3.350	
(incl. leg. inst.)		(0.369)***			(0.876)***	
Prop. rights			2.395			4.535
(incl. writ. rec.)			(0.293)***			(1.026)***
Trade	1.388	1.436		3.271	2.812	
	(0.263)***	(0.347)***		(0.662)***	(0.715)***	
Trade			1.456			2.867
(incl. sup. rels.)			(0.332)***			(0.888)***
Geography	0.002			0.023		
	(0.008)			(0.016)		
Latitude		0.001	0.002		0.019	0.020
		(0.007)	(0.007)		(0.015)	(0.016)
Longitude		-0.004	-0.004		0.006	0.007
		(0.001)***	(0.002)***		(0.003)*	(0.004)*
R^2 (adj.)	0.383	0.395	0.399	0.432	0.451	0.433
N	327	327	335	242	242	247

† Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

A.5.3 Restriction to pre-Common Era subsample

One potential objection to the inclusion of the full Seshat dataset in our analysis is that property rights are *de rigueur* in all modern economies, and hence the inclusion of contemporary economies in the analysis could potentially bias the results in favor of a positive effect. Yet even a cursory examination of relatively recent economic history would reveal the spuriousness of this claim. China abolished landlord rights and instituted common land ownership in 1947, under the rubric of the "Basic Program of the Chinese Agrarian Law," during the early phase of Communist rule (Lee 1948) (these have only been largely reinstituted under the Property Law in 2007). And even though Papua New Guinea gained independence from Australian colonial rule in 1975, the significant majority of land is held under customary ownership, rather than title (Lea 2002), as it has been in the Oro region for centuries.

Even in earlier periods of the Common Era, property rights routinely fluctuated between regimes. State land in Mesopotamia, Sogdiana, and Susiana under the Timurid Empire was conditionally transferred under the *soyurghal* to the sovereign and members of the ruling dynasty, statesmen of high rank, and military leaders (Mukminova 1998). And the the Valley of Oaxaca under the Zapotecs, despite demonstrating engineering sophistication in terms of irrigation systems, practiced common ownership, and it was the recognition of private property rights that enabled colonial exploitation of indigenous resources (McClure 2022).

Nevetheless, it is worth considering a restriction on the sample coverage to just ancient polities, to rule out such inadvertent bias. We do so by defining these as those that were established before the Common Era, and repeating our exercise. The specifications reported in Tables A.7 and A.8 follow those of Tables 1 and 2, respectively. The main qualitative results remains unchanged, even as the sample size drops to about half of our original.

Table A.7: Regression results for main theoretical propositions, pre-Common Era subsample†

	Proposition 1					
	Dependent: Ag. capital (narrow)			*Dependent: Ag. capital (broad)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.598			1.534		
	(0.064)***			(0.123)***		
Prop. rights (incl. leg. inst.)		0.361			0.998	
		(0.037)***			(0.081)***	
Prop. rights (incl. writ. rec.)			0.395			1.106
			(0.053)***			(0.099)***
Crop type?	No	Yes	Yes	No	Yes	Yes
R^2 (adj.)	0.393	0.575	0.524	0.538	0.677	0.629
N	168	123	124	179	134	135
	Proposition 2					
	Dependent: Prop. rights		*Dependent: Prop. rights (incl. leg. inst)*		*Dependent: Prop. rights (incl. writ. rec.)*	
	(7)	(8)	(9)	(10)	(11)	(12)
Initial ag. needs (narrow)	0.454		-1.087		-0.764	
	(0.609)		(1.267)		(1.332)	
Initial ag. needs (broad)		-1.291		-2.012		-1.249
		(0.312)***		(0.848)**		(0.665)*
Add. needs?	No	No	Yes	No	Yes	No
Crop type?	No	No	Yes	Yes	Yes	Yes
R^2 (adj.)	-0.005	0.080	0.155	0.137	0.125	0.103
N	103	94	94	94	95	95
	Proposition 3					
	Dependent: Prob. civilization			*Dependent: Settlement hierarchy*		
	(13)	(14)	(15)	(16)	(17)	(18)
Prop. rights	0.623			1.006		
	(0.166)***			(0.112)***		
Prop. rights (incl. leg. inst.)		0.395			0.609	
		(0.094)***			(0.076)***	
Prop. rights (incl. writ. rec.)			0.530			0.780
			(0.135)***			(0.079)***
R^2 (adj.)				0.437	0.421	0.479
N	180	180	181	177	177	178

† Coefficients estimated via OLS and Probit, with the dependent variable listed in the top row of each panel. Crop type are indicators corresponding to one of 12 different crop types. Additional agricultural needs include the fertilizer and crop system coefficients. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table A.8: Regression results comparing the effect of institutions against other fundamental determinants, pre-Common Era subsample†

	Dependent: Civilization (hierarchy)			*Dependent: Civilization (population)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.727			1.301		
	(0.104)***			(0.455)***		
Prop. rights		0.424			0.574	
(incl. leg. inst.)		(0.080)***			(0.205)***	
Prop. rights			0.518			0.923
(incl. writ. rec.)			(0.072)***			(0.333)***
Trade	0.447	0.434		0.859	1.058	
	(0.161)***	(0.174)**		(0.365)**	(0.291)***	
Trade			0.401			0.799
(incl. sup. rels.)			(0.102)***			(0.221)***
Geography	-0.017			0.018		
	(0.015)			(0.030)		
Latitude		-0.019	-0.006		-0.016	0.015
		(0.018)	(0.017)		(0.035)	(0.034)
Longitude		0.001	0.001		0.018	0.020
		(0.002)	(0.002)		(0.008)**	(0.007)***
R^2 (adj.)	0.460	0.432	0.538	0.344	0.399	0.473
N	132	132	136	79	79	81

† Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the geographic area level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

A.5.4 Alternative clustering of standard errors

One obvious alternative clustering choice, relative to the baseline, is to cluster at the geographic level. Since each geographical region is likely to experience correlated shocks—think a regional flood, or cold weather conditions that inhibit the harvest—this is a plausible choice, even if less encompassing that clustering by polity, which would cater to many more unobservables experienced by a polity that extend beyond a given region (which explains our choice to cluster at that level in the baseline).

Another clustering approach is to cluster at multiple levels. This requires that we also introduce a fixed effect. Since doing so at the polity level would result in almost perfect collinearity with our explanatory variable of interest (property rights), we set this fixed effect at the geographic level, which unfortunately means that our measures of initial agricultural needs and geographic controls (both of which are defined at the geographic level) instead become irrelevant. We regard this as a necessary evil, and proceed with two-way clustering by polity and period.[†]

We report regressions with these alternative clustering approaches, for the two tables in the main text, in Tables A.9–A.10 and Tables A.11–A.12, respectively. By and large, our qualitative findings are unaltered by these alternative clustering choices. The coefficients when clustering by geographical area are exactly the same as clustering by polity, but with wider standard errors. Even so, the point estimates retain their statistical significance.

However, the constraints associated with being unable to control for key variables of interest—especially when two-way clustering is introduced—mean that we are unable to draw inferences about Proposition 2 in Table A.11. Given the importance of this objective, and the qualitative irrelevance of clustering by geographical area, we favor the choice of clustering errors at the polity level for the baseline.

[†]This somewhat distasteful choice over what variables we are able to control for is, nevertheless, the reason why we chose to cluster only at the polity level in the baseline.

Table A.9: Regression results for main propositions, clustered by geographical area†

	Proposition 1					
	Dependent: Ag. capital (narrow)			*Dependent: Ag. capital (broad)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.568 (0.075)***			1.470 (0.140)***		
Prop. rights (incl. leg. inst.)		0.290 (0.029)***			0.809 (0.060)***	
Prop. rights (incl. writ. rec.)			0.389 (0.058)***			1.089 (0.111)***
Crop type?	No	Yes	Yes	No	Yes	Yes
R^2 (adj.)	0.326	0.519	0.472	0.422	0.574	0.512
N	386	312	313	403	329	330

	Proposition 2					
	Dependent: Prop. rights		*Dependent: Prop. rights (incl. leg. inst)*		*Dependent: Prop. rights (incl. writ. rec.)*	
	(7)	(8)	(9)	(10)	(11)	(12)
Initial ag. needs (narrow)	0.520 (0.774)		-3.176 (1.319)**		-1.470 (0.650)**	
Initial ag. needs (broad)		-0.749 (0.316)**		-1.623 (1.027)		-0.774 (0.573)
Add. needs?	No	No	Yes	No	Yes	No
Crop type?	No	No	Yes	Yes	Yes	Yes
R^2 (adj.)	0.003	0.027	0.201	0.150	0.185	0.166
N	225	205	205	205	206	206

	Proposition 3					
	Dependent: Prob. civilization			*Dependent: Settlement hierarchy*		
	(13)	(14)	(15)	(16)	(17)	(18)
Prop. rights	0.591 (0.122)***			1.031 (0.083)***		
Prop. rights (incl. leg. inst.)		0.351 (0.058)***			0.584 (0.038)***	
Prop. rights (incl. writ. rec.)			0.508 (0.095)***			0.813 (0.062)***
R^2 (adj.)				0.382	0.451	0.420
N	409	409	410	399	399	400

† Coefficients estimated via OLS and Probit, with the dependent variable listed in the top row of each panel. Crop type are indicators corresponding to one of 12 different crop types. Additional agricultural needs include the fertilizer and crop system coefficients. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the level of the geographic area, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table A.10: Regression results comparing the effect of institutions against other fundamental determinants, errors clustered by geographical area†

	Dependent: Civilization (hierarchy)			*Dependent: Civilization (population)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.607			1.092		
	(0.130)***			(0.358)***		
Prop. rights		0.428			0.622	
(incl. leg. inst.)		(0.074)***			(0.135)***	
Prop. rights			0.541			1.054
(incl. writ. rec.)			(0.058)***			(0.196)***
Trade	0.613	0.486		1.142	0.883	
	(0.119)***	(0.139)***		(0.291)***	(0.251)***	
Trade			0.475			0.643
(incl. sup. rels.)			(0.050)***			(0.113)***
Geography	0.002			0.029		
	(0.011)			(0.021)		
Latitude		0.001	-0.001		0.021	0.019
		(0.011)	(0.011)		(0.020)	(0.022)
Longitude		-0.003	-0.004		0.009	0.008
		(0.002)	(0.002)*		(0.004)**	(0.004)*
R^2 (adj.)	0.447	0.491	0.514	0.419	0.478	0.471
N	327	327	335	242	242	247

† Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the level of the geographic area, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table A.11: Regression results for main theoretical propositions, errors clustered two-way by polity and period[†]

	Proposition 1					
	Dependent: Ag. capital (narrow)			*Dependent: Ag. capital (broad)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.515 (0.055)***			1.423 (0.108)***		
Prop. rights (incl. leg. inst.)		0.288 (0.027)***			0.815 (0.048)***	
Prop. rights (incl. writ. rec.)			0.398 (0.044)***			1.127 (0.078)***
Crop type?	No	Yes	Yes	No	Yes	Yes
R^2 (adj.)	0.497	0.570	0.551	0.601	0.660	0.631
N	386	312	313	403	329	330

	Proposition 2					
	Dependent: Prop. rights		*Dependent: Prop. rights (incl. leg. inst)*		*Dependent: Prop. rights (incl. writ. rec.)*	
	(7)	(8)	(9)	(10)	(11)	(12)
Initial ag. needs (narrow)	0.000 (.)		0.000 (.)		0.000 (.)	
Initial ag. needs (broad)		0.000 (.)		0.000 (.)		0.000 (.)
Add. needs?	No	No	Yes	No	Yes	No
Crop type?	No	No	Yes	Yes	Yes	Yes
R^2 (adj.)	0.195	0.209	0.280	0.280	0.232	0.232
N	225	205	205	205	206	206

	Proposition 3					
	Dependent: Prob. civilization			*Dependent: Settlement hierarchy*		
	(13)	(14)	(15)	(16)	(17)	(18)
Prop. rights	0.591 (0.095)***			1.037 (0.091)***		
Prop. rights (incl. leg. inst.)		0.351 (0.045)***			0.580 (0.045)***	
Prop. rights (incl. writ. rec.)			0.508 (0.074)***			0.823 (0.061)***
R^2 (adj.)				0.482	0.537	0.510
N	409	409	410	399	399	400

[†] Coefficients estimated via OLS and Probit, with the dependent variable listed in the top row of each panel. Crop type are indicators corresponding to one of 12 different crop types. Additional agricultural needs include the fertilizer and crop system coefficients. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered two-way by polity and period, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table A.12: Regression results comparing the effect of institutions against other fundamental determinants, errors clustered by polity and period†

	Dependent: Civilization (hierarchy)			*Dependent: Civilization (population)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.561			0.894		
	(0.137)***			(0.319)***		
Prop. rights		0.374			0.566	
(incl. leg. inst.)		(0.080)***			(0.144)***	
Prop. rights			0.462			0.959
(incl. writ. rec.)			(0.074)***			(0.223)***
Trade	0.702	0.573		1.132	0.977	
	(0.114)***	(0.139)***		(0.228)***	(0.238)***	
Trade			0.506			0.738
(incl. sup. rels.)			(0.065)***			(0.133)***
Geography	0.000			0.000		
	(.)			(.)		
Latitude		0.000	0.000		0.000	0.000
		(.)	(.)		(.)	(.)
Longitude		0.000	0.000		0.000	0.000
		(.)	(.)		(.)	(.)
R^2 (adj.)	0.557	0.587	0.598	0.535	0.567	0.574
N	327	327	335	234	234	239

† Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

A.5.5 Additional controls related to institutions, exchange, measures of civilizational development

Our baseline restricted the analysis to a suite of variables constructed from indicators that we believed were most appropriate in terms of capturing the relevant concepts. However, there are a number of additional measures that are *tangentially* related to each of our key variables, whose inclusion may offer some additional insight into the key drivers of early civilizational development.

Given their conceptual distinction, we introduce these variables as controls instead of enfolding them into our main explanatory variables. This choice is further bolstered by the fact that some of these additional variables are only available at the geographic area level, which would typically result in the need to drop the control for crop type (as per the baseline). Regardless, adding these variables severely reduces the size of our sample for Propositions 1 and 3 (to 15 observations or less), which compromises statistical inference. Accordingly, we refrain from including them in our baseline, and report them here only in the interest of completeness.

The two variables we consider for related institutions have to do with (nascent) *voice and accountability* (an estimate on whether the ruler, as executive, faces constraints), and the *rule of law* (a measure of whether the rule of law generally applies to all agents within the polity). For initial agricultural needs, we add narrow and broad definitions of agricultural capital, as controls.[‡] Finally, we also consider the inclusion of a new measure of *geographic constraints*, based not on the associated crop or farming practices but purely on features of the physical geography, defined at the geographic area level.[§]

The specifications reported in Tables A.13 and A.14 follow those of Tables 1 and 2, respectively. However, Table A.13 includes voice and accountability (columns 1–3 and 13–15) or rule of law (columns 4–6 and 16–18) as additional controls for Proposition 1 and 3, respectively, as well as narrow (columns 7, 9, and 11) and broad (columns 8, 10, and 12) versions of agricultural capital as controls for Proposition 2.

Perhaps owing to the significantly underpowered sample, our results are weaker than those reported in Table 1. However, in most specifications, the estimated coefficients do not differ qualitatively from the baseline, and mostly retain the significance. Among the newly-introduced variables, two (pertaining to accountability and geographic constraints) enter consistently enough and breach statistical significance, although the very small sample sizes involved preclude definitive conclusions. Still, one takeaway from this exercise is that there are potentially other institutional variables—beyond property rights—that may be important for the early development of civilizations. We leave such explorations to future research.

[‡]The main issue with doing so—and the reason we do not include this in the baseline—is that endogeneity concerns inevitably arise, especially in light of the claims of Proposition 1.

[§]This variable is an indicator that takes on unity when the terrain, rainfall, and drainage needs appear to be relatively more challenging and requiring substantial human intervention to enable successful farming, versus a friendlier setting where the land is flat, rainfall abundant, and drainage pathways natural.

Table A.13: Regression results for main theoretical propositions, with additional controls[†]

Proposition 1

	Dependent: Ag. capital (narrow)			*Dependent: Ag. capital (broad)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.621 (0.229)**			2.166 (0.687)***		
Prop. rights (incl. leg. inst.)		0.667 (0.244)**			2.731 (0.838)**	
Prop. rights (incl. writ. rec.)			0.477 (0.229)*			1.771 (0.565)**
Voice and accountability	-1.010 (0.557)*	-0.444 (0.347)	-0.721 (0.284)**			
Rule of law				0.526 (1.067)	0.192 (1.279)	-0.186 (1.578)
Crop type?	No	Yes	Yes	No	Yes	Yes
R^2 (adj.)	0.167	0.054	0.119	0.552	0.515	0.473
N	15	11	11	13	9	9

Proposition 2

	Dependent: Prop. rights		*Dependent: Prop. rights (incl. leg. inst)*		*Dependent: Prop. rights (incl. writ. rec.)*	
	(7)	(8)	(9)	(10)	(11)	(12)
Initial ag. needs (narrow)	0.427 (0.336)		-1.747 (0.954)*		-0.648 (0.542)	
Initial ag. needs (broad)		-0.432 (0.202)**		-0.555 (0.363)		-0.358 (0.274)
Ag. capital (narrow)	0.639 (0.058)***		1.145 (0.126)***		0.708 (0.095)***	
Ag. capital (broad)		0.300 (0.022)***		0.635 (0.041)***		0.398 (0.030)***
Add. needs?	No	No	Yes	No	Yes	No
Crop type?	No	No	Yes	Yes	Yes	Yes
R^2 (adj.)	0.331	0.462	0.492	0.533	0.427	0.450
N	212	204	192	204	193	205

Proposition 3

	Dependent: Prob. civilization			*Dependent: Settlement hierarchy*		
	(13)	(14)	(15)	(16)	(17)	(18)
Prop. rights	1.136 (0.539)**			0.583 (0.719)		
Prop. rights (incl. leg. inst.)		0.154 (0.070)**			0.383 (0.539)	
Prop. rights (incl. writ. rec.)			0.947 (0.446)**			0.567 (0.457)
Voice and accountability	0.000 (.)	-0.260 (0.163)	0.000 (.)			
Rule of law				1.263 (0.753)	1.210 (0.747)	0.983 (0.696)
R^2 (adj.)		0.367		0.080	0.105	0.124
N	11	17	11	13	13	13

[†] Coefficients estimated via OLS and Probit, with the dependent variable listed in the top row of each panel. Crop type are indicators corresponding to one of 12 different crop types. Additional agricultural needs include the fertilizer and crop system coefficients. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table A.14: Regression results comparing the effect of institutions against other fundamental determinants, with additional controls†

	Dependent: Civilization (hierarchy)			*Dependent: Civilization (population)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	0.579		0.345		0.533	
	(0.735)		(0.141)**		(0.105)***	
Prop. rights		0.102		0.215		0.355
(incl. leg. inst.)		(0.139)		(0.076)***		(0.056)***
Voice and	-1.134	1.992				
accountability	(1.385)	(0.950)*				
Rule of law		1.279				
		(0.758)				
Trade	0.271		0.524		0.646	
	(0.531)		(0.092)***		(0.091)***	
Trade		0.646		0.263		0.438
(incl. sup. rels.)		(0.301)*		(0.091)***		(0.073)***
Couriers			1.901	1.680		
			(0.293)***	(0.272)***		
Postal system				1.001		
				(0.245)***		
Geography	0.014		-0.007		0.007	0.008
	(0.126)		(0.008)		(0.008)	(0.007)
Latitude		-0.097		-0.006		
		(0.021)***		(0.006)		
Longitude		0.523		-0.004		
		(0.054)***		(0.001)***		
Geographic					0.547	0.468
constraints					(0.151)***	(0.146)***
R^2 (adj.)	-0.055	0.939	0.597	0.722	0.464	0.536
N	16	11	248	209	325	333

† Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

A.5.6 Alternative measures of civilizational development

The baseline considered two alternative measures of civilizational development, settlement hierarchy (in both levels and as a dummy in the probabilistic model), and (the logarithm of) population. For reasons explained in Section A.3, these offer two relatively distinct views of development, with the former being more comprehensive, but the latter being a proxy for per capita incomes commonly used in the economic history literature. In this section, we consider two alternative metrics for our dependent variable of interest.

First, we consider the (logarithm of) territorial size (in squared kilometers) as a measure of civilizational emergence. One major issue with this metric is that territories expand and contract for many reasons beyond development, with the main alternative method being war and conquest. Yet it is entirely possible for a civilization to retain relatively lower levels of development (such as the Mongol Empire under Chinggis Khan and his immediate successors, prior to the consolidation of the Chagatai Khanate, Golden Horde, Ilkhanate, and Yuan Empire), or for a polity circumscribed by a relatively small territory to be a fairly sophisticated civilization (such as China during the Southern Song, or the late Byzantine Empire). These justify our decision not to use territory in our baseline measure of civilizational development, but we explore this possibility here.

Second, we also consider the number of administrative levels for a society. These are not simply the settlement hierarchy (which tends to incorporate more nuance), but usually capture whether the polity has only an overall ruler, lower levels of government, ranging from provincial/regional governments, to town mayors, to village heads. While this measure is likely to be strongly correlated with our settlement hierarchy measure, the extent of administrative centralization need not represent the extent of civilizational development. After all, there was *de minimus* retrogression in development during the imperial period of Rome, for example.

All things considered, however, the use of these alternative metrics do not alter our main conclusion that property rights remains central to civilizational emergence.

Table A.15: Regression results comparing the effect of institutions against other fundamental determinants, with alternative dependent variables†

	Dependent: Civilization (territory)			*Dependent: Civilization (admin levels)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Prop. rights	1.226 (0.236)***			0.876 (0.111)***		
Prop. rights (incl. leg. inst.)		0.510 (0.111)***			0.619 (0.065)***	
Prop. rights (incl. writ. rec.)			0.934 (0.188)***			0.786 (0.079)***
Trade	0.736 (0.199)***	0.555 (0.209)***		0.741 (0.093)***	0.496 (0.108)***	
Trade (incl. sup. rels.)			0.428 (0.126)***			0.492 (0.064)***
Geography	0.033 (0.014)**			0.010 (0.007)		
Latitude		0.024 (0.012)**	0.020 (0.012)*		0.011 (0.006)*	0.008 (0.006)
Longitude		0.014 (0.003)***	0.012 (0.003)***		-0.001 (0.001)	-0.002 (0.002)
R^2 (adj.)	0.327	0.394	0.407	0.558	0.634	0.601
N	270	270	276	309	309	317

† Coefficients estimated via OLS, with the dependent variable listed in the top row of each panel. A constant term was included in all regressions, but not reported. Heteroskedasticity-robust standard errors, clustered at the polity level, reported in parentheses, where *, ** and *** indicates significance at the 10 percent, 5 percent, and 1 percent level, respectively.

A.6 The Secondary Role of Trade in the Transfer of Agricultural Capital

In the main text, we explained how economic integration through trading linkages was unlikely to have been a direct mechanism for civilizational emergence. However, there is a secondary, indirect channel by which trade could potentially harness growth and development: economic exchange may give rise to technological diffusion and adoption, leading eventually to greater capital accumulation and growth. This appendix provides historical evidence that trade in ancient times did not serve such a purpose. There is a substantial literature that supports the notion that such exchange relationships may support technology transfer and hence growth. Trade in goods may enable knowledge spillovers and encourage domestic innovation (Grossman & Helpman 1991b), or allow the importation of intermediate goods that embody technologies (Eaton & Kortum 2002; Grossman & Helpman 1991a). Migratory flows can also promote knowledge spillovers (Arrow 1962), knowledge transfer (Kerr 2008), or network effects (Rauch 2001). In this subsection, we document how trade the transfer of agricultural capital between the major civilizations, via the medium of trade, appears to have been relatively limited during the periods of interest.

In spite of the flourishing overseas trade between Harappa and Mesopotamia, especially in terms of consumer goods exchange (Allchin & Allchin 1982), trade between the two did not appear to have effected much transfer of capital goods. Indeed, the nature of goods traded appears to suggest that trading patterns were more reflective of Heckscher-Ohlin-type relative factor abundance, rather than comparative advantage derived from Ricardian productivity differentials, or technology transfer embedded in traded goods. For instance, copper—one of the major imports into Mesopotamia via the Gulf—was primarily a luxury good in the mid-3rd millennium BCE, and even when its use became much more widespread as an intermediate good to production around 2200 BCE, there is little evidence that trade was sufficiently intra-industry to offer much potential for technological spillovers (Edens 1992). Moreover, evidence on the actual form of irrigation techniques deployed in Harappa appear to have been distinct from those employed in Mesopotamia, which would have further limited the possibility of direct transfer: in contrast to the channel-based irrigation methodologies common across Mesopotamia, Harappan agriculture was reliant on land inundation as the Indus flooded due to the monsoon (Giosan *et al.* 2012).

Trade between Egypt and Mesopotamia likewise did not appear to have been accompanied by broad-based capital transfer. For starters, trading relations between the two civilizations were only first established significantly after their respective civilizations had taken root, during the reign of Assyrian ruler Sargon II (between 721–705 BCE), with Egypt having maintained an isolationist stance until then (Oppenheim 1964). Even after trading took off between Egypt and Mesopotamia—largely along the ancient route of Wadi Hammamat—this trade did not involve the transfer of irrigation capital or technology, at least in the earlier periods (Rice 2003). Rice (2003, p. 37) does speculate that the more or less simultaneous development of hydraulic engineering by the two civilizations could be due to more than chance and instead be attributable to the exchange of ideas. However, the available archeological evidence from the Eastern Desert indicate that goods exchange involved ornamental stone tools associated with religious ceremonies or funerary rites (Hobbs 2002), and not tools and implements related hydraulic control and technology.

By and large, trading caravans across the Eastern Desert carried natural resources (such as gold or precious stones) or aromatic resins (such as myrrh) (Bradbury 1988). Furthermore, while the two civilizations were engaged in hydraulic engineering, the more unpredictable nature of the Tigris and Euphrates dictated irrigation practices that were distinct from those involving the Nile, with its cyclical floodwaters. Mesopotamian irrigation tended to favor the abandonment of irrigation canals (due to silting) (Tamburrino 2010), as opposed to the larger-scale hydrology projects that were deployed to continuously sustain the irrigation channels of the Nile (Singer *et al.* 1954). While some learning probably did occur—the design of the *shaduf*, for example, was likely a technological import from Mesopotamia (Stroubal 1992)—technological transfers were not systematic and ongoing. More generally, traces of Sumerian practices on Egyptian culture in predynastic and early dynastic times appears to be very minute (King 1910), which casts doubt on how much in influence either civilization had on the other, insofar as the exchange of agricultural capital and technology via trade was concerned.

Although there is some historical evidence of hydraulic engineering as far back as the Shang dynasty, larger-scale irrigation and damming projects in ancient China only began in earnest in the Zhou period (around 4th century BCE) (Creel 1937), and by that period Sinic civilization had probably advanced furthest among ancient civilizations in hydraulic tools and technology. The existing historical record provides little reason to believe, however, that such engineering knowledge for large-scale projects were routinely exchanged with other civilizations via movements of goods or factors, at least in ancient times (Biswas 1970).[¶] The major hydraulic engineering projects of the ancient world—such as the diversion of the Nile by King Menes, the Indus river drainage systems, and flood control of the Yellow River by the "Great Yu"—all appear to have been undertaken independently with available technologies in their respective civilizations. And while there could have been agricultural technology adoption at the peripheries of these civilizations, such transfers were by and large small-scale in nature, with innovative activity firmly centered within the civilizational cores.

[¶]This was not necessarily the case by the Classical period. For example, Muslim engineers adopted *saqiyas* from Ptolemaic Greece (Stroubal 1992), while *norias* were adapted and improved by engineers in Song China, who subsequently actively spread the technology (Elvin 1973).

A.7 The Complementary Role of Writing in Reinforcing Property Rights

In the main text, we alluded to how records were critical to demarcating property rights. In this section, we document ancillary evidence consistent with the importance of property rights for civilizational formation: the coincident emergence of independent writing systems in many of these civilizations, as property rights became gradually more established. The fact that writing systems did *not* develop in the other non-civilizational settlements also provides additional indirect evidence against the possibility that property rights were a feature of those societies, although this is difficult to definitively ascertain due to the paucity of the historical record.

Among the civilizations considered, a script (or proto-script) dates back to the earliest stages of each civilization. Mesopotamian cuneiform was invented in the Uruk period, having built on proto-script in the Ubaid period (Pollock 1999). Archaic Chinese writing, as recorded on the oracle bones at Anyang, corresponds to the period of the early Shang dynasty (Creel 1937; Wilkinson 1998). Hieroglyphic symbols were already foreshadowed in predynastic Egypt, as civilization was only just taking hold in the Nile valley, and indigenous invention of the hieroglyphic and hieratic scripts occurred in the Early Dynastic period (Baines 1983; Shaw 2003; Wilkinson 2010). And rudimentary symbols began to appear on pottery dated to the early Harappan, with prototypical logographic inscriptions found on square stamp seals associated with the late Kot Diji Phase (2800–2600 BCE) level of a Harappan mound at Kunal (Khatri & Acharya 2005), with a standardized script circulating across all major settlements by the mature Harappan phase (2600–1900 BCE) (Kenoyer 2006).

As these civilizations advanced, there would have been increased demand for a method for recording the myriad transactions that occurred, mainly within their civilizational borders, but also between different civilizations. Writing, undoubtedly, facilitated the sort of long-distance, indirect communication necessitated by trade; and trade, in turn, supported the dissemination of writing. It is in this sense that commerce and trade was important for the early development of civilizational entities.‖ Of course, inasmuch as writing was critical for meeting the needs of economic exchange, it was also important in several other aspects. First, production technologies could be documented and transmitted across time and space (Damerow 2012), which further stimulated capital accumulation. Second, property rights—which were likely enforced informally through social sanction—could now be formally codified, and as we have seen, such property rights were central to the adoption of new capital. Independent writing systems also eventually underpinned the codification of the rule of law, which is yet another cornerstone in the political-economic development of civilizations.

Would the ancient civilizations have emerged even in the absence of a writing system? There is a profound endogeneity issue here, since both civilizations and their writing systems probably coevolved, and in some cases scholars have even defined civilizations in terms of whether they possessed a writing system. While resolving the direction of causality is beyond the scope of this paper, it is clear that there were important feedback effects between the development of the two, and we can only conjecture as to whether

‖In this, we see a parallel to the argument raised by Acemoğlu *et al.* (2005b) that commercial trade was central to strengthening the position of the merchant class and spurring the development of property rights institutions, several millennia later.

writing was a sufficient condition for property rights to become entrenched, and in turn spark the development of civilizations. At the very least, it would appear to be a necessary one.

This is corroborated in part by examining the timing in which writing systems subsequently developed independently in later civilizations that emerged around the Bronze Age. We examine two other major groups of writing systems: other Near Eastern protohistoric scripts (Proto-Elamite, Proto-Sinaitic, and Proto-Canaanite), and Cretan protohistoric writing (Cretan Hieroglyphic, Minoan Linear A, and Mycenaean Linear B).

The group of Near Eastern scripts under consideration can be further classified into Proto-Sinaitic (Proto-Canaanite was almost certainly an antecedent of Proto-Sinaitic), and Proto-Elamite. Although not widely used in its times, Proto-Sinaitic is the likely parent script for the Phoenician alphabet, which in turn was adopted for the Greek alphabet. Proto-Sinaitic probably emerged as an intermediate step from Egyptian hieroglyphs (Hamilton 2006), rather than as an independent creation; consequently, the script was securely entrenched by the mid-11th century BCE,[**] and hence would have been available for recording purposes by the time of the rise of Archaic Greek civilization in the 8th century BCE.

In contrast, Proto-Elamite is probably best viewed as a script associated with broader Mesopotamian civilization. Although Proto-Elamite is distinct from the cuneiform script prevalent in other parts of Mesopotamia—being composed of both lines and circles, rather than wedged markings alone—the geographic location of the Proto-Elamite and Elamite kingdoms, just east of the Tigris on the Iranian plateau, suggests that it is best regarded not as a distinct civilization but rather as part of the broader urban civilization that we have designated in this paper as Mesopotamian. Moreover, Proto-Elamite appears to have been in use concurrently with Sumerian cuneiform by settlements in Elam (Walker 1987).

The other major class of script we consider are those of the Cretan family. Cretan protohistoric writing systems developed sequentially, beginning with Cretan Hieroglyphic—which dates back to the third millennium BCE—and was followed by Minoan Linear A and Mycenaean Linear B.[††] Although the development of these writing systems were likely in response to economic needs, it is unlikely that writing was independently discovered without knowledge of Mesopotamian or Egyptian systems (Olivier 1986). The innovativeness of the script notwithstanding—Cretan writing introduced a remarkably uncomplicated syllabulary—the Cretan writing family disappeared with the decline of Mycenaean society (ancient Greek civilization ultimately adopted the Phoenician alphabet).

[**]Indeed, it is conventional to refer to Phoenician inscriptions dated prior to 1050 BCE as Proto-Canaanite (Healey 1990).

[††]Although the invention of Linear A and Linear B is attributed to the Minoans and Mycenaeans, respectively, their use was more widespread across the Bronze Age Aegean, with evidence of Linear A found on the Greek mainland, and large archives of Linear B found in Knossos, on Crete.