THE FRACTURED-LAND HYPOTHESIS*

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Patterns of state formation have crucial implications for comparative economic development. Diamond (1997) famously argued that "fractured land" was responsible for China's tendency toward political unification and Europe's protracted polycentrism. We build a dynamic model with granular geographical information in terms of topographical features and the location of productive agricultural land to quantitatively gauge the effects of fractured land on state formation in Eurasia. We find that topography alone is sufficient but not necessary to explain polycentrism in Europe and unification in China. Differences in land productivity, in particular the existence of a core region of high land productivity in northern China, deliver the same result. We discuss how our results map into observed historical outcomes, assess how robust our findings are, and analyze the differences between theory and data in Africa and the Americas. *JEL Codes:* H56, N40, P48.

Here begins our tale. The empire, long divided, must unite; long united, must divide. Thus it has ever been.

—Romance of the Three Kingdoms, chapter 1

I. Introduction

The economic rise of Western Europe is often attributed to its polycentric state system (Jones 2003; Mokyr 2016; Scheidel 2019).

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In this reading of the historical record, the European state system (i) fostered intellectual pluralism, which made a competitive market for ideas possible (and, with it, the Scientific and Industrial Revolutions); and (ii) created incentives for institutional innovation and incremental investment in state capacity. Correspondingly, many explanations of China's failure to achieve sustained economic growth focus on its long history as a centralized empire and the barriers to riches that such centralization induced. But what factors account for the prevalence of political polycentrism in Europe and the prominence of political centralization in China?

Researchers have proposed numerous mechanisms for the divergence in state systems across the two extremes of Eurasia. A popular mechanism, made famous by Diamond (1997, 1998), argues that "fractured land," such as mountain barriers, dense forests, indented coastlines, and rugged terrain, impeded the development of large empires in Europe compared with other parts of Eurasia.

The fractured-land hypothesis is not without its critics. Hoffman (2015) points out that China is in fact more mountainous than Europe. Peter Turchin and Tanner Greer have advanced similar arguments.[1] Turchin goes so far as to claim that it is not Europe's fragmentation that needs explanation but China's precocious and persistent unification. The fractured-land hypothesis has also been challenged for being static and overly deterministic. Hui (2005, 1) contests the idea that China was "destined to have authoritarian rule under a unified empire," while contending that Europe's political fragmentation was a highly contingent outcome. After all, China has not always been unified. As the opening lines of *Romance of the Three Kingdoms* remind us, China has experienced long periods of fragmentation throughout its history. Besides, the degree of fragmentation in Europe has varied over time.[2]

1. See http://peterturchin.com/cliodynamica/why-europe-is-not-china/ and https://scholars-stage.org/geography-and-chinese-history-the-fractured-land-hypothesis/.

2. There is a question about how we measure political fragmentation before the rise of the modern nation-state. Can we consider the Holy Roman Empire as a unified polity? Under Otto I (r. 962–973, all dates are CE unless otherwise noted), perhaps yes. Under Francis I (r. 1745–1765), most likely no. For operational purposes, and following the Weberian tradition, we call a "polity" or "state" an organization that keeps a quasi-monopoly of violence over a fixed territory (Weber 1972; Tilly 1990).

This article has two goals. First, we provide a quantitative investigation of the fractured-land hypothesis. We gauge why China became a large state early in history, whereas Europe experienced protracted polycentrism, by modeling the dynamic process of state building and exploring how fractured land shaped interstate competition in nonlinear ways. Second, we study state formation more generally. Using rich data on topography, climate, and land productivity, we simulate this model for the whole world, including Africa and the Americas, at a fine grid cell geographical level and look at the resulting probability distributions of political structures.

Inspired by Crafts (1977) and Turchin et al. (2013), we focus on pattern predictions rather than replicating specific outcomes. We report probability distributions over outcomes because history is contingent. An independent event could interact with existing conditions to trigger unanticipated consequences. Without that event, history may develop in a different direction. Our model allows for contingency in the outbreak and outcome of wars. Thus, our simulations are random, but with probabilities assigned by structural conditions. If and when a state emerges to dominate its neighbors is neither fluke nor destiny but a balance of structure and contingency. Our model does not aim to capture the precise borders of specific countries—which are the product of chance events—but it does aim to generate patterns in border formation that correspond to what we observe historically.

We find that fractured land provides a robust explanation for the political divergence observed at the two ends of Eurasia: a unified China and a polycentric Europe. Our model allows us to distinguish between two versions of the fractured-land hypothesis. First, in a narrow sense, scholars have equated fractured land with mountainous and rugged topography. Second, a broader definition considers the location of productive agricultural land.

We document that topography alone is sufficient but not necessary to explain polycentrism in Europe and unification in China. The location of Europe's mountain ranges ensured that several distinct geographical cores of equal size could provide the nuclei for future European states. In contrast, China was dominated by a single vast plain between the Yangtze and the Yellow Rivers. But the presence of a dominant core region of high land productivity in China—in the form of the North China Plain—and the lack thereof in Europe can also explain political unification in China and division in Europe.

Only when we neutralize the effects of fractured land in the broad sense do Europe and China cease to move at different paces toward political unification. Thus, geographical features that go beyond ruggedness are crucial to understanding why China unified and Europe remained polycentric. Our analysis highlights the importance of having core geographical regions of high land productivity unbroken by major mountain, desert, or sea barriers.

Importantly, we establish that fractured land can explain why Europe was fragmented into medium-sized states rather than a large number of tiny and fragile polities as in Southeast Asia. Researchers have argued that this configuration of medium-sized polities played a critical role in developing European institutions. For instance, Mokyr (2016) has emphasized how a politically fragmented Europe fostered a competitive "market for ideas" that led to the intellectual milieu that made the Industrial Revolution possible. In other words, polycentrism can set up the preconditions required for the technological change highlighted in Galor and Weil (2000) and Galor (2011). Scheidel (2019) stresses the importance of fragmentation for preventing innovation from being shut down, while highlighting the importance of military competition in generating institutional innovation.

In comparison, a centralized empire like China could more easily suppress ideas that challenged the status quo through many channels, such as the civil service exam that dominated elite selection (Lin 1995), the limits to the development of "useful knowledge" (Mokyr 2016), or the prevailing patterns of social cooperation (Greif and Tabellini 2017). Jami (2012, 389) has even talked about "the continued imperial monopoly of 'science as action'." Thus, political centralization might account for the "Needham paradox" of why China did not experience an industrial revolution despite having most of the preconditions that existed in Great Britain in the eighteenth century.[3] A critical insight of this interpretation is that the costs and benefits of China's state system varied with the overall level of technology. Civil service examinations based on the Confucian classics can create an efficient bureaucracy to run a preindustrial society based on extensive Smithian division of labor, but it cannot spawn a scientific revolution.

We assess how our quantitative results depend on the assumptions and calibration of the model through an extensive

3. Mokyr (2016, chap. 16) reviews other proposed explanations of the Needham paradox.

battery of robustness tests. These tests confirm the key role of fractured land in the broad sense.

Next we identify those dimensions where the simplest fractured-land hypothesis needs improvement. We discuss how the model misses the slow growth of a state system in Africa and the Americas and use the model as a measurement device to suggest possible channels (e.g., the disease environment in Africa, the slow diffusion of maize in the Americas) that can reconcile theory and data.

Our dynamic model of state building is also of methodological interest because it would be easy to extend it to incorporate other factors—such as religious, linguistic, genetic, and ethnic diversity or technological and climatic change—that have played a role in state formation. Kung et al. (2022) examine the link between the timing of the adoption of agriculture and the emergence of the earliest states in China. Arbatli et al. (2020) and Spolaore and Wacziarg (2016) have documented the importance of diversity for the frequency of intrasocietal conflicts. Ashraf and Galor (2013) suggest that greater genetic diversity in Europe than in China may drive polycentricity. Conversely, the standardization of the Chinese characters by Qin Shi Huang has been a unifying force throughout China's history. Olsson and Hansson (2011) suggest that a long history of statehood is associated with less ethnolinguistic fractionalization.

Our model ignores the role of improvement in military technology through interstate competition highlighted by Hoffman (2015). According to Hoffman, a political-military tournament eradicated polities that could not compete and accelerated military and political innovation through learning-by-doing. Our results show that this is not necessary to account for the comparative political structures of Europe and China. In a richer model, the political-military tournament could complement fractured land.

Our analysis contributes to several literatures. First, we build on Turchin et al. (2013), who pioneered using quantitative simulations to understand the causal link between geography and state fragmentation. However, both our questions and findings differ. Turchin et al. (2013) focus on the diffusion of cultural traits and military technology. They argue that the intensification of warfare—a process influenced by proximity to the Eurasian steppe and antagonistic relations between nomads and settled agriculturalists—selected for ultrasocial traits and large-scale states by pressuring premodern polities to strengthen and invest in state capacity. In comparison, we focus on the systematic differences in the size and pattern of state formation and offer a quantitative account of Europe's polycentricity.

Second, we complement a long-standing literature that attributes the rise of Western Europe to its multistate system by investigating the causes of Europe's political fragmentation. Without being exhaustive, the literature includes Hume (1752), Montesquieu (1989), Pirenne (1925), Hicks (1969), Baechler (1975), Jones (2003), Rosenberg and Birdzell (1986), Cowen (1990), Tilly (1990), Mokyr (2007), Karayalçin (2008), Chu (2010), Olsson and Hansson (2011), Voigtländer and Voth (2013a), and Lagerlöf (2014).

Third, we add to the literature on state formation in China and Europe. One strand emphasizes the importance of the threat from the steppe in Chinese state development (Lattimore 1940; Huang 1988; Barfield 1989; Turchin 2009; Bai and Kung 2011; Chen 2015; Ko, Koyama, and Sng 2018). Other scholars contrast the greater absolutist power of Chinese rulers relative to their European counterparts (Fukuyama 2011; Jia, Roland, and Xie 2021). Another strand considers military competition in European state formation (Parker 1988; Tilly 1990; Voigtländer and Voth 2013b; Gennaioli and Voth 2015; Becker et al. 2020), or the relative dearth of interstate conflicts as a hindrance to the rise of representative government in China (Dincecco and Wang 2018). Finally, the literature on the size of nations pioneered by Alesina and Spolaore (1997, 2003, 2005) relates state size to conflict and trade.

Fourth, our study is related to work that investigates the relationship between agricultural productivity, state formation, and conflict (Mayshar, Moav, and Neeman 2017; Mayshar, Moav, and Pascali 2022). For instance, Iyigun, Nunn, and Qian (2017) examine the link between a permanent rise in agricultural productivity and conflict between 1400 and 1900, whereas Acharya and Lee (2018) develop a model in which economic development generates rents that lead to the formation of territorial states.

Empirically, Kitamura and Lagerlöf (2020) find that mountain ranges and rivers influence the location of political boundaries in Europe and the Near East. Other empirical tests of other parts of Diamond's hypothesis include Turchin, Adams, and Hall (2006), Laitin, Moortgat, and Robinson (2012), and Bologna Pavlik and Young (2019).

Last, we contribute to the literature on the relationship between geography and economic and political outcomes.

Geography can shape economic outcomes directly via access to trade routes or vulnerability to disease vectors (Sachs 2001) or indirectly via its effect on ethnic fragmentation (Ahlerup and Olsson 2012; Michalopoulos 2012) or political institutions and social norms (Acemoglu, Johnson, and Robinson 2001; Roland 2020). We provide an example of the latter phenomenon: geography mattered because it gave rise to a centralized state in China and polycentrism in Europe.

The remainder of the article is organized as follows. Section II outlines the fractured-land hypothesis. Section III builds a model of interstate competition that integrates geographical characteristics. Section IV calibrates the model, and Section V presents the quantitative results. Section VI discusses some aspects of Chinese and European history in light of our model. Section VII looks at the implications of our model for Africa and the Americas. Section VIII discusses extensions of the model. Section IX concludes.

II. Fractured Land?

Researchers have long argued that early states only formed when three conditions were satisfied. First, there was a sufficiently large area of productive agricultural land to generate the food surplus required to feed and clothe a political elite and its bureaucracy. Second, this food output needed to be appropriable (Mayshar, Moav, and Pascali 2022). Third, there were geographical boundaries that made it possible to coerce the transfer of food surpluses to the political elite (Carneiro 1970). Indeed, agrarian states struggled to project power into rugged, hilly, or mountainous lands where coercion was too costly (Mayshar, Moav, and Neeman 2017; Scott 2017).

Based on these ideas, geographers built the concept of a geographical core to describe the nucleus of successful states (Whittlesey 1944; Pounds and Ball 1964; Hechter and Brustein 1980). The cores of most early states were centered around self-contained regions that had fertile agricultural land and good transport connections and were defensible from external invasion. Conversely, geographical cores that satisfied the above conditions experienced earlier and faster state formation.

Many authors (e.g., Hume 1752; Kennedy 1987; Jones 2003) have postulated that since Europe's topographical peculiarities were less favorable to the formation of early states, the posterior

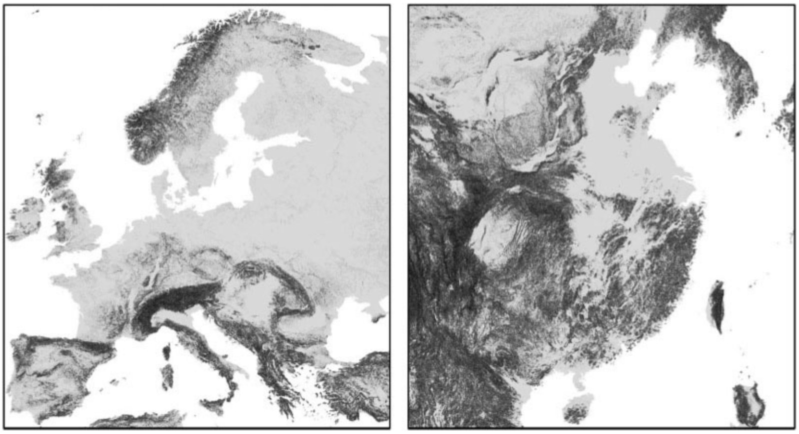


FIGURE I
Ruggedness in Europe and China Proper

history of the continent was plagued by fragmentation. The most influential formulation of this idea is the fractured-land hypothesis of Diamond (1997, 1998). Diamond makes three observations: (i) China was not threatened by the presence of large islands off its mainland (Taiwan and Hainan were too small and Japan too far away); (ii) the Chinese coastline was smooth compared to the European coastline; and (iii) most important, unlike Europe, China was not fractured by high mountains and dense forests.

The claims of the fractured-land hypothesis have come under heavy criticism. Hoffman (2015, 109–112) observes that China is significantly more mountainous than Europe (see Figure I). Over 37% of modern China is defined as mountainous compared with little more than 10% of Europe. Even if one restricts attention to so-called China proper, that is, the traditionally agrarian part of China south of the Great Wall and east of the Tibetan plateau, more than 33% is elevated above 1,000 m compared with only around 6% in Europe.

However, the crucial factor might not be the ruggedness of the terrain at large but the location of either continent's mountainous regions. Beyond the total amount of ruggedness, Figure I illustrates that mountain ranges at or near the center of Western Europe play an important role in separating Italy and Spain from

France and making core regions of central Europe (Switzerland, Austria) difficult to conquer.[4]

Consequently, Europe comprises several cores: the British Isles, Scandinavia, the Iberian peninsula, and the Italian peninsula. France, the Low Countries, Germany, and Poland span what is known as the northern European Plain. The easternmost part of this plain borders the Russian forest in the northeast, the steppe in the east, and the Carpathian Mountains in the south; it corresponds loosely to modern Poland and the territory controlled by the Polish-Lithuanian Commonwealth in the early modern period. The central part of the plain corresponds to modern Germany, and France occupies the western part of the plain.

Meanwhile, the most mountainous regions in China are in the south and west, and they do not intersect the Central Plain in the north that historically played a crucial role in China's early unification. The Central Plain, centered on the Yellow River basin, is blocked from Korea in the northeast by the Changbai Mountains and the Taihang Mountains in the west. The plain itself is flat, except for the Taishan Mountains in Shandong and the Dabie Mountains of Anhui. Southern China is more mountainous. The Yunnan-Guizhou plateau has a particularly high elevation. Mountains and dense forests divided Lingnan and Yunnan from Vietnam and Burma, respectively. Diamond (1997, 414) himself emphasizes the existence of a large core region capable of dominating the other regions in China:

> China's heartland is bound together from east to west by two long navigable river systems in rich alluvial valleys (the Yangtze and Yellow Rivers), and it is joined from north to south by relatively easy connections between these two river systems (eventually linked by canals). As a result, China very early became dominated by two huge geographic core areas of high productivity, themselves only weakly separated from each other and eventually fused into a single core.

The previous arguments are qualitative. As such, they cannot be assessed quantitatively (e.g., how rough must the terrain be to make a difference for political unification?) or used to measure

4. During World War II, Switzerland planned a retreat to a "réduit national" in the central part of Switzerland in case of a German invasion. The 12 Battles of the Isonzo during World War I between the Italian and Austro-Hungarian armies suggest that taking over such a redoubt is extremely costly, even for a modern army.

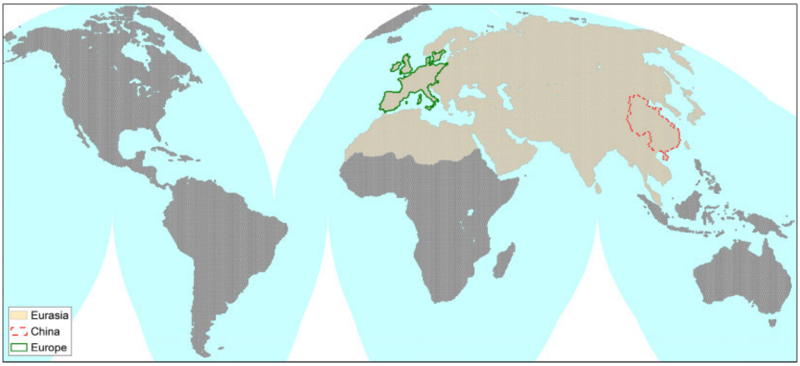


FIGURE II

The World in Hexagons

the role of structure versus contingency in the observed outcomes (perhaps China's early leaders were luckier or better than their European counterparts?).

Can we bring quantitative data and a simple model of state formation and competition to the table and formally evaluate the fractured-land hypothesis and the range of distributions of probability that it can span? The following section introduces such a model.

III. MODEL

First, we describe how we divide the world into hexagonal cells. Second, we measure each cell's geographical, climatic, and resource availability characteristics. Third, we highlight Eurasia, the region we focus on for our baseline exercises. Fourth, we present a formal model of how polities evolve through conflict and secession by gaining or losing cells.

III.A. The Geographical Space

Our first step is to divide the Earth's landmass (excluding Antarctica, which is largely uninhabited even today) into 65,641 hexagonal cells of radius 28 km, each potentially capable of sustaining a polity and allowing armies to pass through it (Figure II). This radius corresponds to the distance a healthy adult travels by

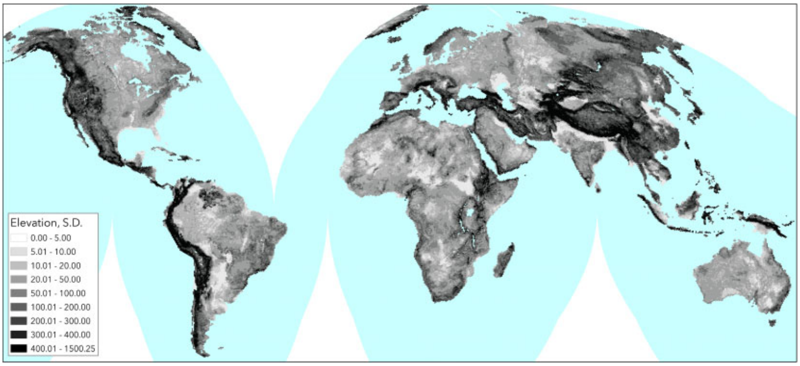


FIGURE III

Terrain Ruggedness (Standard Deviation of Elevation)

foot per day on flat terrain.[5] As a result, a 28-km hexagon roughly represents the surface that the simplest polities can monitor and defend with rudimentary Bronze Age technologies. Section III.D explains why we fill our geographical space with hexagons instead of other shapes.

III.B. Geographical, Climatic, and Resource Characteristics

Our second step is to measure, in each cell, a vector of geography and climate characteristics, $\mathbf{x}$, and historical resource availability, y.

1. *Geography and Climate.* We consider terrain ruggedness, x_{rugged}. We measure ruggedness by the standard deviation of elevation in each cell, an index of topographic heterogeneity computed using the CGIAR-CSI data set (see Online Appendix A.4). Plains and plateaus score low on this measure, while mountain ranges and valleys score high (Nunn and Puga 2012). Figure III depicts x_{rugged}. There, we can see the high ruggedness of the Alps, the Balkans, the Caucasus, and the Himalayas, and the low ruggedness of the northern European Plain, much of Russia, the Indian subcontinent, and north China.

5. This distance assumes a seven-hour march at a leisurely pace of 4 km/h. In Roman times, recruits were required to complete about 30 km in six hours in loaded marches. In the U.S. Army, the average march rate for foot soldiers is estimated to be between 20 to 30 km per day. See Headquarters, Department of the Army (2017, figs. 1 and 2).

Second, we identify cells in hot and cold climates using the WorldClim 1.4 historical data on annual average monthly maximum and minimum temperatures during the mid-Holocene epoch (4000 BCE), which was relatively warm in historical context (Hijmans et al. 2015) (in the Online Appendix, as a robustness check, we rerun our simulations using climatic data from the 1960s). Hot and cold climates hinder the movement of large armies because exposure to extreme temperatures induces physiological stress that can impair body functions and cause death (Department of the Army 2016; Sanford, Pottinger, and Jong 2017) and change the behavior of insect vectors (Bellone and Failloux 2020).

We set $x_{hot} = \log(t_{\max} - 21)$ for tropical cells with an annual average maximum temperature $t_{\max}$ of 22°C or above, and $x_{hot} = 0$ otherwise.[6] We set $x_{cold} = \log(9 - t_{min})$ if the annual average minimum temperature t_{min} of a cell is below 8°C, and $x_{cold} = 0$ otherwise.[7] In Figure IV, cells with a minimum temperature below 8°C are depicted in gray. Most of them are in the northern frontier of our study area or mountainous regions (the Himalayas, the Alps, and the Caucasus). Cells with a maximum temperature above 22°C appear in red (gray; color version available online). Most of those are in the Indian subcontinent and Southeast Asia.

We include these three geographical variables in the vector $\mathbf{x} = \{x_{rugged}, x_{hot}, x_{cold}\}$. The vector $\mathbf{x}$ could be enriched with further geographical, climatic, cultural, and technological variables. We return to this point later.

2. *Resource Availability.* Our primary measure of historical resource availability is drawn from the Food and Agriculture Organization's Global Agro-Ecological Zones database, version 4 (GAEZ v4, FAO 2021). The database divides the world's land surface into grid cells of size 5' latitude/longitude (approximately 75 km^2). The data set publishes the hypothetical annual yields (in tons per ha) of different crops for each grid cell. We focus on cereal grains, which formed the basis of taxation in early states (Childe 1936; Carneiro 1970; Mayshar, Moav, and Neeman 2017).

6. According to the Wet Bulb Globe Temperature (WBGT) index, the most widely used measure of heat stress risk, a temperature of 22°C is equivalent to a WBGT of 25°C (assuming a relative humidity of 85%, a humidity level often observed in the tropics). Beyond this level, it is advisable to adjust outdoor activities accordingly (Surgeon General 2008; Department of the Army 2016).

7. A temperature of 8°C or below is defined as frigid under European Union regulations (see Council of Europe 2020).

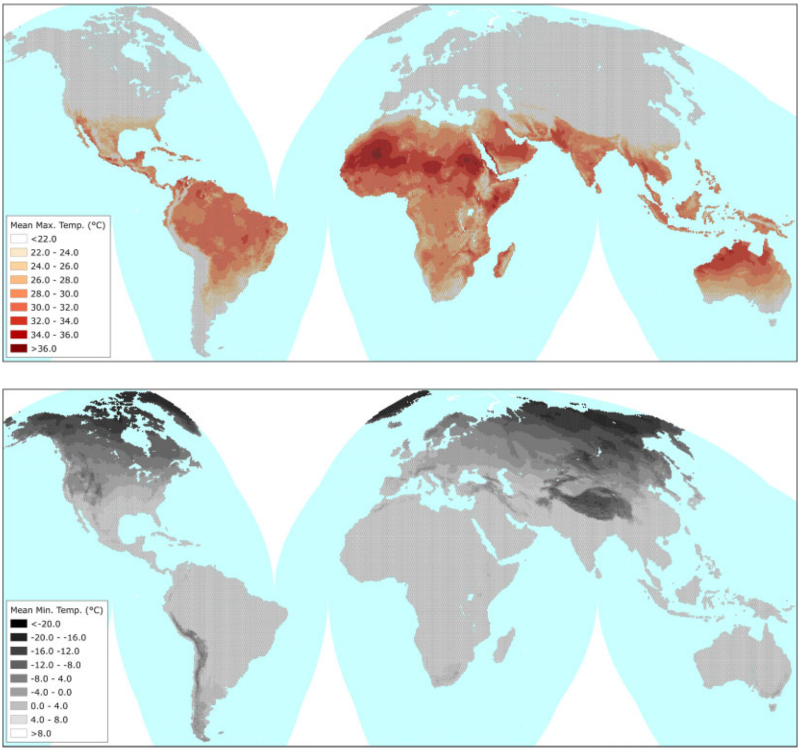


FIGURE IV

Annual Average Maximum and Minimum Monthly Temperatures

Following Galor and Özak (2016), for each of our cells, we generate its highest attainable yield, y_{GAEZ}, in calories by (i) extracting the hypothetical yield of every cereal that existed in the continent where the cell is located before the Columbian Exchange, (ii) converting the yields into calories, and (iii) selecting the highest calorie-yielding cereal for the cell. Figure V shows the result of this exercise, with high densities in the Italian peninsula, India, and China and low densities in Russia, the Arabian peninsula, and inner Asia. In our model, productivity will determine the ability of the polity that controls it to mobilize resources for military purposes.

GAEZ v4 yields might miss that agricultural states developed earlier along river corridors rich in alluvial soil, which is

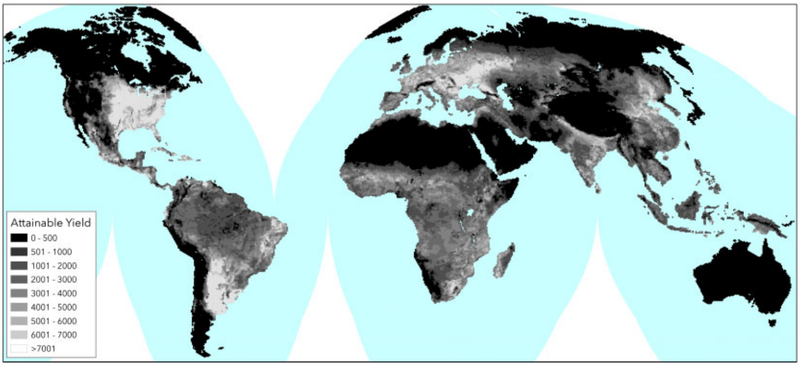


FIGURE V

Attainable Caloric Yield Based on Pre-Columbian Cereals (GAEZ v4)

naturally irrigated by regular floods and not covered by thick forests (Scott 2017). This soil is easy to work on with primitive tools and has the highest productivity among different soils (Fried 1967; Driessen and Deckers 2001). Indeed, the alluvium-rich regions of Mesopotamia (Tigris River), Egypt (Nile), the Indus Valley (Indus), and north China (Yellow River) were comparatively advanced in the exploitation of resources in 1000 BCE. To account for this phenomenon, we measure the percentage of alluvial soil in every cell based on the FAO Digital Soil Map of the World (DSMW) and denote it as r.

In our baseline model, we set $y_0 = r \cdot y_{GAEZ}$ at $t = 0$ and $y_{500} = y_{GAEZ}$ at $t = 500$, with the assumption that y grows at a constant rate between $t = 0$ and $t = 500$ for every cell. Later, as a robustness check, we measure r using estimates from the KK10 Anthropogenic Land Cover Change database. Separately, we will check if ignoring initial developmental differences by setting $r = 1$ affects our results. We also show that our findings are robust to the use of alternative measures of resource availability, including agricultural productivity (Ramankutty et al. 2002) and historical population estimates (Klein Goldewijk et al. 2017).

III.C. Eurasia, China, and Europe

Our baseline exercises report results from the 28,822 cells that include most of Europe, North Africa, the Middle East, continental Asia, and Japan (cells with brown, red, and green borders in Figure II). This area is often called Eurasia. We consider this space because intense political, trade, and cultural contacts across Eurasia took off after the beginning of the Iron Age (c. 1200–1000 BCE).[8]

As Hodgson (1954, 716) put it, our area of interest corresponds to:

> the various lands of urbanized, literate, civilization in the Eastern Hemisphere, in a continuous zone from the Atlantic to the Pacific, [that] have been in commercial and commonly in intellectual contact with each other, mediately or immediately.

What phenomena did Hodgson have in mind? For instance, the Roman Empire and Han China traded indirectly and knew of each other's existence. A Roman delegation visited China in 166, and Chinese historian Yu Huan wrote a description of the Roman Empire—named *Daqin*—sometime between 239 and 265. Roman commerce with the Indian subcontinent was lively, with the tariffs on it accounting for as much as one-third of the empire's revenue (McLaughlin 2010). Roman coins made their way to Japan, and Buddhism was present in Rome.

Significantly, Eurasia has accumulated a large share of the world's population for most of history and has been the origin of many technological developments and social and political forms (Kremer 1993; Diamond 1997). Understanding the dynamics of the political forms that evolved in this space is critical for understanding global economic history.

Within the 28,822 Eurasian cells, 1,415 cells cover "China," defined as the lands south of the Great Wall (cells enclosed by red dash lines in Figure II). This region corresponds to the historical core of Imperial China until the Qing expansion to the west (Perdue 2005). Another 1,285 cells, enclosed by green lines in Figure II, are in (Western) "Europe," defined as the lands west of the line running from St. Petersburg to Trieste and delimiting the region of the European marriage pattern (Hajnal 1965). Many historians have used this marriage pattern as a proxy for close cultural and social similarities of the loosely called "Western world."

Calling a cell "Eurasia," "China," or "Europe" has no implications for the model. It is just a label to build the statistics that summarize the outcomes from our simulations.

8. The Iron Age starts at slightly different times over Eurasia, with the earliest transitions in the Middle East and the latest in northern Europe. For compactness of exposition, we ignore such heterogeneity.

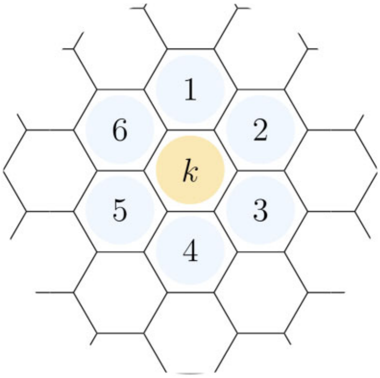


FIGURE VI
Cell k and Adjacent Cells

III.D. Evolution of Polities

We take the hexagonal cells defined above, with their geographical, climatic, and resource availability characteristics, and consider how polities evolve in them over discrete periods $t = 0, 1, 2, \ldots$. At $t = 0$, each cell begins as an independent polity. Thus, the space is filled by a hexagonal tiling, with each cell bordering adjacent cells 1–6 (Figure VI). This setup is analogous to the hexagonal close-packing (HCP) system in crystallography. We consider a regular tiling to impose ex ante homogeneity on the geographical shapes of polities. We prefer a hexagonal tiling to the other two regular tilings of the Euclidean plane because its vertex configuration is simpler than that of a triangular or square tiling. This simplicity better reflects the frontiers that most polities have had over time in our reading of the historical data.

Over time, some polities expand by conquering neighboring cells, while others lose control of cells. We describe now how the conquest and the secession of cells operate.

1. *Conquest across Land.* In each period, a cell k finds itself in a border conflict with one of its adjacent cells with probability $\alpha \cdot y_k$, where $\alpha > 0$. For simplicity, we assume that when a cell experiences a border conflict, only one of its six borders is affected. Relaxing this assumption is straightforward, but it makes the model less transparent with little additional insight.

The probability of a border conflict depending on the productivity of the cell embodies the notion that more productive cells are more tempting for neighbors to exploit. This assumption is motivated by the Hobbesian thesis that the desire for gain, safety, and reputation was a major driver of conflict, and that consequently, highly productive lands are more likely to experience war.[9] This idea is also consistent with Malthusian arguments, which see warfare as an outcome of population pressure.

Social scientific explanations of conflict all face the so-called Hicks paradox. As Hicks (1932) first observed, it is hard to see how rational agents might fail to reach an efficient agreement that avoids a conflict and the subsequent deadweight loss. The literature has highlighted commitment problems due to time inconsistency as a fundamental obstacle to the peaceful resolution of political disputes (Fearon 1995; Acemoglu 2003; Monteiro and Debs 2020). The anarchic nature of the international environment and the absence of a higher authority to adjudicate violations of an agreement imply that states often have the incentive to undertake preemptive strikes, especially if they have more to lose. In Online Appendix B, we present two empirical checks to show that our choice of a higher probability of border conflict in richer cells is consistent with historical data; later in Section V.C, we conduct robustness tests based on alternative conflict mechanisms to verify that the assumption is not critical to the findings.

Most cells in our geographical space are inland. Conditional on inland cell k encountering a border conflict, the probability that its adversary is cell $\bar{k} \in \{1, 2, 3, 4, 5, 6\}$ is:

$$\frac{y_{\bar{k}}}{y_1 + y_2 + y_3 + y_4 + y_5 + y_6},$$

where $y_1, \ldots, y_6$ are the respective productivities of the six adjacent cells (see next section for the case where the cell has sea frontiers). This assumption follows the idea explained above: two highly productive cells are more likely to be tempted into a conflict with each other than one low- and one high-productivity cell.

9. Studies of early states also suggest that the main objective of war was resources, including population and properties. States more eagerly sought control of productive lands than poor terrains. Military expeditions were expensive, and soldiers would not fight well if they expected meager rewards even in victory (Scott 2017).

A conflict between cells has two interpretations. If a different polity controls each cell (as occurs, for sure, in $t = 0$), we consider this conflict a war. The victor of this war, to be determined in the next paragraph, annexes the losing cell. If the cells are controlled by the same polity (as may occur after previous annexations), we think about this conflict as a political struggle for resources in the polity. The unified government will resolve the conflict by reallocating resources or through other policies in a manner that is inconsequential to our model.

Victory in a war between two polities is given by a contest function that depends on (i) the aggregate productivity of the polities in conflict, and (ii) the geographical characteristics $\mathbf{x}$ of the cells in conflict. Specifically, if a war takes place between polities i and j, which controlled cells k and $\bar{k}$, respectively, polity i wins with probability:

$$\pi_i = \frac{Y_{i,t}}{(Y_{i,t} + Y_{j,t}) \times (1 + \max\{\Theta \cdot \mathbf{x}_k, \Theta \cdot \mathbf{x}_{\bar{k}}\})}, \tag{1}$$

where $Y_{i,t}$ ($Y_{j,t}$) denotes the sum of productivities of all cells controlled by polity i (j) at period t; $\mathbf{x}_k$ ($\mathbf{x}_{\bar{k}}$) denotes the geographical characteristics of cell k ($\bar{k}$); Θ is a parameter vector that controls the weights of each geographical and climatic characteristic, and $\Theta = \{\theta_{rugged}, \theta_{hot}, \theta_{cold}\}$.

The contest function (1) reflects two forces. First, more productive polities win more often, but the vagaries of war might bring victory to the weaker side. This may be due to factors we do not model, such as exceptional military leadership or strong state capability. Second, the relevant variable is the sum of the productivities of the cells of a polity, not the average productivity. Estonia in 1939 had a higher income per capita than the Soviet Union (Norkus 2019), but due to the difference in size, it could do almost nothing to resist annexation.

Second, the geographical and climatic variables make conquest harder or easier depending on the values of Θ, which mediate the probability of victory. The probability of the war ending with no victor and thus no annexation is:

$$1 - \pi_i - \pi_j = 1 - \frac{1}{1 + \max\{\Theta \cdot \mathbf{x}_k, \Theta \cdot \mathbf{x}_{\bar{k}}\}},$$

which is strictly positive and is increasing in $\max\{\Theta \cdot \mathbf{x}_k, \Theta \cdot \mathbf{x}_{\bar{k}}\}$. If $\theta_{rugged} \gg 0$ (i.e., conquering very rough terrain is daunting, as scores of armies over millennia have discovered in Afghanistan), the probability of no annexation after a war that involves a cell with rough terrain is high.

Two secondary assumptions deserve further discussion. First, we assume that only the cell of the losing polity in the conflict is annexed, not the whole polity. While complete conquest sometimes occurs in history (e.g., the fall of the Sasanian Empire to the Arab invaders between 642 and 651), most conflicts end up by trading small pieces of land (recall the dynastic struggles that plagued Europe during the early modern period and the subsequent small exchanges of territories).

Second, because a polity may share borders with multiple polities, it may face simultaneous wars with several of them. We assume that a polity fighting more than one war will channel its resources proportionately according to the strengths of its adversaries. Otherwise, these wars are independent of each other. A good example of simultaneous struggles, albeit a little later than the period for which our model is most appropriate, is the wars of Charles V, Holy Roman Emperor (r. 1519–1556), against his many enemies. The emperor always carefully weighed where to allocate his resources. His strategic choices were lamented by Francis I of France (r. 1515–1547) during his captivity in Madrid, but thoroughly enjoyed by Elector John of Saxony (r. 1525–1532) while organizing the Schmalkaldic League.

We could generalize the previous two assumptions by allowing the annexation of larger parts (or the totality) of a polity and the correlation of wars across frontiers. In our example above, Francis I and Suleiman the Magnificent (r. 1520–1566) signed an improbable alliance in 1536 against Charles V. However, these generalizations require the introduction of many free parameters, and we prefer to keep our model tightly parameterized. We could also introduce strategic considerations (e.g., alliances and strategic conquests). Section VI discusses these issues.

2. *Conquest across the Sea.* Our model allows for conquest to take place across the sea. For our period of study (1000 BCE to 1500, see Section IV for an explanation), invasions via the sea occasionally took place (e.g., the Roman conquest of Britain). Still, they were much less common than conquest over land for at least two reasons. First, ships were not stout enough for long-distance power projection across rough seas until the early fifteenth

century, which saw the emergence of bigger, full-rigged ships with three masts (Clowes 1932; Vance 2021). Second, until the development of better boats and more powerful guns and the synthesis of the two into a new form of assault employed by the European powers against the non-Europeans during the Age of Sail, naval battles were essentially infantry battles fought on water or beach.[10] This setting disadvantaged the aggressor, whose capacity to conquer was constrained by the number of ships it could gather that could survive the journey to the opposite shore (Padfield 1979). While extensive maritime trade existed, there were no navies to dominate the oceans until the sixteenth century. Historically, no major naval battles were fought in the Indian, the Pacific, or the Atlantic Oceans before 1500. The exceptions were the straits and the Mediterranean Sea, almost entirely enclosed by land and thus calmer and less dangerous to traverse than other seas. Even an invasion across a narrow strait was militarily risky and logistically challenging (see Koyama, Rahman, and Sng 2021).

We incorporate this "stopping power of water" for military conquest (Mearsheimer 2001, 84) in two ways. First, consider a coastal cell k, which borders $l \in \{1, ...5\}$ cells by land and $6 - l$ by sea. Let L denote the set of cells that border cell k by land, and let S denote the set of cells that lie no more than six cells ($\sim$330 km) from cell k by sea. We assume that conditional on cell k encountering a border conflict, the probability that its adversary is cell $\overline{k}$ is:

$$\frac{y_{\overline{k}}}{\sum_{i \in L} y_i} \cdot \frac{l}{6}, \tag{2}$$

if $\overline{k} \in L$ and:

$$\frac{y_{\overline{k}}}{\sum_{i \in S} y_i} \cdot \frac{6-l}{6} \cdot \alpha_{sea}, \tag{3}$$

if $\overline{k} \in S$. In other words, we do not allow sea conquests in the model over more than $\sim$330 km.[11]

10. For example, the Battle of Sluys in 1344 was one of the largest naval battles of the Middle Ages. It took place at the port of Sluys and was contested by men-at-arms fighting from the platforms of static cogs.

11. This upper limit is wider than the English Channel, the Irish Sea, the Sound, the Bosporus, the Strait of Sicily, the Red Sea, the Palk Strait, the

The parameter $\alpha_{sea} \in [0, 1]$ measures the likelihood of wars arising across the sea relative to land conflicts. For completeness, we will consider both the case $\alpha_{sea} < 1$, that is, conflicts across the sea are less likely to take place than conflicts over land, and the case of $\alpha_{sea} = 1$, that is, conflicts are as likely to take place across the sea as over land.

Second, if a polity controls two or more clusters of cells that are separated by sea, when a war involving one of these clusters breaks out, the polity can mobilize the full resources of that cluster and a fraction $\sigma \in [0, 1]$ of the resources of the other clusters to fight the war. This accounts for the fact that moving large armies and supplies across a sea strait is capital-intensive and depends on factors such as the possession of a large navy or the ability to mobilize a large merchant fleet and the availability of good harbors for loading and unloading. Circumstances such as unpredictable sea weather or changes in wind direction also affect the ability of troops and supplies to arrive promptly (recall the "Protestant Wind" that favored William of Orange's invasion of England in 1688 while keeping James II's fleet in port). Again, for completeness, we will consider both the case $\sigma < 1$ and $\sigma = 1$.

3. *Secession.* To reflect the historical tendency for border regions in large states to seek secession, we allow border cells to secede from the polity they belong to with strictly positive probability in each period. A border cell is one that shares an edge with one or more cells ruled by another polity.

The border cell k's probability of secession is high if (i) the cell has a high $\Theta \cdot \mathbf{x}_k$ (i.e., geographical and climatic characteristics that make secession hard to suppress), (ii) if the parent polity i controls a large number of cells (and is therefore heterogeneous), or (iii) if polity i has a long frontier relative to its interior (which increases the difficulty of monitoring and controlling the population). Specifically, the probability of border cell k seceding

Indonesian Straits, and the Korea and Taiwan Straits—the straits that witnessed sea conquests before 1500. It also allows for conquest through the Mediterranean Sea via island or coast hopping. As Abulafia (2011, loc. 412) puts it: "Conflicts for control of the Mediterranean thus have to be seen as struggles for mastery over its coasts, ports and islands rather than as battles over open spaces."

from polity i is:

$$\beta \times \Theta \cdot \mathbf{x}_k \times \sum_{m}^{65,641} \mathbb{1}_i(m) \times \frac{\sum_m^{65,641}(\mathbb{1}_i(m) \cap \mathbb{1}_B(m))}{\sum_m^{65,641} \mathbb{1}_i(m)}$$

$$= \beta \times \Theta \cdot \mathbf{x}_k \times \sum_{m}^{65,641} (\mathbb{1}_i(m) \cap \mathbb{1}_B(m)), \tag{4}$$

where $\beta > 0$ is a constant determining the likelihood of secession, $\mathbb{1}_i(m) = 1$ if cell m is ruled by polity i and $\mathbb{1}_i(m) = 0$ otherwise, and $\mathbb{1}_B(m) = 1$ if cell m is a border cell and $\mathbb{1}_B(m) = 0$ otherwise.

To simplify, we assume that if a polity is cut into disjoint parts due to war or secession, each part becomes a separate polity. The exception is when the disjoint parts are separated by sea by a distance no further than six cells (Section III.D.2), in which case the polity survives. Geographically divided polities such as Pakistan between 1947 and 1971 seldom live long.

As before, we consider that each cell separates independently from other cells for simplicity. However, since a polity might have several cells sharing edges with other polities, it may suffer the separation of several cells in the same period.

4. *Summary.* As conflicts between polities and unrest in polities occur, states consolidate over time if the probability of secession is not too high. Larger states have access to more resources and hence are likely to consolidate further. However, it is more challenging to conquer some cells than others due to their geographical and climatic characteristics. These features will lead to regular patterns of state formation.

To summarize, the timing of events is as follows:

(i) At $t = 0$, each cell is a separate polity (i.e., zero state consolidation).
(ii) At each t, the probability of conflict breaking out in cell k is $\alpha \cdot y_k$, where $\alpha > 0$ and y_k is the productivity of cell k.
(iii) If cell k encounters a border conflict, only one of its six borders is affected. The conditional probability that its adversary is cell $\bar{k}$ is given by equation (2) if $\bar{k}$ borders k by land, and by equation (3) if $\bar{k}$ is connected to k by sea.
(iv) If there is a conflict between cells controlled by different polities, a war occurs.

(v) In a war between cells k and $\bar{k}$, controlled, respectively, by polity i and polity j, polity i wins and annexes cell $\bar{k}$ with the probability given by the contest function (1).

(vi) A polity may fight no war, one war, or multiple wars in any period. If it fights multiple wars, it splits its resources proportionally according to the resources of its adversaries.

(vii) Cell k secedes from polity i with the probability given by equation (4).

IV. Calibration

To calibrate our model, we need to pick an initial and endpoint of the simulation, a time unit, and the values of seven parameters: α, α_{sea}, σ, θ_{rugged}, θ_{hot}, θ_{cold}, and β.

For the initial and endpoint of the simulation, our baseline exercises gauge whether our model can account for the evolution of the Eurasian polity structure between the beginning of the Iron Age (c. 1200–1000 BCE) and the dawn of the Age of Exploration in the second half of the fifteenth century. Thus, we pick 1000 BCE to 1500. These points give us a total of 2,500 years.[12]

At the start of the Iron Age, Eurasia was nearly entirely fragmented. Even areas where larger polities existed previously, such as the Fertile Crescent, were recovering from the Late Bronze Age collapse: Egypt was transitioning through its third intermediate period, the palace economies of the Aegean had crumbled, and the Kassite dynasty of Babylonia and the Hittite Empire had disappeared (see Drews 1993; Cline 2014). The Shang in China had somewhat progressed toward unification, but the documentary record of the effectiveness of their territorial control is scant (Campbell 2018, chap. 4).

The Age of Exploration quickly integrated the whole world. Juan Sebastián Elcano completed the first circumnavigation of the globe in 1522, only 103 years after the Portuguese started systematically exploring the West African coast. By 1565, the Manila galleons had opened a regular trade route between Europe, Asia, and the Americas.

Our choice of time unit must balance the need for a detailed account of the evolution of political forms and the computational burden. Hence, we pick five years to get 500 simulation periods

12. Later, we discuss the implications of our model for Africa and the Americas during this period.

(2,500 years divided by 5). This time unit is also a reasonable approximation to the median length of many conflicts, which, in the data, have a huge variation.[13]

Fortunately, the values of all parameters in the model, except β, are time independent. They represent the geographical relative attractiveness or difficulties of conquest, which are static properties.[14] Thus, our pick of an initial and end period and a five-year time unit only matters when mapping the lengths of outcomes in the model with the lengths of outcomes in the data.

We can move now to calibrate our seven parameters. Since $\alpha \cdot y_k$ determines the probability of conflict occurring in cell k, we set $\alpha = \frac{1}{y_{\max}}$, where $y_{\max}$ is the productivity of the cell with the most resources in our data set. In such a way, $\alpha \cdot y = 1$ for the cell with the highest value of y and $0 \leqslant \alpha \cdot y \leqslant 1$ for all other cells. We pick $\sigma = 0.33$, based on Dupuy (1979), a well-regarded source among military scholars and historians. Dupuy (1979) uses military history statistics to weight variables that predict war outcomes (these weights are used, for example, to calibrate war games at general staff colleges). We set $\alpha_{sea} = 0.1$ to account for the observation that about 10% of the historical battles listed on Wikipedia were sea battles.[15]

Drawing again from Dupuy (1979), we pick θ_{rugged} so that $\theta_{rugged} \cdot x_{rugged} = 2$ for the cell at the 90th percentile of the ruggedness ranking.[16] At this value, a war between two adversaries of equal strength fighting in this cell will end in a stalemate with a

13. Computing this variance becomes even more challenging once one realizes it is hard to agree on what constitutes a war. Think about the long conflict between the Spanish Empire and the Provinces of the Netherlands (1568–1648): was it one long war or several consecutive ones?

14. We do not model changes in military technology. Although some of those changes could be biased toward one geographical feature, there is not much evidence of this bias in the data (Dupuy 1979).

15. While Wikipedia data might have biases in its coverage, we checked that other sources, such as Phillips and Axelrod (2005), do not have more comprehensive data sets. Fortunately, our robustness exercises document that the model's results do not depend materially on the value of α_{sea}.

16. According to Dupuy (1979), a formula that fits the historical data well is c (combat power) = s (military strength and other factors) $\times$ r (role, either attack or defense) $\times$ w (weather/terrain obstacles), where $r = 1$ for attack, $r = 1.3$ for defense, $w = 1$ for attack, and $w = 1.5$ for defense when obstacles are present. All else equal, this formula implies that the combat power of defense is approximately twice ($1.3 \times 1.5 \approx 2$) that of attack under unfavorable weather/terrain obstacles. This power of defense translates into a $\frac{2}{3}$ probability that the war ends with no conquest. An alternative approach is to incorporate topographical features in the

TABLE I
BASELINE CALIBRATION

Parameter	Value
α	$\frac{1}{y_{\max}}$
α_{sea}	0.1
σ	0.33
θ_{rugged}	$\frac{2}{x_{rugged}=90th\text{ percentile}}$
θ_{hot}	$\frac{2}{x_{hot}=90th\text{ percentile}}$
θ_{cold}	$\frac{2}{x_{cold}=90th\text{ percentile}}$
β	1×10^{-5}

probability of $\frac{2}{3}$. Likewise, we pick θ_{hot} and θ_{cold} so that $\theta_{hot} \cdot x_{hot} = \theta_{cold} \cdot x_{cold} = 2$ for the respective cells at the 90th percentile of the annual average monthly maximum and minimum temperature rankings.

Finally, we set $\beta = 1 \times 10^{-5}$. Given Europe's long coastline compared with China's, European states tend to be noncompact in our simulation. Our low β prevents secession from being the main cause of Europe's fragmentation. At the calibrated β, a polity that comprises Europe's cells would have to annex territories at a rate of 90 cells (approximately the size of two Austrias) every 50 periods (250 years) to compensate for the loss of cells through secession. In comparison, a polity that controls China's cells would only need to annex approximately 22 cells (approximately half the size of Austria) every 50 periods to maintain its territorial size.

Table I summarizes the calibration. We call this the "baseline calibration." We will also have a "preferred specification," with the same parameter values, but we make our model more realistic by adding the roles of rivers, steppes, loess soil, and climate in state formation. Section V will show that both specifications deliver nearly the same quantitative results regarding the speed of state consolidation. But since the preferred specification requires additional discussion, we delay the presentation of its details until Section V.D and focus first on the more parsimonious and easier-to-analyze baseline calibration.

Lanchester equations, a popular set of ordinary differential equations used to compare military forces (see Przemieniecki 2000, chap. 4). Following this strategy, Engel (1954)—using combat data from the battle of Iwo Jima—and Weiss (1966)—using combat data from the U.S. Civil War—also estimate that weather/terrain obstacles roughly double the effectiveness of the defense.

In Section V.C and Online Appendix D, we conduct many sensitivity tests to document that our results are robust not only to changes in the values of the parameters in Table I but also to the use of alternative data sets and modifications to the conflict mechanism.

V. Quantitative Results

We are ready to simulate our model: we divide the world into hexagonal cells, feed in each cell's geographical and climate characteristics and historical resource availability, and draw random paths of conflicts and secession. Because the evolution of the model is stochastic, replicating the idea that history is a mix of structure and contingency, we simulate the model 30 times.[17] Based on this sample, we conduct bootstrap analysis to compute the mean Herfindahl indices of the areas we called "China" and "Europe" and their confidence intervals by drawing a sample of 30 simulations with replacement 10,000 times. Our simulations cover the whole world. But for now, and only for reporting purposes, we focus on the results for Eurasia. We discuss the results on Africa and the Americas in Section VII.

Despite its simplicity (and the omission of many plausible mechanisms of state formation), our model generates patterns of political consolidation that resemble those observed in history. Figure VII, Panel A depicts Eurasia in a representative simulation from our preferred specification in period 50 (i.e., 750 BCE). While nearly every cell is still an independent polity, we start seeing a consolidation of power in northern China resembling the core areas of the Shang and the Zhou dynasties. In comparison, no large polities appear in Europe.

Figure VII, Panel B depicts the same simulation after 300 periods (i.e., 500 CE). In the east, a large polity has unified northern China but has yet to control the southern half fully. In the west, we see polities roughly resembling Spain or France (including a polity very similar to the Kingdom of the Suebi in the northwest of the Iberian peninsula, which existed 409–585). The year 500 is around the time when the Germanic kingdoms that inherited the western Roman Empire were formed. The Indian subcontinent is divided into many polities (with an emerging power in the

17. A short movie with an illustrative simulation can be found alongside the replication data files.

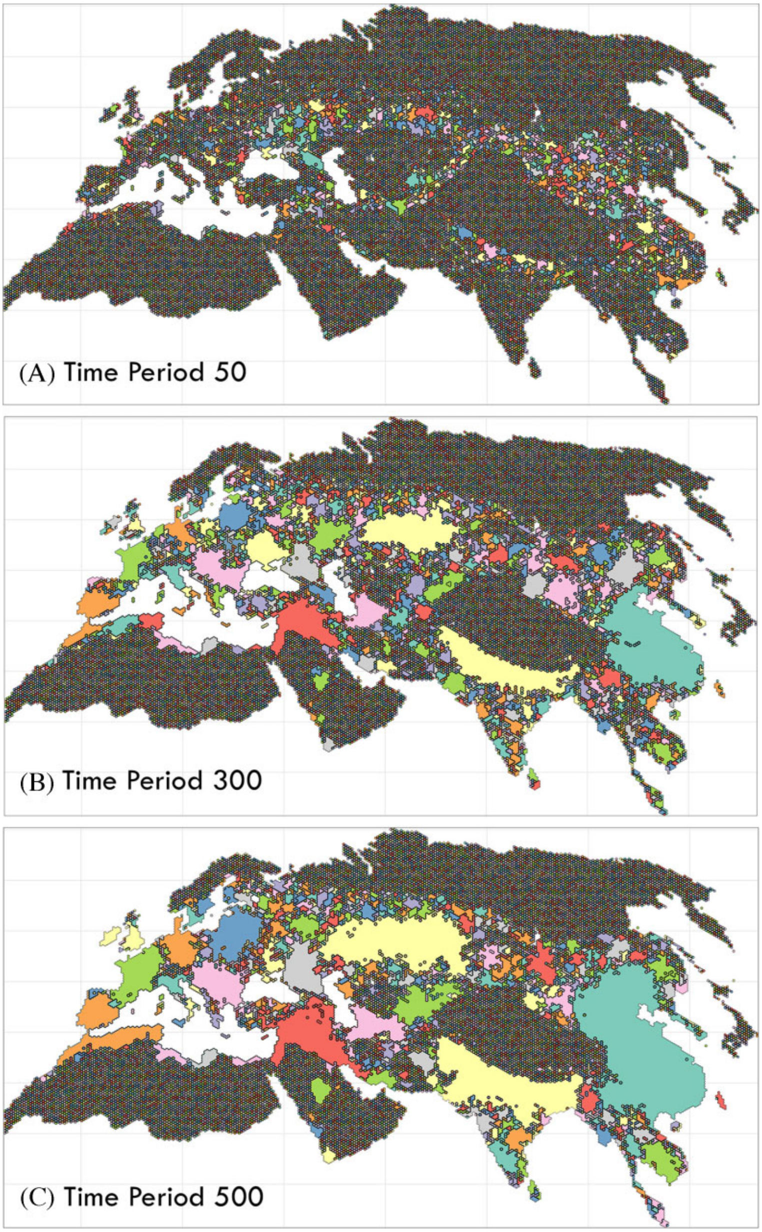


FIGURE VII

One Representative Simulation Run

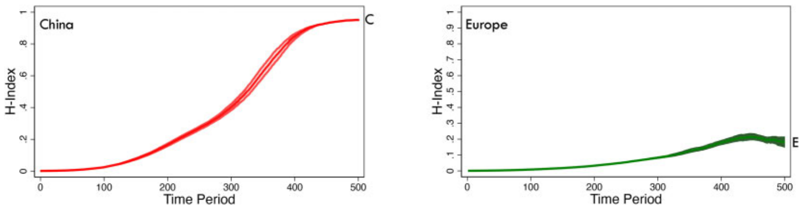


FIGURE VIII

Baseline Calibration (Fan Chart for 30 Simulations)

north), while the Arabian peninsula, given the low productivity of its land, is fragmented (we revisit this point in Section VIII and Online Appendix E.6).

Figure VII, Panel C depicts the same simulation at the end of the simulation after 500 periods (i.e., 1500). The large polity occupying China and dominating East Asia has expanded to the south toward Vietnam and Yunnan. The polity controlling India has expanded toward the south, occupying an area similar to the Delhi sultanate (1206–1526) at its peak. In Europe, we see a nearly unified Iberian peninsula (as happened between 1580 and 1640), polities resembling England, Scotland, and Ireland, a larger France, and the Ottoman Empire.

At the end of the simulation, European Russia and (in particular) Siberia are highly fragmented. Both observations match the historical record during the period we consider. The Grand Duchy of Moscow only started to grow quickly after 1300, and the conquest of Siberia did not commence until the sixteenth century and the arrival of gunpowder. However, our simulation misses anything resembling the Mongol Empire and its successor states, such as the Golden Horde, even if these unification processes were transient. Online Appendix E.2 discusses what we need to change in the model to generate states resembling the Mongol Empire.

V.A. *Chinese Unification, European Polycentrism*

Figure VII is not an anomaly. The central result of our model is that larger polities emerge early in China and this part of the world tends to become unified under a single state. In contrast, polycentrism is persistent in Europe. Figure VIII depicts the evolution of the Herfindahl indices of political unification for China and Europe over 500 periods for the 10,000 bootstrap samples based on the 30 simulations under the baseline calibration.[18] We start with the baseline calibration to have the simplest scenario. The colored intervals denote the 95% confidence intervals of the estimated indices in each period.

Across all simulations, China centralizes quickly. The Herfindahl index for China crosses 0.5 after around 300 periods and converges to 1 toward the end of the 500 periods. In history, China was first unified in 221 BCE when the armies of Qin Shi Huang conquered the state of Qi, the last independent kingdom in northern China. Still, much of southern China continued to be occupied by minorities such as the Yue and Man (Twitchett and Fairbank 1986; Dien and Knapp 2019). When the Han dynasty replaced the Qin, the present-day provinces of Fujian, Guangdong, Guangxi, Guizhou, and Yunnan were outside Chinese control (notice the similarities between Figure A18 in Online Appendix F and Figure VII, Panel B). Over time, the Chinese set up an increasing number of new counties in the south and replaced nominal suzerainty with actual bureaucratic control. Yunnan, the last of the provinces above to be brought under Chinese rule, was officially incorporated into China only in 1276, close to the end of our study period. Hence, our model captures China's political consolidation and its speed. In comparison, Europe always remains fragmented. The Herfindahl index for Europe stays as low as 0.2 as late as 500 periods into the simulations.

V.B. *Inspecting the Mechanism*

We inspect the mechanism behind Figure VIII by varying the parameter values of the obstacles and the productivities of the cells. First, we eliminate the role of climate in making conquest difficult by setting $\theta_{hot} = \theta_{cold} = 0$. This exercise, which we call "minimum set of obstacles," is motivated by Diamond (1997), who focuses on mountain ranges and seas, and irregular coastlines as barriers to conquest.[19] Figure IX, Panel A shows that China unifies more rapidly than Europe. The main difference with

18. We define the Herfindahl index of political unification of a region as $H_{pc} = \sum_{i=1}^{N} s_i^2$, where N is the number of polities existing in the region and s_i is the percentage of the cells in the region controlled by polity i.

19. Table A5 in Online Appendix C summarizes all the specifications reported by Figures VIII–XI. The two regions are comparable in resource availability across our different specifications.

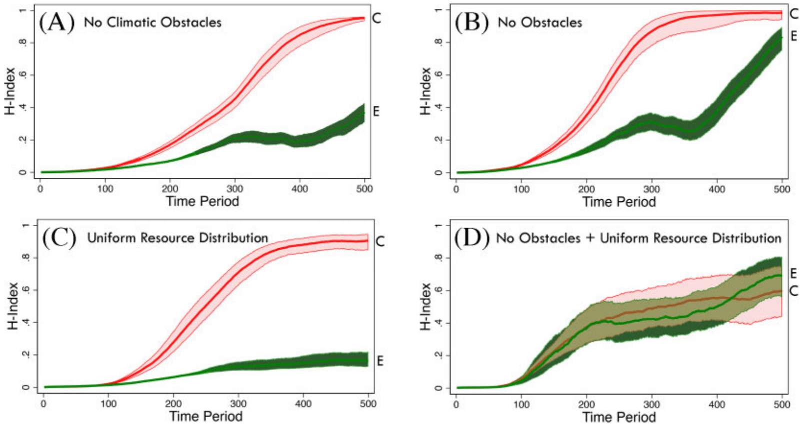


FIGURE IX

Varying Parameter and Productivity Values

For each specification, we conduct the simulation exercise 30 times and display the average Herfindahl (unification) indices for China (red; light gray) and Europe (green; dark gray). The shaded intervals depict the 0.95 bootstrap confidence intervals.

respect to Figure VIII is that Europe unifies more by the end of the simulation.

We push the previous argument to its limit by eliminating the sea and geoclimatic obstacles to conquest: $\alpha_{sea} = 1$, $\sigma = 1$, and $\Theta = \mathbf{0}$. We call this exercise "no obstacles." In this case, cells will no longer secede as the probability of secession given by equation (4) is now always zero. Furthermore, indented coastlines no longer slow political consolidation as a war between two coastal cells across the sea is now as likely to occur and end up in annexation as a war between two neighboring cells on a flat plain. Figure IX, Panel B shows that, absent geographical and climatic barriers to conquest, Europe still unifies later than China, but will end up in a similar situation a few centuries later as an empire from Eastern Europe emerges to conquer the West. European unification remains sluggish because China's core productive areas are more compact, facilitating early consolidation.

Next we assume that attainable caloric yield is uniform across our study area, with $y = 0.5$ for all cells. Thus, every cell is equally likely to engage in conflict. We call the third alternative exercise "uniform resource distribution." Figure IX, Panel C is nearly the same as Figure VIII, our baseline calibration.

Figure IX, Panel D combines “no obstacles” and “uniform resource distribution.” In this counterfactual, our geographical space is neither “fractured” by geographical and climatic obstacles, nor separated into land clusters of varying productivity levels. Panel D of Figure IX shows that China no longer unifies earlier once we neutralize both aspects of fractured land. Panel D is a key result in our paper. It indicates that nonlinearities play a central role in accounting for patterns of state formation: only when we remove both geographical obstacles *and* differences in resources do China and Europe unify at a comparable pace.

V.C. Robustness

How robust to the details of our exercise is our central finding of fast Chinese unification and persistent European polycentrism? We conduct two sets of robustness tests, and Online Appendix D reports the results of many additional tests.

1. *Alternative Data Sets.* We choose the GAEZ v4 attainable caloric yields as our primary measure of productivity and the percentage of alluvial soil to account for early state formation because they are transparent and objective. However, they are not perfect (see Online Appendix A for details). Focusing on alluvium overlooks a vital source of China’s early agricultural advantage: the deep loess deposits along the upper reaches of the Yellow River (see Section V.D). These issues suggest that under a better measurement, China’s unification might be faster than in our baseline model.

Hence, we undertake two robustness checks. First, we replace the highest attainable yield based on the GAEZ v4 database with the Cropland Suitability Index computed by Ramankutty et al. (2002) as our y variable. The result is reported in Figure X, Panel A Under this alternative measurement, China completes its unification a bit earlier, while the consolidation of polities in Europe is even slower than in the baseline results in Figure VIII.

Second, we use the KK10 Anthropogenic Land Cover Change data set in 1000 BCE (our $t = 0$) constructed by Kaplan and Krumhardt (2011) in place of the percentage of alluvial soil to capture the early lead that some areas enjoyed. The KK10 data set estimates the fraction of land under human use in 1000 BCE (see Online Appendix A.2 for some potential problems with the

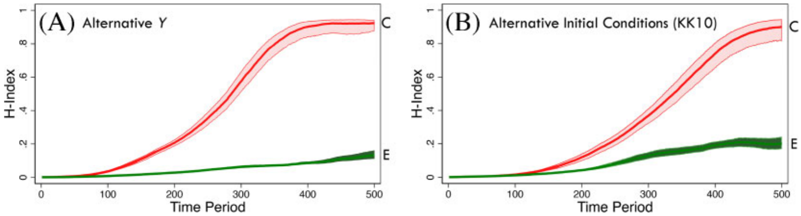


FIGURE X

Alternative Data Sets

For each specification, we conduct the simulation exercise 30 times and display the average Herfindahl (unification) indices for China (red; light gray) and Europe (green; dark gray). The shaded intervals depict the 0.95 bootstrap confidence intervals.

KK10). Figure X, Panel B shows that China unifies even faster than in the baseline specification.

Online Appendix D.2 presents more checks using alternative data sets, including the History Database of the Global Environment (HYDE) version 3.1, the FAO Harmonized World Soil Database version 1.2, and temperature data of the 1960s drawn from WorldClim 1.4. In each case, we see China unifying much faster than Europe.

2. Alternative Conflict Mechanisms. Our second set of robustness tests modifies how wars occur in our model. In the baseline model, a cell enters into a war with one of its neighbors with a probability that depends on the relative productivities of the neighboring cells: the more productive a neighbor, the higher the probability that conflicts arise along its border.

Figure XI changes this probability. In Panel A, the adversary of the cell is the neighboring cell that offers the highest expected gain of conquest to the regime that controls cell k. In Panel B, all the adjacent cells are potential adversaries with equal probability. In both instances, we continue to observe faster unification in China. Online Appendix D.3 implements two more alternative conflict mechanisms that consider the cost of transporting resources from where they originate to the location of fighting. The results are qualitatively the same.

V.D. Enriching the Model

Next, we add more realism to our model by considering the roles of rivers, the steppe, nomadic pastoralism, loess soils, the

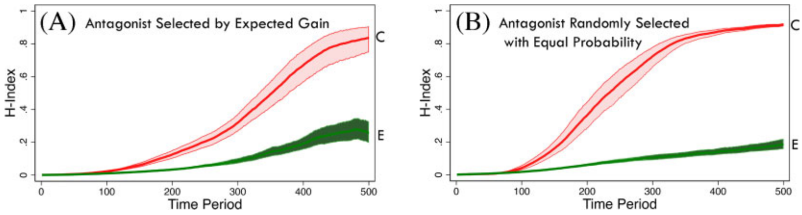


FIGURE XI

Alternative Conflict Mechanisms

For each specification, we conduct the simulation exercise 30 times and display the average Herfindahl (unification) indices for China (red; light gray) and Europe (green; dark gray). The shaded intervals depict the 0.95 bootstrap confidence intervals.

disease environment in the tropics, and the risk of hypothermia in cold regions. We first consider these enrichments separately before taking them jointly into account. This last case constitutes our preferred specification mentioned in Section IV.

Scholars have linked riverine connectivity and state building. Diamond (1997, 331) noticed that "China's long east-west rivers (the Yellow River in the north, the Yangtze River in the south) facilitated diffusion of crops and technology between the coast and inland." The role of rivers in England's early development is widely discussed by medievalists and geographers (see Langdon 1993; Jones 2000). Armies used major rivers as a source of supply. For example, the Roman invasions of Persia often followed the Euphrates. Even as recently as the U.S. Civil War, most operations in the West followed rivers (the Mississippi, the Cumberland, etc.). At the same time, rivers separate basins and can impede movement between left and right banks. Historically, numerous battles took place by the crossing of an important river.[20]

Figure XII, Panel A captures the role of rivers by increasing the probability of conquest when cells along the same river come into conflict and decreasing the probability of conquest when a riverine cell fights a nonriverine cell. The extension yields results similar to our baseline calibration, with only slightly slower

20. Some notable examples include the Battle of Granicus (334 BCE), the Battle of Rhone Crossing (218 BCE), the Battle of the Medway (43), the Battle of Red Cliffs (208), the Battle of the Milvian Bridge (312), the Battle of Fei River (383), the Battle of Stamford Bridge (1066), and the Battle of Stirling Bridge (1297).

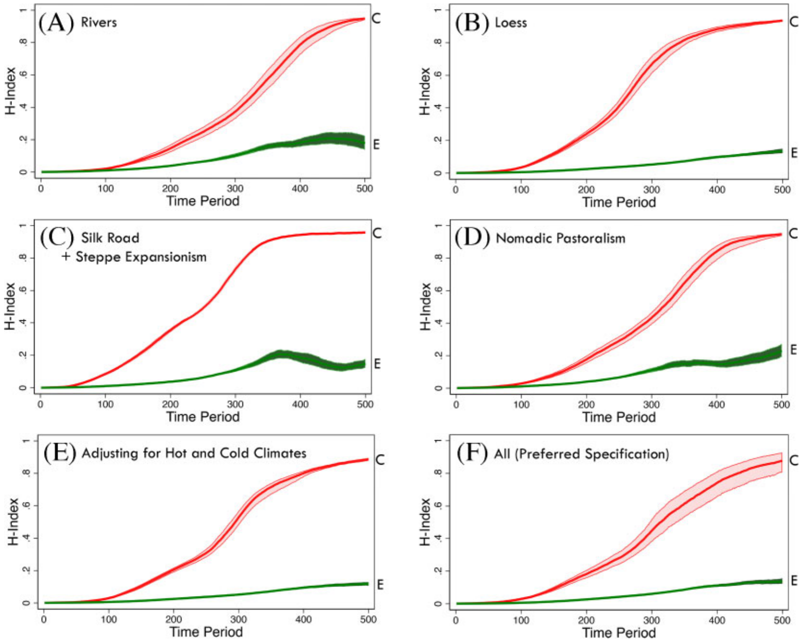


FIGURE XII

Enriching the Model

For each specification, we conduct the simulation exercise 30 times and display the average Herfindahl (unification) indices for China (red; light gray) and Europe (green; dark gray). The shaded intervals depict the 0.95 bootstrap confidence intervals.

political unification in China (see Online Appendix E for details about this and the following exercises).

Panel B considers the early agricultural advantage enjoyed by areas with rich loess deposits and easy access to water (Scott 2017). One such area is the loess plateau in the middle reaches of the Yellow River. This plateau was an important source—if not the crucial source—of Chinese civilization (Ho 1975). Twenty thousand years ago, the region was covered mainly by grass (Jiang et al. 2013). This, coupled with the nature of loess soil—soft and stoneless—and easy access to water, made agriculture extremely rewarding, even with primitive tools. Thus, we give cells with deep loess deposits a higher r, equivalent to alluvial areas having a head start in our baseline specification. While China unifies faster, the main findings remain unchanged.

The next two exercises focus on the Eurasian steppe as depicted in Ramankutty and Foley (1999). The first exercise (Figure XII, Panel C) considers the role of the steppe as a "highway of grass," that is, a network of overland routes that facilitated the movement of caravans, pack animals, and people between Europe and Asia (Frachetti 2008). We also engage with Turchin et al. (2013), who note that the Eurasian steppe influenced state building both directly, because steppe nomads eliminated weaker and less cohesive polities, and indirectly, by developing and spreading technologies that intensified warfare. Barfield (1989) observed that the fragile ecology of the steppe helped shape a culture and practice of military expansionism.[21] The steppe east of the Altai Mountains, where temperature swings are greater than in any other part of the world, was especially prone to outward expansionism (Gibbon 2003; Neparáczki et al. 2019; McNeill 2021). Our second steppe exercise in Panel D adjusts the productivity of cells belonging to the Eurasian steppe to acknowledge that nomadic pastoralism, rather than cereal cultivation, was the primary mode of livelihood in the steppe. In both exercises, we observe a slightly faster pace of unification in China, but no qualitative effect on our main findings. These modifications do not affect the productivity and barriers to conquering the core areas of state formation.

Figure XII, Panel E allows for the influence of climate on pathogens and production. Historically, in tropical regions, diseases limited the use of farm animals and lowered human health and capital. In cold areas, land must be set aside for firewood in the winter and for pastoral activities, for example, for meat (heme iron), fur, or wool to keep warm (Rosenzweig and Volpe 1999). We discount the historical productivity values of cells in hot ($>22^{\circ}$C for average monthly maximum temperature) and cold ($<8^{\circ}$C for average monthly minimum temperature) regions by $\chi_{hot} \cdot \log(t_{\max} - 21)$ and $\chi_{cold} \cdot \log(9 - t_{min})$, respectively. The formulas ensure that cells with more extreme temperatures are discounted more

21. Lattimore (1940) emphasizes the ecological foundation of the struggle between the pastoral herders in the steppe and the settled populations in China. Geography created a natural divide between the river basins of China and the Eurasian steppe. In the Chinese river basins, fertile alluvial soil, sufficient rainfall, and moderate temperatures encouraged the early development of intensive agriculture. In the steppe, pastoralism emerged as an adaptation to the arid environment. During periods of cold temperatures, when droughts led to catastrophic deaths among animal herds, the steppe nomads were often impelled to invade their settled neighbors for food (Bai and Kung 2011).

heavily. We set χ_{hot} and χ_{cold} so that cells at the 25th (-4°C) and 75th (29.5°C) percentile average temperature values have their productivities discounted by 80%.[22] In this exercise, Europe's pace of political consolidation is somewhat slower, but the main results are unchanged.

Finally, in Panel F, we consolidate the modifications in Panels A–E to construct our preferred specification. Comparing this panel with Figure VIII shows that our central result is roughly the same as with the baseline calibration and the preferred specification. The former is more transparent, the latter richer in details and, thus, our favorite choice.

V.E. Taking Stock

This section has demonstrated that it is insufficient to compare average levels of ruggedness between China and Europe. Instead, what matters is the distribution of mountains and other geographical obstacles. While China is, indeed, more rugged than Europe, the location of geographical barriers promoted faster political unification in China. Furthermore, although topography alone is a sufficient condition to explain China's recurring unification and Europe's persistent polycentrism, it is not necessary. Take away topography, and we continue to observe more rapid unification in China. Only removing both geographical barriers and land productivity ensures that China and Europe unify at a comparable pace.

VI. Historical Discussion Informed by the Model

We can now use our model to discuss China and Europe, the role of the balance of powers, and the feedback between economic prosperity and political polycentrism.

1. *China*. At first glance, it is not obvious why geography should contribute to China's recurring political unification. China's terrain is significantly more rugged than Europe's (Hoffman 2015). Also, the climatic distinction between China's temperate north and subtropical south is stark. Different climatic conditions divided China into two agricultural zones: historically,

22. This is a very cautious correction. Cells at the 25th and 75th percentile temperature scales are mostly marginal lands for cultivation. Only 38% of the global land surface is arable (cropland and pastures).

millet, sorghum, and wheat were the staple crops in northern China, whereas rice was dominant in the south. Different crops, in turn, encouraged the development of different social organizations and cultural norms (Talhelm et al. 2014).

China's political unification intrigued the Chinese themselves. During the late Warring States period, Lü Buwei, the chancellor of the Qin kingdom, asked why the number of states in China had decreased from tens of thousands c. 2200 BCE to 3,000 c. 1600 BCE to only a handful in his time (Sellmann 2002). Not long after Lü's death, all but one of the remaining surviving states perished as Qin built China's first unified empire in 221 BCE. While the Qin dynasty lasted only 15 years, it marked a watershed. From 221 BCE to the founding of the Chinese Republic in 1911, China was unified for 1,142 out of 2,132 years (Ko and Sng 2013). The record is unparalleled in world history.

Our model highlights the role of north China, referred to as the "Central Plain" in historical records, in driving these phenomena. While north China is only one of several macroregions of China (Figure XIII), it has played an outsized role in Chinese history. The silty and flood-prone Yellow River, China's "mother river," runs through the region. Regularly inundated by flooding, which replenished the soil, north China was agriculturally precocious and productive even with primitive agricultural tools (Huang 1988). Notably, north China is close to the flat cores of northwest China (Guanzhong Plain), Middle Yangzi (Jianghan Plain), and Lower Yangtze (Yangtze Delta), which, together with the Central Plain, form the heartland of traditional China. In 1943, Sha Xuejun, one of the first modern political geographers in China, used the term "the hub of China" to describe the centrality of north China and its contiguous plains (Sha 1972). Paraphrasing Mackinder (1942), he remarked: "To control China, one needs to first control its heartland; To control China's heartland, one needs to first control its hub."

In our simulations, north China stands out for its flat terrain and high agricultural productivity. Its flatness facilitates military conquest and political consolidation (Figure XIV plots the cells from where the empire originates in each simulation). Once a unified state emerges in north China, the wealth of resources at its disposal makes it nearly impossible for the other Chinese regions—which find internal unification harder to achieve due to their rugged terrains—to resist conquest. This explains why the states of Qin and Jin could unify China despite their adversaries'

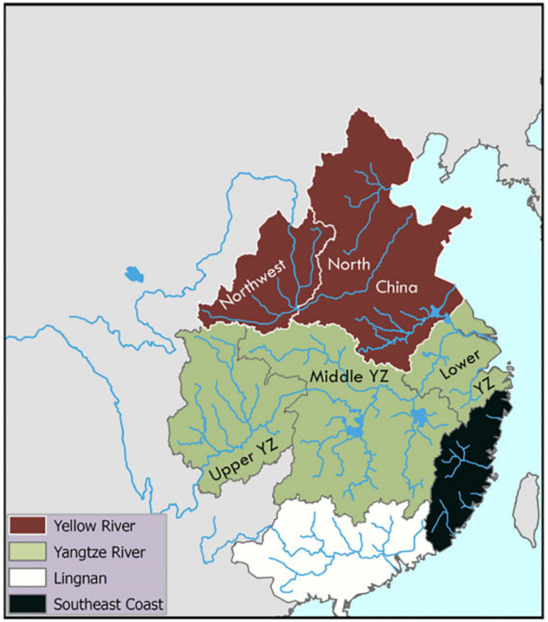


FIGURE XIII

China's Macroregions (Skinner 1977; CHGIS 2007)

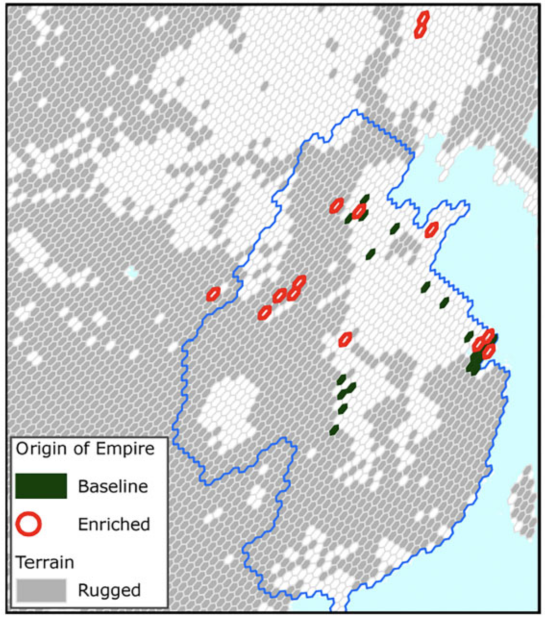


FIGURE XIV

Flatness and Centrality of North China

attempts to maintain a balance of power during the Warring States and the Three Kingdoms periods (see Section VI.3 for a discussion of balancing and bandwagonning).[23]

Unlike the northern European Plain, which is noncompact and open to being invaded from multiple directions, north China was shielded by the Tibetan plateau and the Pacific Ocean on its two flanks. Meanwhile, the steppe and deserts north of China limited the expansion of the Chinese state in that direction. In our simulations, the north Chinese state typically expands in a southerly direction until it hits the tropical rainforests of Indochina, and an increased probability of secession hinders further expansion. Thus, the resulting empire often approximates the shape of China proper.

Besides the size and flatness of north China, its proximity to the core areas of northwest China, Middle Yangtze, and Lower Yangtze also allowed a single powerful state to overcome its rivals and build a centralized polity. In our baseline simulation run, all unifications of China originate from three contiguous plains: the Central Plain, the Jianghan Plain, and the Lower Yangtze Delta (Figure XIV). The proximity of north China to the Mongolian steppe likely provided a further martial impetus to China's unification. When we enrich the model by incorporating the roles of the steppe and the loess plateau, the Guanzhong Plain of northwest China and eastern Mongolia-Manchuria are added to the list of origins of the Chinese empire. This is broadly consistent with the historical record summarized in Online Appendix F, Table A6. All 10 dynasties that controlled most or all of China proper at their peaks originated north of the Yangtze River, and all had their capital cities in the north (except for the Ming dynasty for several decades). Historically, there were long periods of political fragmentation in China: the Warring States period (475–221 BCE), the Six Dynasties period (220–589), the Five Dynasties and Ten Kingdoms period (907–960), and the Southern Song period (1127–1279). However, if a powerful Chinese state arose to

23. The historical literature points to the reforms enacted by the Qin state, notably by Shang Yang. These included conscription, large-scale irrigation projects, and a system of land registration (Hui 2005). However, other warring states also pursued these reforms.

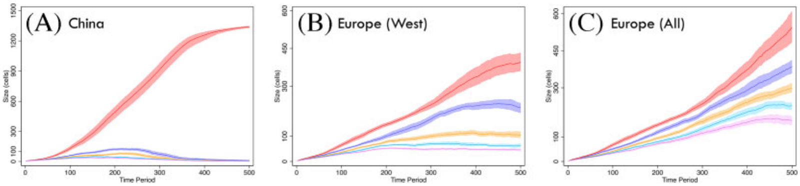


FIGURE XV

Land Area of the Five Largest Regimes in China and Europe

establish stable rule in North China, it would often subdue rival kingdoms and unify “all under heaven.”

2. *Europe*. Figure XV shows the evolution of the average size of the five largest polities in China and Europe in our preferred specification. In contrast to China, where one polity quickly dominates the rest, in Europe (including or excluding Eastern Europe), we typically observe the simultaneous emergence of several middle-sized polities. The size gap between the largest and fifth-largest European polities is never of the same magnitude as in China. In other words, Europe is distinctively polycentric and develops into a series of medium-sized states surrounded by small polities.

This result is in line with European history from the Middle Ages onward. Scheidel (2019, 338–339) notes that after the fall of Rome, Europe was composed of “multiple states that did not dramatically differ in terms of capabilities.” This had significant implications for the balance of power (discussed below).

The closest Europe came to being ruled by a single polity was during the Roman Empire. This was a unique development in European history; at no other point did a single polity come close to establishing stable rule over the majority of Europe. Numerous factors are important in explaining the rise of Rome: the Mediterranean Sea as a conduit to empire, Rome’s peripheral position on the edge of the eastern Mediterranean state system based around the Fertile Crescent, its early ability to incorporate nearby populations and build an alliance system of Italian cities, its unusual bellicosity (Harris 1979, 1984), and favorable climatic conditions during the classical period (Braudel 1972; Horden and Purcell 2000; Harper 2017; Scheidel 2019). In Section VIII, we use our model to study under what conditions a Mediterranean empire could emerge. We find that the rise of Rome likely depended on the highly contingent factors for which these historians have argued.

After the fall of the Roman Empire, the closest Europe came to being unified by a single ruler was during the sixteenth century under the Habsburg emperor Charles V. Importantly, for our purposes, Charles V did not acquire this empire by conquest but by generations of successful marriages and dynastic luck. He also did not create a unified state but ruled his disparate kingdoms as separate entities. Our model does not directly speak to how the Habsburgs chanced on a European-wide empire. However, it speaks to the difficulties Charles V had in managing his domains. Geography prevented Charles V from focusing on facing the Ottomans in the Mediterranean, driving France out of Italy, or subduing Protestant German princes. The final admission of the power of geography came when, upon his abdication, Charles divided his territories between his son Philip II of Spain (r. 1556–1598) and his brother Ferdinand I (r. 1556–1564).

Beyond accounting for the Habsburgs' experience, our model also speaks to the failures of Louis XIV and Napoleon to successfully build a hegemonic state in Europe against a combination of several medium-sized states led by Great Britain. Our model delivers many medium-sized states not only because of the presence of mountain barriers in Europe but also because the most productive agricultural land in Europe is dispersed rather than concentrated as in China.

3. *The Balance of Power.* Our model lacks strategic interactions: polities enter conflicts and win or lose them based on exogenous probability distributions. For instance, we do not allow polities to think about issues such as state power investment, a dynamic path of conquest, or the formation of alliances—for instance, through strategic marriages, a common form of political consolidation in European history (Levine and Modica 2013; Dziubiński, Goyal, and Minarsch 2021).

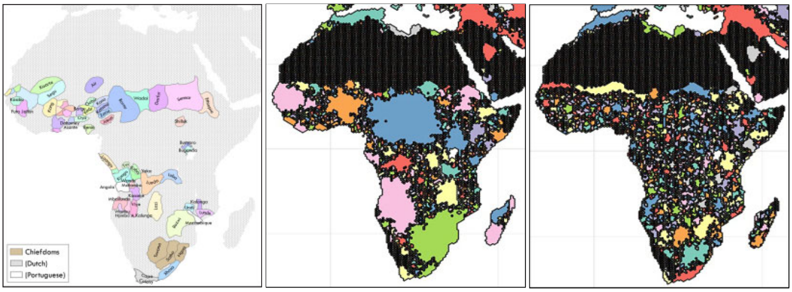
The most important reason we do this is computational. Introducing even a minimum of strategic thinking will complicate the model so much that simulations would become unfeasible given computing power and current algorithms.

However, we conjecture that strategic interactions will likely strengthen our results. A key idea in international relations is the balance of power (Morgenthau 1948; Waltz 1979; Mearsheimer 2001). States form alliances against potential hegemons, limiting their expansion. Examples of balancing in European history include the shifting compositions of the Greek poleis leagues,[24] the polyhedric structure of arrangements in the Italian peninsula during the Middle Ages and early modern period, or the alliances in Europe first against the Habsburgs and later against the House of Bourbon. More recently, balancing explains why the French Third Republic, probably the most democratic nation in Europe around 1914, could be the staunchest ally of tsarist Russia, the epicenter of reaction, or why Winston Churchill wrote: “If Hitler invaded Hell I would make at least a favourable reference to the Devil in the House of Commons” (Churchill 1950, 370). Because Europe had different nuclei for forming states that could form the seed of multifaced balancing coalitions, the balance of power was the predominant structure of international relations for much of its history, reinforcing the mechanisms in our model.

Why did the same balancing logic not prevail in China? Because the early formation of a large polity in northern China, illustrated by our simulation, triggered the opposite force to balancing: bandwagonning. In this situation, weaker states align themselves with the hegemon (or integrate), because resistance is futile without alternative nuclei. The Three Kingdoms period (220–280), which opened at the end of the Han dynasty, shows this point. The alliance between Wu and Shu could only resist Wei until the northern kingdom regained its strength. But Wu and Shu were doomed once Wei could mobilize the northern plain’s resources. Our model suggests that the lack of geographical barriers in northern China and the potential for cumulative conquests in this core region of historical China as the reasons for bandwagoning. In other words, given the geographical features of China, balancing was likely never a feasible Nash equilibrium, but bandwagonning was, reinforcing the mechanisms in our model.

4. *Feedback between Economic Growth and Political Fragmentation*. To keep the model simple, we also abstract from how political fragmentation or unification might feed back into economic growth and, through it, into the power of different polities to conquer or defend. Abramson (2017) has argued that the economic prosperity that small independent polities, such as Venice or the United Provinces of the Netherlands, enjoyed thanks to Europe’s

24. The oligarchic Corinth is a textbook example of a balancer, deftly switching between its alliances with Sparta, Athens, and Thebes to ensure that none of its rivals became too powerful.



(A) States in 1750 (Overy, 2004)

(B) Baseline calibration: illustrative output ($t = 500$)

(C) Climate & timing adjusted: illustrative output ($t = 500$)

FIGURE XVI

Accounting for the Relative Absence of Large-Scale States in Sub-Saharan Africa

polycentrism allowed them to punch above their weight militarily and survive for centuries. Eisenstadt and Rokkan (1973) argue that the core of the modern European states appeared where no large urban centers could assert their independence. Conversely, once a sufficiently large polity has emerged, its urban structure and the transportation network built around it can further unify the country (think about London in England). Thus, these feedback channels will likely reinforce the main mechanisms in our simulations.

VII. Africa and the Americas

In this section, we investigate the predictions of our model for state formation in Africa and the Americas. Due to length constraints, we discuss these results briefly here and leave their detailed assessment to the Online Appendix.

VII.A. *Africa*

Historically, state formation in Africa differed from state formation on other continents. No large, sustained agrarian state had emerged in sub-Saharan Africa outside Ethiopia before 1500, the calibrated end of our simulation (many states rose and disappeared without long persistence over time). Figure XVI, Panel A shows how by 1750 the region was still composed of many small states and communities.

Our baseline simulations, however, suggest that Africa should be home to several large states (Figure XVI, Panel B). While the prediction is off the mark, it is unsurprising. As we discussed earlier, the GAEZ v4 data set overestimates agricultural productivity in hot regions like sub-Saharan Africa. Because of this, in our baseline simulations, we observe political consolidation in every part of sub-Saharan Africa.

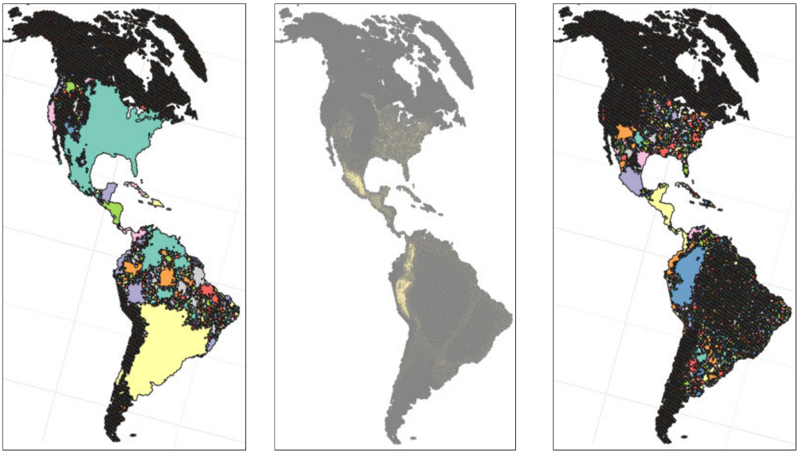
How can we make progress reconciling theory and data? Scholars have highlighted sub-Saharan Africa's relative isolation from the rest of Eurasia in leading it onto a path of technological and agricultural development that was less conducive to state formation (Childe 1957; Goody 1971; Diamond 1997), and a climate-enabled disease environment that slowed growth (Weil 2014; Alsan 2015; Bellone and Failloux 2020). We consider these factors by delaying the start of the cells' ability to conquer other cells to $t = 150$ and by correcting the GAEZ v4 productivity as in our preferred specification (see Online Appendix G for details). When we do so, Figure XVI, Panel C shows results that look much closer to what we observed historically (without affecting state formation in Eurasia due to geographical distance).

Our results also suggest other possibilities to improve the model. For example, it might be the case that social structures in Africa mean that small rulers were less willing to go to war with their neighbors, which might have slowed the formation of large states (for some intriguing evidence, see Moscona, Nunn, and Robinson 2018).

VII.B. The Americas

According to GAEZ v4, the Americas are home to the world's most productive lands. Each of the 50 hexagons with the highest attainable caloric yields in the world is in present-day Argentina or the United States. As a result, in our baseline simulations, we generally observe empires emerging in Argentina and the eastern United States (Figure XVII, Panel A), which is inconsistent with the historical observation that precontact state formation was most advanced in Mesoamerica and the Andes.

This counterfactual result is driven by the fact that our use of GAEZ v4 assumes that maize, the major indigenous crop in the Americas, is available throughout the continent from $t = 0$. Historically, this is inaccurate. While maize was domesticated from Balsas teosinte, a wild grass, in the Mexican plateau about



(A) Baseline calibration: illustrative output ($t = 500$)

(B) Maize cultivation in 1500 (Goodman and Galinat, 1988)

(C) Maize & guano considered: illustrative output ($t = 500$)

FIGURE XVII

Locating the Large States in Pre-Columbian Americas

9,000 years ago, its spread across the Americas was slow (Staller, Tykot, and Benz 2006). Possible reasons include the wide climate and terrain variability across the vertically oriented American continent, which created obstacles to its adaptation across latitude and elevation. Also, the lack of iron tools in the Americas to deal with the prairie sod might have restricted maize cultivation in the fertile plains of the Midwest United States and northern Argentina (Hudson 2004; Bamforth 2021). For example, the earliest evidence of maize consumption in the middle Ohio Valley is as late as 900 (Staller, Tykot, and Benz 2006, 230). On the eve of the Columbian Exchange, the crop was most intensely cultivated in the Mexican plateau and neighboring Guatemala and Yucatán, as well as Peru (Figure XVII, Panel B).

Furthermore, in the case of Peru, scholars have highlighted the role of guano, the accumulated feces of marine birds and bats. Guano was the richest organic source of nitrogen compounds known in the premodern world. Archaeological evidence suggests that Andean inhabitants understood the use of guano as a natural fertilizer as early as 2000 BCE (Poulson et al. 2013). This was made possible by an abundance of guano-producing birds, including the Peruvian cormorant, the Peruvian pelican, and the Peruvian booby. Guano turned the relatively infertile Andean highlands and coastlines into some of the most productive fields in precontact America (Cushman 2014) and, thus, it enabled the agricultural development and political ascendancy of the Inca Empire and its predecessors (Santana-Sagredo et al. 2021; Rodrigues and Micael 2021).

We incorporate these insights by accounting for (i) the timing and spread of maize cultivation in the Americas and (ii) the use of guano in the Cusco basin and its surroundings. As Figure XVII, Panel C illustrates, once we consider these factors in our simulations, the Americas cease to produce supersized polities. Now, relatively large states typically emerge on the Pacific coast and in the Andean highlands, as well as in Mesoamerica, states that resemble the Triple Alliance and the Inca Empire. As in the case of Africa, these modifications do not change the results of the simulations in Eurasia. See also Online Appendix G, Figure A20.

During the last decades, we have learned much about the precontact Americas, with the consensus among researchers tilting toward the Americas being more populated and having more sophisticated state structures than previously thought (Mann 2006). Our results in Figure XVII, Panel C with a wide variety of emerging polities, can be interpreted as providing additional support to this emerging consensus and hint that there are still complex societal structures, such as those uncovered in Llanos de Moxos (north Bolivia), that remain to be discovered.

VII.C. *Taking Stock.* The study of Africa and the Americas shows that the simplest fractured-land hypothesis falls short in these two regions and that it requires additional mechanisms to account for state formation. We have used our model to suggest which of these additional mechanisms one needs to reconcile theory and data.

VIII. Extensions

This section considers several extensions of our model as external validity checks.

VIII.A. Exogenous Shocks and Dynastic Cycles

Introducing exogenous shocks allows us to probe path dependence. Are the patterns of state formation observed in the model generated by initial conditions? Or, on the contrary, can the introduction of large-scale shocks create changes in the overall distribution of polities?

The idea that external shocks explain the rise and fall of particular polities is a popular thread in Chinese historiography, where the rise of empires is often interpreted through the lens of dynastic cycles (Usher 1989; Chu and Lee 1994). Recently, scholars have pointed to climate change as a cause of these dynastic cycles (see Zhang et al. 2006; Fan 2010). Climatic factors have also been adduced as necessary in the rise and fall of the Roman Empire and the social upheavals in late medieval and early modern Europe (Parker 2013; Campbell 2016).

We incorporate climatic and other random sociopolitical shocks by distinguishing between general system-wide and regime-specific crises. General shocks such as the collapse of Bronze Age empires c. 1177 BCE or the Little Ice Age of the seventeenth century are potentially significant as they have the potential to generate synchronized changes across a region—something observed by Lieberman (2003, 2009), who notes the "strange parallels" of synchronized administrative cycles across Eurasia. In contrast, regime-specific crises are modeled as localized shocks, such as the Twenty Years' Anarchy in the Byzantine Empire (695–717), the An Lushan rebellion of Tang China (755–763), or the War of the Roses of fifteenth-century England. In our extension, these two types of crises occur randomly given exogenous probabilities.

In this version of the model, political cycles are muted in Europe, which never achieves complete unification despite short periods of a hegemonic state. By contrast, China intersects periods of sustained unification interrupted with periods of disunity, resembling the successive dynasties of Chinese history (which motivated the opening quote of this article). The result echoes Root (2017, 2020), who contrasts patterns of network stability in China and Europe and argues that China's organization as a hub-and-spoke system was less resilient than Europe's polycentricity, and Ko, Koyama, and Sng (2018), who show that the Chinese empire displayed greater volatility of population and economic output than Europe after the collapse of the Roman Empire.

VIII.B. The Mediterranean Sea

In our baseline simulations, we do not see political consolidation in Europe. But then: what about the Roman Empire? We can use our model to shed light on the conditions necessary to generate the Roman Empire and explore why, after its collapse, no subsequent state ever came close to unifying as large a territory again.

In the first exercise, we improve the agricultural productivity of the area around the Mediterranean. We are motivated by historians such as Harper (2017), who have pointed to the confluence of favorable climatic conditions that facilitated the rise of the Roman Empire. This exercise generates slightly larger polities in the Mediterranean but does not come close to causing a polity like the Roman Empire.

In the second exercise, we give Rome a military advantage. Classicists like Harris (1979, 1984) have argued that republican Roman culture was uniquely bellicose and that this gave Rome an edge in war. This extension also does not generate anything like a Roman Empire.

Finally, we combine both extensions. In this case, we find larger empires emerging, another example of nonlinear effects in our model. These Mediterranean-based empires, however, do not regularly extend beyond the Alps and hence do not resemble the full extent of the Roman Empire. This suggests that while exogenous factors such as climate may have played a role in the expansion of the Roman Empire, this was both highly contingent (such as Rome's good fortune in gaining early control of the entire Mediterranean before many competing powers could appear), as many historians have observed, and also a one-off event that was not repeated.

VIII.C. What If Europe Had a Head Start?

Historically, the Roman Empire overlapped in time with the Han Empire in China. While the empire of Han was repeatedly reconstructed over time, the Roman Empire was never reinstated (Scheidel 2009). Was this a fluke?

To investigate, we use the world map of 250 CE as the starting point of a new set of simulations. In 250 CE, the Roman Empire was still the dominant force in Europe, while the Han Empire had fragmented into three kingdoms, an episode that gave rise to the opening quote of our article. We incorporate exogenous regime-specific shocks, as discussed already, to allow polities to fragment and consolidate. We find that despite Europe's head start in political consolidation vis-à-vis China, its level of political consolidation tends to fall over time as China's level rises quickly to cause a switch of places. We also observe that if the "Roman Empire" that exists at $t = 0$ collapses under a regime-specific shock, it is never restored. But in China, every political collapse is followed by a new phase of political consolidation. Online Appendix E.5 provides more details.

As a further robustness check, we examine an alternative scenario whereby, at the start of the simulation, China is fragmented into its seven constituent regions, as depicted in Figure XIII, while a large polity of the size and shape of the Carolingian empire dominates Europe. In this fictional scenario, we still observe that China always ends with a higher Herfindahl index even though it starts from a lower place by artificial construct. In sum, a high degree of political consolidation in Europe is unsustainable, just as political fragmentation in China does not last. More generally, these two exercises show that the initial conditions of our simulation do not change the main result of our article: unification in China and polycentrism in Europe.

VIII.D. State Formation across Eurasia

Consistent with the historical record, in our simulations, the formation of large states is pronounced in East Asia. As Scheidel (2019) notes, the "easternmost macro-region, East Asia, has been characterized by much stronger dominance of hegemonic empire than any of the others." By contrast, Europe is distinctively polycentric (Figure XV). To what extent can our model also explain broader patterns of state formation across Eurasia beyond East Asia and Europe?

To answer this question, we compute the size of the five largest regimes in Europe, East Asia, South Asia, Southeast Asia, and the Middle East. We observe a hegemonic state regularly emerge in China, northern India, and the Middle East (Figure XVIII). However, full political consolidation occurs nowhere except in China. Inspecting the simulations, we can gauge, for example, why a single huge polity does not always conquer the entire Indian subcontinent. First, the Himalayas and the Hindu Kush in the north, the Thar Desert in the west, and the thick jungles of Burma and Gondwana in the east presented significant impediments in terms of either rugged terrain or low agricultural productivity that discouraged state expansion in these

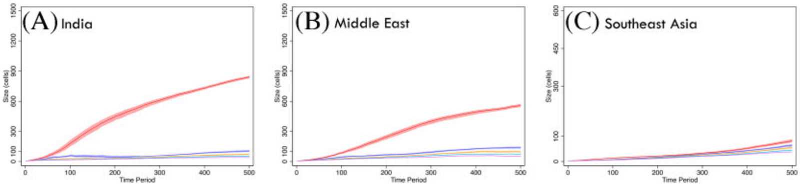


FIGURE XVIII

Land Area of the Five Largest Regimes in India, Middle East, and Southeast Asia

directions.[25] Second, the rugged Deccan plateau in southern India was a significant barrier to empire-building.[26] Third, the tropical climate of southern India, which historically posed difficulties in gathering and moving armies (Lieberman 2003, 2009), further impeded the conquest of the south by the north.

Likewise, although we also observe large states arising in the Middle East, the process of political consolidation in the region is typically incomplete because of the region's relatively rugged terrain and large tracts of deserts in the region's interior.

In the case of Southeast Asia, the tropical climate and the rugged terrain explain why, in our simulations, polities in the region are usually small, and the political map is highly fragmented even compared with Europe.[27] In sum, comparing Figures XV and

25. While the thick jungles of Burma and Gondwana created unbridgeable outer limits to Mughal expansion (Gommans 2002, 198), the mountains were not insurmountable to armies. The Mughals conducted mountainous expeditions into Kashmir (1561, 1585, 1588), Garhwal (1635, 1656), Baltistan (1637), and Ladakh and Tibet (1679–84). However, the lack of forage and food impeded the extension of permanent political authority north of India. As Gommans (2002, 23) puts it: "Indian armies were faced by tremendous logistical problems. One mid-18th-century source considered the Kabul area a land of snow: 'Men and cattle from India are not able to withstand the icy cold winds of that area. That is why it is difficult for the people of India to capture and occupy the Muslim countries of that area'." See also Nath (2019) for Mughal warfare and the South Asia environment.

26. The Deccan plateau rises to over 1,000 m. It was the site of numerous conflicts between states from northern India and those from southern India. Multiple Hindu states in the Deccan could resist the expansion of Muslim empires such as the Mughals.

27. Southeast Asia was less populous than other major regions of Eurasia until the nineteenth century, and state formation took place later and under less favorable conditions there than elsewhere (Lieberman 2003, 2009). Some periods saw the formation of states with a considerable geographical scope, such as the Khmer Empire in the ninth century, the Taoungoo Empire in the sixteenth century, or the Kingdom of Siam in the eighteenth and nineteenth centuries. But these

XVIII, while China is unique in its extremely robust tendency toward political unification, Europe's inclination toward polycentrism is also unparalleled.

IX. Conclusion

This article has developed a dynamic model to adjudicate among competing explanations of Europe's polycentrism and China's political centralization. Our analysis evaluates Jared Diamond's argument that Europe's mountain barriers and the shape of its coastline were responsible for its polycentrism, whereas Chinese geography encouraged political centralization. By developing a model of state formation that quantitatively incorporates the role of topography and agricultural productivity, we provide a rigorous formulation of the fractured-land hypothesis. Our simulations demonstrate that either topography or the location of productive land can generate political unification in China and persistent polycentrism in Europe.

We documented how the simplest fractured-land hypothesis misses the observed slow speed of state formation in Africa and the Americas. We proposed several additional mechanisms, previously suggested by many historians, that can reconcile our model with the data. In that sense, we used our model as a measurement device to suggest improvements in the theory.

Finally, our model can be a starting point for additional explorations. For example, we could incorporate military technological change (Hoffman 2015), investment in state capacity (Gennaioli and Voth 2015; Johnson and Koyama 2017; Becker et al. 2020), or epidemic diseases (Voigtländer and Voth 2013b). We could add climatic change, migration, time-varying agricultural technology (new crops, irrigation systems), variation in transportation capabilities (Bakker et al. 2018), or cultural aspects that feed back into the creation of states. For instance, after a state has existed for many periods, its inhabitants may have developed an "imagined community," making it harder to conquer and easier to maintain unified (Anderson 1991). Think about how, in a few generations during the late Republic and the Principate, the conquered peoples of Italy started thinking about themselves as "Romans." Also,

larger states only retained regional hegemony for brief periods, and the more common pattern was political fragmentation.

some cells may share a religion, which makes unification easier, or be separated by it, which makes conflict more likely.

In summary, evaluating the relative contributions of geographical and human endowment to state formation would be essential. Although such a measurement is beyond the scope of the current (already lengthy) paper, our methodological approach is flexible in allowing for these and many other quantitative exercises and generating probability distributions of historical outcomes. We hope to see many of those extensions soon.

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Supplementary Material

An Online Appendix for this article can be found at *The Quarterly Journal of Economics* online.

Data Availability

The data underlying this article are available in the Harvard Dataverse, https://doi.org/10.7910/DVN/OSTVNR (Fernández-Villaverde et al. 2022).

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