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Computing the Steppes: Data Analysis for Agent-Based Modeling of Polities in Inner Asia

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Abstract. Inner Asia has a long history of influential polities in world history. This study reports new data and findings from an ongoing collaborative project between Mason and the Smithsonian to develop empirical and computational (agent-based) models of the rise and fall of polities in Inner Asia, between the 4th century BCE and the aftermath of the Mongol empire. A statistical survival analysis of original data based on archaeological and historical dates shows a nearly exponential birth-death process of polity formation-termination and, interestingly, a linear increasing hazard force for termination (Rayleigh distribution of polity durations). Beyond ther intrinsic value, these theoretically informed statistics provide new standards for testing and calibrating agent-based models within the broader project.

INTRODUCTION

Motivation

Inner Asia—the region of the Asian continent centered on Mongolia and surrounding territories of northern China, southern Siberia, eastern Kazakhstan, and western Manchuria—has a long political history of thousands of years including the rise and fall of numerous polities. Among these is the puzzling case of the Mongol Empire (1206–1368 CE), the largest territorial polity ever (29,491,900 km^2), and the much earlier Xiongnu Empire (200 BCE to 155 CE) shown in Figure 1a. (In this paper we use the BCE/CE dating convention used by world historians and comparative social scientists.) Paradoxically, from a social and political science perspective, the Mongol system of government was significantly simpler than that of most smaller polities (e.g., the Roman Empire, the modern French Republic). More than a dozen state-level polities, including several empires, span the 2,000 year period between the rise of the Xiongnu (or Hünnü, as called by the Mongols) and end of the Zunghar state in the same geographic region. This was also a sufficiently long time span for climate change to have occurred.

Many puzzles surround the polities of Inner Asia, from both regional and broader comparative perspectives. We focus on the onset, life cycle, territorial size, and survival dynamics of these polities, with two main goals. First, the empirical analysis of their formation and evolution has intrinsic value, especially from a long-range perspective that includes environmental and technological change. Second, documenting the precise empirical patterns of these polities—as precisely as measurement error and uncertainty in the primary sources allows—is critical for testing and validating agent-based simulation models of the evolution of the region (Cioffi, 2002; Cioffi et al. 2007). Until recently, both goals have been elusive due to lack of systematic data and a multidisciplinary effort.

(a)

(b) **(c)**

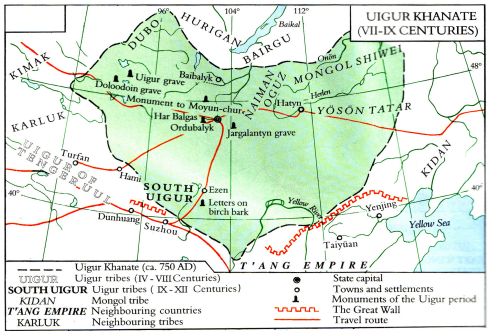

Figure 1. Maximal territorial extent of three early Inner Asian polities: (a) the first documented state of Inner Asia, the Xiongnu polity, ca. 200 BCE to 155 CE, contemporary to Rome and the Qin and Han empires in China; (b) the first Turk polity, 6th to 8th cent. CE; (c) the Uighur polity, 7th to 9th cent. CE. Rectangle in 1a shows approximate area under study as Inner Asia. *Source:* ESRI base map (1a).

Background

Over the last century, significant historical and archaeological research has contributed to an increasingly complete picture of the emergence of polities in Inner Asia. This effort has been spearheaded by Russian and Mongolian researchers (Kradin 2002, 2005; Dashnyam et al. 1999; Perlee 1961), and since 1990, by a wide variety of international research teams (Honeychurch 2004; Moriyasu and Ochir 1999; Rogers et al. 2005; Roth and Ulambayar 2002). The results of this ongoing work are producing detailed chronologies from the Paleolithic through the period of major empires, providing a better understanding of the early polities in terms of dynamic cultures. Research on the Bronze Age (1500–400 BCE), for example, has found significant variation in the distribution of populations and cultures across the region (Erdenebaatar 2002; Frachetti 2004; Fitzhugh and Bayarsaikhan 2008).

The fundamental social system that emerged on the steppes of Inner Asia, and set the stage for the first significant polities, had its origins in a mobile pastoralist economy. The domestication of the horse around 4000 BCE and the availability of other herd animals, including sheep, goats, cattle, yaks, and camels led to the development of a highly adaptive, yet volatile means of exploiting the vast grasslands of Central and Inner Asia. As the Greek historian, Herodotus, noted over 2,400 years ago, this is a vast region where herders tend their flocks from horseback (Godley 1920). While pastoralism was certainly the most important aspect of the economy, hunting and gathering and limited amounts of agriculture were also practiced throughout the region. By approximately 1400 BCE the landscape of Inner Asia was extensively populated by increasingly hierarchical local groups, often referred to as tribes, but conforming to a type of political organization more typically described in the anthropological literature as chiefdoms (Earle 1991; Johnson and Earle 1987).

Following the Bronze Age chiefdoms, the Xiongnu were the first society of Inner Asia to develop a major confederation under centralized leadership. We know details of the Xiongnu polity from early Chinese historial sources and from extensive archaeological research, especially focusing on elite tombs and regional settlement patterns (Honeychurch and Amertuvshin 2006). At its greatest extent, the polity occupied a region considerably larger than modern-day Mongolia (Figure 1a). The polity was organized into a center and two branches, described as "left" and "right". The "central" region was controlled by the imperial elite, while the left and right regions were subordinate but relatively autonomous. The concept of a center, left, and right was replicated in several subsequent steppe polities, as was the institutional form of an imperial confederation, as shown by the Jujan, Turk I, Turk II, Uighur, Oirat, Eastern Mongol, and Zunghar political systems (Barfield 1989:8).

In world history and according to various theories of cultural evolution, the pastoralists of Inner Asia are generally relegated to a peripheral or intermediate role (e.g., Pletneva 1982:145), or as facilitators of interaction between the sedentary centers of civilization. In this perspective, the polities established by pastoralists in Inner Asia are viewed as ephemeral and relatively unimportant in comparison to the complex urban societies of China and the Middle East, where cities first emerged, fueled by highly productive and stable agricultural systems. The

marginalization of the steppe pastoralist polities has its origin in our first, and persistent, interpretations derived from the early Chinese historians, who characterized the northern peoples as barbarians and the lands they occupied as only barely suitable for human habitation (Li 1973, vol. 1). Considering that China was frequently in conflict with the northern polities, it is not surprising that official histories were written from this perspective. However, the cultural traditions of the steppe pastoralists formed a strong basis for the emergence of distinctive elite organization and relatively unique systems of government. The cultural traditions and styles of political organization reflect indigenous steppe developments and the utilization of ideas from several sources, including China, Persia, and Russia (DiCosmo 2002:172-173).

Early polities developed in China by about 2100 BCE, (Chang 1986; Lee 2002; Liu 1996; Shen 2003), but not in the steppe regions bordering China for another 1800 years—around 200 BCE with the emergence of the Xiongnu empire (Rogers 2007). Although early histories mention other northern groups and even major steppe polities at this time (e.g., Dinling, Yűeh-chih, and Tung-hu), these were eventually subsumed by the expanding Xiongnu (Di Cosmo 1999, 2002). The struggles that emerged between the Xiongnu and the Han Chinese empire set the stage for a long series of conflicts that involved and produced successive polities for the next 1900 years (Barfield 1989).

METHOD

Data and Measurement

From a methodological perspective, this study consisted of a cross-sectional and cross-temporal comparative analysis (Bennett and Stam 1996; Bienen 1989; Cioffi and Landman 1999; Landman 2008), with extensions and additions as noted. The geopolitical area of the study consisted of present-day Mongolia plus a broad rim of neighboring regions comprised of territories from northeastern to northwestern China (namely Inner Mongolia, Gansu, and Xinjiang) and southern Siberia (Di Cosmo 1994). The total territory included in the study covers approximately 5,407,000 km^2 that consist of multiple biomes and ecological zones, such as steppe (primarily), desert, grasslands, forests, and mountains. Our definition of Inner Asia follows the consensual demarcation of the region as defined by most area specialists (e.g., Di Cosmo 1994, 1999; Rogers 2007; Sinor 1981).

The time period covers 1,957 years, from ca. 200 BCE when the first reliably documented state-level polity of Inner Asia formed (the Xiongnu state, see Figure 1a), to 1757 CE when the last nomadic empire in eastern Turkestan (present-day Xinjiang) fell (the Dzungar or Zuhngar imperial confederation of the Oirat Mongol tribes). Following the recent periodization due to W. Honeychurch and J. D. Rogers (2007), this corresponds to several distinct chronological periods, not one homogeneous time interval. The Honeychurch-Rogers periodization is based on field archeology (burials and other excavated sites, regional surveys), epigraphy, early historical records, oral traditions, and ethnographic records.

The cases in our data set consist of Inner Asian polities with demonstrable levels of social, political, and economic complexity in the form of states and empires. Accordingly, chiefdoms and other pre-state polities with lesser political complexity are omitted from this study. Operationally, each case shows evidence of a centralized system of governance and collective action problem-solving through public policies extending over a putative territorial region (stable or contested). The typical organizational form of Inner Asian polities is a tribal confederation, meaning a large coalition of local nomadic units under the leadership of a strong leader at the head of his own tribe or clan (Rogers 2007; Rogers and Cioffi 2008; Cioffi, Latek, Honeychurch, and Tsvetovat 2008). Although nomadic—i.e., migratory seat of power—Inner Asian tribal confederation polities meet all the defining criteria of a polity (society or populace with one or more cultural identity, and system of government that produces policies for managing public issues affecting the populace).

Included in our study were all known Inner Asian polities (not only archaeological sites) for the approximately 2,000 year-long time period defined above. As detailed below, a total of 18 polities were identified, most of which qualified as empire polities (i.e., polities with large multi-ethnic populations, territorially extensive polities covering several environmental zones, and a redistributive political economy; as opposed to simpler states with greater ethnic uniformity, reduced territorial size, and fewer ecological zones). While the focus is on pastoralist polities, our sample also includes adjacent polities practicing a more sedentary agricultural economy. We used primary, secondary, and tertiary sources to measure the dates of formation and termination. In addition, maps were used to measure the maximal territorial size, following a similar procedure to Taagepera's (1997; and earlier papers cited therein). When inconsistent or contradictory information was found, greater credibility was assigned to the more specialized or better documented source. Accordingly, some sources were weighted more than others, depending on their accuracy. Data were also collected by the second author during field seasons in Mongolia between 2002 and 2007.

In the future we intend to add more cases and validation controls to the data set by circulating it among area experts. However, two limitations of our data must be considered, given the nature of archaeological and epigraphic information. First, we made every attempt to be as accurate as possible, but complete accuracy cannot be guaranteed in this type of measurement. We estimate the average accuracy of our dates to be within an acceptably small range of the dates reported, based on the extant evidence. This margin of error (at most +/– a few years, not decades) is sufficiently small for the statistical analysis we conducted, considering that the total span covers just under 2 millennia (i.e., approximately 0.5 %), and the nature of the aggregate, system-level hypotheses we tested. Second, research on Inner Asian polities and societies is undergoing significant developments, so a similar study conducted several years from now may well yield new results. Nonetheless, the accuracy attainable today warrants this first study.

Variables and Models

Based on formation and termination dates reported in Table 1, we measured the following variables directly related to the evolution of polities in a political system (Cioffi-Revilla 1998:

ch. 4):

1. *Duration*, denoted by D;
2. *System size N*, or number of contemporaneously existing polities in the system;
3. *Hazard rate* relative to both formation $H(f)$ and duration $H(d)$, also known as event intensity;
4. *Stability,* based on the exponential ratio of uncertainty, sd^2/μ, or stochastic structure of D (i.e., the hyper-exponential, exponential, or hypo-exponential form of the distribution of durations);
5. *Half-life* (median value) of polity duration;
6. *Maximal size*, denoted by S (largest territorial range), and degree of accuracy or error (10–20 %);
7. Type of economy (pastoral or sedentary).

Note that duration alone, or turnover rate, is not per se a measure of polity stability, which is a deeper and more dynamic property given by the hazard rate or event intensity (Cioffi-Revilla 1998: 68–82). Together, these variables (and other theoretically based data that we will report in the future) describe the evolution of a political system across epochs, providing a basis for theoretically explaining why, how, or when change might occur.

The first three of these variables are the most important for this study; the stability coefficient sd^2/μ and the half-life are derived from these. The duration d_i of polity i (where $i = 1, 2, 3, ..., n$) is a value (realization) of the stochastic variable D defined by the probability density function (p.d.f.), denoted by $p_D(d)$, and the cumulative density function (c.d.f.), denoted by $F_D(d)$. Polity duration D is defined as the length of time elapsed between the formation date (t_0) and termination date (t_f) for each polity, or $d = t_f - t_0$.

The hazard rate with respect to duration, denoted by $H_D(d)$ plays a central role in the theory of political uncertainty (Cioffi-Revilla 1998:chs. 2–4), and is defined by convention as the conditional probability that a polity will terminate in the next instant ($d + \Delta$) —in one of various modes, such as conquest, secession, or transformation—given that it has lasted until time d. Thus, H measures a polity's probability of imminent termination (akin to a state failure potential), a dynamic property linked to political stability, as given by the statistical odds against continued survival beyond a duration of d years. Formally, the hazard rate or termination intensity function is defined as

$$H(d) = \mathbf{Pr}(d < D < d + \Delta \mid D = d),$$

where Δ denotes "the next instant", to capture the notion of imminent fall. In other words, informally, the hazard rate measures the chances of a polity terminating if it lasts for one more year. The hazard rate function of a set of polities can be: (i) *constant* (i.e., the Poisson case, $\partial H/\partial d = 0$), (ii) increasing ($\partial H/\partial d > 0$), or (iii) *decreasing* ($\partial H/\partial d < 0$), depending on the stability features of the set of polities. Accordingly, from a dynamic perspective, stable or increasingly stable polities will show a decreasing hazard function for termination (because they have a declining probability of imminent termination, or increasing probability of enduring), whereas

unstable or increasingly unstable polities will show an increasing hazard function for termination (rising probability of imminent termination, or decreasing probability of enduring). *Thus, the qualitative form of the observed hazard function for a given set of polities—whether increasing, decreasing, or constant—shows the stable (decreasing) or unstable (increasing) nature of those polities in terms of their termination propensity.* This theoretical approach explains the stability of a political system (polity) in terms of the deeper dynamic forces at work on society and government, not simply in terms of the presence or absence of violence without regard to governance capacity.

Operationally, the hazard is measured by the empirical p.d.f. $p_D(d)$ and c.d.f. $F_D(d)$ obtained directly from the observed realizations $d_1, d_2, d_3, ..., d_n$, of the polity duration variable D. This yields

$$H(d) = p(d) / [1 - F(d)]$$

as the operational expression for estimating values of the empirical hazard function based on observed values of D (Kaplan-Meier estimate or product limit estimator). Note that the complementary c.d.f. is also the survival function, defined by $S(d) = \mathbf{Pr}(D > d)$.

Analysis

Univariate and survival analysis were the principal statistical procedures used (Cioffi-Revilla 1998; King et al. 1990). In this paper analysis is limited to the univariate implicit model of the hazard rate functions for formation T and duration D (i.e., type I models in the theory of political uncertainty), because data collection for more complex explicit multivariate models, $H(x_1, x_2, x_3, ..., x_m)$ with co-variates $\{x_1, x_2, x_3, ..., x_m\}$, such as territorial size, polity type, and others, is still in-progress and we will report on those models at a subsequent time. (In addition, we plan to examine different epochs within the overall time period of almost 2,000 years, as additional polities are added beyond the initial eighteen state-level polities reported in this paper.) The graphic form of the empirical hazard rate function $H(d)$ was also obtained to observe and evaluate the termination risk of Inner Asian polities.

Competing Hypotheses

The data and procedures just described allowed us to conduct a preliminary test of several sets of competing hypotheses concerning the following features of Inner Asian political evolution:

1. *Formation-termination process:* Comparable patterns vs. marked differences in formation and termination processes. Polity formations are expected to be Poisson-distributed (negative exponential density), based on standard political assumptions: the formation of a new polity is a rare event with low and constant probability ($H_{\text{formation}} = k$).

2. *Duration and stability:* The form of the empirical hazard function, based on observed durations, provides critical insights regarding the stability of polities (or lack thereof). Based on earlier studies (e.g., Bienen and van de Wall 1989; Cioffi-Revilla 1984), we also expected a constant or near-constant hazard for polity durations ($\partial H_D/\partial D \approx 0$).

We discuss the results of testing these and other competing hypotheses below, together with the presentation of our main empirical findings. However, we note the usual caveat for pre-modern polities: some tests may yield different results with future improvements in the basic data, so alternative explanations should not yet be rejected with the same confidence as with comparable data for modern polities or political systems (Landman 2008). We also used our analysis to evaluate the putatively significant effect that Chinese polities in the southern rim may have had on the steppe polities of Inner Asia (Barfield 1989, 2001; Di Cosmo 1999).

RESULTS AND DISCUSSION

Polities of Inner Asia

Table 1 reports preliminary findings for the set of Inner Asia polities in this study, including polity name, dates of formation and termination, maximal territorial size *S*, and total duration *D*. We report this initial dataset so others may use it and improve upon it as new, raw information sources become available. While we also report size and type, the emphasis here is on the time variables only, leaving the analysis of size (Alesina and Spolaore 2005) and other variables for subsequent papers. Similar to other long-range comparative social science research projects (e.g., Cioffi-Revilla and Lai 2001; Taagepera 1997; Wilkinson 2000; Wright 1942), the Mason-Smithsonian Project on Inner Asia will disseminate an extended dataset published through the Harvard-MIT Data Center. Polity names are given in the modern Chinese pinyin romanization; equivalent Wade-Giles names are used in earlier sources. All durations and years are rounded to the closest whole number.

Table 1. Polities of Inner Asia from 200 B.C. to A.D. 1757.

Polity name	Dates	Size *S* [km^2]	Duration *D* [years]	Type	Size accuracy [%]
1. Xiongnu	199 B.C.-A.D. 155	4,031,200	354	P	10
2. Wu-Huan	100 B.C.-A.D. 218	400,000	317	P	20
3. Xianbei	A.D. 155-235	4,500,000	80	P	10
4. Jujan	A.D. 380-555	4,031,200	175	P	10
5. Toba-Wei	A.D. 386-581	1,488,700	195	P	10
6. S. Ch'i	A.D. 479-502	2,147,000	23	S	10
7. Turk I	A.D. 552-630	2,106,000	78	P	20

8. Turk II	A.D. 683-744	2,106,000	61	P	20
9. Bohai	A.D. 698-926	438,000	228	S	10
10. Uighur	A.D. 745-840	1,466,200	95	P	10
11. Khitan/Liao	A.D. 907-1125	2,535,800	218	P	10
12. Xi Xia	A.D. 990-1227	637,900	237	S	10
13. Khwarazm	A.D. 1098-1231	4,014,000	133	P	10
14. Jurchen Chin	A.D. 1115-1234	1,716,000	119	S	10
15. S. Sung	A.D. 1127-1279	1,733,600	152	S	10
16. Kara-Khitai	A.D. 1143-1211	2,511,900	68	P	10
17. Mongol	A.D. 1206-1368	29,491,900	162	P	10
18. Zunghar	A.D. 1625-1757	3,600,000	132	P	20

Note: Type: P = nomadic pastoralist society; S = sedentary.
Source: Compiled by the authors based on sources cited.

As reported in Table 1, we identified a total of 18 Inner Asian polities for which it was possible to measure date of formation, termination, and maximal size with acceptable accuracy ($N = 18$ cases). Although the size of the dataset is statistically small, this is a population of state-level polities and not a sample. Previous studies have shown that it is possible to conduct a variety of analyses and test models on a small data set if the data are reasonably well-behaved (Cioffi-Revilla 1998: chs. 2–4); otherwise the results are not meaningful or robust. Polities in Table 1 comprise all those presently known for the region, including some of the largest empires in world history—e.g., the Mongol Empire. At its maximal size the Mongol Empire actually extended well beyond Inner Asia, from the China Sea to the Mediterranean Sea. All other polities in the set were significantly smaller than the Mongol Empire but comparable to large modern countries with territorial size in the range of 10^6 km^2 or several Mkm^2.

Polity Formation and Termination Processes

Results show that most polities formed during the second half of the first millennium (ca. 500 to 1000 CE), a period of great turbulence and relative fragmentation preceding the formation of Khwarazm, the second largest polity (> 4 Mkm^2). It was followed by several smaller but significant polities (Jurchen, S. Sung, and Kara-Khitai) that preceded the formation of the Mongol Empire (ca. 30 Mkm^2). The 13th century is also marked by the largest number of polity terminations, concurrent with the Mongol expansion and consolidation. Formation and termination processes are graphically summarized in Figure 2.

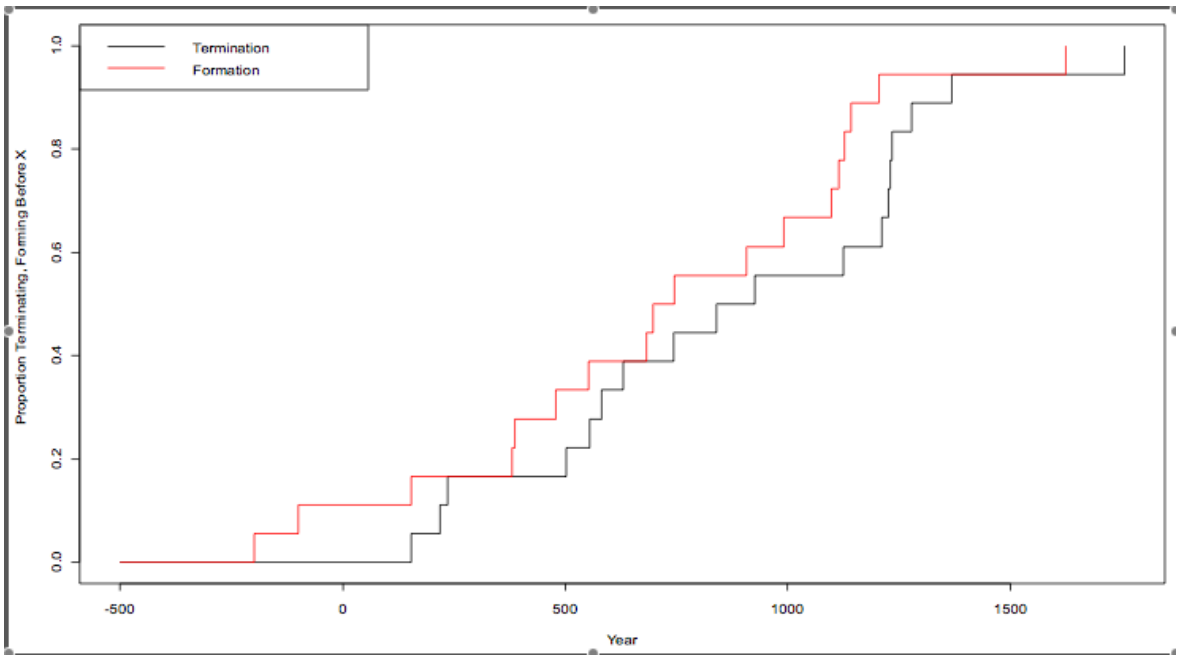

Figure 2. Combined formation (red) and termination (black) processes of polities in Inner Asia, 500 BCE to 1757 CE. Note the multipolar period with several contemporary polities during the 1300s CE, otherwise the system consists of one or at most two polities. *Source:* Prepared by the authors.

Results also show that—except for one intriguing case—the distribution of time between polity formations T is approximately exponentially, $p(t) = k\, e^{-kt}$ (p.d.f.) and $F(t) = 1 - e^{-kt}$ (c.d.f.), with nearly identical (< 1%) first moments: mean = 107 years ≈ 108 years = variance, so $H(t) = k = 1/\mu \approx 0.009$ formations/year. This is consistent with a Poissonian process of rare events (low and constant probability per year), as is typical of many temporal patterns in political processes. (The same is not true of *size* patterns, where other distributions, such as Weibull or power laws, are often more common.) Hence, the hazard rate function for formations was also found to be constant: $H(t) = k$.

The intriguing case in the data set is the inter-formation period between Mongol and Zunghar polities, between 1206 CE (rise of Gengis Khan) and 1625 CE (formation of the Zhungar polity). This 419-year period is exceptionally long relative to the overall distribution, indicating a somewhat "fat" or "heavy" tail. (This type of discontinuity is also called a "dragon tail", because of the lack of observations separating the last quantile from the next observed lower quantile; Cioffi-Revilla 2008:202.) This long interval is also consistent with the Mongol Empire having had an extraordinary effect on the long-range pattern of polity formations in Inner Asia; no other polity came close to having such an impact. Once the Zhungar polity formed, however, it was effective in standing up to China (Qing dynasty, 1644–1912 CE). Note that the standard analysis

eliminates outliers such as these very long durations, thereby missing the potentially important heavy tail property.

Polity Duration Process

The first moments of the distribution of polity duration were $\mu = 157$ years and Var = 89.2 years^2 (s.d. = 9.4 years), indicating a hypo-exponential process with very low variability (s.d./$\mu \approx$ 0.06) and, consequently, rather high regularity. Results from the empirical survival function (Figure 3a) yield a half-life $h \approx 150$ years, or about the same as the mean duration. These results are roughly comparable to those of modern polities in the global system (e.g., Gleditsch and Ward 1999).

Interestingly, the distribution of polity duration D approximates a Rayleigh distribution, ranging from 23 years (S. Ch'i polity) to 354 years (Xiongnu polity) and half-life $h \approx 150$ years. This finding is rare and noteworthy, especially because mathematically the Rayleigh distribution is a special case of several other important distributions (Weibull, Rice, Chi, Maxwell-Boltzmann). Figure 3b shows observed values of the nearly-linear ramp-like hazard function that is characteristic of the 2-parameter general Weibull model for the special case of the Rayleigh distribution. Other reports of the Rayleigh distribution do not seem to be present in the extant literature.

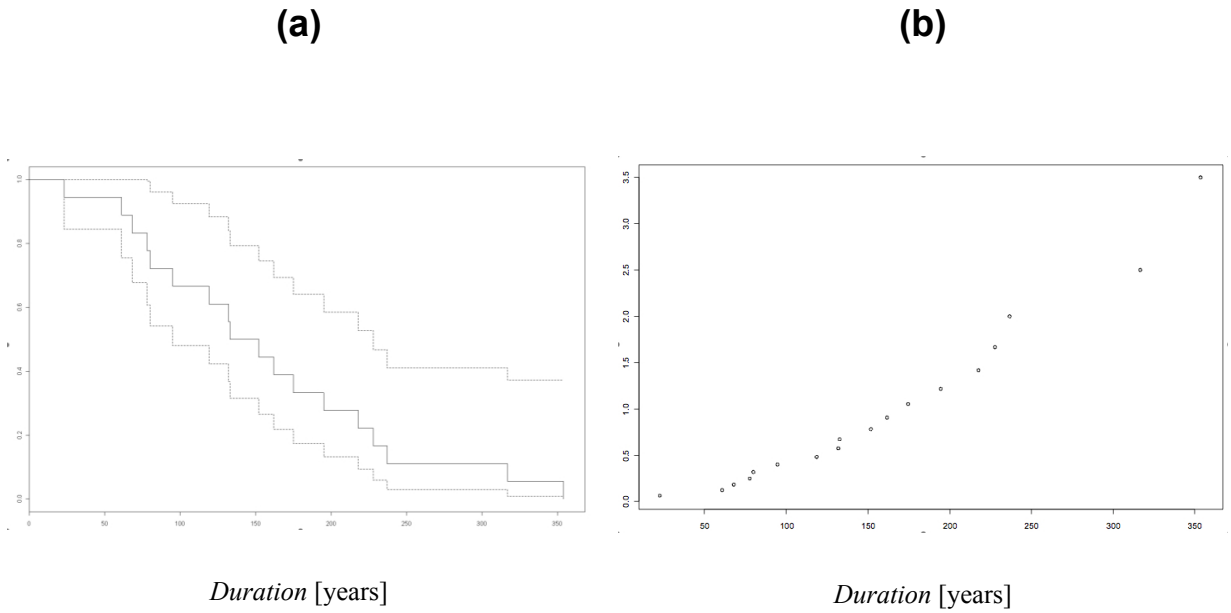

Figure 3. (a) Survival function $S(d)$ and (b) hazard rate function $H_D(d)$ of the distribution of polity durations in Inner Asia. *Source:* Prepared by the authors.

The three main results from the empirical hazard analysis of duration are the *increasing rate*, the approximately *linear* form, and the *strict monotonicity*. The increasing hazard rate means that Inner Asian polities were fundamentally unstable (as opposed to stable or stationary): they were more likely to terminate as time went on (as opposed to less likely), consistent with mounting difficulties in solving collective action problems in domestic and foreign policy. Domestically, the multi-ethnic composition of these polities posed many governance challenges, as did constant external pressures from China along the southern frontier. (The first Inner Asian polity, the Xiongnu, was established by a 3rd century BCE nomadic society that was expelled from the Ordos region as a direct result of a ruthless military campaign by the Chinese army—a state-sponsored action of ethnic cleansing that lasted decades.)

Increasing hazard rates associated with political processes are not rare (see, e.g., Cioffi-Revilla 1998: ch. 4), but actually measuring a linear or approximately linear rate, such as that shown in Figure 3b resembling a Rayleigh distribution, is rare. More frequently, empirical hazard rates are neither linear nor perfectly monotonic. Rather, they are usually nonlinear (concave or convex) or non-monotonic (e.g., U-shaped). The fact that the hazard rate of Inner Asian polities is both linear and monotonic (i.e., Rayleigh-distributed) means that the forces acting on these polities, both endogenous (societal) and exogenous (foreign), operated as a remarkably steady or uniform process from formation to termination.

The finding concerning the linear and monotonic hazard rate seems remarkable for another reason: the small size of the data set ($N = 18$ cases). This finding indicates a very well-behaved pattern, uncommon in long-range political processes evolving on such a long time-scale where technological, societal, or environmental changes can introduce significant heterogeneity. It remains to be seen whether a larger dataset will confirm or invalidate this finding.

The Rayleigh distribution observed for polity duration is also a non-equilibrium distribution, with upper tail fatter or heavier than a normal or Gaussian distribution. This means that Inner Asian polities *could* occasionally last longer than "normally" expected, as some in fact did (Xiongnu, Wu-Huan, Bohai, Khitan, Xi Xian). The same is not true for polity formations, which have exponential distribution. This non-equilibrium property associated with the heavy tail is also consistent with the inherent instability of the increasing hazard rate for duration.

Finally, it was mentioned at the outset that a second important motivation for this analysis—besides the intrinsic scientific value—came from the need to obtain empirical validation targets or real world benchmarks for testing and calibrating (technically "verifying") new agent-based simulation models of Inner Asian polities (e.g., Cioffi-Revilla et al. 2006, 2008) within a broader project on long-term adaptation and socionatural complexity. These results provide additional metrics and specific patterns that the simulation models must now match. Additional such patterns and statistics ("stylized facts", as called in economics) are necessary and will be reported as analysis continues and new cases are added to the initial data set investigated in this paper.

SUMMARY

The polities of the Inner Asian steppes are among the most influential in world history and among the least investigated by political and social scientists. This paper reported initial findings from a preliminary data set aimed at systematically recording formation, duration, and other measured features of these polities over a long time span; sufficiently long to also record environmental, technological, and cultural change and adaptations. The main findings consist of (1) the exponential (Poisson) or near-exponential process reported for polity formations, consistent with most earlier studies for other polities, and (2) the Rayleigh-type hazard function for polity durations, which represents a new and arguably intriguing finding due to its rareness and special properties—monotonically increasing probability of instantaneous termination—as opposed to more common forms reported in the extant literature. The main implications of these findings are, in terms of polity formations a confirmation of previous findings, but in terms of polity durations a new pattern suggesting relentless destructive pressures from internal and external forces combined. Further analysis will be necessary to more fully understand these patterns in a proper theoretical context—whether through the theory of political uncertainty or other explanatory frameworks. These findings and their implications provide significant progress in terms of offering new target data and patterns for testing and validating the emerging generation of agent-based simulation models .

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