

# Survival of the Weakest: Why the West Rules\*

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## Abstract

We study a model of institutions that evolve through conflict. We find that one of three configurations can emerge: an extractive hegemony, a balance of power between extractive societies or a balance of power between inclusive societies - the latter being most conducive to innovation. As extractive societies are assumed to have an advantage in head to head confrontations we refer to this latter possibility as the survival of the weakest. Our contention is that the reason that the West “rules” can be traced back to two events both taking place in China: the invention of the cannon, which made possible the survival of the weakest in Europe; and the arrival of Genghis Khan, which led to the survival of the strongest in China.

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## 1. Introduction

There are as many theories of “why the West rules,” which is to say, why the industrial revolution took place in the West rather than, say, China, as there are historians and economists.<sup>3</sup> One element on which there seems to be agreement (see, for example, Landes (2003), Lin (1995) and Liu and Liu (2007)) is that competition between relatively inclusive institutions such as those in Western Europe is more likely to generate innovation - and an industrial revolution - than the relatively extractive hegemonies found in China.<sup>4</sup> Accepting this basic conclusion we ask: why was there competition between relatively inclusive institutions in Europe while in China we find an extractive hegemony? Why did India - made up of competing societies not an extractive hegemony - generate relatively little innovation? These are the main questions addressed in the paper.

Across history we observe a wide array of different institutions both across space and time. There are competing societies in some times and places and hegemonies in others, with political systems ranging from quite democratic to relatively autocratic - inclusive or extractive in the terminology of Acemoglu and Robinson (2012). Some, such as Diamond (1998), have argued that the geography of Europe is more favorable to competing societies than China. This not only leaves unanswered the question of India, but a careful examination of a map by Hoffman (2013) shows that the premise cannot be taken for granted.<sup>5</sup> We think instead that answers to questions about hegemony and competition among institutions must be found in models of institutional evolution. Our starting observation is that historically people and institutions have more often spread through invasion and conflict than through peaceful change.<sup>6</sup> In addition, significant institutional change has most often arisen in the aftermath of the disruption caused by warfare and other conflicts between societies. Consequently, we are led to a theory of institutional change that arises from conflict, as in Rosenthal and Wong (2011), and not, as in Bisin and Verdier (2001) or Greif and Tabellini (2010), from internal evolution within a single society.<sup>7</sup>

This paper presents a simple model of institutions that evolve through conflict. We find that one of three configurations can emerge in the long run: an extractive hegemony, a balance of power between extractive societies, or a balance of power between inclusive societies.<sup>8</sup> As extractive

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<sup>3</sup>Many readers will note a reference to the recent book Morris (2010) in our title. McNeil (1963) and Cipolla (1965) are some earlier contributions to what is now an extensive literature.

<sup>4</sup>Why the character of the industrial revolution was different than earlier episodes of innovation we do not address - for discussion of this issue see Mokyr (2002) and Dutta et al (2018).

<sup>5</sup>Hoffman (2013) argues that a key difference between Europe and China was the role of the Catholic Church in Europe - it plays a role in his theory similar to the outsiders in ours.

<sup>6</sup>This was apparently true even in the earliest of times. Bowles and Choi (2013) argue that farming was initially an inferior technology to foraging and became widespread not because it was eagerly adopted by imitators, but rather because farmers had “formidable military technology” that enabled them to successfully encroach on foragers.

<sup>7</sup>There are several theories specific to Europe and China that combine internal evolution with conflict. All ignore India and none engage with the existence of competing extractive states - a situation that constitutes the bulk of Indian history and substantial periods in both China and Europe. One such theory is Dincecco and Wang (2018) who argue that fragmented states naturally tend towards greater inclusiveness. Another is Ko et al (2018) who argue that the unidirectional threat of outsiders in China is responsible for hegemony there. India, however, also faced a unidirectional threat.

<sup>8</sup>We should note that there is an extensive literature in international relations to the effect that a balance of power

societies are assumed to have an advantage in head to head confrontations<sup>9</sup> we refer to the latter possibility as the survival of the weakest. In short, our contention is that the reason the West “rules” is that the invention of the cannon made possible the survival of the weakest in Europe - leading to competing inclusive societies - while the arrival of Genghis Khan led to the survival of the strongest in China - leading to extractive hegemony.

Since extractive institutions generally levy higher taxes and have larger armies, if evolution is driven by conflict why do these “strong” extractive institutions not predominate over “weaker” inclusive institutions? In our earlier work Levine and Modica (2013) we suggested that the answer was to be found in the presence of outsiders: while models of evolutionary conflict generate a tendency towards hegemonies, interfering outsiders such as English or Central Asians made it difficult to form hegemonies in Europe and India. Unfortunately, that theory left unanswered the question of what happens when hegemonies do not form and why the record of innovation in India is so much different than that in Europe.

Here we re-examine the evolutionary conflict model. We simplify the model by omitting the details of conflict found in Levine and Modica (2013) and strengthen it along the lines suggested in Levine and Modica (2017) by adding a “home field advantage” for a society defending its own land. In this model two societies with two possible institutions - inclusive or extractive - compete through conflict. Each society has two groups - commercial elites and military elites<sup>10</sup> - and conflicts occur based on the incentives of these groups. In a head to head contest between an extractive and inclusive society the extractive society is assumed to be more likely to prevail. Never-the-less we show that competition between inclusive societies may persist in the long run. The circumstances that favor this are strong outsiders - as in Levine and Modica (2013) - and a military technology in which strong defensive forces are important. Strong outsiders are needed because they favor a balance of power over a hegemony. Military technology on the other hand determines the economic incentives of the groups in each society. Strong defensive forces are needed when fixed fortifications become less effective, and in this case the incentives of the military elites to establish an extractive society decrease relative to the incentives of the commercial elite to fight for an inclusive society.

After we develop the basic model and prove our main theorem characterizing stochastically stable states (in the sense of Young (1993)) we apply it to see how well our two variables - outsiders and military technology - explain the history of hegemony and institutions (and by implication innovation). We claim that an important difference between early medieval military technology

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is a natural outcome of military competition. From a theoretical point of view this is difficult to justify since even under mild assumptions absent some sort of geographical barriers there is a natural tendency towards hegemony (see Levine and Modica (2016)). From an empirical point of view our data rejects the idea that a balance of power is typical or normal and using data from much earlier periods Wohlforth et al (2007) also decisively reject this idea.

<sup>9</sup>We will explain why this assumption is consistent with the literature that argues that democracies are more effective than autocracies at conflict.

<sup>10</sup>During pre-industrial revolution period we are interested in the masses - the peasant farmers - never had political power for any substantial length of time in any society. There were peasant revolts over high taxes - to this extent we count them with the commercial elites. There were also landed elites whose interests were much the same as the military elites.

and later military technology is that the advent of the cannon made it impossible to defend with little effort behind a secure wall and made defense a far more demanding endeavor. We think that this, together with the presence of strong outsiders, made possible the survival of the weakest in Europe. On the other hand, we will argue, the arrival of Genghis Khan and the building of the Mongolian Empire which weakened outsiders in China was decisive for the development of the extractive hegemonies which prevailed there. In India on the other hand outsiders were strong but modern military technology did not arrive until the British advent, and this favored balance of power among extractive institutions.

There are recent papers by Dziubinski, Goyal and Minasch (2021) and by Bilancini, Boncinelli and Marcos-Prieto (2022) that have theoretical results with a flavor similar to ours. Dziubinski, Goyal and Minasch (2021) model closely what happens between societies studying the network over which conflict takes place. Our model is more detailed about what happens within societies but is more abstract in what happens between societies. Bilancini, Boncinelli and Marcos-Prieto (2022) take a more abstract approach in order to focus more clearly on how the type of conflict leads to hegemony or balance of power. In Dziubinski, Goyal and Minasch (2021) the emphasis is on whether the technology of conflict is rich or poor rewarding, while in Bilancini, Boncinelli and Marcos-Prieto (2022) it is on whether stronger or weaker groups are more likely to initiate conflict. These are similar in that we may think of richer groups as stronger. In Dziubinski, Goyal and Minasch (2021) rich rewarding technologies leads to incessant conflict and hegemony, and the Bilancini, Boncinelli and Marcos-Prieto (2022) result is similar in that a balance of power can be sustained only when weaker groups are likely to initiate conflict. Neither of these models matches perfectly with our study of similar societies contending in the face of outsiders protected by one-way barriers, but as the periphery is poorer than the core our result that a weak periphery means hegemony has a flavor similar to their results.

## 2. The Model

Two societies (or countries) with the same technology contend over land (and the people, physical capital, and other resources that reside there). There are two units of land, one for each society. There are two possible configurations: a *balance* of power in which each society occupies its own unit of land and *hegemony* in which one society, the *occupier*, occupies both units of land, in which case the other society is referred to as the *occupied*.

There are two groups in each society: the *commercial elites* and the *military elites*. There are two types of institutions, inclusive institutions  $w$  and extractive institutions  $s$ . Roughly speaking with inclusive institutions the commercial elites have the upper hand, while with extractive institutions the military elites have the upper hand. As will be made formal shortly, what characterizes a type of institution is the extent of a transfer from the commercial elite to the military elite. Depending on circumstances either society may have either type of institution. There are five possible states of the system:  $z \in Z = \{w, s, ww, sw, ss\}$ . The first two correspond to hegemony in which the occupier has inclusive and extractive institutions respectively, and the remaining three correspond

to a balance of power in which both have inclusive, one has extractive and the other inclusive, or both have extractive institutions.

Conflict between societies takes place over time  $t = 1, 2, \dots$ . At the beginning of period  $t$  there is a status quo given by the state from the previous period  $z_{t-1}$ . A conflict game between the two groups in the two societies is played and the outcome determines the state  $z_t$  in the current period. The particular game depends upon the status quo  $z_{t-1}$  and a iid random shock. It takes place in two stages. In the first stage only one of the four groups is *active* and may decide to initiate a conflict to achieve a particular *goal*. The decision is based on a stochastic utility shock. If the active group is part of an occupied society the conflict is a *rebellion* to liberate their land and the goal is to install particular institutions there; thus if the rebellion is successful the hegemonic state will transit to a balance of power. If the active group is part of a balance of power the conflict is to *attack* the other society and the goal is to occupy their land; in this case success will result in hegemony. If the active group chooses not to initiate a conflict the status quo remains unchanged and  $z_t = z_{t-1}$ . If the active group initiates a conflict a second stage simultaneous move game is played. The active group initiating the conflict is designated as the *aggressor* and one group from the opposing society is the *defender*. Each simultaneously decides the level of effort to devote to the conflict and these effort levels stochastically determine the new state. All of the groups are myopic in the sense that they care only about the consequences of their actions in the current period.<sup>11</sup> All random events are iid conditional on the state: they do not otherwise depend on history.

### *Outsiders*

In addition to the four decision making groups of *insiders* there are a number of *outsiders* whose strength relative to the insiders is denoted by  $\eta > 0$ . These outsiders do not make decisions but help determine in an important way the environment in which conflict takes place. They complete the global picture of the context in which the two societies contend: they represent societies and people outside of the model who are protected from the insiders. Outsiders may be protected by asymmetrical geographical barriers or by superior force. They represent forces that may be able to “get at the insiders” but cannot easily be “got at by the insiders.” Both geography and technology matter: the English channel was not a barrier to continental invasion given English and Roman technology in Julius Caesar’s time. After 1400 naval technology and standing navies favored strongly the short coastline of England over the long coastline of continental Europe so that England could interfere easily in the continent but could not so easily be invaded from the continent. Hence in the centuries long conflict between France and Austria/Germany the country of England was effectively an outsider.

Our basic hypothesis is that outsiders are disruptive of hegemony but supportive of a balance of power. The motivation for this is simple: unlike in an area where multiple powers coexist and are possibly in conflict with each other, a hegemonic power is stronger, and notwithstanding the possible barriers or the superior force of the outsiders it may pose a more dangerous threat to them.

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<sup>11</sup>We comment on this assumption in Section 6.

As discussed in detail in Levine and Modica (2017) this is in broad accordance with historical facts. The most notable example is the role of England in maintaining a balance of power on the continent, which is well documented.

Outsiders have been disruptive to hegemony in a variety of ways. Uganda provided a refuge rebel Tutsi forces who regrouped and in 1994 invaded Rwanda and overturned the Hutu hegemony along with the genocide it incited. In other occasions outsiders have provided direct support in the form of weapons or even troops. For example, in the final battle of the US revolutionary war in which the British were decisively defeated the rebel force consisted of 11,000 US soldiers - together with 8,000 French soldiers and crucially the support of a French naval fleet. Finally, and in many ways most important, the outsiders have often been opportunistic and have taken advantage of a military committed in a distant war to raid or otherwise stab an invader in the back. A classical example was Napoleon's march on Moscow in 1812: as soon as his army was committed Wellington invaded the French-dominated Spain.

We now describe in greater detail the game and payoffs: the model is simple and stylized. Subsequently, we analyze the robustness of the main results to departures from this basic model.

### *The Initiation of Conflict*

In a balance of power each society has an equal chance of being active. In a society with inclusive institutions the active group is the commercial elite. In a society with extractive institutions the active group is the military elite. The goal is to occupy the land belonging to the other society and install the active group's institutions there.

In an inclusive hegemony the active group is the occupied commercial elite. In an extractive hegemony the active group is the occupied military elite. There are two possible goals. With probability  $1 > G(z_{t-1}) > 0$  the goal is to revolt and install inclusive institutions and with the remaining probability the goal is to revolt and install extractive institutions. The probability may depend upon current institutions: it may be that when the commercial elites are calling the shots it is more likely that the goal will be revolt to inclusive institutions than when the military elites are calling the shots. Notice that we assume an element of culture inherited from the occupying power: groups in the occupied territory are assumed to operate under the institutions imposed on them by the occupier. In a society run by generals it is generals who are most likely to rebel. In a society where the support of the commercial elites is essential a revolt is only possible with their support. We refer here, in particular, to the fact that in the process of decolonization the support of the commercial elites played an important role despite the fact that in precolonial times they had little voice. Notice, however, that a revolt may adopt either type of institution depending upon the goal. It is possible, for example, that the commercial elites would agree to extractive domestic institutions in return for liberation from foreign domination by inclusive institutions.

Once the active group and goal are determined an iid random utility shock  $\tilde{u}$  occurs: this is standard for a random discrete choice model. The active group then decides whether or not to initiate conflict - to attack or revolt. If the active group decides not to initiate a conflict the game ends and the state remains unchanged. In this case  $z_t = z_{t-1}$  and the utility of all groups is that

in the status quo. If the active group decides to initiate conflict the utility of the active group is increased by  $\tilde{u}$ , the current state  $z_t$  is randomly determined through conflict resolution, and the utility of all groups is determined by the current state (as specified shortly) minus the costs of conflict plus the utility shock for the active group.

As conflict - at least in the sense of an all-out revolt or attempt to occupy a foreign nation - is rare, we assume that the utility shock is with high probability negative. If  $\tilde{u}$  is very negative the active group will not choose to initiate a conflict, so it is only the upper tail of this random variable that matters. We assume this has an exponential form given by three parameters  $U > 1$ ,  $0 < P < 1$  and  $\sigma > 0$  so that if  $v \geq -U$  then  $\Pr(\tilde{u} \geq v) = Pe^{-\sigma(v+U)}$ . Note that  $\Pr(\tilde{u} \geq -U) = P$ . With probability  $1 - P$  the shock is smaller than  $-U$  and no conflict is initiated. The parameter  $\sigma$  is a scale parameter for the utility shock distribution. If it is large the probability of a shock much bigger than  $-U$  is very small. We will be interested in the case in which  $\sigma$  is large.

### *Conflict Resolution*

Next, we describe the simultaneous move game following the decision of the active group to initiate a conflict. If conflict takes place the active group - now called the *aggressor* - determines the level of effort  $1 \geq x_a \geq 0$  to devote to the conflict. In a balance of power the defender is the commercial elite if the society under attack has inclusive institutions and the military elite if the society under attack has extractive institutions. In an inclusive hegemony the defender is the occupier commercial elite; in an extractive hegemony the defender is the occupier military elite. The defender determines a level of effort  $1 \geq x_d \geq 0$  to devote to the conflict. Each contestant group  $i \in a, d$  faces a quadratic cost of effort provision  $C(x_i) = (\gamma/2)x_i^2$  where  $\gamma \geq 1$ . Note that the two groups who are neither aggressor nor defender do not bear any cost of conflict - although if they did it would not matter since they have no decision making power. Note also our base assumption that every society regardless of its type faces the same cost of raising resources. Our explanation of social outcomes - in contrast to Hoffman (2013)'s theory of the great divergence after 1600 - does not rest on the idea that there are systematic differences in the cost of raising resources due to social organization.<sup>12</sup>

Let  $\zeta \in \{h, b\}$  be an indicator of whether the state is hegemonic or a balance of power. We analyze a contest in which the two groups have roughly similar military technology. Hence the probability the aggression succeeds depends on the resources committed by the contestant groups and is given by a conflict resolution function<sup>13</sup>

$$\pi(x_a, x_d) = \Pi_\zeta(\eta) + \alpha(x_a - [(1 - \varphi)x_d + \varphi])$$

where  $0 \leq \varphi \leq 1$ ,  $\Pi_\zeta(\eta) > 0$  is continuous with  $\Pi_h(\eta)$  strictly increasing in  $\eta$ ,  $\Pi_b(\eta)$  strictly decreasing in  $\eta$  and  $\alpha > 0$ . The assumption on the dependence of  $\Pi_\zeta(\eta)$  on  $\eta$  is consistent with our view

<sup>12</sup>The assumption can be relaxed, we provide details in the Web Appendix.

<sup>13</sup>See Hirshleifer (2001) and Hausken (2005) for a broader discussion of the use of conflict resolution functions.

of that outsiders help rebels chances of success -  $\Pi_h(\eta)$  increasing - but hurt those of an aggressor in a balance of power -  $\Pi_b(\eta)$  decreasing. We assume, moreover, that  $\max\{\Pi_h(\infty), \Pi_b(0)\} + \alpha < 1$  and  $\min\{\Pi_h(0), \Pi_b(\infty)\} - \alpha > 0$  so that regardless of the choices of effort and value of  $\varphi$  the probability of success is positive but not certain. Finally, we assume the boundary condition that  $\Pi_h(\infty) > \Pi_b(\infty)$  and  $\Pi_b(0) > \Pi_h(0) + \alpha$ . The boundary assumption on  $\Pi_\zeta$  says that outsiders are potentially important in the sense that (given efforts) if they are strong enough then rebels have a better chance of success than balance of power aggressors and if they are weak then balance of power aggressors have a better chance of success than rebels. Notice the implication that there is a unique value  $\eta^*$  such that  $\Pi_h(\eta^*) = \Pi_b(\eta^*)$ .

The parameter  $\alpha$  measures the sensitivity of the outcome to the differential effort of the two combatants. We have assumed that this is not too large. The parameter  $\varphi$  measures the sensitivity of the outcome to defensive effort. The coefficient on  $x_d$  is  $(1 - \varphi)x_d + \varphi$ , a weighted average of the defensive effort and 1. Our interpretation is that  $\varphi$  measures the value of fixed fortifications. The reason for this is that the benefit of fortifications is that they enable a small army to hold off a much larger force. In Masada in 66 CE, for example, a group of roughly 1,000 men women and children held off the Roman Empire for about seven years before being overcome by a military force of around 15,000. On the other hand, effective fortifications reduce the benefit of a larger defending force: it is unlikely that a Jewish force of 2,000 or 3,000 would have had much more success against the Romans than 1,000. Here the effectiveness of defense is measured by  $(1 - \varphi)x_d + \varphi$  where  $\varphi$  captures the basic idea that with effective fortifications the defense is strong but not particularly sensitive to defensive strength. Hence our interpretation of  $\varphi$  as the effectiveness of fortifications.

If the aggression fails the status quo remains unchanged,  $z_t = z_{t-1}$  and the utility of all groups is that in the status quo less the effort and plus the utility shock. If the status quo is a balance of power and the aggression succeeds the new state is a hegemony with the institutions of the aggressor. If the status quo is a hegemony and the aggression succeeds the new state is a balance of power in which the defender institutions are unchanged and the aggressor institutions are those determined by its goal. In all success cases the utility of all groups is that of the new state less the effort and plus the utility shock.

### *Economic Incentives: Transfers and Utility*

As will be clear from the analysis of the model it is economic incentives of the groups, not just military technology or geographical configuration, which drive the results. They are modeled in a simple way as a transfer from the commercial to the military elite, as spelled out presently.

In addition to the random utility shock and conflict costs the utility of groups is determined by the current state  $z_t$ . From the economic point of view the two groups in each society are characterized by a *transfer* of resources from the commercial elites to the military elites.<sup>14</sup> Extractive

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<sup>14</sup>We note that transfers are distinct from taxes. An inclusive society might have taxes as high as an extractive society, but as long as more of the benefit of those taxes goes to the commercial elites the resulting transfer is low. Evidence that transfers are lower in an inclusive society for more modern historical data can be found in Stasavage

societies are defined so that this transfer is larger than in inclusive ones. So there are two possible transfer levels representing a transfer from the commercial elites to the military elites on each unit of land; we normalize high transfers to 1, and low transfers are  $0 < \tau < 1$ . In a balance of power the military elites receive the transfers from their own land, so for example in a  $w$ -type society we can write the transfer vector as  $(-\tau, \tau)$ . In hegemony the occupier military elites receive the transfers from both units of land (so the occupied military elites receive nothing); high transfers are always taken from the occupied commercial elites; and the occupier commercial elites pay  $\tau$  in an inclusive hegemony and 1 if the hegemony is extractive; so for example in an extractive hegemony the transfer vector is  $(-1, 0)$  in the occupied society and  $(-1, 2)$  for the occupiers (the occupier military elites collect all the transfers). The transfers are summarized in the following table:

		type of society	
		$s$	$w$
configuration	balance of power	$-1, 1$	$-\tau, \tau$
	hegemony: occupier	$-1, 2$	$-\tau, 1 + \tau$
	hegemony: occupied	$-1, 0$	$-1, 0$

### *Equilibrium*

An equilibrium is the stochastic process in which a Nash equilibrium of the conflict game occurs within each period. We will show that this equilibrium is unique and depends only on the state  $z$  in the previous period. Likewise, the probability of the current state conditional on the within period equilibrium depends only on the previous state. Hence an equilibrium is a Markov process on the state space  $Z = \{w, s, ww, sw, ss\}$ . From what we have seen the possible transitions other than remaining at the status quo are the following:

$$w \rightarrow ww, sw \quad s \rightarrow ss, sw \quad ww \rightarrow w \quad sw \rightarrow s, w \quad ss \rightarrow s$$

Notice that there is a positive probability of remaining in place and a positive probability of each of the eight feasible transitions. Hence the process is aperiodic and ergodic. This means that every state is visited infinitely often and there is a well-defined long-run frequency with which that state occurs. We denote this unique ergodic probability distribution over the state space by  $\mu_\sigma$ . From Young (1993) we also know that as  $\sigma \rightarrow \infty$  the ergodic distributions  $\mu_\sigma$  have a unique limit  $\mu$ . Those states that have positive probability in the limit distribution  $\mu$  are called *stochastically stable*. When  $\sigma$  is large and there is a unique stochastically stable state this means it has a frequency near one and the other states a frequency near zero. While the ergodic nature of the Markov process implies that with probability one there will be a departure from the stochastically stable state, the amount of time before that departure will be relatively long and the length of the departure will be relatively short. In short, stochastically stable states are those which are observed “most of the

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(2011) and Dincecco (2011).

time” when  $\sigma$  is large. As we are interested in the case where  $\sigma$  is large - that is serious conflict is infrequent - we will characterize the stochastically stable states.

### 3. Stochastic Stability

We now state the main result of the paper, which characterizes “typical” institutional configurations. As to the “survival of the weakest”, as anticipated in the introduction it emerges as a long run possibility with strong outsiders and ineffective fortifications. The role of the  $\varphi$  parameter is more subtle than it may appear: it is true that as it becomes lower more defense effort is needed, but it is equally true that the probability of success with equal forces increases - because  $\pi(x, x) = \Pi_\zeta(\eta) - \alpha\varphi(1 - x)$  - so the result is not due to the mechanics of conflict directly. Rather, technology affects the economic incentives to subvert the status quo order in the conflict subgame, and these turn out to be weaker with low  $\varphi$ .

**Theorem 1** (Main Theorem). *For generic values of the parameters there is a unique stochastically stable state. Only  $s, ss, ww$  can be stochastically stable;  $w$  and  $sw$  cannot. There exist an  $\eta^* > 0$ , a  $0 < \tau^* < 1$  and a strictly decreasing function  $0 < \varphi_\tau < 1$  such that*

1. *if  $\tau > \tau^*$  or  $\varphi > \varphi_\tau$  then  $ww$  is not stochastically stable, with  $s$  stochastically stable for  $\eta < \eta^*$  and  $ss$  stochastically stable for  $\eta > \eta^*$*
2. *if  $\tau < \tau^*$  and  $\varphi < \varphi_\tau$  then  $ss$  is not stochastically stable and there is a positive continuous strictly decreasing function  $\eta(\varphi) \leq \eta^*$  with  $s$  stochastically stable for  $\eta < \eta(\varphi)$  and  $ww$  stochastically stable for  $\eta > \eta(\varphi)$ .*

We prove the result later in the section. To parse this result, consider first the case  $\tau > \tau^*$ , which is to say inclusive institutions do not offer such a great advantage over extractive institutions. In this case we find that inclusive institutions are never stochastically stable. Roughly: the commercial elites are unwilling to make much effort to defend inclusive institutions that are not all that inclusive. We do not find this fact terribly interesting: there are institutions of varying degrees of inclusiveness - and our focus naturally is on whether sufficiently inclusive institutions may survive. Nevertheless this result is interesting: it implies that we will not often see “somewhat inclusive” institutions, only extractive or “strongly inclusive” institutions. Hence for the remainder of the paper we are going to focus on the case  $\tau < \tau^*$ , that is “strongly inclusive” institutions and ask how they fare against extractive institutions.

With  $\tau < \tau^*$  a careful reading of theorem 1 shows that if  $\eta < \min_\varphi \eta(\varphi)$  then only extractive hegemony is stochastically stable. If there are sufficiently few outsiders then we should generally observe extractive hegemonies - and this is true regardless of military technology. By contrast with stronger outsiders, that is, larger values of  $\eta$ , we will see a balance of power - but military technology determines which type. When  $\varphi$  is large (specifically  $\varphi > \varphi_\tau$ ) then an extractive balance of power is stochastically stable, while if  $\varphi$  is small then an inclusive balance of power is stochastically stable. Large  $\varphi$  - effective fortifications - favors extractive institutions, while small  $\varphi$  - good siege technology - favors inclusive technology. To anticipate: the invention of gunpowder led to a great reduction in

the effectiveness of fortifications. With small  $\varphi$  inclusive institutions may be stochastically stable - and an inclusive balance of power indeed emerged in Europe, but not generally speaking in China or India. We will examine this history in greater detail below.

Before getting to history, the remainder of this section is devoted to proving Theorem 1: in doing so we will outline the key forces that drive the result. Since outsiders increase the likelihood of hegemonies failing and the likelihood of a balance of power surviving it is not terribly surprising that when outsiders are strong only the balance of power can be stochastically stable and when outsiders are weak only hegemonies can be stochastically stable. The less obvious but crucial point is to establish which type of balance of power or hegemony is stochastically stable in each case: weak or strong? To do this we must first analyze how the conflict subgame maps the incentives of the military elites and commercial elites to the probabilities of outcomes.

### *The Conflict Subgame*

To analyze how incentives determine success and failure in conflict we must find the equilibrium  $\hat{x}_a, \hat{x}_d$  of the subgame in which conflict takes place. We show in the Appendix that this equilibrium is unique and does not depend on the state or strength of outsiders. It does depend on  $y_a$ , the transfer benefit to the prospective aggressor from the change in state and on  $y_d$ , the loss to prospective defender from the change in state. These are just the changes in transfers: for instance in the transition  $s \rightarrow sw$  the aggressor is the occupied military elites with the goal of establishing an inclusive society in their land so they pass from 0 to  $\tau$  meaning  $y_a = \tau - 0 = \tau$ ; the defender is the occupier military elites, whose revenues would fall from 2 to 1, whence  $y_d = 1$ . Note that these values lie between 0 and 1. Define the *partial utility gain* to the aggressor as the part of the equilibrium gain that is independent of the state and strength of outsiders:

$$u(y_a, y_d, \varphi) = \alpha (\hat{x}_a - [(1 - \varphi)\hat{x}_d + \varphi]) y_a - (\gamma/2)\hat{x}_a^2.$$

The *overall utility gain* of the aggressor can then be written as  $\Pi_\zeta(\eta)y_a + u(y_a, y_d, \varphi)$ . The partial utility gain is the key measure of incentives for conflict that we need to analyze stochastic stability. We report the relevant facts proven in the Appendix:

**Theorem 2.** *The conflict subgame has a unique Nash equilibrium independent of the state and strength of outsiders. The total utility gain to the aggressor  $\Pi_\zeta(\eta)y_a + u(y_a, y_d, \varphi)$  is non-negative, less than or equal to one and strictly increasing in  $y_a$ . The partial utility gain  $u(y_a, y_d, \varphi)$  is decreasing in  $y_d$ , and satisfies  $u(0, y_d, \varphi) = 0$  and  $u(y_a, y_d, 1) = u(y_a, 0, 1)$ . There is a  $0 < \tau^* < 1$  and a strictly decreasing function  $0 < \varphi_\tau < 1$  such that the function  $v(\varphi) \equiv u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi) - u(1 - \tau, 0, \varphi)$  satisfies  $-\alpha < v(\varphi) < \alpha$ , with  $v(\varphi) < 0$  for  $\tau < \tau^*$  and  $\varphi < \varphi_\tau$  and  $v(\varphi) > 0$  otherwise.*

As will be clear from the proof of the main theorem, the sign of the function  $v$  determines which of  $ww$  and  $ss$  is stochastically stable: the former if positive, the latter if negative. For  $\eta$  sufficiently

low neither of them is; with strong outsiders on the other hand this says that  $ww$  will prevail with efficient siege technology.

### *Resistance and Incentives, and Proof of the Main Theorem*

The key technical concept used to analyze stochastic stability is the notion of *resistance*. Under our assumptions with high probability the state remains unchanged: we are interested in the probabilities of transitions that change the state. The *ex-ante* probability of aggression has the form

$$Q \cdot \Pr(\Pi_{\zeta}(\eta)y_a + u(y_a, y_d, \varphi) + \tilde{u} \geq 0) = Qe^{-\sigma[U - \Pi_{\zeta}(\eta)y_a - u(y_a, y_d, \varphi)]}$$

where  $Q$  takes account of the probability that the group is in fact active and that a particular goal is on the table.<sup>15</sup> The key point is that in our model  $Q$  is independent of  $\sigma$  and bounded away from 0 and 1. This enables us to analyze stochastic stability using the standard notion of resistance (see, for example, Young (1993) or Kandori, Mailath and Rob (1993)). Here we take  $\epsilon = e^{-\sigma}$  so that as  $\sigma \rightarrow \infty$  then  $\epsilon \rightarrow 0$ . The resistance  $r$  is then defined as the derivative of the logarithm of the probability with respect to the logarithm of  $\epsilon$ . Roughly speaking the expected length of time before the transition takes place is  $\epsilon^{-r} = e^{\sigma r}$ .

What then is the resistance of  $r(z \rightarrow z')$  to a transition from a state  $z$  to  $z' \neq z$ ? The states  $z, z'$  determine who is the aggressor and defender and the incentives  $y_a(z \rightarrow z'), y_d(z \rightarrow z')$  of each, along with the indicator  $\zeta(z)$  of whether  $z$  is hegemony or balance of power. Hence the resistance depends on incentives and is given by

$$r(z \rightarrow z') = U - \Pi_{\zeta(z)}(\eta)y_a(z \rightarrow z') - u(y_a(z \rightarrow z'), y_d(z \rightarrow z'), \varphi).$$

This equation highlights a key feature of the model. The only certain thing about conflict is that it will be costly: there is no guarantee of either success or failure. Hence resistance is not driven directly by the chance of winning or losing both of which have a substantial chance of occurring. Rather it is driven by the relatively rare decision to initiate conflict. One subtle consequence of this is that the strength of outsiders does not directly impact resistance. It is not true that simply because outsiders are strong hegemony is bound to fail or that because they are weak a balance of power must collapse. Outsiders cannot in this model initiate conflict, they are relevant only if one of the decision makers decides to initiate conflict - they are relevant only if they are invited. We can see this in the term  $\Pi_{\zeta(z)}(\eta)y_a(z \rightarrow z')$  in the equation for resistance: if the aggressor has little reason to initiate a conflict then the strength of the outsiders does not matter very much. In the extreme case  $y_a(z \rightarrow z') = 0$  and outsiders are irrelevant. This happens, for example, in a weak society in a balance of power: the commercial elites who control the decision making have no reason to attack their neighbor and do not invite the outsiders.

The technical details of the proof can be found in the Appendix.

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<sup>15</sup>We assume that  $U$  is larger than the (finite) upper bound of  $\Pi_{\zeta}(\eta)y_a + u(y_a, y_d, \varphi)$ .

### Driving Force of the Model

The key result of the model is that when outsiders are strong and fortifications weak a balance of power  $ww$  between inclusive societies is stochastically stable. Since strong outsiders favor a balance of power over hegemony, the crucial thing to understand is why  $ww$  can beat  $ss$ , or from a technical point of view, why the modified radius  $R(ww)$  can be larger than  $R(ss)$ . The key idea is this. If an inclusive balance of power is to be possible the tax rate  $\tau$  must be low enough the the commercial elites have an incentive to defend themselves. In this case we will show that what matters between  $ww$  and  $ss$  is the incentive for occupied commercial elites to revolt against unresisting (commercial) occupiers. With high  $\varphi$  (highly effective fixed fortifications) the fact that the commercial occupiers do not provide much defensive effort does not matter much because they are well protected by forts. This gives the advantage to  $ss$ . With low  $\varphi$  the lack of defensive effort means that the revolting elites will face little resistance and this gives the advantage to  $ww$ .

To understand better these modified radii, observe that each resistance has two components, an “outsider” component of the form  $U - \Pi_{\zeta}(\eta)T_a$  and an incentive component of the form  $\underline{r} = -u(T_a, T_d, \varphi)$  where  $T_a, T_d \in \{0, \tau, 1 - \tau, 1\}$  are the relevant transfers. When we take the difference  $R(ss) - R(ww)$  all the outsider components cancel out - not surprising since both balances of power are on an equal footing with respect to the influence of outsiders - so we can focus on the incentive component. That is, we may compare  $\underline{R}(ss) = \underline{r}(ss \rightarrow s) - \underline{r}(s \rightarrow ss) + \underline{r}(s \rightarrow sw) + \underline{r}(sw \rightarrow w) - \underline{r}(sw \rightarrow s)$  and  $\underline{R}(ww) = \underline{r}(ww \rightarrow w) - \underline{r}(w \rightarrow ww) + \underline{r}(w \rightarrow sw)$ .

Turning first to the incentive component of the extractive balance of power  $\underline{R}(ss)$  we see first that  $\underline{r}(ss \rightarrow s) = \underline{r}(s \rightarrow ss) = u(1, 1, \varphi)$  is a wash. That is, the incentive for the military elite is always the transfer 1 from the commercial elites - this represents a gain to the aggressor and a loss to the defender regardless of whether there is hegemony or balance of power. Hence we can write  $\underline{R}(ss) = \underline{r}(s \rightarrow sw) + [\underline{r}(sw \rightarrow w) - \underline{r}(sw \rightarrow s)]$ . This in turn has two parts. The first part  $\underline{r}(s \rightarrow sw) = -u(\tau, 1, \varphi)$  is zero if  $\tau$  is zero, and since we know  $\tau$  must be small this term must also be small. Hence the critical determinant of the modified radius of the extractive balance of power is  $[\underline{r}(sw \rightarrow w) - \underline{r}(sw \rightarrow s)] = u(1, 1 - \tau, \varphi)$  which we refer to as the *incentive component of extractive advantage*.

To understand this better, when we account for the outsider component we can find the overall *extractive advantage*  $r(sw \rightarrow w) - r(sw \rightarrow s) = \Pi_b(\eta) + [\underline{r}(sw \rightarrow w) - \underline{r}(sw \rightarrow s)] = \Pi_b(\eta) + u(1, 1 - \tau, \varphi) > 0$ . This measures what happens in a head to head contest between an extractive and an inclusive society. That is, it measures which side is more likely to prevail in the state  $sw$ : if  $r(sw \rightarrow s)$  is lower than  $r(sw \rightarrow w)$  then the extractive society is (much) more likely to prevail over the inclusive society than the other way around. Since the extractive advantage is positive it represents the sense in which an extractive society is “strong” and an inclusive society “weak:” the former is more likely to prevail in a head to head contest.

It is the incentive component of the extractive balance of power  $\underline{R}(ss)$  which must be compared to that of the inclusive balance of power  $\underline{R}(ww) = \underline{r}(ww \rightarrow w) - \underline{r}(w \rightarrow ww) + \underline{r}(w \rightarrow sw) = -\underline{r}(w \rightarrow ww) = u(1 - \tau, 0, \varphi)$ . That is, what provides stability to the weak balance of power is

the fact that the weak hegemony collapses very fast into a weak balance of power - the occupied commercial elites have every reason to revolt and the occupying commercial elites no reason to resist. Hence the comparison between  $\underline{R}(ww)$  and  $\underline{R}(ss)$  boils down to comparing  $u(1 - \tau, 0, \varphi)$ , which measures the incentive for occupied commercial elites to revolt against unresisting occupiers, and  $u(1, 1 - \tau, \varphi)$  which is the extractive advantage - the incentive for military elites to invade an inclusive neighbor. There are two key things about this: first, the lower is  $\tau$ , that is the more inclusive is an inclusive society, the more the commercial elites want to revolt against the hegemon and the more they will resist an invasion by neighboring military elites - this of course works in favor of  $ww$  over  $ss$ , and indeed for  $\tau = 0$  the comparison is  $u(1, 0, \varphi)$  versus  $u(1, 1, \varphi)$ , with the former clearly greater when  $\varphi > 0$ . Second, from this we also see clearly the role of fortifications. If  $\varphi$  is large then the incentives of the defender do not matter much: indeed for  $\varphi = 1$  by Theorem 2  $u(1, 1 - \tau, 1) = u(1, 0, 1)$  which is larger than  $u(1 - \tau, 0, 1)$ , which is to say the inclusive society is less stable. As  $\varphi$  declines and fortifications are less effective the incentive of the commercial elites to defend themselves against invading military elites increases so the extractive advantage declines relative to  $u(1 - \tau, 0, \varphi)$ . The point is, the incentive to defend only matters if defensive effort makes a difference to the outcome.

### *Robustness: Linear Quadratic Technology*

While the basic model is highly stylized the results in theorem 2 are robust to many details. We discuss several extensions here.

With respect to the specific linear/quadratic conflict resolution function we observe that theorem 2 relies only on the conclusion of theorem 2: any conflict technology that results in a  $u(y_a, y_d, \varphi)$  function satisfying the qualitative properties of that theorem yield our main theorem, theorem 1. Certainly small perturbations from the linear quadratic model will do so. In fact these conclusions are relatively robust. Consider the more general conflict resolution function  $\pi(x_a, x_d) = \Pi_\zeta(\eta) + \alpha\pi_0(x_a, x_b, \varphi)$  where  $\pi_0$  is strictly increasing in  $x_a$  and decreasing in  $x_b$ , strictly so for  $\varphi < 1$  and independent of  $x_b$  for  $\varphi = 1$  together with convex effort cost  $c(x_a)$ . If, as in the base model, the outcome of  $\pi_0$  is uncertain enough and  $c(x_a)$  is convex enough existing results (see Herrera, Morelli and Nunnari (2015)) imply the existence of a unique interior pure strategy equilibrium. Defining  $u(y_a, y_d, \varphi) = \alpha\pi_0(\hat{x}_a, \hat{x}_b)y_a - c(\hat{x}_a)$  then certainly  $\Pi_\zeta(\eta)y_a + u(y_a, y_d, \varphi)$  is non-negative, less than or equal to one and under mild conditions the intuitive conditions that it is strictly increasing in  $y_a$  and that  $u(y_a, y_d, \varphi)$  is strictly decreasing in  $y_d$ , and satisfies  $u(0, y_d, \varphi) = 0$  hold. The key qualitative features of the model require also that  $v(\varphi) = u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi) - u(1 - \tau, 0, \varphi)$  is negative for small  $\tau$  and  $\varphi$  and positive for large  $\varphi$ . Consider first that for  $\tau = 0$  and  $\varphi < 1$  we have  $v(\varphi) \equiv u(1, 1, \varphi) - u(1, 0, \varphi) < 0$  by monotonicity, so indeed  $v(\varphi)$  is negative for small  $\tau$ . For large  $\varphi$  consider  $v(1) = u(1, 1 - \tau, 1) - u(\tau, 1, 1) - u(1 - \tau, 0, 1) = u(1, 0, 1) - u(\tau, 0, 1) - [u(1 - \tau, 0, 1) - u(0, 0, 1)]$  so that  $v(1) > 0$  if  $u(y_a, 0, 1)$  is strictly convex in  $y_a$ . To see why this must be the case, notice that when  $\varphi = 1$  defensive effort does not matter, the defender optimally chooses  $x_d = 0$  and the aggressor faces the simple problem of maximizing  $(\Pi_\zeta(\eta) + \alpha\pi_0(x_a, 0, 1))y_a - c(y_a)$ . The first and

second order conditions for the optimum together with the implicit function theorem show that the solution of this problem is a convex function of  $y_a$  and therefore  $u(y_a, 0, 1)$  is convex as well.

#### 4. History

The theory suggests that institutions and international competition can be explained by two variables: the strength of outsiders and military technology. In particular, weak outsiders should result in extractive hegemonies regardless of military technology. Strong outsiders should result in a balance of power: between extractive states if fixed defenses are strong and between inclusive states if fixed defenses are easily overcome. Here we see whether this idea is useful in organizing historical facts. We focus on the main centers of world population: India, China and Europe. We are constrained going back in time by lack of reliable data: for this reason we chose to take our base starting point as 1 CE. It is also the case that an enormous improvement in transportation and military technology changed the world from one of militarily isolated regions with similar technologies into a world where Europe was able to dominate the world. This occurred around 1550 CE which we take as our base ending point. Since the basis of our analysis are societies, we include the entire history of each society that overlaps with our base interval of 1 CE to 1550 CE, so, for example, the classical medieval Indian society lasted from 200 BCE to 320 CE overlapping our base interval, so we include the entire history of that society including the portion prior to 1 CE. Within this context we analyze the strength of outsiders and fortifications, the existence of hegemony, and the inclusiveness of societies.

We should emphasize that our model is a simple one of two societies that compete on a more or less equal footing and outsiders who are protected by a one-way barrier. While this is an imperfect description of the world prior to the 16th Century, it is a reasonable approximation. During and after the 16th Century the world changed in such a way that the model no longer applies.

Analyzing the world after the 16th Century is beyond the scope of this paper, but it is worth briefly pointing out the elements of change and why they change what states are stochastically stable. After the 16th Century the Europeans became “strong outsiders” with respect to the rest of the world. Incentives for elites within Europe changed as it became lucrative to build foreign empires. Moreover, unlike earlier outsiders who successfully conquered the insiders, conquest by Europeans did not mean that they were simply absorbed into the conquered society and became insiders, on the contrary, they shuttled to and from their safe bases in Europe, extracting from their colonies all the while. While earlier and weaker outsiders had reason to prevent hegemony the Europeans had no reason to do so, and indeed in the 19th Century Europeans fought to preserve rather than destroy hegemony in China.

##### *Core Areas*

We take as core areas India, China and Europe, where the majority of the population lived. As the theory says we should observe stochastically stable states for a random length of time we use observations of variable period length based on evidence of changes. For the most part the

exact start and end dates of the observations do not matter, and we adopted conventional dates used by historians. The details of the construction of the core areas in the analysis are in the Data Appendix.

### *Matching Theory with Data*

To match the theory with data we need to accomplish several tasks:

1. We must locate the core areas over which there is conflict and the peripheral areas that contain outsiders. The key distinction in the model is that within the core conquest is possible, while the peripheral areas are on the one hand able to interfere in the core but relatively immune from conquest, which is the case if there is evidence of a one-way barrier.
2. We must assess the strength of outsiders  $\eta$  in the periphery. Here we rely on demographic data.
3. We must assess the military technology  $\varphi$  in the core. Here we assess the efficacy of siege technology.
4. We must assess the geopolitical situation in the core. Is there hegemony or balance of power?
5. We must assess social circumstances in the core: how inclusive are societies? In our context inclusiveness refers to the relative strength of commercial over military elites. The criteria we will apply assesses the strength of civilian government, the breadth of the base from which political leaders are drawn and the ability of military elites to command resources for their own use.

In principle these are daunting tasks, but they are made much easier by the fact that - as the model requires - these variable do not change much over time, varying little from one century to the next. The analysis of these points is detailed, for each region, in the Data Appendix.

### *Data Overview*

Each region and period is assigned an empirical state  $z$  in  $ss, s, ww$  based on whether or not there was hegemony of the region during that period and the degree of inclusiveness of societies in that region. The theory tells us that outsiders and fortifications matter only above and below some threshold. As the data is noisy, we categorize these each into two categories *strong* and *weak*, based on the evidence reported in the Data Appendix.

The data consists of 15 observations. Each observation provides a binary variable for the exogenous variables, the strength of outsiders  $\eta$  and fortifications  $\varphi$  together with the endogenous variable, the empirical state  $z \in \{ss, s, ww\}$ . Table 1 shows the data.

#### *4.1. Key Historical Facts*

Between China and Europe there are two key differences. First, the conquests of Genghis Khan and his successors led to a large outmigration of population from the Mongolian region of China (reversing the earlier outmigration from Central Asia), weakening the outsiders, and indeed China

Table 1: Data (duration measured in centuries).

region	description	period	duration	outsiders $\eta$	fortifications $\varphi$	actual state	stochastically stable state	technological progress
India	Classical/Medieval	200 BCE - 320	5.2	strong	strong	<i>ss</i>	<i>ss</i>	0
India	Classical	321 - 650	3.3	strong	strong	<i>ss</i>	<i>ss</i>	0
India	Early Medieval	651-1200	5.5	strong	strong	<i>ss</i>	<i>ss</i>	0
India	Late Medieval	1200 - 1525	3.3	strong	strong	<i>ss</i>	<i>ss</i>	0
India	Mogul	1526 - 1748	2.2	weak	weak	<i>s</i>	<i>s</i>	0
China	Han	202 BCE - 220	4.2	weak	strong	<i>s</i>	<i>s</i>	1
China	Warring Kingdoms	221-588	3.7	strong	strong	<i>ss</i>	<i>ss</i>	0
China	Sui/Tang	589 - 906	3.2	strong	strong	<i>s</i>	<i>ss</i>	0
China	Song	960 - 1279	3.2	strong	weak	<i>ww</i>	<i>ww</i>	1
China	Yuan/Ming/Qing	1280-1839	5.6	weak	weak	<i>s</i>	<i>s</i>	0
Europe	Roman	149 BCE - 329	4.8	weak	strong	<i>s</i>	<i>s</i>	0
Europe	Byzantine	330 - 628	3.0	strong	strong	<i>ss</i>	<i>ss</i>	0
Europe	Medieval	629 - 1054	4.3	strong	strong	<i>ss</i>	<i>ss</i>	0
Europe	Middle Ages	1054 - 1292	2.4	strong	strong	<i>ss</i>	<i>ss</i>	0
Europe	Renaissance	1293-1607	3.1	strong	weak	<i>ww</i>	<i>ww</i>	1

slipped back into extractive hegemony after the Song period. Second, effective siege technology arrived later in Europe than China, so that an inclusive balance of power developed later: the European Renaissance was some 400 years after the start of the Song dynasty in China. The key theoretical point here is that the cannon only helps if outsiders are strong.

While the details of the construction of our data can be found in appendix, we discuss the key historical points here. In the data there are only two episodes of inclusive societies (both highly innovative, both a balance of power). In the European case it continued, in the Chinese case it died. The historical puzzle (“The Great Divergence”) is why the European and Chinese experiences were so different. Our theory says that for an inclusive balance of power two conditions must be met: good siege technology and strong outsiders. Our argument is that for the periods in question both had good siege technology but that in China the Mongolian diaspora weakened the outsiders so much that only extractive hegemony was possible. India during the Moghul period provides some corroborating evidence: they also had cannons but outsiders were weak and again as in China we see an extractive hegemony.

For the key transition in China to the extractive hegemonies following the Song dynasty we should therefore provide evidence for the inclusiveness of Song China and for the Mongolian diaspora, and check that the timing of siege technology and inclusiveness is correct. For example, if the revolution in siege warfare in China was the development of a cannon capable of knocking down city walls, if this did not happen until after the end of the Song dynasty it could scarcely have played a role in its rise or persistence. While the theory does not require the development of effective siege technology prior to an episode of inclusiveness (according to the theory that could be a random event), for inclusiveness to persist effective siege technology must at least develop contemporaneously. We turn next to the evidence.

### *Was the Song Dynasty Inclusive?*

The Song dynasty from 960 to 1234 CE is widely celebrated as a golden age of Chinese history - especially in science, engineering, technology, innovation, manufacturing, commerce, and economic prosperity. In contrast to the Renaissance in Europe historians have had less to say about the

dawning rights of man during this period. There is substantial evidence, however, that the Song era was unique also in Chinese history for its inclusiveness.

Recall that in our context inclusiveness refers to the relative strength of commercial over military elites. With this in mind we set out criteria for inclusiveness:

1. Civilian government: The medieval system in which local military commands are charged with administration and the collection of taxes is evidence of the strength of the military elite. By contrast the absence of such local military units and government by local civilians is evidence of inclusiveness.
2. Mobility. If the base from which political leaders are drawn is broad we judge that to be relatively inclusive.
3. Transfers: How much is transferred to military elites? A key element of our theory is that inclusiveness means the transfers are low, while extractiveness means they are high.

With these criteria in mind, what do we know about the Song and other periods in Chinese history? The basic resource for historical government in China is *Finer and Finer (1997)*. They give detailed information about governance in China in all but the Song period for which we turn to other sources that give explicit comparisons of the Song to earlier and later periods. We should indicate that we are by no means the first to point out the parallels between Song dynasty China and Renaissance Europe: this is the heart of the “Naito Hypothesis” much researched in the Japanese studies of Song China - a good description can be found in *Miyakawa (1955)*. The basic point is that during this period medieval rule by local military leaders was replaced by collaboration between the Emperor and the “masses” - mostly commercial interests to be sure, but also the peasants gained many rights. We discuss the three criteria for inclusiveness given above in the Data Appendix.

### *The Mongolian Diaspora 1200 - 1300 CE*

A key element of our story of why China fell back into extractive hegemony and Europe did not was that the strength of outsiders fell. Mongolian demography is not a widely studied subject, and indeed there are no demographic studies of Mongolia prior to the modern era we have been able to locate. “Mongolian diaspora” is also not a term commonly used by historians. Yet the evidence is plain and straightforward. While we have no count of how many people remained in Mongolia, we have a great deal of data that indicates that most of them left. That is: Genghis Khan and his successors led large armies consisting of the bulk of the male Mongolian population together with their families to conquer wide areas of Asia and Europe. These conquests were successful and the conquerors did not return to Mongolia with loot but settled in to rule their conquered territories. Although generally viewed as warfare, Genghis Khan’s conquests were also a demographic event - reversing in many ways the earlier diaspora from Central Asia.

When and where the Mongols conquered is not a subject of great dispute. When Genghis Khan’s empire was divided, it was divided into four regions. The Great Khanate constituted China and whoever remained in Mongolia. The Chagatai Khanate constituted most of Central Asia; the Golden Horde were based in Eastern Russia but ruled as well over most of the Kiev region. The

Ilkhanate constituted Persia and the surrounding areas. The point of course is that these are large areas and not particularly close to Mongolia.

Aside from the fact it would have been difficult to maintain rule over such large areas for centuries if all the Mongolian soldiers returned to Mongolia, we have direct evidence that the Mongolians settled where they conquered. We find, first, that where the Mongol men went so did the Mongol women: see for example De Nicola (2017). Moreover, there are accounts of what happened to the Mongol conquerors:

Once China was taken over, the Mongol garrison troops had to get their livelihood from their own agriculture and that of their slaves on the depopulated lands allotted to them in North China. The fighting capacity of their hereditary military households soon deteriorated. Mongol officers formed a segregated and self-perpetuating salaried aristocracy - the superior military wing of the imperial bureaucracy - but in general the Mongol soldiery in China became impoverished. ...many lost their lands, even had to sell their families, sometimes absconded and became vagrants. To be hereditary soldiers in peacetime turned out to be a disaster. King (1992)

### *Siege Technology and Inclusiveness*

In the model we have studied timing is not irrelevant. If an inclusive balance of power requires weak fortifications - or what amounts to the same thing - strong siege technology, that siege technology must be contemporaneous with the inclusive society. There is no point that arguing the developments in siege technology that took place long before or long after inclusiveness are somehow correlated with it. Here we briefly examine the history and timing of siege technology.

Every tourist has noticed that a feature of ancient cities absent from modern cities is the existence of walls. There is archaeological evidence of brick city walls as early as 2500 BCE (Fletcher and Cruikshank (1996)). Since that time there has been a race between the technology of walls and the technology of siege: better design and construction techniques for walls have competed with the development of battering rams, ladders, siege towers, ballistas and catapults. With the development of the gunpowder the technology of walls gradually became obsolete: city walls today would be completely useless for defensive purposes as modern artillery would reduce them to ruin in a matter of moments. In World War II the immense and sophisticated Belgium fortress of Eben-Emael was rendered ineffective by a German force of 75 men in a few hours (Kauffmann and Jurga (2002)).

In the Data Appendix we argue that there is fairly strong evidence that the revolution in siege warfare was contemporaneous with the Song era. In the case of Europe the rise of the inclusiveness began before the advent of effective siege warfare and continued to rise after. The theory, however, does not say “cannons cause inclusiveness.” It says “without the advent of the cannon the inclusiveness that began earlier was unlikely to persist.”

*Was the State ww?*

*China.* It is not enough to know that Song China was relatively inclusive: for the state  $ww$  to hold the same must be true of the rival power. The balance of power lay between Song dynasty China and the competing northeastern Liao/Jurchen state. King (1992) gives a good overview Liao/Jurchen governance. The Liao/Jurchen state was a hybrid state consisting both of northern nomads (the rulers) and Han Chinese. A mixed system of government was employed - one that was relatively more inclusive than the Song as the nomads did not have emperors but determined the succession through elections. However, the Han Chinese also were incorporated into the Liao court (after about 1011) and the Liao/Jurchen state used civil service exams adopted from those used by the Song. In our view Liao/Jurchen was at least as inclusive as Song China.

*Europe.* There were throughout the era in question often many more than two societies in Europe. However, the contest between great power after the fall of Rome was largely between the Holy Roman Empire - basically the German-speaking peoples - and France. During the Renaissance when inclusiveness was increasing we see from Blank, Dincecco and Zhukov (2017) account of parliamentary power that indeed both sides: France on the one side, and especially Austria and Bohemia on the other did indeed become more inclusive.

## 5. Data Analysis

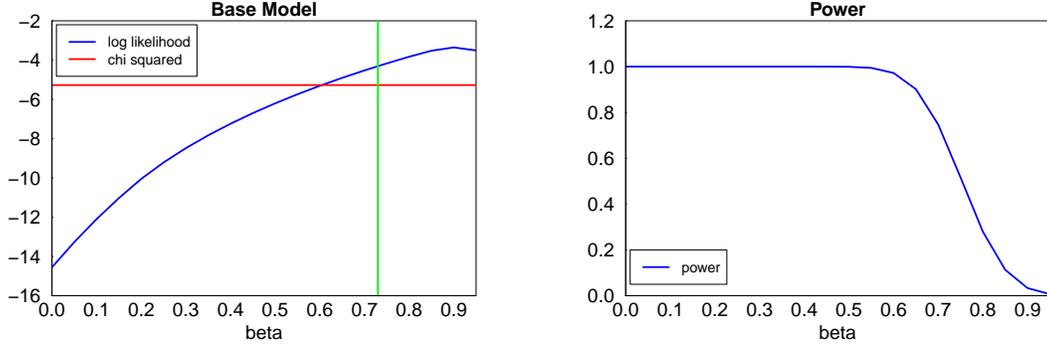
We turn to a formal analysis of the data. According to the theory only  $ss, s, ww$  can be stochastically stable. Denote by  $z \in \{ss, s, ww\}$  be the observed state; and let  $\hat{z}(\eta, \varphi)$  the stochastically stable state determined by the exogenous variables (strength of outsiders  $\eta$  and efficacy of fortifications  $\varphi$ ). Over sufficiently long periods we should observe  $\hat{z}(\eta, \varphi)$  with high probability. To put this into a statistical framework we take “long periods” to mean 2.2 to 5.6 centuries. We model “high probability” empirically by assuming that with probability  $\beta$  the stochastically stable state  $\hat{z}(\eta, \varphi)$  is observed and that with probability  $1 - \beta$  the observed state is drawn randomly with probabilities  $\alpha(z)/(1 - \beta)$  where  $\sum_{z \in \{ss, s, ww\}} \alpha(z) = 1 - \beta$ . This gives rise to the linear conditional probability model  $\Pr(z|\eta, \varphi) = \alpha(z) + \beta \cdot \mathbf{1}\{z = \hat{z}(\eta, \varphi)\}$ .

From Table 1 the log-likelihood is equal to  $8 \ln(\alpha(ss) + \beta) + 4 \ln(\alpha(s) + \beta) + \ln \alpha(s) + 2 \ln(\alpha(ww) + \beta)$ . The maximum likelihood estimates are  $\bar{\alpha}(ss) = \bar{\alpha}(ww) = 0$  and  $\bar{\beta} = 0.91$  with a standard error 0.08.<sup>16</sup> This indicates that the model does well in both economic terms -  $\bar{\beta}$  is close to 1 and far from 0 - and in statistical terms -  $\bar{\beta}$  is estimated with a high degree of reliability.

To better understand the importance of sampling error we plot  $\lambda(\beta)$  the log likelihood function as a function of  $\beta$  in the left graph below. The solid vertical line in the graph is the left limit of the 95% confidence interval based on the estimated standard error of  $\bar{\beta}$ . The graph in the right panel shows the power of the corresponding (one-sided, significance level 2.5%) Wald test showing the test discriminates well against values of  $\beta$  below 0.60.

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<sup>16</sup>The solution to the constrained maximization was computed using *R* (code available).



Because of the non-linearity of the system this is not an entirely accurate guide as to the importance of sampling error. An alternative is to use a likelihood ratio test. Observe that twice log of the likelihood ratio  $-2(\lambda(\beta) - \lambda(\bar{\beta}))$  is approximately chi-squared with one degree of freedom. The cutoff for the 5% upper tail is  $\bar{\chi} = 3.841$ , so the acceptance region is  $-2(\lambda(\beta) - \lambda(\bar{\beta})) \leq \bar{\chi}$  or  $\lambda(\beta) \geq \lambda(\bar{\beta}) - \bar{\chi}/2$ : the chi-squared line in the left panel above plots  $\lambda(\bar{\beta}) - \bar{\chi}/2$ , so the 5% acceptance region is above the line, and rejection region below it. Hence the range  $[0.60, 0.99]$  are those values of  $\beta$  that cannot be rejected at the 5% level. The crucial point is that to the left of 0.60 the likelihood drops rapidly implying that  $\bar{\beta}$  is a lot different in both economic and statistical terms (despite the limited data) than 0: The variables of outsider and fortification strength do a good job of explaining social organization.

### 5.1. Robustness

To study the robustness of our results we examine three variations on the base model.

#### A. Measurement Error

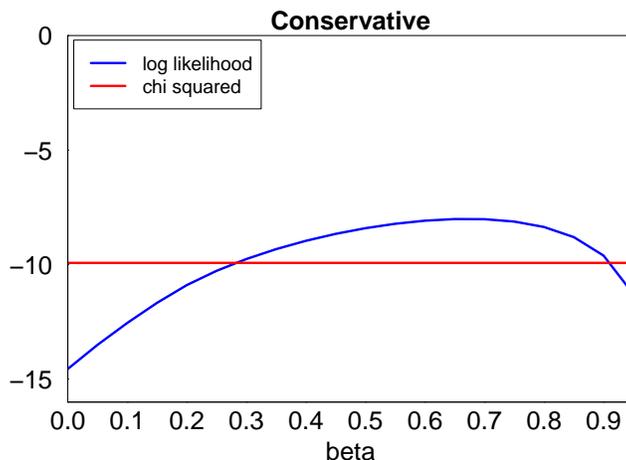
Measurement error is a serious issue when we deal with data from up to two thousand years ago. Military history and the technology used for sieges is well recorded and does not pose much of an issue. By contrast, demographic data, especially on peripheral areas, is spotty and questionable. There are two main issues with our evaluation of the strength of outsiders: when did outsiders first become strong in China? And did outsiders really become weak in India?

In the case of China we know that the strength of the periphery increased with the arrival of the “five barbarians” from Central Asia, causing the fall of the Han Dynasty and the beginning of a period of warring states in 206 CE. This comes well before the Sui/Tung dynasty that begins in 581 CE. But are we correct to classify them as strong between 206 and 581 CE?

In the case of India there is evidence that the population of the subcontinent grew between 1000 and 1500 CE relative to surrounding areas. But are we correct in concluding that the outsiders’ strength was below the threshold in the 16th Century when the Moguls took power? Against the relatively poor demographic data we observe that the Mogul hegemony was short lived and that it fell apart partially because of an invasion from Afghanistan. The situation is complicated because by that time Europeans had arrived on the scene with much better military technology. However,

we must recognize the possibility that outsiders were strong even during the period of the Mogul hegemony.

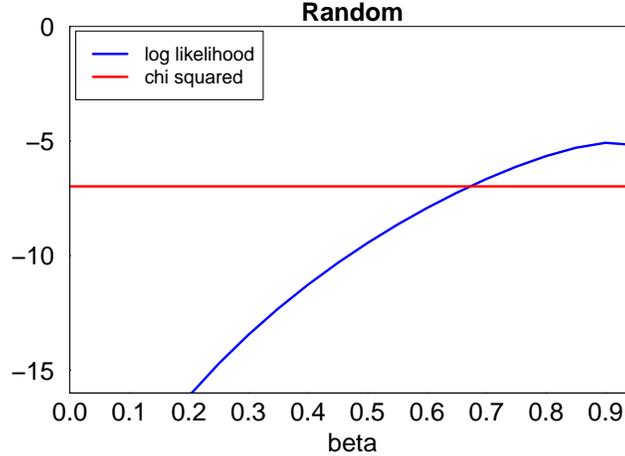
To evaluate the importance of measurement error we take the worst case: we assume that outsiders became strong in China only at the beginning of the Sui/Tung dynasty and that they were always strong in India. This leads to three failures of the theory: the original fact that the model predicts  $ss$  for the hegemonic Sui/Tung, plus the additional facts that the model predicts  $s$  for the warring states period prior to the Sui/Tung and the fact that the model predicts  $ss$  for the hegemonic Mogul period. We reran the estimation: below we plot the likelihood function with the revised data



Not surprisingly the theory fares less well - although getting 12 right out of 15 is still not bad. Here the estimate of the slope parameter falls to  $\bar{\beta} = 0.67$  and the range generated by the 95% acceptance region for the likelihood ratio test becomes  $[0.21, 0.91]$ . While this is shifted substantially left even the lower bound at .21 is still economically very different than 0.

### B. Missing States

One thing the model does get right is that it correctly predicts that the states  $sw$  and  $w$  will never be observed. An alternative specification of the model is to assume that with probability  $\beta$  the stochastically stable state  $\hat{z}(\eta, \varphi)$  is observed and that with probability  $1 - \beta$  the observed state is drawn randomly with equal probabilities of  $1/5$  over each of the five states. This leads to a slightly higher estimate  $\bar{\beta} = 0.92$  and a tighter 95% acceptance region for the likelihood ratio test  $[0.68, 0.99]$ . Below we plot the likelihood function:

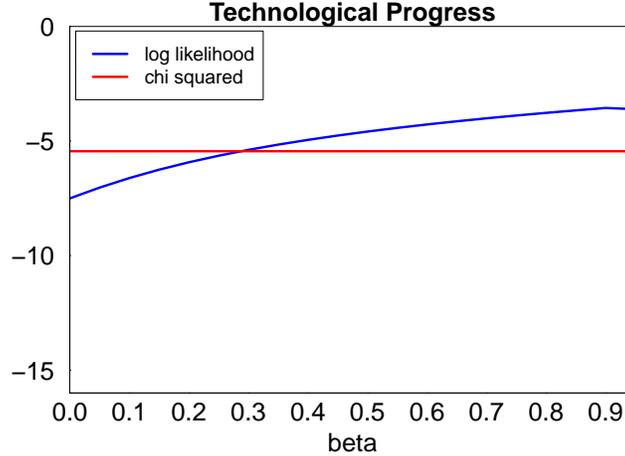


The main difference is in the likelihood ratio against the hypothesis  $\beta = 0$ . In the base case this was  $-14.6$ , a uniform distribution over states yields the much lower value of  $-24.1$ .

### 5.2. Forecasting Technological Progress

Although the motivation for our model lies in understanding technological progress our model is one of social organization. As indicated in the introduction, we simply accept the hypothesis put forward by others that it is a balance of power that favors technological progress, augmenting this with the observation that to have any hope of explaining any data we need to modify that hypothesis to reflect that it is only an inclusive balance of power that favors technological progress. As an additional check on the model, we can employ that theory. Each observation is assigned an indicator  $\xi$  of high (1) or low (0) technological progress and we now take the stochastically stable state to be high technological progress if the social state is  $ww$  and one of low technological progress otherwise. We continue to employ a linear probability model, albeit with two rather than three parameters, as there are now two rather than three categories of observed state. The linear conditional probability model is then  $\Pr(\xi|\eta, \varphi) = \alpha(\xi) + \beta \cdot 1(\xi = \hat{\xi}(\eta, \varphi))$  where  $\hat{\xi}(\eta, \varphi) = 1$  for strong  $\eta$  and weak  $\varphi$  and 0 otherwise.

This leads to the same estimate for the slope as in the base model  $\bar{\beta} = 0.92$  but a considerably wider 95% acceptance region for the likelihood ratio test  $[0.29, 0.99]$ . Below we plot the likelihood function:



The key fact that underlies wide range of possible  $\beta$ 's is the fact that one observation is wrong: the Han dynasty in China was an extractive hegemony, but in fact was innovative and there was a great deal of technological progress in the economy (see the Data Appendix). This is not a shortcoming of our model, but is something that students of the history of technological change might wish to account for in their models.

## 6. Comments on the Model

### *The Weak and the Strong*

As we observed, the extractive advantage is positive. How can we justify this conclusion that inclusive societies are weaker than extractive ones in light of a modern literature (see, for example, Reiter and Stam (2002)) which argues that democracies are more successful than autocracies at conflict, at least in the last several centuries? First we observe that “strength” in the way we measure it here means “prevails more frequently” and this is driven in the model by stronger incentives to initiate conflict, not a greater ability on the battlefield. Indeed, if the parameters of the conflict resolution function favor the defense sufficiently, then in a head to head competition at  $sw$  it will be the case that  $w$ , being most often the defender, will have a higher success rate than  $s$ , which is most often the attacker. This idea is consistent with the modern literature: Reiter and Stam (2002) attribute the greater success of democracies to greater selectivity in the wars that they fight. Second: the greater success rate is controversial. Desch (2008) argues that using data over a longer period of time (several millennia rather than centuries - more relevant to the period we consider) there is no particular advantage of inclusive societies, and that it is material advantage that matters (our assumption). This is backed up by Biddle and Long (2004) who analyze data on battles in the last hundred years showing that when factors such as material strength is accounted for democracies actually do less well in battle than autocracies.

There is potentially a second form of extractive advantage: a society politically dominated by military elites may find it less costly to raise resources for conflict. Specifically we might suppose that in the cost of effort provision  $C(x_i) = (\gamma/2)x_i^2$  instead of a common cost factor  $\gamma$  we have cost

factors  $\gamma_s, \gamma_w$  with  $\gamma_w > \gamma_s$ . We analyze this case in the Web Appendix. In the crucial case where  $\tau = 0, \varphi = 0$  we find that it remains the case the modified radius of  $ww$  is greater than that of  $ss$  provided that  $\gamma_w$  is not too large. Specifically in this case we show that  $R(ww) > R(ss)$  if (and only if)  $\gamma_w < 3\gamma_s$ .

### *The Home Field Advantage*

Although it plays no role in our historical analysis, there is a feature of our model worth pointing out: using the fact that  $u(0, y_d, \varphi) = 0$  we have  $r(ww \rightarrow w) - r(ss \rightarrow s) = \Pi_b(\eta) + u(1, 1, \varphi) > 0$ . This says that in attacking a strong power the strong do better than the weak do in attacking a weak power. In other words, that the strong perform well on foreign ground while the weak do not. The inequality also embodies the idea of “home field advantage”, particularly for the weak. The idea that defending home turf is an advantage is an important feature of this model that differs from our earlier work. Levine and Modica (2013), Levine and Modica (2016) and Levine and Modica (2017) use a common framework in which there are many units of land and the weaker society always has zero resistance. Here we have simplified by having only a single unit of land belonging to each society, but resistance is endogenously brought about by the decisions of groups and not an exogenous “state power” similar to the notion of “state capacity” used by Besley and Persson (2010).

The idea that the strong perform well whether they are fighting “at home” or “away” while the weak perform well only when they are fighting “at home” arises in this model because the commercial elites have little reason to attack but much reason to defend. The fact that the strong do well both at home and away while the weak only do well at home is common phenomenon well known to sports fans. For example, we gathered data from NBA basketball<sup>17</sup> and found that when weak teams play each other the visiting team won about half as often as when strong teams play each other.

### *Robustness and Time*

In the model conflict is rare and the expected time between conflicts long. This has two consequences. First, the random choice of active group does not much matter. It might be that under hegemony the prospective rebels draw two independent utility shocks one for inclusive and one for extractive institutions - if the larger of the two resulting utilities is positive then a rebellion attempting to install the “more profitable” institutions is launched. However, since the probability either is positive is very small, the chance that both are simultaneously positive is negligible and we might as well assume one is chosen at random as a prospective agenda. Similarly in a balance of power each society may simultaneously draw independent utility shocks: again the chance both are positive simultaneously is negligible. A more technical way to say this is that the resistance to

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<sup>17</sup>Using data for the 2016 NBA season from [http://www.espn.com/nba/team/schedule/\\_/name/gs/year/2017](http://www.espn.com/nba/team/schedule/_/name/gs/year/2017) we computed the records of the three best teams in the Western Conference against each other and the same for the three worst teams.

a single positive shock is much less than the resistance to a simultaneous shock, so least resistance transitions involve only a single positive shock.

The other consequence of conflict being rare is that the model is robust to the assumption that groups are myopic. If we interpret the utility shocks as the long-term present value of the effect of conflict (death, disruption of social organizations, destruction of capital, political popularity and so forth) then groups may as well discount the future with a discount factor  $\delta < 1$ . With high probability another “good” draw of the utility shock will be a long time in coming so that in effect the decision is a static one: stay with the status quo for a long time, or attempt to switch to an alternative which if successful will also last a long time.

In a similar vein: we might wonder whether occupier military elites might not choose to collect transfers lower than the most that they can extract in hopes of reducing the chance of rebellion. Since the chances of rebellion are very small and the transfer reduction would have to be permanent this would not make sense.

### *Who are the Rebels?*

Continuity considerations imply that the model is robust with respect to perturbations that have a small effect on resistances.<sup>18</sup> For example, while it makes sense that in an inclusive society occupier commercial elites take the decisions and in an extractive state occupier military elites do, for the occupied society the situation is less clear cut. Let  $y_m$  and  $y_e$  denote the utility gain in hegemony to the occupied commercial elites and occupied military elite from a rebellion (with respect to some already determined goal). The basic model assumes that if the hegemony is inclusive only the incentives of the commercial elites  $y_m$  matter, while if the hegemony is extractive only the incentives of the military elites  $y_e$  matter. Consider instead a model where in an inclusive hegemony a weighted average  $(1 - \omega)y_m + \omega y_e$  of the gain to each group represents the “overall gain” to rebellion, and likewise in an extractive hegemony  $\omega y_m + (1 - \omega)y_e$  represents the overall gain. Simple continuity considerations show that the qualitative results of theorem 1 are robust to  $\omega$  slightly positive. In fact  $\omega$  can be quite large: instead of assuming  $\omega = 0$  assume only that  $\omega < 1/2$  to reflect that in an inclusive society commercial elites do have greater political strength than military elites and vice versa. In the Web Appendix we show that the qualitative conclusions of the model are robust to this perturbation. The structure of circuits remains unchanged and it remains the case that only  $s$ ,  $ss$  and  $ww$  can be stochastically stable. The cutoff for an extractive hegemony over an extractive balance of power  $\eta^*(\varphi, \omega)$  now depends on the military technology and on  $\omega$ , and the specific numeric value of the cutoff  $\tau^*$  changes: but we show that when  $\tau = 0$  and  $\varphi > 0$  then  $ww$  has a greater modified radius than  $ss$  and that when  $\varphi = 0$  and  $\tau > 0$  then  $ss$  has greater modified radius than  $ww$ .

This is an appropriate place to comment on an important driving force in the model: that  $r(w \rightarrow sw) = U - \Pi_h(\eta) - u(0, 0, \varphi)$  and  $u(0, 0, \varphi) = 0$  implying very high resistance to moving

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<sup>18</sup>Perturbations such as a random determination of whether commercial elites or military elites are in control that have a discontinuous effect on resistances and lead in general to entirely different conclusions.

from an inclusive hegemony to a balance of power where rebellion has led to extractive institutions. In the basic model this is due to the fact that political power among the rebels lies with the commercial elites who have no reason to replace extractive foreign institutions with extractive domestic institutions ( $y_a = 0$ ). It might seem that the commercial elites being indifferent and the military elites standing to gain 1 by rebellion the commercial elites might go along with the military elites so that in fact  $y_a = 1$ . Our analysis of  $\omega < 1/2$  shows that this is not true. Why not? The point is that  $y_a = 0$  does *not* imply the commercial elites are indifferent. Their utility gain is 0 *plus* the utility shock which is with high probability very negative. If we assume that a common utility shock is drawn by the commercial elites and the military elites then because the probability of larger shocks drops very rapidly the most likely scenario in which the military elites wish to rebel is one in which they have only a slight preference for doing so. On the other hand, a utility shock that leaves the military elites slightly preferring to rebel will have the commercial elites rather more strongly preferring not to rebel: it is not the cases that the commercial elites are indifferent so should defer to the wishes of the military elites, rather the opposite. Our analysis in the web appendix of the full model shows, however, that this is not enough: some slight political advantage must lie with those favored by the dominant institutions to generate the qualitative features of the basic model.

## 7. Conclusion

In this paper we develop a simple stylized model of conflict between societies. There are two societies contending over resources and one may or may not rule over the other. There are two groups in each society: commercial elites and military elites. Institutions can be either inclusive or extractive with inclusive institutions substantially more favorable for the commercial elites. We examine stochastic stability and show that when outsiders are weak extractive hegemonies will predominate. When outsiders are strong military technology matters: if outcomes are insensitive to defensive strength - fortifications are well able to resist siege - an extractive balance of power will predominate, while good siege technology (the cannon in particular) will result in the predominance of an inclusive balance of power. This, as is widely agreed, is the configuration more favorable to innovation and economic development.

We apply this theory historically. We argue that generally speaking the importance of outsiders has increased over time and siege technology has improved. We document that the increased importance of outsiders in Europe and India preceded the advent of good siege technology: our theory implies that we should see an extractive hegemony followed by an extractive balance of power followed by an inclusive balance of power. In Europe this corresponds roughly to the Roman Empire, followed by the early medieval period, followed by the Renaissance. In India we argue that outsiders were strong and that good siege technology arrived “too late” so that in India there was generally an extractive balance of power. In China we see a back and forth between extractive hegemony and extractive balance of power until the relatively early arrival of good siege technology coincides with the flowering of the Song and rival states. However a striking demographic event

- the Mongolian diaspora - greatly weakened the strength of outsiders resulting in a reversion to extractive hegemony from the Yuan dynasty onward.

The notion that the growth of modern inclusive societies was driven by the “democratization” of warfare is not a new one; nor, of course is the idea that outsiders destroy hegemonies. Our account is a more subtle one: we view “democratization” of warfare as being driven by the decline of the fortress because of the cannon rather than the introduction of hand held fire-arms. We also see the impact of outsiders not so much in conquering empires but in weakening their resistance to revolution and strengthening the balance of power. The theory appears to do a reasonably good job of organizing the historical data.

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## Appendix I: The Conflict Subgame

**Theorem.** [Theorem 2 in the text] The conflict subgame has a unique Nash equilibrium independent of the state and strength of outsiders. The total utility gain to the aggressor  $\Pi_\zeta(\eta)y_a + u(y_a, y_d, \varphi)$  is non-negative, less than or equal to one and strictly increasing in  $y_a$ . The partial utility gain  $u(y_a, y_d, \varphi)$  is strictly decreasing in  $\varphi$ , decreasing in  $y_d$ , and satisfies  $u(0, y_d, \varphi) = 0$  and  $u(y_a, y_d, 1) = u(y_a, 0, 1)$ . There is a  $0 < \tau^* < 1$  and a strictly decreasing function  $0 < \varphi_\tau < 1$  such that the function  $v(\varphi) \equiv u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi) - u(1 - \tau, 0, \varphi)$  satisfies  $|v(\varphi)| < \alpha$  with  $v(\varphi) < 0$  for  $\tau < \tau^*$  and  $\varphi < \varphi_\tau$  and  $v(\varphi) > 0$  otherwise.

*Proof.* Recall that  $0 \leq x_a, x_d \leq 1$ ,  $0 \leq y_a, y_d \leq 1$ . The objective functions for the aggressor and for the defender are respectively

$$\begin{aligned} & \Pi_\zeta(\eta)y_a + \alpha(-\varphi + (x_a - (1 - \varphi)x_d))y_a - (\gamma/2)x_a^2 \\ \text{and } & [1 - \Pi_\zeta(\eta) - \alpha(-\varphi + (x_a - (1 - \varphi)x_d))]y_d - (\gamma/2)x_d^2. \end{aligned}$$

In this simple linear quadratic model the optimal choice for aggressor and defender are independent of each other, so the equilibrium is certainly unique. Set  $\beta = \alpha/\gamma$ . The optimum for the aggressor is  $\hat{x}_a = \beta y_a$  and for the defender is  $\hat{x}_d = \beta(1 - \varphi)y_d$ . Observe that we certainly have  $\alpha < 1/2$  while  $\gamma \geq 1$  so that  $\beta < 1/2$  and these are interior solutions. Hence the partial utility gain to the aggressor is given by

$$\begin{aligned} u(y_a, y_d, \varphi) &= \alpha(-\varphi + (\beta y_a - \beta(1 - \varphi)^2 y_d))y_a - (\gamma/2)\beta^2 y_a^2 \\ &= \alpha[(-\varphi - \beta(1 - \varphi)^2 y_d)y_a + (1/2)\beta y_a^2]. \end{aligned}$$

This is clearly strictly decreasing in  $y_d$  and satisfies  $u(y_a, y_d, 1) = u(y_a, 0, 1)$ ; and its derivative with respect to  $\varphi$  is proportional to  $2\beta(1 - \varphi)y_d - 1$  which is negative since  $\beta < 1/2$  and  $y_d \leq 1$ . Observe that the total utility gain is  $[\Pi_\zeta(\eta) - \alpha(\varphi + \beta(1 - \varphi)^2 y_d)]y_a + (\alpha/2)\beta y_a^2$  and that  $\Pi_\zeta(\eta) - \alpha(\varphi + \beta(1 - \varphi)^2 y_d) \geq \Pi_\zeta(\eta) - \alpha > 0$  by assumption. Hence the total utility gain is non-negative and strictly increasing in  $y_a$ .

We next observe that  $u(y_a, y_d, \varphi)$  is decreasing in  $y_d$  and satisfies  $u(0, y_d, \varphi) = 0$ . We compute  $v(\varphi) \equiv u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi) - u(1 - \tau, 0, \varphi)$ . The computation gives

$$v(\varphi) = \alpha\beta((1 - \varphi)^2(2\tau - 1) + (1 - \tau)\tau).$$

Hence  $-\alpha \leq v(\varphi) \leq \alpha(-\tau^2 + 3\tau - 1) \leq \alpha$  for  $0 \leq \tau \leq 1$ . If  $2\tau - 1 > 0$  clearly  $v(\varphi) > 0$  for all  $\varphi$ . For  $2\tau - 1 < 0$  the function  $v(\varphi)$  is increasing in  $\varphi$  and we may solve  $v(\varphi_\tau) = 0$  to find

$$\varphi_\tau \equiv 1 - \sqrt{\frac{(1 - \tau)\tau}{1 - 2\tau}}.$$

This is obviously strictly less than 1. It is positive if  $q(\tau) = 1 - 2\tau - (1 - \tau)\tau > 0$ . From the

quadratic equation we find  $q(\tau^*) = 0$  for  $\tau^* \approx 0.38 < 1/2$ . For  $\tau > \tau^*$  we have  $q(\tau) < 0$  hence  $v(\varphi) > 0$  for all  $\varphi$ . When  $\tau < \tau^*$  then  $0 < \varphi_\tau < 1$  and for  $\varphi > \varphi_\tau$  we have  $v(\varphi) > 0$  while for  $\varphi < \varphi_\tau$  we have  $v(\varphi) < 0$ . Finally, we compute  $\frac{d\varphi_\tau}{d\tau} \propto -\frac{(1-2\tau)^2+2(1-\tau)\tau}{2(1-2\tau)} < 0$ .  $\square$

## Appendix II: Proof of the Main Theorem

*Proof of Theorem 1.* The resistance equation enables us to compute the resistances of all transitions. To do so we first observe that the Markov process has a birth-death like structure: each state can at most move only to one of two adjacent states. From  $ss$  the only non-trivial transition is to  $s$ . From  $s$  it is possible only to transition back to  $ss$  or forward to  $sw$ , and so forth. In the table below we lay out the resistances of the non-trivial feasible transitions. We indicate first the transition then the benefit from the transition to the commercial elites and military elites respectively. This is divided into two columns for occupier or occupied; if the initial state is hegemony these are the hegemony's four groups; in case the initial state is a balance of power occupier versus occupied refers to the situation after transition - for example in the transition  $sw \rightarrow s$  the inclusive society's groups end occupied and extractive society's groups become occupiers; the  $s$  military elites have  $y_a = 1$  while the  $w$  military elites have  $y_d = \tau$ . The asterisks denote which group is making the decision about attacking or paying for defense. Note that the defender never gains from a transition and consequently the negative values in the table always correspond to the defender. The value  $y_d$  is the negative of the defender "benefit" reported in the table: it represents the loss avoided when the defenders prevent the transition from taking place. The final column reports the resistance.

transition	occupier	occupied	$r(z \rightarrow z')$
$ss \rightarrow s$	$0, 1^*$	$0, -1^*$	$U - \Pi_b(\eta) - u(1, 1, \varphi)$
$s \rightarrow ss$	$0, -1^*$	$0, 1^*$	$U - \Pi_h(\eta) - u(1, 1, \varphi)$
$s \rightarrow sw$	$0, -1^*$	$1 - \tau, \tau^*$	$U - \Pi_h(\eta)\tau - u(\tau, 1, \varphi)$
$sw \rightarrow s$	$0, 1^*$	$-(1 - \tau)^*, -\tau$	$U - \Pi_b(\eta) - u(1, 1 - \tau, \varphi)$
$sw \rightarrow w$	$0^*, 1$	$0, -1^*$	$U$
$w \rightarrow sw$	$0^*, -1$	$0^*, 1$	$U$
$w \rightarrow ww$	$0^*, -1$	$1 - \tau^*, \tau$	$U - \Pi_h(\eta)(1 - \tau) - u(1 - \tau, 0, \varphi)$
$ww \rightarrow w$	$0^*, 1$	$-(1 - \tau)^*, -\tau$	$U$

The attribute of a state that determines the relative time the process spends in it is the *modified radius*. We denote by  $R(z)$  the modified radius of the state  $z$ . *The critical fact is that the stochastically stable states are exactly those with the greatest modified radius.* The general definitions are given in Levine and Modica (2016), section 6.3, we sketch here the concept to apply it to the present setting. We say that a collection of states form a *circuit* if any two of them are connected by a least resistance path. The states can be partitioned into circuits, and then one defines circuits of circuits - 2nd-order circuits we may say - by taking as modified resistance the incremental resistance needed to move from one to the other over that needed to move within the circuit. It is possible to define

even higher order circuits: the highest order circuit in this model is the 3rd order circuit consisting of all the states.

We start by determining the structure of circuits. We observe that  $r(s \rightarrow sw) = U - \Pi_h(\eta)\tau - u(\tau, 1, \varphi) > U - \Pi_h(\eta) - u(1, 1, \varphi) = r(s \rightarrow ss)$  by the monotonicity property of  $u(y_a, y_d, \varphi)$ . This implies that  $ss$  and  $s$  form a circuit. Also by monotonicity we have  $r(w \rightarrow ww) = U - \Pi_h(\eta)(1 - \tau) - u(1 - \tau, 0, \varphi) < U - u(0, 0, \varphi) = r(w \rightarrow sw)$  so that  $ww$  and  $w$  form a circuit. The only remaining question is at the next level which circuit  $sw$  joins. It will join the circuit to which it has the least resistance of reaching. By monotonicity  $r(sw \rightarrow s) = U - \Pi_b(\eta) - u(1, 1 - \tau, \varphi) < U - u(0, 1, \varphi) = r(sw \rightarrow w)$  so the resistance of joining the  $ss \leftrightarrow s$  circuit is less than joining the  $w \leftrightarrow ww$  circuit. We may summarize the situation of circuits by the following diagram:  $[(ss \leftrightarrow s) \leftrightarrow sw] \leftrightarrow (w \leftrightarrow ww)$ , where round brackets mean “in a circuit with” and square brackets mean “in a 2nd order circuit with” and the entirely forming a 3rd order circuit.

In general we compute modified radii by moving between circuits adding in the incremental cost of moving up to the next level until the highest level circuit is joined.<sup>19</sup> This can be complicated since there may be many ways of moving between states, but in this model because of the birth-death like structure matters are simplified since there is exactly one way to get from one state to another. Start with  $s$ . To get to the highest level we must move to  $sw$  then to the other circuit at  $w$ . The radius of  $s$  is  $r(s \rightarrow ss)$ . To this we add the incremental resistance of moving to  $sw$  which is  $r(s \rightarrow sw) - r(s \rightarrow ss)$  and the incremental resistance of moving to  $w$  which is  $r(sw \rightarrow w) - r(sw \rightarrow s)$ . Denoting the modified radius by  $R(z)$  we then have

$$\begin{aligned} R(s) &= r(s \rightarrow ss) + r(s \rightarrow sw) - r(s \rightarrow ss) + r(sw \rightarrow w) - r(sw \rightarrow s) \\ &= r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s) \end{aligned}$$

Notice how the backward looking part  $r(s \rightarrow ss)$  cancels out. This is a general property in a birth-death like model in which movement is one step in a single dimension.

We may apply this idea to all five states to compute the modified radius. The second column shows how the modified radius depends upon the resistances, the third how they depend on the model parameters. In that computation we make use of the fact that  $u(0, y_d, \varphi) = 0$ .

state	$R$	$R$
$ss$	$r(ss \rightarrow s) - r(s \rightarrow ss) + r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$U + \Pi_h(\eta)(1 - \tau) + [u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi)]$
$s$	$r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$U + \Pi_b(\eta) - \Pi_h(\eta)\tau + [u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi)]$
$sw$	$r(sw \rightarrow w)$	$U$
$w$	$r(w \rightarrow sw)$	$U$
$ww$	$r(ww \rightarrow w) - r(w \rightarrow ww) + r(w \rightarrow sw)$	$U + \Pi_h(\eta)(1 - \tau) + u(1 - \tau, 0, \varphi)$

Since  $R(ww) > U$  we immediately see that neither  $sw$  nor  $w$  is stochastically stable. We compare  $R(ss) - R(s) = \Pi_h(\eta) - \Pi_b(\eta)$  and  $R(ss) - R(ww) = u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi) - u(1 - \tau, 0, \varphi) = v(\varphi)$ . We see that between  $ss$  and  $s$  stochastic stability is determined entirely by whether  $\eta > \eta^*$  or

<sup>19</sup>This is similar to the computation of Ellison (2000)'s co-radius.

$\eta < \eta^*$ . Between *ss* and *ww* we see that stochastic stability is determined entirely by  $v(\varphi)$ . Putting this together with Theorem 2, the only fact remaining to prove in the final case for  $\eta$  sufficiently small is that *s* is in fact stochastically stable, that is,  $R(s) = U + \Pi_b(\eta) - \Pi_h(\eta) + \Pi_h(\eta)(1 - \tau) + [u(1, 1 - \tau, \varphi) - u(\tau, 1, \varphi)] > U + \Pi_h(\eta)(1 - \tau) + u(1 - \tau, 0, \varphi) = R(ww)$ . This will hold for sufficiently small  $\eta$  if  $\Pi_b(0) - \Pi_h(0) + v(\varphi) > 0$  which is true since  $|v(\varphi)| < \alpha$  and we assumed that  $\Pi_b(0) - \Pi_h(0) > \alpha$ .  $\square$

### Appendix III: Data

We provide details of the construction of the data in Table 1.

#### 1. Core Areas and Outsiders

There is not much doubt about the great historical centers of civilization being Europe (including the Middle East), China and India. According to the model the core should have limited geographical obstacles to conquest and hegemony should be feasible given the military technology of the time. Hence within the core we should see at least some time hegemony, and certainly not see regions that remain immune from conquest over long periods of time. By contrast the periphery should be historically immune from invasion, while have a demonstrated capability of military intervention in the core: there should be evidence of a one-way geographical barrier.

Our primary sources are historical maps. We examine the history of each of the regions.

#### *India*

We take the core area of India to be the area occupied by the British during the Raj and the periphery to be Central Asia. Specifically the boundaries of the core are the Himalayas in the North, the jungles of Myanmar in the East, and Afghanistan in the West.

*Period.* Our start date is 200 BCE which is considered as the beginning of the “classical” period of Indian history which overlaps substantially into the Common Era. Prior to the British Raj in 1858 the only evidence of military interaction with other regions is the rather ill-fated expedition of Alexander the Great. Here we take the end data to be collapse of Mogul rule in 1748.

*Possibility of hegemony in the core.* The Moguls ruled over India starting in about 1526. Prior to 1 CE the Maurya Empire held hegemony over the subcontinent for several hundred years. During the era of interest there were several empires that briefly ruled over the bulk of the region: the Delhi Sultanate between 1321 and 1398 and the Kushan Empire under the rule of Kanishka I between 127 and 140.

*Evidence for a one way barrier.* As the Himalayas now and then impose an impenetrable barrier at least as far as military action is concerned, the relevant outsiders are the Southeast Asians in the East and Central Asians in the West. As we can find no record of any successful conquest or military intervention in Southeast Asia or by Southeast Asians, we conclude that the geographical

barrier on the East isolates the two regions at least as far as military action is concerned. The situation on the West is one of classical outsiders: there is no record of any military action from India that made it past Kabul in Afghanistan. In the other direction, however, successful invasions from Central Asia and Persia into India have been common: we have the Kushans around 1 CE, the Huns around 400 CE, and beginning in the 600s a series of incursions by the Muslims

From the time Muslims started arriving, around 632 AD, the history of India becomes a long, monotonous series of murders, massacres, spoliations, and destructions. It is, as usual, in the name of “a holy war” of their faith, of their sole God, that the barbarians have destroyed civilizations, wiped out entire races. (Basu and Miroshnik (2017) pp.52 ff.)

This culminated with the successful invasion from the Central Asia by Babur in 1526 CE.

### *China*

We take the core area of China to be the current area of China minus the Mongolian region (the provinces of Heilongjiang, Inner Mongolia (Neimongol), and Xingjiang) and the periphery to be the Mongolian region. Specifically the boundaries of the core are the Gobi desert in the West, the Himalayan mountains in the South and the Mongolia region (including Mongolia) in the North.

*Period.* As the Han dynasty overlaps the beginning of the Common Era, we take the start of that dynasty in 202 BCE as our start date. For the end date the Opium Wars are the first significant military intervention in China by the European powers, so we take the beginning of that war in 1839 as our end date.

*Possibility of hegemony in the core.* The history of China is one of hegemony more often than not: in our data 60% of our observations are of hegemonic societies.

*Evidence for a one way barrier.* There are several potential peripheral areas of China: Southeast Asia, Korea and Japan and Mongolia. Korea and Southeast Asia fall into a peripheral category that is not relevant to the model: both have been successfully invaded and conquered from China, both have successfully regained their independence from China, but we can find no evidence of important military intervention into the core of China. With Japan the only evidence we have of military action in either direction is the ill-fated adventure of Kubla Khan in 1281 that gave rise to the well known expression “kamikaze.” In this context it should be noted that while England is quite close both the European continent and the population centers there, Japan is relatively far from the Asian continent and more so from the population centers.

Mongolia is a different story. Never occupied by the Chinese, the interventions of the Mongols in China have been constant and well-documented. The building of the great wall specifically to keep the Mongols out, as well as the conquests of Genghis and Kublai Khan make this clear. We should note that while the Mongols were mostly raiders, the threat of being “stabbed in the back” by a raid while military forces were committed in a war of conquest was an important one.

## *Europe and the Middle East*

We take the core areas to be continental Europe, by which we mean Europe excluding Britain, the Scandinavian peninsula and Russia and the periphery to be Britain, the Scandinavian peninsula and Russia. Specifically the boundaries of the core are the sea, including the Atlantic, Mediterranean, English Channel, North Sea, Baltic Sea and Black Sea, along with the border with the former USSR, which is to say roughly the current eastern borders of Poland, Slovakia and Romania.

*A problem of Europe.* There are two distinct ways of mapping Europe and the Middle East (including North Africa and Persia) into the model: we can view them as two separate cores each an outsider with respect to the other, or we can view them as a single core. Each view has merits. The Romans had hegemony over both regions (but not Persia); after the Roman period each region posed a threat to the other, but neither made substantial inroads into the core of the other region. Geographically it is the presence of the Mediterranean sea that makes the situation difficult: this posed both a barrier to invasion and a road to invasion. Moreover due to technological change and migration the location of the periphery has changed: Germany which was clearly peripheral in Roman times was not so subsequently.

Fortunately for the purposes of the model it does not make a great deal of difference which point of view we take. For the bulk of the period, from the division of the Roman empire in 330 CE until the fall of Constantinople in 1453 CE the only important incursion from the Middle East into Europe was the prolonged Islamic occupation of Spain. After about 800 CE the various Islamic principalities in Spain were largely independent of North Africa - that is, European, not Middle Eastern - and did not in any case make incursions outside of Spain. After 1453 CE the Ottomans ruled over the Balkans but after their defeat in Vaslui in 1475, they did not pose a threat to the core areas of Europe. Hence we will take the view that the core area is what we will call Europe - which is to say Western and Eastern Europe excluding Britain and the Scandinavian peninsula. We will take the periphery to be Britain, the Scandinavian peninsula and Russia.

In the Roman period we do not include Persia as outsiders. Because of incompatible military technology the Persian mounted archers were unable to make progress against Roman forts and Roman foot legions were unable to make progress against the Persian mounted archers. As a result neither posed a threat to the other. Roughly speaking military technology created a two way barrier.

*Period.* The start date clearly lies with the Roman hegemony. There are two sensible start dates: the fall of Carthage in 149 BCE and the effective fall of the Republic with the crossing of the Rubicon in 49 BCE. It makes no difference to the analysis which we choose and we took the fall of Carthage as the start date. The end date is also unclear as other regions even today have not had a military impact on Europe. Rather it makes sense to choose the end date the point at which Europe began to look outwards rather than inwards for conquest. Any such date is arbitrary: we took the end date as the date of the settlement of Jamestown, the first permanent settlement in

North America. If we took the end date a century earlier or later it would not change the empirical analysis.

*Possibility of hegemony in the core.* During the Common Era hegemony has not been common in Europe, but it was achieved by the Romans (excluding Germany), nearly achieved, albeit briefly, by the Holy Roman Empire, and even more briefly by Napoleon and Hitler in the modern era.

*Evidence for a one way barrier.* Britain was occupied indeed by the Romans, but the improvement in British naval technology made Britain immune from serious invasion from the continent from 1066 on. The Swedes ruled over various parts of Europe but were never successfully invaded by the Europeans. Similarly there have been successful Russian interventions into Europe, but to date there has been little success going the other direction.

## 2. Strength of Outsiders

We measure the strength of outsiders by the ratio of the population of peripheral areas to the core. We start by giving the raw population numbers from which we work

Table 2: Population in Millions.

region	1 CE	500 CE	1000 CE	1500 CE	2000 CE
SNU		1.4	2.6	4.8	
Germany	3.0	3.5			
Czechoslovakia	1.0	1.0			
Europe	28	24	29	65	
Roman	44	35	45	76	
Mongolia	3.3	4.9	6.5		86
Japan	3.0	4.5	7.5	15.4	130
China	59	48	59	103	
Central Asia					87
Afghanistan	2.0	2.5	2.25	2.0	
Iran	4.0	4.8	4.5	4.0	66
India	75	75	75	110	

SNU is Sweden, Norway and the UK; Europe is Western plus Eastern Europe less SNU. Roman is the area of the Roman Empire under Augustus. Though 1500 CE Mongolia consists of itself plus Inner Mongolia, Manchuria and Chinese Turkistan. In 2000 CE it is roughly the same, consisting of itself plus the Chinese provinces of Heilongjiang, Inner Mongolia (Neimongol) and Xingjiang. Japan and China are according to the modern borders. Central Asia are the former Soviet central Asian republics (the “stans”) Azerbaijan, Kazakhstan, Kyrgysatan, Tajikstan, Turkmenistan and Uzbekistan, plus Afghanistan. Afghanistan and Iran are according to the modern borders. India includes Pakistan and Bangladesh.

Except as otherwise indicated the population figures are from Maddison (2013) except for 500 CE which are extrapolated from the Maddison data using the 1 CE, 500 CE and 1000 CE data

from McEvedy and Jones (1978). The figures for the “Mongolian” provinces of China are from the State of China Atlas 2009 (<http://www.sacu.org/provtable.html>).

The Roman area data was computed using as the base Maddison (2007)’s estimates from 1 CE. Again using Maddison (2013) and extrapolating 500 CE from McEvedy and Jones (1978) we then computed population from all available regions of the Roman Empire under Augustus. As this gives a substantially smaller number than Maddison (2007) we adjusted figures after 1 CE upwards accordingly.

We computed the population of outsiders as a percentage of core population for each of the three regions using two different methods (labeled A and B). The Table below summarizes our results.

Region	1 CE	500 CE	1000 CE	1500 CE
India A	7.1%	8.4%	8.0%	4.8%
India B	8.0%	9.7%	9.0%	5.5%
China A	3.5%	6.5%	8.8%	5.0%
China B	5.5%	10%	11%	
Europe A		5.6%	8.9%	7.4%
Europe B	4.5%	6.2%		

Both methods give similar estimates for each region. This demographic record of the first half of the Common Era is marked by what we would call early globalization: the rising population of peripheral areas relative to the core areas of civilization (Western Europe, China and India). It is consistent with what we know more broadly about the central Asian diaspora of 200-400 CE: the massive movement of Germanic peoples from Central Asia to Northern Europe around 200 CE is well known - and their influence in the decline and fall of the Roman Empire well documented. In China a similar event occurs with the arrival of the “five barbarians” around 300-400 CE while in the 400s the Alchon Huns arrived in India from Central Asia. It is probably accurate to say that population centers that had been largely separate (Central Asia, Europe, China, India) began to collide as population grew in all of these areas. We find that taking 5.5% or less to represent weak outsiders and 5.6% or higher to represent strong outsiders organizes the data well and is consistent with the strengthening of outsiders during the Germanic migrations.

We now give the details of the methods used.

*India A:* We use the more reliable Iranian data as a proxy for Central Asia region and use the ratio of Central Asia to Iran in 2000 to adjust the Iranian population.

*India B:* We combine data from Iran, which has had the greatest influence on Afghanistan and India with the population of Afghanistan to compute Central Asian population.

*China A:* We use the more reliable Japanese data as a proxy for the Mongolian region and use the ratio of the Mongolian region to Japan in 2000 to adjust the Iranian population. We make an additional adjustment. Between 1000 and 1500 CE the Japanese population more than doubled. Given the huge exodus documented in the text around 1200-1300 it is more likely that the population of the Mongolian region declined. As a conservative estimate we take the population of the Mongolian region in 1500 CE to be the same as in 1000 CE.

*China B:* We used the Mongolian data. This is inappropriate in 1500 CE because it includes the heavily populated of Manchuria which became part of the core of China by that time.

*Europe A:* We took the ratio of SNU to European population. This is clearly inappropriate in 1 CE prior to the Norse era. These estimates are conservative in that we ignore Denmark, Russia and the Middle East as outsiders.

*Europe B:* We computed the ratio of “German” population to Roman population. Magna Germania, the German area during Roman times, has quite different borders than the modern borders. It includes Bohemia, which is now in part of what was Czechoslovakia, while the Rhineland area of Germany was Roman. Based on the fact that Roman occupied Hungary contained about two-thirds of the population of Hungary, and the fact that the Rhineland was considerably more densely populated than Magna Germania, we take one third the population of Germany and the entire population of Czechoslovakia as belonging to Magna Germania. This may be a slight overestimate because the Czechoslovakian tribes were reputed to be stronger than those in what is now Germany. This method is clearly inappropriate after 500 CE.

### *3. Strength of Fortifications*

*China.* Gunpowder was invented in China sometime before 808 CE (Unknown (808)). Early in the Song period it began to play an increasingly important role in Chinese warfare. A military manual (Gonglang, Du and Weide (1044)) from 1044 CE describes a variety of gunpowder weapons that were widely used. What proved most important in practice was the development of the bomb. Siege technology prior to gunpowder involved the use of catapults and ballistas of various types to hurl stones at or over city walls. Replacing stones with bombs proved extremely effective. In the 1100-1200s during the various wars between the Song and Liao/Jurchin there was an R&D race with each side vying to develop improved explosives and each holding a temporary military edge over the other as they developed larger and more explosive bombs. Large bomb factories were built and bombs produced in large quantities by both sides and we read, for example, descriptions of armies as having three thousand men and three thousand thunderclap bombs (Andrade (2016)).

Ancient sieges had been chancy because a besieged city, with its stored supplies, often could outlast the besiegers foraging in the barren countryside. The new Song weapons now could batter walls and gates, explode gunpowder mines, and light fires within the walls. King (1992)

Thus the evidence that the revolution in siege warfare was contemporaneous with the Song era is strong.

*Europe.* Gunpowder technology did not reach Europe until some 400 years after it was invented in China - most likely brought by the Mongols. The first hard evidence we have is that of Bacon (1276) from 1276 who describes the manufacture and use of gunpowder. By 1346 cannons were used in the siege of Calais and in the 1375 siege of Saint-Sauveur-le-Vicomte the French breached the fortress walls with guns weighing over 1 ton and firing 50 kg stone balls. The fall of Constantinople to a handful of cannons in 1453 marked the end of the era of the castle and the fort.<sup>20</sup>

We know that Europe during the Renaissance flowered with the disappearance of medieval fiefdoms and the development of relatively inclusive societies in Italy, the Netherlands and the Hanseatic area. When did this happen relative to the revolution of siege warfare? We note that the fall of Constantinople was itself an important event intellectually in the sense that it triggered the exodus of Byzantine scholars to Italy where they brought with them Greek ideas, including political ideas such as democracy. However, unlike Song China where we have only anecdotal evidence of inclusiveness, in Europe there are two datasets that indicate the timing of the spread of inclusiveness. The first is from Serafinelli and Tabellini (2017) who document the rise of the Comune - charters granting urban areas substantial power of self-governance. In 1000 CE there is no Comune. In 1100 about 10% of urban areas are Comune. This rises to 55% in 1200 and 65% by 1500. The second is from Blank, Dincecco and Zhukov (2017) who document in which European countries the parliament had a voice over taxes. In 1200 this consisted of one country, Sicily, under the Normans. By 1400 the parliaments of Austria, Bohemia, Castille, France, Poland, Portugal and Sicily as well as many smaller states had a voice over taxes. We somewhat arbitrarily chose the date of the publication of the Ordinances of Justice in Florence in 1293 CE as an important political event marking the beginning of the era of greater inclusiveness.

*India.* For India gunpowder and cannons seem to arrived only with the Moguls: according to Baburnama, Habib and Baipakov (2004) sometime after 1496.

#### 4. *Geopolitics: Hegemony*

Is there hegemony or balance of power? Here we take balance of power to mean “not hegemony” - in reality there were often more than two powers. While the model does not allow for more than two societies competing, in the absence of hegemony there was typically a competition between two alliances even if each alliance was made up of independent political entities.

*India.* Until the Mogul conquest of India in 1526 of the many Empires that came and went on the subcontinent the closest to hegemony there is record of were the Kushan Empire under the rule of Kanishka I between 127 and 140 and Delhi Sultanate between 1321 and 1398. Following the Mogul

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<sup>20</sup>See, for example, Sumption (1999) for an account of the use of cannons in siege warfare during the hundred years war and Philippides and Hanak (2011) for their use during the siege of Constantinople.

conquest in 1526 India was hegemonized for the first time in the Common Era and - depending on how one counts Pakistan and Bangladesh - has remained one since.

*China.* The records for China are well established. The Han dynasties were a hegemony that began in 206 BCE and lasted through 220 CE. From 220 CE - 581 CE there was a period of warlordism that was most certainly not hegemony. This is followed in 581 CE - 907 CE by the hegemonic Sui and Tang dynasties. In 907 CE - 960 CE there were the Five Dynasties and Ten Kingdoms which as the name suggests did not constitute hegemony. This was followed by Song dynasty in 960 - 1279 CE which also was not hegemony: the Song only ruled over part of China: it was in a balance of power with a powerful northern state: initially ruled by the Liao and subsequently by the Xia and Jin. After 1279 CE China reverted again to hegemony with the Yuan, Ming and Qing dynasties.

*Europe.* During the period 1 CE - 330 CE the Roman Empire was a hegemony. After the Empire was split in half in 330 CE the closest there was to hegemony in Europe prior to 1550 CE was during the brief reign of Charlemagne.

##### *5. Inclusiveness: the Case of the Song Dynasty in China*

*Civilian Government.* Finer and Finer (1997) indicate that in the non-Song eras the emperor ruled through military commanderies which were charged with local government and fighting “banditry” - which is to say keeping the locals in line. This system declined during the Song period as the Song emperors were deeply suspicious of the military. Military establishments were reduced and military elite lost prominence. A good account can be found in King (1992). During the Song era local control passed from the military and landed aristocracy to a new class - the *Shih*, highly educated literati or gentlemen. These were often those who studied for but failed the imperial exams. Membership in this class arose from becoming classically educated and was certified by taking the exam. As result the elite expanded to include local magnates, family heads, and informal public servants as well as ex-officials. The commanderies declined in importance and the *Shih* played a key role in organizing local markets and in the collection and allocation of taxes. Fogel (1984) gives a good account of this. The decline in the political power of the military during the Song era is noted by many authors - see also Miyakawa (1955).

*Mobility.* The primary source of mobility in China has been access to the imperial bureaucracy through the examination system. Although the imperial bureaucracy existed throughout the era Elman (2000) indicates that “Before the Northern Sung, the principal means of entry into the social and political elite was by official recommendation or kinship relations” while Finer and Finer (1997) indicate that after the Song dynasty the examination system became corrupted and eunuchs loyal to the emperor were relatively more important than bureaucrats selected through exams. By contrast during the Song era the imperial examination system reached its peak. Elman (2000), Kracke (1957) and Lee (1985) provide detailed accounts. During the Song many reforms were made to avoid corruption: in particular the grading of exams became anonymous and the exams themselves were recopied before grading. Most civil service positions were filled through the

examination system. The exams themselves were relatively democratic as many private schools served to provide training for the exams to local elites. Chaffee (1985) tells us that by the early 1100s the state school system had 1.5 million acres of land that could provide a living for some 200,000 students, and by the end of the dynasty it is estimated (see Ebrey and Walthall (2006)) there were some 400,000 students, more than ten times the number at the beginning of the dynasty. The invention and widespread use of the printing press also proved a key element to democratizing education.

*Transfers.* During the Song era there was little or no increase in the size of central government or the military establishment during a period in which the population nearly doubled and there was an explosion in commerce. We have in particular data from Hartwell (1988) on the finances of the Song government: palace expenses (transfers) increased not at all, and a substantial portion of revenues that had been under the control of local military leaders moved instead to the control of the Shih. We can reasonably characterize this as a substantial reduction in relative transfers from the commercial to military elite. After the Song era the military again gained prominence and the central government and military establishment were greatly increased under the Mongols, even in the face of declining population.

#### 6. *China after the Song*

In the Yuan, Ming, and Qing dynasties that followed the Song Dynasty China once again fell into an extractive hegemony. The system of the civilian rule of the Shih was replaced with the older system of medieval military commanderies. The imperial examination system became corrupted and was bypassed through family ties, and eunuchs loyal to the emperor held power over the bureaucracy. The military was larger and received more money in the non-Song periods: under the Ming Dynasty there was an enormous army with over one million troops.<sup>21</sup> The founding Emperor of the Ming dynasty attempted to reorganize the country into isolated and self-sustaining farming towns which would provide him with soldiers. When this failed, he instead put his many sons in charge of regional government.<sup>22</sup>

#### 7. *The case of India*

We have judged India extractive throughout the historical period in question - finding no evidence for a period or periods of inclusiveness. Although the caste system waxed and waned it existed throughout the period and the superiority of the warrior castes over the merchant castes is strong evidence of extractiveness. Moreover, throughout the era India sported a medieval type of political organization in which local princes together with their warriors ruled over local districts.

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<sup>21</sup>See Dutta et al (2018).

<sup>22</sup>See Zhang (2008).

### *8. Conquest by Outsiders*

To what extent are the outsiders so strong that they conquer the insiders? There are two relevant historical episodes: the conquest of China by the Mongols, and the conquest of India by the Moghuls. In both cases the invading outsiders quickly were absorbed and became insiders, and in neither case were they able to maintain control over the outsiders. In the case of the Mongols they did indeed depopulate Mongolia, but this was as much by their migration to the west as their movement south into China.

With respect to the Mongols, Genghis Khan's grandson Kublai Khan successfully invaded China and established the Yuan Dynasty. The relevant point is that he did not retain control over Mongolia and, the depopulation of Mongolia aside, the situation in the Yuan Dynasty was not particularly different than in other dynasties with the Yuan Dynasty forced to establish border garrisons along the great wall, and with Mongolian nomads continuing to raid into China.

With respect to the Moghuls, Babur was driven out of Central Asia and invaded India with 12,000-25,000 men, not a demographically significant event, and quickly lost control of Afghanistan. His successors, particularly his grandson Akbar, who hegemonized India was the ruler of a North Indian state when he carried out his conquest.

There is a third "non-episode" which is the Manchurian conquest of the Ming Dynasty. However, this was, in fact, an internal revolt as Manchuria was part of the Yuan hegemony until 1618 when the Manchu's declared the "seven grievances" and successfully revolted.

## Web Appendix

### Shared Political Power

We first study the situation where in an inclusive hegemony a weighted average  $(1 - \omega)y_m + \omega y_e$  of the gain to each group represents the “overall gain” to rebellion, and likewise in an extractive hegemony  $\omega y_m + (1 - \omega)y_e$  represents the “overall gain.” Instead of assuming  $\omega = 0$  as in the basic model assume only that  $\omega < 1/2$ .

**Theorem.** *The structure of circuits is the same as in the basic model and it remains the case that only  $s, ss$  and  $ww$  can be stochastically stable. The cutoff for an extractive hegemony over an extractive balance of power is  $\eta^*(\varphi, \omega)$  which is larger than the  $\eta^*$  of the basic model. When  $\tau = 0$  and  $\varphi < 1$  then  $ww$  has a greater modified radius than  $ss$ ; when  $\varphi = 1$  then  $ss$  has greater modified radius than  $ww$ .*

*Proof.* We modify the resistance table used in the proof of theorem 1 to account for utility of rebels that is a weighted average of that of the commercial elites and that of the military elites. As before we indicate first the transition then the benefit from the transition to the commercial elites and military elites respectively. This is divided into two columns for occupier or occupied where as in the text, if the initial state is hegemony these are the hegemony’s four groups; in case the initial state is a balance of power occupier versus occupied refers to the situation after transition. The difference is that now for example in the transition  $s \rightarrow sw$ , we had  $y_a = \tau$  - the elite’s gain - we now have the average  $(1 - \omega)y_e + \omega y_m = (1 - \omega)\tau + \omega(1 - \tau)$ . As before the asterisks denote which group is making the decision about attack and paying for defense and the final column reports the resistance.

transition	occupier	occupied	$r(z \rightarrow z')$
$ss \rightarrow s$	$0, 1^*$	$0, -1^*$	$U - \Pi_b(\eta) - u(1, 1, \varphi)$
$s \rightarrow ss$	$0, -1^*$	$0, 1^*$	$U - \Pi_h(\eta)(1 - \omega) - u(1 - \omega, 1, \varphi)$
$s \rightarrow sw$	$0, -1^*$	$1 - \tau, \tau^*$	$U - \Pi_h(\eta) ((1 - \omega)\tau + \omega(1 - \tau)) - u((1 - \omega)\tau + \omega(1 - \tau), 1, \varphi)$
$sw \rightarrow s$	$0, 1^*$	$-(1 - \tau)^*, -\tau$	$U - \Pi_b(\eta) - u(1, 1 - \tau, \varphi)$
$sw \rightarrow w$	$0^*, 1$	$0, -1^*$	$U - u(0, 1, \varphi)$
$w \rightarrow sw$	$0^*, -1$	$0^*, 1$	$U - \Pi_h(\eta)\omega - u(\omega, 0, \varphi)$
$w \rightarrow ww$	$0^*, -1$	$1 - \tau^*, \tau$	$U - \Pi_h(\eta) ((1 - \omega)(1 - \tau) + \omega\tau) - u((1 - \omega)(1 - \tau) + \omega\tau, 0, \varphi)$
$ww \rightarrow w$	$0^*, 1$	$-(1 - \tau)^*, -\tau$	$U - u(0, 1 - \tau, \varphi)$

We again start by determining the structure of circuits. We observe that

$$\begin{aligned} r(s \rightarrow sw) &= U - \Pi_h(\eta) ((1 - \omega)\tau + \omega(1 - \tau)) - u((1 - \omega)\tau + \omega(1 - \tau), 1, \varphi) \\ &> U - \Pi_h(\eta)(1 - \omega) - u(1 - \omega, 1, \varphi) = r(s \rightarrow ss) \end{aligned}$$

for  $\omega < 1 - \omega$  by the monotonicity property of  $u(y_a, y_d, \varphi)$ . This implies that  $ss$  and  $s$  form a circuit. Also by monotonicity we have  $r(w \rightarrow ww) = U - \Pi_h(\eta) ((1 - \omega)(1 - \tau) + \omega\tau) - u((1 - \omega)(1 - \tau) + \omega\tau, 0, \varphi) < U - \Pi_h(\eta)\omega - u(\omega, 0, \varphi) = r(w \rightarrow sw)$  for  $\omega < 1 - \omega$  so that  $ww$  and  $w$

form a circuit. Since the resistance at a balance of power is unchanged the resistance of joining the  $ss \leftrightarrow s$  circuit is still less than joining the  $w \leftrightarrow ww$  circuit. Hence circuits are still described by the diagram  $[(ss \leftrightarrow s) \leftrightarrow sw] \leftrightarrow (w \leftrightarrow ww)$ .

We next revise the table of modified resistances. The second column shows how the modified radius depends upon the resistances, the third how they depend on the model parameters. In the computation we make use of the fact that  $u(0, y_d, \varphi) = 0$ .

state	$R$	$R$
$ss$	$r(ss \rightarrow s) - r(s \rightarrow ss) + r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$\Pi_h(\eta)(1 - \omega) + u(1 - \omega, 1, \varphi) - \Pi_b(\eta) - u(1, 1, \varphi) + R(s)$
$s$	$r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$U - \Pi_h(\eta)((1 - \omega)\tau + \omega(1 - \tau)) - u((1 - \omega)\tau + \omega(1 - \tau), 1, \varphi) + \Pi_b(\eta) + u(1, 1 - \tau, \varphi)$
$sw$	$r(sw \rightarrow w)$	$U$
$w$	$r(w \rightarrow sw)$	$U - \Pi_h(\eta)\omega - u(\omega, 0, \varphi)$
$ww$	$r(ww \rightarrow w) - r(w \rightarrow ww) + r(w \rightarrow sw)$	$U + \Pi_h(\eta)((1 - \omega)(1 - \tau) + \omega\tau) + u((1 - \omega)(1 - \tau) + \omega\tau, 0, \varphi) - \Pi_h(\eta)\omega - u(\omega, 0, \varphi)$

As before  $R(ww) > R(w), R(sw)$  so these two states are not stochastically stable. We compare

$$R(ss) - R(s) = \Pi_h(\eta)(1 - \omega) + u(1 - \omega, 1, \varphi) - \Pi_b(\eta) - u(1, 1, \varphi).$$

We seen then that  $\eta^*(\varphi, \omega)$  is the unique solution from equating this to zero. Notice that

$$\Pi_b(\eta)(1 - \omega) + u(1 - \omega, 1, \varphi) - \Pi_b(\eta) - u(1, 1, \varphi) < 0$$

so that  $\Pi_h(\eta^*(\varphi, \omega)) - \Pi_b(\eta^*(\varphi, \omega)) > 0$  implying that fewer outsiders are needed to tip towards a balance of power than in the basic model.

Next, consider  $\tau = 0$ . We have

state	$R$	$R$
$ss$	$r(ss \rightarrow s) - r(s \rightarrow ss) + r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$\Pi_h(\eta)(1 - \omega) + u(1 - \omega, 1, \varphi) - \Pi_b(\eta) - u(1, 1, \varphi) + R(s)$
$s$	$r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$U - \Pi_h(\eta)\omega - u(\omega, 1, \varphi) + \Pi_b(\eta) + u(1, 1, \varphi)$
$ww$	$r(ww \rightarrow w) - r(w \rightarrow ww) + r(w \rightarrow sw)$	$U + \Pi_h(\eta)(1 - \omega) + u((1 - \omega), 0, \varphi) - \Pi_h(\eta)\omega - u(\omega, 0, \varphi)$

from which

$$\begin{aligned} R(ss) - R(ww) &= \Pi_h(\eta)(1 - \omega) + u(1 - \omega, 1, \varphi) - \Pi_b(\eta) - u(1, 1, \varphi) \\ &\quad - \Pi_h(\eta)\omega - u(\omega, 1, \varphi) + \Pi_b(\eta) + u(1, 1, \varphi) \\ &\quad - \Pi_h(\eta)(1 - \omega) - u(1 - \omega, 0, \varphi) + \Pi_h(\eta)\omega + u(\omega, 0, \varphi) \\ &= u(1 - \omega, 1, \varphi) - u(\omega, 1, \varphi) - u(1 - \omega, 0, \varphi) + u(\omega, 0, \varphi). \end{aligned}$$

From  $u(y_a, y_d, \varphi) = \alpha [(-\varphi - \beta(1 - \varphi)^2 y_d) y_a + (1/2)\beta y_a^2]$  we see that

$$R(ss) - R(ww) = -\alpha\beta(1 - \varphi)^2(1 - 2\omega) < 0.$$

Finally consider  $\varphi = 1$ . We re-display the three relevant rows for convenience:

state	$R$	$R$
$ss$	$r(ss \rightarrow s) - r(s \rightarrow ss) + r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$\Pi_h(\eta)(1 - \omega) + u(1 - \omega, 1, \varphi) - \Pi_b(\eta) - u(1, 1, \varphi) + R(s)$
$s$	$r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$U - \Pi_h(\eta)((1 - \omega)\tau + \omega(1 - \tau)) - u((1 - \omega)\tau + \omega(1 - \tau), 1, \varphi) + \Pi_b(\eta) + u(1, 1 - \tau, \varphi)$
$ww$	$r(ww \rightarrow w) - r(w \rightarrow ww) + r(w \rightarrow sw)$	$U + \Pi_h(\eta)((1 - \omega)(1 - \tau) + \omega\tau) + u((1 - \omega)(1 - \tau) + \omega\tau, 0, \varphi) - \Pi_h(\eta)\omega - u(\omega, 0, \varphi)$

To compute  $R(ss) - R(ww)$  observe that the  $U$  terms and all the  $\Pi_\zeta(\eta)$  terms cancel out. Hence

$$\begin{aligned} R(ss) - R(ww) &= u(1 - \omega, 1, \varphi) - u(1, 1, \varphi) - u((1 - \omega)\tau + \omega(1 - \tau), 1, \varphi) + u(1, 1 - \tau, \varphi) \\ &\quad - u((1 - \omega)(1 - \tau) + \omega\tau, 0, \varphi) + u(\omega, 0, \varphi) \end{aligned}$$

We have  $u(y_a, y_d, \varphi) = \alpha [-y_a + (1/2)y_a^2]$ . All the linear terms cancel out, so we compute all the quadratic terms, that is the sum of squared offensive elements  $S_a^2$ . We get

$$\begin{aligned} S_a^2 &= -1 + (1 - \omega)^2 - ((1 - \omega)\tau + \omega(1 - \tau))^2 + 1 - ((1 - \omega)(1 - \tau) + \omega\tau)^2 + \omega^2 \\ &= 2\tau(1 - \tau)(1 - 2\omega)^2 \end{aligned}$$

which is positive since  $\omega < 1/2$ . □

### *Extractive Cost Advantage*

We suppose now that extractive and inclusive societies  $k \in s, w$  have different costs of raising resources for conflict  $\gamma_k$  with  $\gamma_w > \gamma_s > 1$ . From the proof of Theorem 2 we have the optimum for the aggressor  $\hat{x}_a = \alpha y_a / \gamma_a$  and for the defender is  $\hat{x}_d = \alpha(1 - \varphi)y_d / \gamma_d$ . Hence the partial utility gain to the aggressor is given by

$$u(y_a, y_d, \varphi, \gamma_a, \gamma_d) = \alpha [(-\varphi - \alpha(1 - \varphi)^2 y_d / \gamma_d) y_a + (1/2)\alpha y_a^2 / \gamma_a]$$

and note that this is increasing in  $\gamma_d$  and decreasing in  $\gamma_a$ .

**Theorem.** *The structure of circuits is the same as in the basic model and it remains the case that only  $s, ss$  and  $ww$  can be stochastically stable. The modified radius of  $s$  is remains greater than  $ss$  if and only if  $\eta < \eta^*$ . For  $\tau = 0, \varphi = 0$  the modified radius of  $ww$  is greater than  $ss$  if and only if  $\gamma_w < 3\gamma_s$ .*

*Proof.* The resistance table used in the proof of theorem 1 is now

transition	occupier	occupied	$r(z \rightarrow z')$
$ss \rightarrow s$	$0, 1^*$	$0, -1^*$	$U - \Pi_b(\eta) - u(1, 1, \varphi, \gamma_s, \gamma_s)$
$s \rightarrow ss$	$0, -1^*$	$0, 1^*$	$U - \Pi_h(\eta) - u(1, 1, \varphi, \gamma_s, \gamma_s)$
$s \rightarrow sw$	$0, -1^*$	$1 - \tau, \tau^*$	$U - \Pi_h(\eta)\tau - u(\tau, 1, \varphi, \gamma_w, \gamma_s)$
$sw \rightarrow s$	$0, 1^*$	$-(1 - \tau)^*, -\tau$	$U - \Pi_b(\eta) - u(1, 1 - \tau, \varphi, \gamma_s, \gamma_w)$
$sw \rightarrow w$	$0^*, 1$	$0, -1^*$	$U$
$w \rightarrow sw$	$0^*, -1$	$0^*, 1$	$U$
$w \rightarrow ww$	$0^*, -1$	$1 - \tau^*, \tau$	$U - \Pi_h(\eta)(1 - \tau) - u(1 - \tau, 0, \varphi, \gamma_w, \gamma_w)$
$ww \rightarrow w$	$0^*, 1$	$-(1 - \tau)^*, -\tau$	$U$

We again examine the structure of circuits. We observe that  $r(s \rightarrow sw) = U - \Pi_h(\eta)\tau - u(\tau, 1, \varphi, \gamma_w, \gamma_s) > U - \Pi_h(\eta) - u(1, 1, \varphi, \gamma_s, \gamma_s) = r(s \rightarrow ss)$  by the monotonicity property of

$u(y_a, y_d, \varphi, \gamma_a, \gamma_d)$ . This implies that  $ss$  and  $s$  form a circuit. Also by monotonicity we have  $r(w \rightarrow ww) = U - \Pi_h(\eta)(1 - \tau) - u(1 - \tau, 0, \varphi, \gamma_w, \gamma_w) < U - u(0, 0, \varphi) = r(w \rightarrow sw)$  so that  $ww$  and  $w$  form a circuit. We check which circuit  $sw$  joins. It will join the circuit to which it has the least resistance of reaching. By monotonicity  $r(sw \rightarrow s) = U - \Pi_b(\eta) - u(1, 1 - \tau, \varphi, \gamma_s, \gamma_w) < U = r(sw \rightarrow w)$  so the resistance of joining the  $ss \leftrightarrow s$  circuit is less than joining the  $w \leftrightarrow ww$  circuit. The circuit diagram:  $[(ss \leftrightarrow s) \leftrightarrow sw] \leftrightarrow (w \leftrightarrow ww)$  is unchanged.

For the modified radii we have

state	$R$	$R$
$ss$	$r(ss \rightarrow s) - r(s \rightarrow ss) + r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$U + \Pi_h(\eta)(1 - \tau) + [u(1, 1 - \tau, \varphi, \gamma_s, \gamma_w) - u(\tau, 1, \varphi, \gamma_s, \gamma_s)]$
$s$	$r(s \rightarrow sw) + r(sw \rightarrow w) - r(sw \rightarrow s)$	$U + \Pi_b(\eta) - \Pi_h(\eta)\tau + [u(1, 1 - \tau, \varphi, \gamma_s, \gamma_w) - u(\tau, 1, \varphi, \gamma_s, \gamma_s)]$
$sw$	$r(sw \rightarrow w)$	$U$
$w$	$r(w \rightarrow sw)$	$U$
$ww$	$r(ww \rightarrow w) - r(w \rightarrow ww) + r(w \rightarrow sw)$	$U + \Pi_h(\eta)(1 - \tau) + u(1 - \tau, 0, \varphi, \gamma_w, \gamma_w)$

As before  $R(ww) > U$  so neither  $sw$  nor  $w$  is stochastically stable. As before  $R(ss) - R(s) = \Pi_h(\eta) - \Pi_b(\eta)$  so between  $ss$  and  $s$  stochastic stability is determined entirely by whether  $\eta > \eta^*$  or  $\eta < \eta^*$ . The key comparison remains

$$R(ss) - R(ww) = u(1, 1 - \tau, \varphi, \gamma_s, \gamma_w) - u(\tau, 1, \varphi, \gamma_s, \gamma_s) - u(1 - \tau, 0, \varphi, \gamma_w, \gamma_w).$$

We now specialize to  $\tau = 0, \varphi = 0$ : this becomes

$$\begin{aligned} R(ss) - R(ww) &= u(1, 1, 0, \gamma_s, \gamma_w) - u(1, 0, 0, \gamma_w, \gamma_w) \\ &= (1/\gamma_s)(1/2)\alpha^2 [\gamma_w/\gamma_s - 3] \end{aligned}$$

and we see that  $ww$  is stochastically stable over  $ss$  if and only if  $\gamma_w < 3\gamma_s$ . □