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Computational Social Theory

Invited Speaker

Lars-Erik Cederman

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GROWING SOVEREIGNTY: ORGANIZATIONAL SHIFTS IN STATE SYSTEMS

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ABSTRACT

Drawing on prominent theories of historical sociology, we model the emergence of the territorial state in early modern Europe. Our modeling effort focuses on systems change with respect to the shift from indirect to direct rule. Inspired by the historical logic, we take a first step toward formalization by introducing a one-dimensional model that helps us fix our thoughts about the tradeoff between organizational and geographic distances. To test our initial deductive findings, we also present an agent-based model that features states with a varying number of organizational levels. This model explicitly represents causal mechanisms of conquest and internal state-building through organizational bypass processes. The computational findings confirm our hypothesis that technological change is sufficient to trigger the emergence of modern, direct state hierarchies.

Keywords: Territorial states, agent-based model, international relations theory, systemic change, geopolitical model

INTRODUCTION

Conventional theories of political science assume not only that actors are fixed and given but also that fundamental actor types remain constant. For example, international relations theory postulates the existence of a system of states and then goes on to explore interactions among such actors. However, the world is not made up of only territorial states; moreover, these entities have not always been, and will not necessarily always remain, the most important actors in world politics.

The terrorist attacks of September 11, 2001, highlighted the subversive effect on territorial states from transnational, covert networks of terrorists. Some of these entities have been associated with civilizations (seen as large-scale identities following mostly religious lines). Furthermore, analysts have also drawn the conclusion that the European Union (EU) represents a new type of political actor that violates the traditional norms of territorial sovereignty. The EU, being neither a state nor an intergovernmental organization, represents a *sui generis* social form.

Given the fundamental importance of these developments, our theories need to catch up with the real world. We do so by exploring the emergence of the most important organizational form in world politics, namely, the modern territorial state. Focusing on changes in the internal structure of state organizations, we introduce a series of models that show how the territorial

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modern state came to dominate the Westphalian system. Setting aside other aspects of this transition, we model the shift from "indirect rule" to "direct rule." This change entailed a flattening of medieval hierarchies, which allowed state leaders to govern their territories without intermediaries. Rather than assuming sovereignty, we attempt to grow it.

We start our investigation by classifying different types of change in international systems. This exercise in conceptual ground-clearing indicates that our analysis must confront the problem of systems change, of which the emergence of the territorial state is an important special case. Highlighting the shift from indirect to direct rule, we survey some of the best writing in historical sociology for ideas about the mechanisms that brought about this case of systems change. Inspired by this historical logic, we take a first step toward formalization by introducing a very simple, one-dimensional model that helps us fix our thoughts about the tradeoff between organizational and geographic distance. To test our initial deductive findings, we present an agent-based model that features states with a varying number of organizational levels. The model explicitly represents causal mechanisms of conquest and internal state-building through organizational bypass processes. The computational findings confirm our hypothesis that technological change, captured by a sliding logistical function, is sufficient to trigger the emergence of modern, direct state hierarchies.

CAPTURING CHANGE IN WORLD POLITICS

While many unique aspects characterize the changes that the international system is currently undergoing, world history has always been in flux, albeit at varying levels of structural depth. This point is nicely illustrated by Gilpin's (1981) taxonomy, which introduces three types of change in world politics:

- *Systems change* is the most fundamental type because it concerns the very nature of the units (i.e., the actor types).
- *Systemic change* is the next level, and it relates primarily to the emergence and disappearance of specific units, as well as to shifts in their outer boundaries.
- *Process change* is the least profound type since it relates to the dynamics and behavioral interactions among given units, such as cooperation, conflict, and alliance formation.

Despite the changes associated with the end of the Cold War, *process change* is still the bread and butter of international relations (IR) theory. Given a fixed set of actors, researchers typically study interaction patterns among them. Such analyses tend to focus on the balance between conflict and cooperation. Taking issue with structural theories that expect little change at all (e.g., Waltz 1979), neoliberal theorists explain the emergence of cooperation under anarchy. Drawing on Axelrod's (1984) and other game theorists' important result that cooperative strategies may thrive in iterated games, a whole generation of scholars has applied this logic to the development of cooperative regimes in various issue areas (Oye 1986; Keohane 1984). To a large extent, constructivist IR scholars account for the same phenomenon while relying on ideational factors, including processes of identity formation (Adler and Barnett 1998; Wendt 1999).

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The next level of Gilpin's taxonomy shifts the focus to changes in specific actors and actor constellations. Viewed as an endogenous development, *systemic change* features the rise and fall of states. The so-called hegemonic theories of Gilpin (1981) and Kennedy (1989) explain the shifting fortunes of great powers as instances of systemic change caused by differential growth within the system. For various technological and organizational reasons, individual states are sometimes able to pull far ahead of the competition and assert themselves as hegemons. Over time, however, competitors tend to catch up with the hegemon, which ultimately loses its leading role, typically by losing a hegemonic war.

All these theories of systemic change assume that there is only one actor type in the system: the territorial state. Variation merely concerns the scale of the actors, without any reference to changes in their underlying structure. *Systems change*, on the other hand, implies a more radical transformational logic that introduces entirely novel organizational forms. This emphasis on novelty requires a much more flexible ontology than standard theories assume (Cederman 1997). This type of transformation is truly configurative rather than merely purposive because it presupposes "change in the organising principle governing the distribution of power and authority. It involves a change in the principles that determine the spatial configuration of politics, as well as the moral language used to justify the spatial order" (Reus-Smit 2002, page 137).

Analysis of systemic and systems change, as opposed to process change, requires explicit attention to the actors' corporate identities. A corporate identity denotes an actor's spatio-temporal extension, including the mechanisms that mark its spatial boundaries and that reproduce it over time (Wendt 1999, Chapter 4). Conventional constructivist theory is unable to deal with this type of change because of its exclusive preoccupation with social identities as opposed to corporate identities. Social identities merely specify the role repertoires of actors, such as friendship or enmity.

As suggested by Georg Simmel's process theory, a complete explanation of systems change needs to theorize changes both in terms of space and time (Cederman and Daase 2003). The spatial dimension highlights the actor's internal structure, its external environment, and its boundary to the environment. It is also necessary to specify a set of dynamic mechanisms that provoke changes in spatial structures over time. Evolutionary theory tells us that such processes rely on either natural selection or social evolution (Kahler 1999). Whereas the former involves a Darwinian winnowing of the best-adapted organizational forms, the latter features at least some adaptation of the actors' "internal models." It is also possible to imagine hybrid theories that combine natural selection and learning processes.

THEORIZING SYSTEMS CHANGE: THE EMERGENCE OF THE TERRITORIAL STATE

Any attempt to explain the emergence of the territorial state has to start by considering its constitutive principle: sovereignty. According to Bull's (1977, page 8) classical definition, states can be seen as

> "…independent political communities each of which possesses a government and asserts sovereignty in relation to a particular portion of the earth's surface and a particular segment of the human population."

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Bull (1977, page 8) proceeds by dividing the notion of sovereignty into an internal and an external component:

> "On the one hand, states assert, in relation to this territory and population, what may be called internal sovereignty, which means supremacy over all other authorities within that territory and population. On the other hand, they assert what may be called external sovereignty, by which is meant not supremacy but independence of outside authorities."

As a corollary, it has to be inferred that the distinction between internal and external sovereignty presupposes sharp inter-state boundaries.

How did this configuration emerge over time? An answer to this question calls for a dynamic account of the three dimensions of sovereignty. Internally, sovereign rulers ridded themselves of internal competition within their territories. At the same time, they expanded their territories in the face of external competition. Together, these two processes generated increasingly thin and clearly defined borders.

Before searching for the mechanisms that brought about this complex process, we must first consider what preceded the modern territorial state of modern Europe. Indeed, sovereignty, as it is understood today, did not exist in the Middle Ages (Strayer 1970). Although territorial states had started to emerge as organizational cores, these were characterized by fading central control that occurred as distance from the capital increased. Moreover, centralized political control was limited by feudalism's indirect arrangement for broadcasting power (Poggi 1978, page 28). This was reinforced by the primitive state of the transportation infrastructure, which made it practically impossible to govern large units directly. Tilly (1990, page 104) explains that

> "…city-state, autonomous bishoprics, petty principalities, and other microstates ruled in a relatively direct way. Agents who were immediately responsible to the crown and served at the monarch's pleasure collected taxes, administered courts, tended crown property, and maintained day-to-day contact with local communities falling under the crown's jurisdiction. Larger states, however, invariably opted for some form of indirect rule, co-opting local powerholders and confirming their privileges without incorporating them directly into the state apparatus."

This situation in these large organizations thus stood in stark contrast to that of the smaller, directly ruled units (Tilly 1990, page 104):

> "Before the seventeenth century, every large European state ruled its subjects through powerful intermediaries who enjoyed significant autonomy, hindered state demands that were not to their own interest, and profited on their own accounts from the delegated exercise of power. The intermediaries were often privileged members of the subordinate populations, and made their way by assuring rulers of tribute and acquiescence from those populations."

Under feudalism, "war lords" ruled their own fiefs while offering the state core military services in exchange for the right to extract resources within their own territories. This created a hierarchical organization that rested on several layers of semi-autonomous control.

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In terms of internal organization, we can summarize the process of state formation as a shift from "indirect rule" to "direct" rule. Feudalism's limits on the central state's power were finally swept aside by the ascendance of the modern, territorial state — a process that culminated with the nationalization of state power after the French Revolution.

This process had both an internal and an external dimension, the most obvious being the external one. Thanks to the revolution in military technology (Downing 1992), power centers amassed resources that triggered a snowball process of conquest (Gilpin 1981). War led to conquest, and conquest led to increased resources to wage future wars. Only the largest units managed to survive this cutthroat competition.

The internal facet of this process of geopolitical consolidation was equally important, because as we have seen, sovereignty not only implies freedom from external challenges but also effective subjugation of the emerging state's internal enemies. Again, Tilly (1990, page 69) eloquently describes the process:

> "Since the seventeenth century ... rulers have managed to shift the balance decisively against both individual citizens and rival powerholders within their own states. They have made it criminal, unpopular, and impractical for most of their citizens to bear arms, have outlawed private armies, and have made it seem normal for armed agents of the state to confront unarmed civilians."

Thus, if conquest was the key mechanism that transformed sovereignty's external dimension, a process of *organizational bypass* operated within the emerging state's territory. Organizational bypass occurs when the central ruler manages to supplant the authority of the inferior subunits with direct rule. As a result, the bypass process connects subjects directly to the capital, thus depriving the regional power center of its capacity to extract resources from below.

In reality, this process happened through a prolonged series of conflicts between the center and the subunits and through the consolidating state's gradual penetration of the provinces. As the state expanded its power, "struggles arose between center and periphery over the new 'right' to tax" (Finer 1974, page 98). For example, "Louis XIII, the seventeenth-century monarch who with the air or Richelieu and Mazarin rebuilt the armed forces of the French state, probably tore down more fortresses than he constructed. But he built at the frontiers, and destroyed in the interior" (Tilly 1990, page 99).

Such activities were followed by the replacement of feudal lords with tax collectors and governors who were placed under the direct control of the sovereign (Finer 1974; Ardant 1975). In France, organizational geniuses such as Colbert and Richelieu were the chief architects of this transformation, but other states in Western Europe carried out similar campaigns of centralization. Under the leadership of Louis XIV, "administration, tax collection, the levying, command and disposition of troops had *all* been fully incorporated into the master system as its *functions*, not any longer as so many demarcated sub-systems which were linked in to the center by one or a few prestigious individuals" (Finer 1974, page 114). Throughout the state's territory, weapons were seized, militias demilitarized, and private armies suppressed. Organizational bypass secured the modern territorial state's monopoly on political power.

Finally, the external and internal reconfiguration of sovereignty entailed the gradual crystallization of territorial borders. To be sure, the pre-modern world was characterized by a

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blurred distinction between domestic and international politics. In particular, empires had porous borders constituting "gray", semi-anarchic areas between the power centers. In some cases, even the extent to which there was any difference between domestic and international politics is questionable (Ruggie 1993; Kratochwil 1986).

Although a complete account of state formation would describe this transformation of borders, we will assume the existence of sharply demarcated borders and focus entirely on the internal and external aspects of sovereignty. We assume that these two processes created the modern state. Although repeated acts of conquest consolidated the external dimension of sovereignty, internally, organizational bypass led to a gradual shift from indirect to direct rule.

PREVIOUS ATTEMPTS TO MODEL SYSTEMS CHANGE

Historical sociologists have analyzed systems change along all three dimensions in great detail. However, because of the processes' overwhelming complexity, it is not surprising that few have attempted to model them formally. Nevertheless, several attempts have been made to model the external dimension, particularly through computational models of conquest that allow boundaries to evolve endogenously over time. Already in 1977, Bremer and Mihalka (1977) proposed a model of featuring conquest in a hexagonal grid, which was later extended and further explored by Cusack and Stoll (1990).

Building on the same principles, Cederman (1997) introduced a new generation of models called Geosim. These models share a common architecture that starts with a territorial grid of fixed and indivisible primitive agents that can be thought of as villages or counties (Cederman 2002). Those states that survive grow, and their boundaries expand endogenously through a repeated process of conquest. The resulting states, which are organized in a dynamic network, are hierarchical organizations whose capitals are linked to their respective provinces through direct, asymmetric relations of domination.

Nevertheless, because all these models hard-wire direct rule into their foundational ontology, they are not designed to generate new actor types along the internal dimension of sovereignty. In fact, the only dimension that is explicitly captured by these models is the external aspect of sovereignty. The repeated process of conquest does illustrate the growth of territorial size and leads to organizations that resemble modern territorial states, at least in terms of size. But this process says little about the organizational aspect of sovereign rule. In other words, the models in this research tradition feature only two-level organizations, in which provinces are subordinate to capitals. As we have seen, however, modeling the transition from direct to indirect rule requires an explicit representation of intermediate layers of organization. Without such ontological flexibility, it is impossible to explore the "flattening" of hierarchies that characterize the shift from indirect to direct rule.

Moreover, the notion of sharp territorial borders is hard-wired into the model specification. While secession is explicitly modeled in some versions, and culturally bounded units (such as nations) are modeled in others (cf. Cederman 2002, 2004), state borders remain sharply delineated, thus excluding the possibility of modeling fuzzy frontiers and competing

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internal or external sovereignties. In this sense, the models endogenize systemic change, while ignoring systems change.[1]

In this paper, we focus on systems change with respect to internal structure. The endogenization of boundary types, however, is an interesting topic that needs to be addressed in future modeling efforts. To our knowledge, there are very few models that capture systems change as the emergence of novel social forms. However, computational organization theory and agent-based modeling open new avenues of research in this respect (Lomi and Larsen 2001; Cederman 2005). Organization theorists have typically studied how structural change affects overall performance, but their efforts typically treat the organizational topology exogenously (e.g., Morel and Ramanujam 1999 — though also see Prietula et al. 1998).

Before considering the possibilities of computational modeling, we turn the focus to a simpler, deductive approach. In a series of general conceptual papers, Kochen and Deutsch (1969, 1974) propose a simple mathematical framework for the analysis of organizational decentralization within private or public organizations, including territorial states. Whereas most preceding models had focused on the location of control, Kochen and Deutsch explicitly study organizations' performance as a function of their centralization.

One of their key arguments is that "a system should be decentralized if the additional cost of communication for coordination that a centralized system must have exceeds the difference between the higher expected profit of the centralized form and the lower expected profit of the decentralization" (Kochen and Deutsch 1974, page 107). Relying on this logic, they specify a mathematical model that allows them to draw inferences about the optimal number of organizational levels. The key bottleneck that forces delegation to deeper levels of organization is the cost of coordinating the provision of services at any specific level of organization. Their reasoning is so abstract that it is not obvious what it implies in terms of state formation. In the next section, we therefore take a first step toward modeling the shift from indirect to direct rule. This transformation hinges on a tradeoff between geographic and organizational distances.

ONE-DIMENSIONAL MODEL OF HIERARCHICAL STATE FORMATION

In feudal systems, there were formidable obstacles to geographic mobility that could only be overcome by the power centers' improved geographical reach. The introduction of intermediate instances of taxation and control reduced the geographic distances that had to be overcome. We illustrate this principle with a simple mathematical model that highlights the logic of resource extraction. Following Dacey (1974), the model is represented in one dimension (see also Cederman 1995).

Although we make the assumption of a linear system for tractability reasons, there are some historical cases of state formation that did unfold in a linear fashion. Perhaps the best-known examples are river valleys surrounded by impassable terrain, such as the Nile (Carneiro

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1 Axelrod (1997, Chapter 6) proposes a "tribute" model of new political actors that may be at least a partial exception to this limitation. According to Axelrod's algorithm, collective actors emerge if there is a pattern of interactions that confirms a number of properties that are seen to be constitutive of agency. These include effective control over subordinates, collective action, and recognition by third parties that an actor has been formed.

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1978). Relying on computational methodology, the following section generalizes the mechanism to two dimensions and puts it on a dynamic footing. The purpose of the present discussion is to illustrate the main logic of resource extraction in multi-level state hierarchies.

We start by demonstrating how the tax mechanism operates in a "line state" with three levels of hierarchy (Figure 1). The nodes of the tree are equidistantly spread out along the horizontal axis, starting at location 1 and ending with location 5, and are labeled accordingly. The logic of resource extraction can now be summarized. Each node produces a resource unit on its own in addition to extracting taxes from its inferior units. All of this income is subject to taxation by the next-higher unit at a fixed tax rate k that is discounted δ per distance unit. While k determines the organizational cost of traversing from one level to another, the parameter δ penalizes attempts to reach over large geographic distances. The subunits retain whatever resources are not passed up the tree.

Let us now assume that the tax rate k is 0.5 and the geographic discount rate δ is 0.8. This means that the "leaves" of the state tree pay $0.5 \times 0.8 = 0.4$ of their income in tax to the next-higher instance, which in every case is located only one step from their locations. Nodes 1 and 3 pay node 2, and node 5 sends its taxes directly to the capital, node 4. This means that these subunits can keep $1 - k\delta = 0.6$. The intermediate node 2 receives tax revenue 0.4 + 0.4 from the inferior nodes 1 and 3 and from one resource unit from its own territory, yielding a total of 1.8 units of "taxable income." Taxation to the next-higher instance proceeds in analogy to the first level, but, in this case, the distance-discounting will be more severe because the distance between node 2 and the "capital" at node 4 is two distance units. This means that the effective tax rate amounts to $k\delta^2 = 0.5 \times 0.8 \times 0.8 = 0.32$ and that node 2 has to pass on 32% of its 1.8 resource units (i.e., 0.576) to the capital, while keeping the remaining resources (1.224). We can now compute the total resources controlled by the capital. The tax revenue is 0.576 + 0.4 from nodes 2 and 5. In addition, the resource unit of the capital province has to be taxed at $k = 0.5$, although without distance discounting, which means that the total resources amount to 1.576.

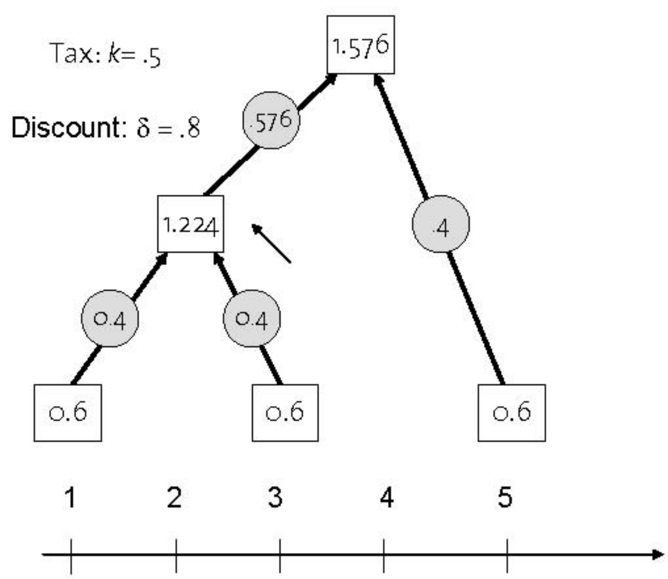

FIGURE 1 A simple example of a linear state with three levels of hierarchy

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In sum, each level of the hierarchy taxes its subordinates while passing on a share of the revenue to the next superior instance. In this simple example, we assumed that the distance-discounting followed a simple exponential decay function $\delta(x) = \delta^x$. Functions of this type are often referred to as loss-of-strength gradients (Boulding 1963), and the functional form is often assumed to be exponential. By using the same discounting as in our first example, $\delta = 0.8$, Figure 2 illustrates how resource extraction declines as the distance from the capital increases. (The step function is discussed shortly.)

We are now ready to compare stylized versions of indirect and direct rule. In both cases, we represent the states' internal structure symmetrically. Figure 3 introduces a "chainlike" state of maximum depth, where the capital is located at zero. On each side of the capital, subordinate nodes are organized such that for each step away from the capital, a new, inferior level is added. Here distance is overcome through repeated acts of delegation, producing a very deep structure.

Thanks to the symmetry of the organizational form, it is sufficient to compute the resources extracted from one of the two branches $f_{IDR}(n)$. The total resources can be obtained as $p_{IDR}(n) = f_{IDR}(n) + k$, where k adds a taxed resource unit for the capital itself.

$$f_{IDR}(n) = k\delta(1)\{1 + k\delta(1)[1 + k\delta(1)(...)]\} = \sum_{i=1}^{n} k^i \delta(1)^i \quad ,$$

where $\delta(1)$ is the discounting for one distance unit. This is a more general functional form than the exponential decay function we relied on in Figure 1.

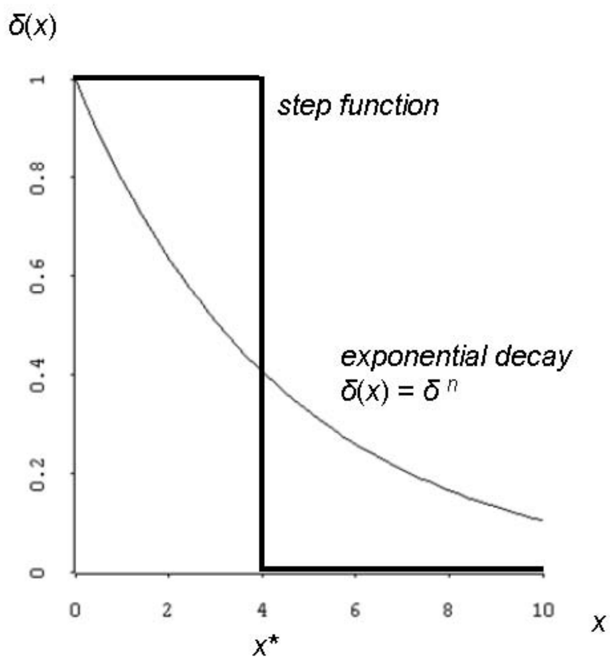

FIGURE 2 Two types of loss-of-strength gradients

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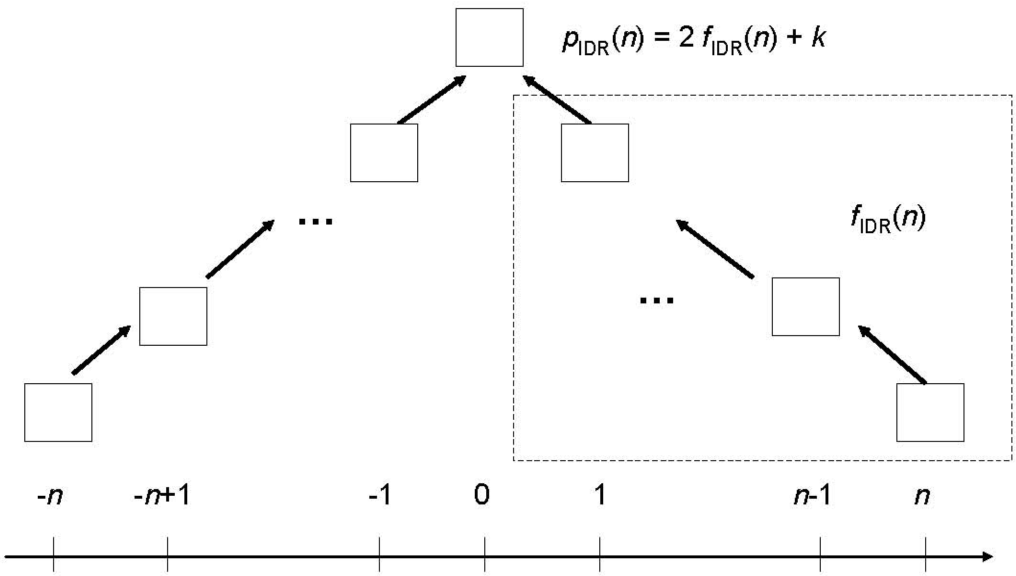

FIGURE 3 Symmetric, indirectly ruled state with a hierarchical depth of *n*

In stark contrast to the logic of indirect rule, Figure 4 illustrates the flattest possible hierarchy featuring a superior capital that rules all other nodes directly. Here it is straightforward to compute the total resources for direct rule as $p_{DR}(n) = f_{DR}(n) + k$, where

$$f_{DR}(n) = k\delta(1) + k\delta(2) + ... + k\delta(n) = \sum_{i=1}^{n} k\delta(i) \ .$$

In this case, the maximum discounting amounts to $\delta(n)$ rather than $\delta(1)$. Clearly, direct rule needs to overcome much more significant distances than does indirect rule.

We can now compare these two organizational forms for the exponentially decaying loss-of-strength gradient $\delta(x) = \delta^x$. This comparison yields our first proposition (see the appendix at the end of this paper for proof):

> *Proposition 1.* For an exponentially decaying loss-of-strength gradient $\delta(x) = \delta^x$, direct rule is always more efficient; that is, $p_{DR}(n) > p_{IDR}(n)$ for all $n > 1$.

We have just shown that, at least in our simplified, one-dimensional world, exponential distance-dependence cannot be responsible for a shift from indirect to indirect rule. Regardless of the value of δ, direct rule is superior. Thus, even if the loss-of-strength function shifts outward over the course of history, directly ruled states are always more efficient organizational forms. Under these conditions, feudalism could never have taken root!

What type of distance dependence has to apply for the shift from indirect to direct rule to occur? It is necessary to postulate a radically different loss-of-strength gradient in order to simulate Tilly's transformation. Let us instead assume a step function that drops from 100% resource extraction to zero at some distance x^* from the capital. We are now ready to state our second proposition (again, see the appendix for proof).

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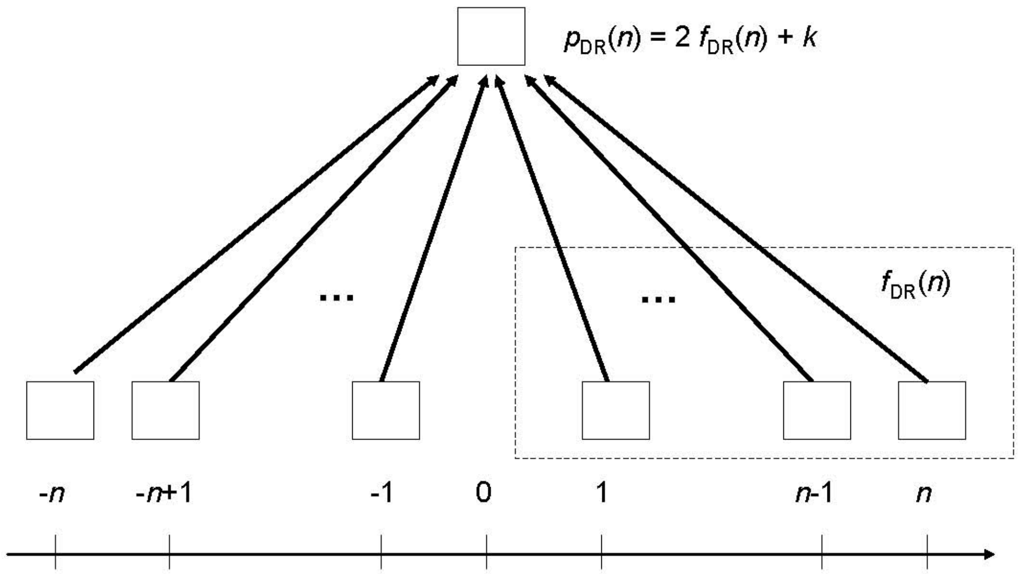

FIGURE 4 Symmetric, directly ruled state with the flattest possible structure

Proposition 2. Assuming that the loss-of-strength gradient is defined by a step function $\delta(x) = 1$, for $x \leq x^*$, and for $\delta(x) = 0$ for $x > x^*$, there are two cases:

Case 1. If $x^* < 1/(1 - k)$, direct rule is more efficient if

$$n < x' = \frac{\log[1-(1-k)x^*]}{\log k}$$

For all other values $n > x'$, indirect rule is superior.

Case 2. If $x^* > 1/(1 - k)$, direct rule is always more efficient.

Figure 5 provides a graphical illustration of the two curves. Direct rule grows as a linear function of n up to x^* and remains flat after that. In contrast, indirect rule yields a slowly growing increase in power that flattens out asymptotically at $k(3 - k)/(1 - k)$. For low cutoff points x^* below $1/(1 - k)$, direct rule is more efficient for low values of n up to x'. After this point, indirect rule surpasses its direct counterpart. However, for high values of x^* (i.e., wherever distance plays less of a role), direct rule is always the best choice.

We can now imagine a shift from indirect to direct rule by sliding the step function's cutoff point x^* from low to high values. In the former case, loss-of-strength gradients with little reach approximate the conditions of the Middle Ages. Here only the smallest political organizations can afford direct rule, as suggested by Strayer (1970) and Tilly (1990). This explains why the pre-modern world contained a combination of large, indirectly ruled empires and very small units, such as city states and other principalities characterized by immediate relations between rulers and the ruled. However, as the logistical conditions improve with increasing values of x^*, we enter the modern era. Now direct rule offers the superior logic, regardless of scale.

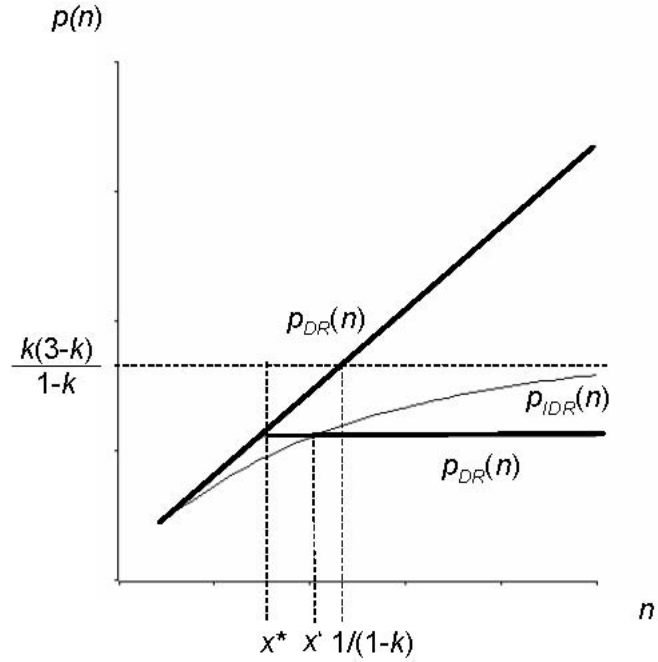

FIGURE 5 Resource extraction under direct and indirect rule based on a step function

Although some caution is appropriate given the starkly simplified situation, it is theoretically significant that exponential loss-of-strength gradients are incapable of triggering a change from indirect to direct governance. If Proposition 1 can be generalized, it represents a powerful argument against exponential decay functions, at least in early modern Europe. It seems that distance-dependence needs to feature some drop, albeit not necessarily as radical as that suggested by the step function.

COMPUTATIONAL MODEL OF TERRITORIAL SYSTEM CHANGE

The preceding section provides important insights into the tradeoff between organizational and geographic distances. However, our exceedingly simple mathematical model leaves many questions open. In particular, the deductive framework forces us to make many strong assumptions for tractability reasons. Therefore, this section introduces a computational model that enables us to relax these assumptions. First, we extend the linear setup to a more general, two-dimensional space. Second, we go beyond static comparisons of organizational efficiency by studying the operational causal mechanisms in a competitive, dynamic setting. Third, we generalize the results of the mathematical model in terms of the loss-of-strength gradient's functional form.

We proceed by building on the principles of Geosim (Cederman 1997, 2002, 2003) while extending the framework to an arbitrary number of hierarchical levels. The new model, which we call OrgForms, has been created from scratch by using the Java-based toolkit Repast. Like Geosim, OrgForms constitutes a dynamic network of endogenous hierarchical organizations that

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engage in constant geopolitical competition. These actors reside in a two-dimensional spatial grid and interact only with their immediate neighbors.

As opposed to the states in Geosim, which feature only two-level hierarchies, the actors in OrgForms resemble the hierarchical line states of the preceding section. We adopt exactly the same recursive taxation mechanism as in the linear case. This means that each actor, whether sovereign or not, produces exactly one resource unit locally. Each superior instance taxes the next inferior level by a constant, globally fixed tax rate of 0.2 that is discounted according to the Euclidian distance between the taxing and taxed units. Obviously, the efficiency of large states' resource extraction tends to decline in the periphery as their territories expand.

In our experiments, we use a 30×30 square lattice that is initially populated with 200 compound, state-like actors with merely two levels. Figure 6 describes such a system. The black lines denote state borders, and the red dots mark the capitals. The figure also indicates the resource level of each state below the capital. This setup is very similar to Geosim's initial configuration (cf. Cederman 2003).

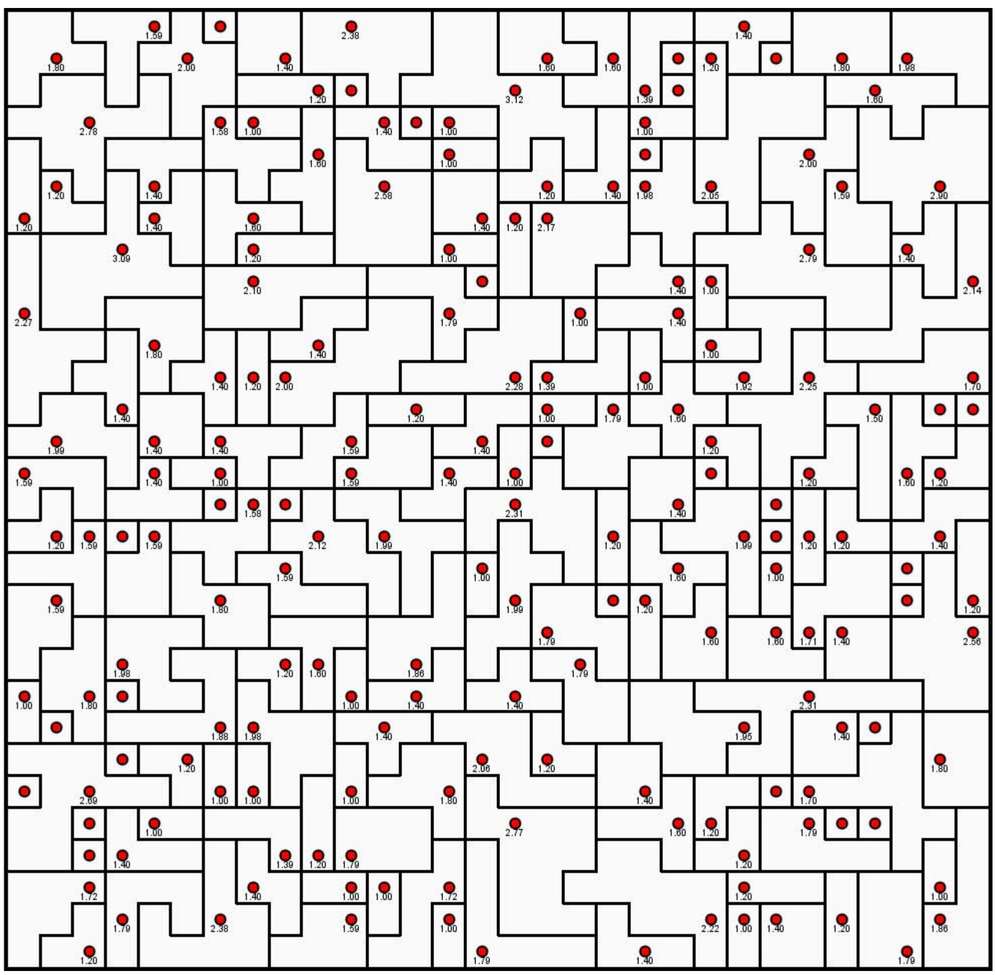

FIGURE 6 Initial state of the OrgForms model (t = 0)

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After having created an initial state system, we now turn to the dynamics of the model. Technological progress is the master process that drives the system forward. In contrast to the perfectly sharp step function used in the previous section, the loss-of-strength gradient in the current, computational model follows a smoother logistical functional form:

$$\delta(x,t) = \frac{1}{1+\{x/x^*(t)\}^{c(t)}} \ ,$$

where x is the distance from the capital; $x^*(t)$ is a time-dependent threshold value for which resource extraction reaches 50%; and $c(t)$ is a dynamic, tunable parameter that controls the curve's steepness. While $c(t) = 0$ yields a totally flat function, a perfect step function forms as $c(t) \to \infty$.

Technological change is modeled by sliding the threshold $x^*(t)$ from lower to higher values and by reducing the slope $c(t)$ over time t (cf. Cederman 2003 for a similar way to model technological change, which focuses on the threshold only). Figure 7 illustrates how the shape of the loss-of-strength gradient $\delta(x,t)$ changes as a function of time t. At the beginning of the simulation, the logistical obstacles are overwhelming. As the curve slides from left to right in the diagram, however, the capital's ability to tax at large distances improves dramatically. More precisely, throughout the course of a simulation run, we slide the threshold $x^*(t)$ from 3 to 10 at time period t = 1,000. At the same time, the slope is reduced from $c(t)$ = 10 to 5.

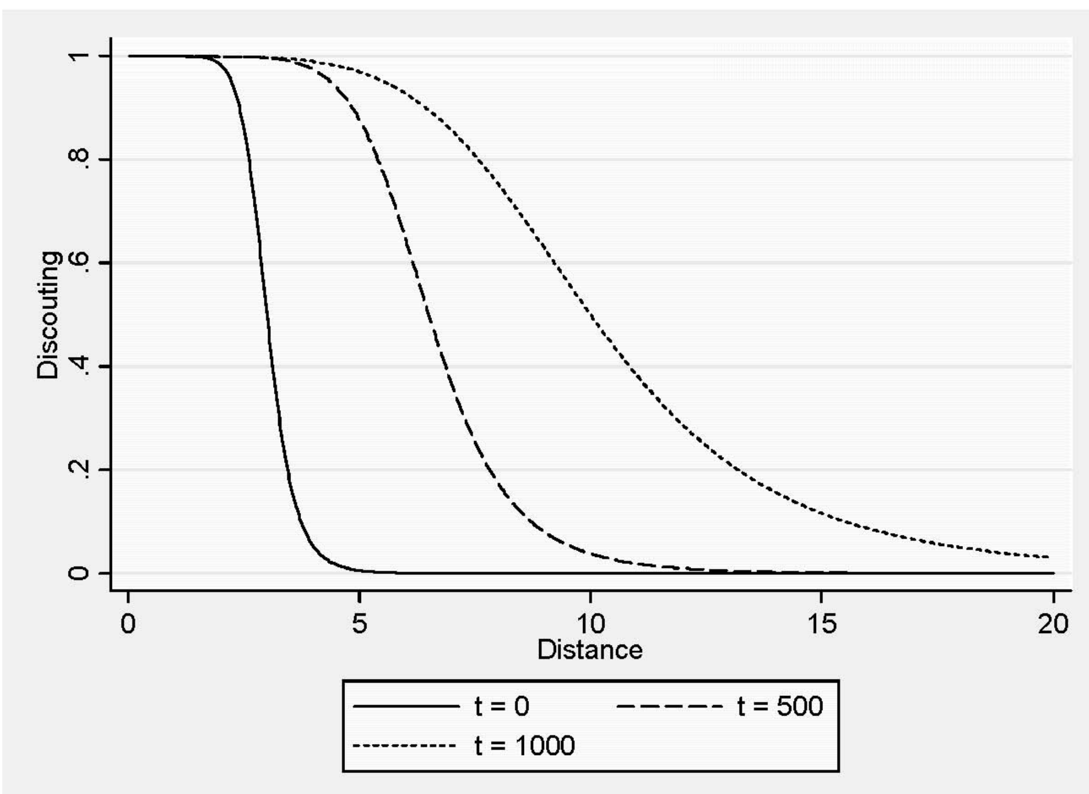

FIGURE 7 Loss-of-strength gradients represented as sliding logistical functions

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How does this technological transformation influence states' organizational forms? First we need to specify explicit geopolitical mechanisms that have the potential to alter the actors' hierarchical structure. Drawing on the qualitative, historical theories discussed above, we postulate two main processes: conquest and organizational bypass. Whereas the former mechanism figures prominently in Geosim and other similar geopolitical models, organizational bypass is an entirely new mechanism that has, to our knowledge, never been modeled formally.

Because there is an arbitrary number of organizational levels in OrgForms, conquest is a more complicated process there than in Geosim. In order to specify the mechanism, three questions need to be answered: (1) When does conquest occur? (2) What is being fought over? (3) How is the conquered organization going to be inserted into the conquering state's multi-level hierarchy?

1. *Conditions of conquest*. Only sovereign states can conquer another neighboring sovereign state. The decision criterion is a deterministic threshold, as in the original Geosim model (Cederman 1997, Chapter 4). A state i with total resources R_i decides to conquer a neighbor j with resources R_j if its share of the dyadic resources exceeds the predetermined threshold (i.e., if $R_i/[R_i + R_j] > 2.5$). Note that in its basic version, the OrgForms model does not attempt any resource allocation to separate fronts. Nor is there any separate battle mechanism. Thus, we assume that conquest is always successful and costless.

2. *The nature of the conquered organization.* While conquest proceeds locally ("nibble by nibble") in Geosim, OrgForms resembles Bremer and Mihalka's (1977) original model in that each conquered state is swallowed as a whole. This rule makes the geopolitical changes more radical, but it also allows for "inheritance" of organizational forms when entire "victims" are incorporated inside the conquering states. This is how the states gain organizational depth.

3. *The point of insertion of the conquered organization.* For our present purposes, the most important aspect of conquest is where the subjugated state is to be inserted. We assume that this decision is resolved efficiently. The conquering state locates all of its own provinces that border on the conquered state. For each such neighboring province, it follows its own organizational tree all the way up to the capital. Repeating this operation for all possible paths from the border to the capital defines a set of potential insertion points, including the capital itself. The point of insertion is the location out of this set that maximizes the resource extraction of the resulting expanded state, given the distance-discounting at the time of conquest.

The second geopolitical mechanism to be specified is organizational bypass. In this case, we need to address two questions: (1) When is bypass conducted? (2) What are the consequences of bypass?

1. *Conditions of bypass*. As the case with conquest, only the capitals are allowed to initiate action, which proceeds within the state's territory. Moving one level down the organizational hierarchy, the capital randomly selects a subordinate unit, which, in turn, controls subordinate provinces itself. Two conditions

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must be fulfilled for bypass to occur. First, the capital must be powerful enough to bypass the intermediate unit. The resource level is given by the taxation algorithm described in the previous section. The decision to bypass is defined by exactly the same deterministic threshold as conquest, here with the capital as state *i* and the subordinate unit to be bypassed as actor *j*. Second, organizational bypass requires that the resulting, flattened organization be more efficient than the status quo.

2. *Consequences of bypass*. Once bypass has been decided, the capital establishes direct organizational links with all sub-trees of the bypassed unit, which itself loses its connection to these provinces. The result is a reduction in organizational depth.

In order to avoid conflicts between the two mechanisms, one or the other is randomly chosen per time period.

We can now summarize the model's logic. Figure 8 depicts how the process of technological change drives the entire system. The two micro-level mechanisms — conquest and bypass — channel the effect of this process on the evolving organizational forms. The main output variable to be measured is the territorial share of indirect rule in the system.

Because the goal is to explore the shift from indirect to direct rule, we first have to "grow" an indirectly ruled, "medieval" system with deep state hierarchies. Given the flat organization of the initial system, this deepening hinges on repeated acts of conquest. At some point, however, technological change makes organizational bypass both possible and desirable, thanks to improved communications. A flattening of the deep state hierarchies follows, which produces a modern state system characterized by direct rule.

We are now ready to test if this logic does materialize from the assumptions made so far. Figure 9 shows a snapshot of the system at time period 136. It is apparent that plenty of conquest has already taken place. Four conquest centers have managed to subjugate their surrounding hinterlands. The picture illustrates the organizational dependencies with thick lines radiating from the capitals to the inferior units. For each level further down the tree, the lines become thinner. To increase the readability of the picture, we suppress lines from the capital to the unitary provinces within the white, directly ruled areas. All other provinces that are indirectly controlled by the capital are shown in grey shading with their organizational connections. Thus,

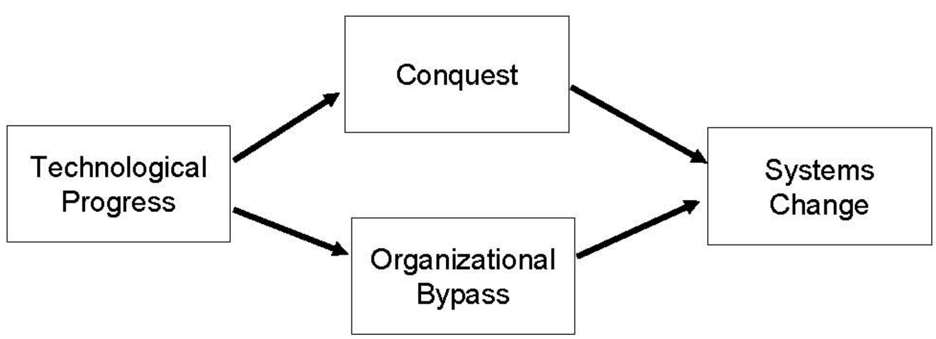

FIGURE 8 Main causal logic of the OrgForms model

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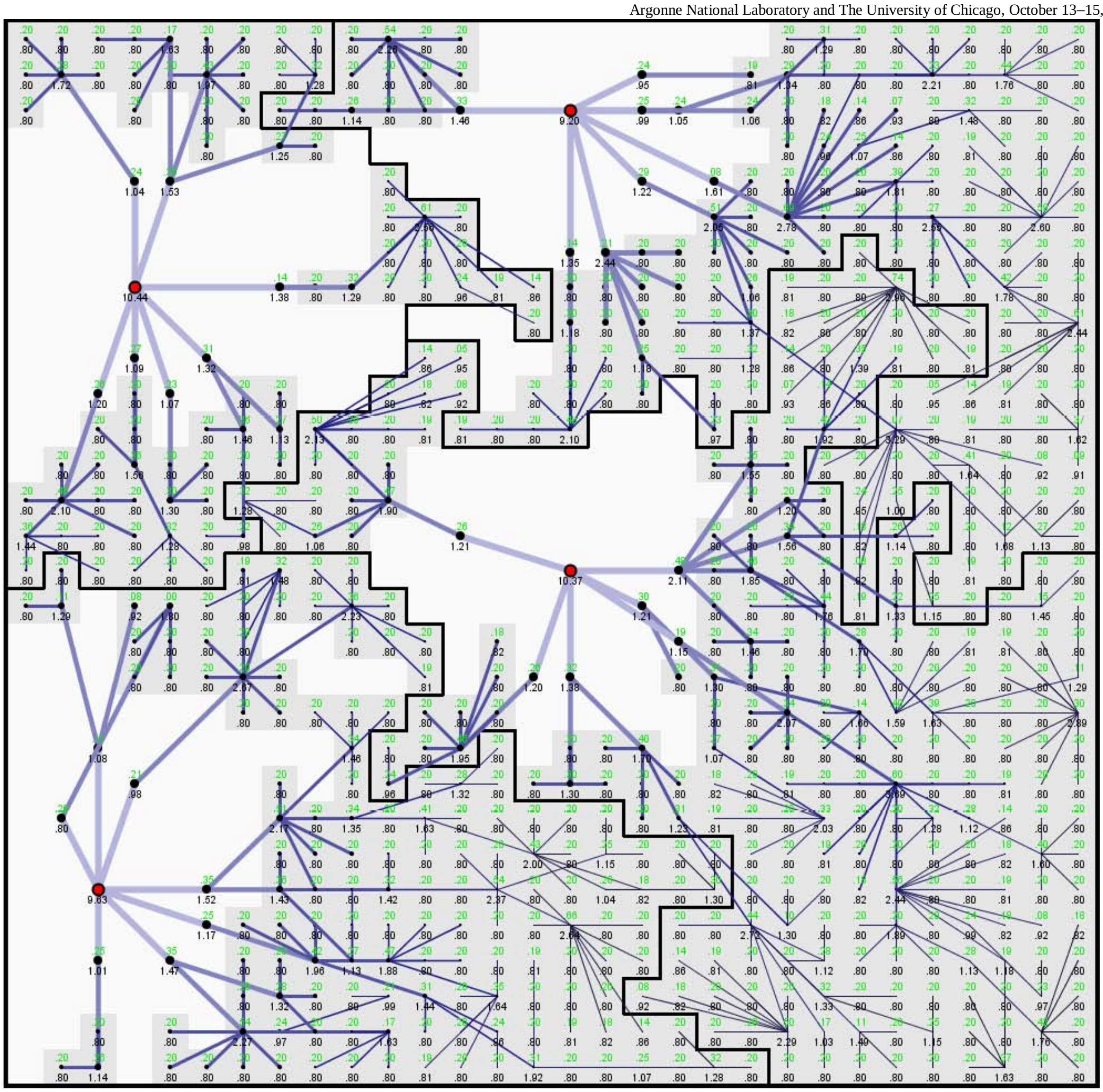

FIGURE 9 Evolution of deep hierarchies in the "Middle Ages" of OrgForms (t = 137)

the extent to which a system is shaded reveals how far indirect rule has been established. In this "medieval" situation, only the basins around the capitals are directly ruled.

The system in Figure 9 is relatively stable. The threshold of the decision function maintains a meta-stable equilibrium amongst the deep hierarchies. However, as technological progress makes long-distance interactions more effective, the conditions of conquest and bypass start to change. Figure 10 depicts the situation at time period 1,000. In contrast to the deep state organizations that characterize the Middle Ages, this modern state system features entirely flat organizations. Organizational bypass has managed to eliminate the internal competition for resources, thus flattening the organizational structure in each of the surviving states. In fact, the final system resembles a modern state system that is completely dominated by direct rule.

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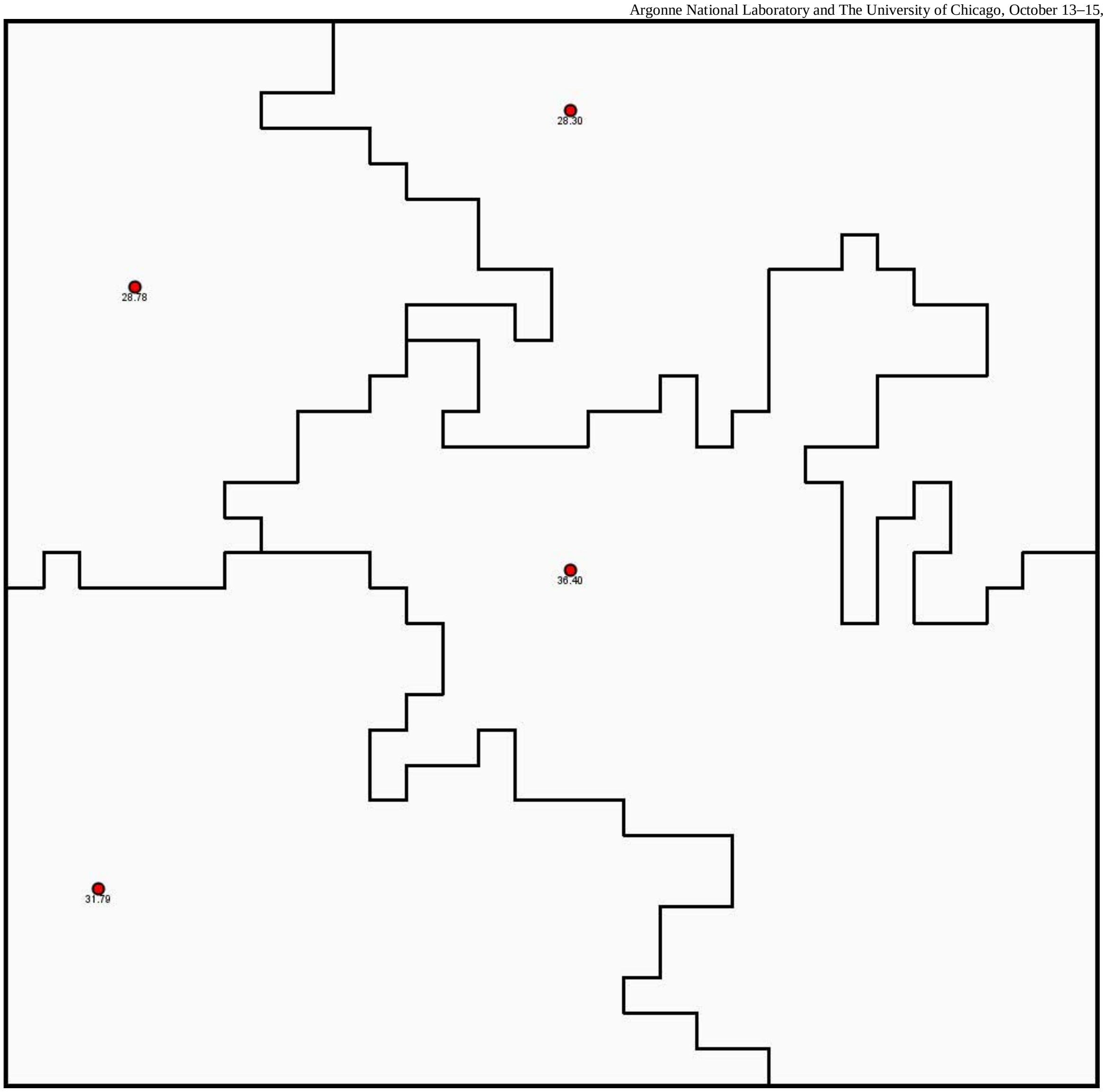

FIGURE 10 Emergence of direct rule in the OrgForms model (t = 1,000)

The snapshots tell us a good deal about how the system develops over time. However, it is desirable to trace its behavior more continuously. Figure 11 charts three important systemic properties over time. First, it shows the system's maximum depth (i.e., the number of hierarchical levels of the deepest organization). The figure reveals that this measure grows very quickly at the beginning of the simulation run, where it briefly reaches a maximum depth of 11, before collapsing abruptly around time period 600. Second, the average maximum depth follows a similar trend line, even though the changes are somewhat less dramatic for statistical reasons. Finally, the average depth of the system is much lower. After a relatively steep ascent, this variable slowly declines down to two, which represents the flattened, modern system.

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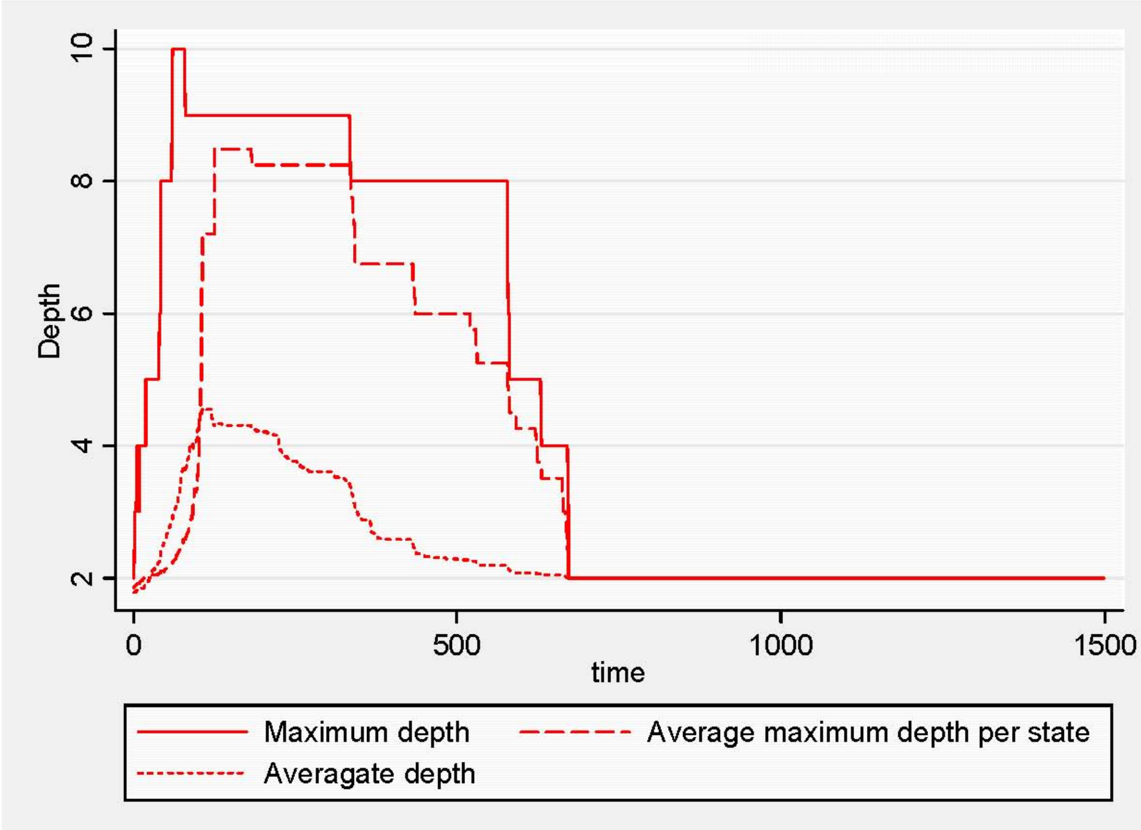

FIGURE 11 Tracing the sample run over the course of the simulation

REPLICATION RESULTS AND POSSIBLE EXTENSIONS

So far, we have only considered a single sample run. In order to check whether the shift from indirect to direct rule is more than a historical accident of the computational specification, we reran the system with 30 randomly generated initial systems, using different random seeds for each configuration. In all cases, the simulations started with 200 states in random locations. Summarizing the behavior of the entire ensemble of replications, Figure 12 traces the share of the system that is governed by indirect rule.

As expected, conquest triggers a rapid, initial increase in indirect rule. The curves peak shortly after time period 100 and then start a steady decline in response to the organizational bypass mechanism. The red curve represents the sample run shown above. Despite plenty of variation among the trajectories, a rising and falling trend is clearly observable. After time period 1,000, the last vestiges of indirect rule disappear. After this point, indirect rule materializes only temporarily in conjunction with conquest. Such situations do not last for long, however, because organizational bypass immediately follows.

In all runs up to this point, we have postulated a logistical loss-of-strength gradient. This choice of functional form is justified by the deductive findings of the previous section, which suggests that there has to be a threshold in the curve for systems change to emerge. To verify if

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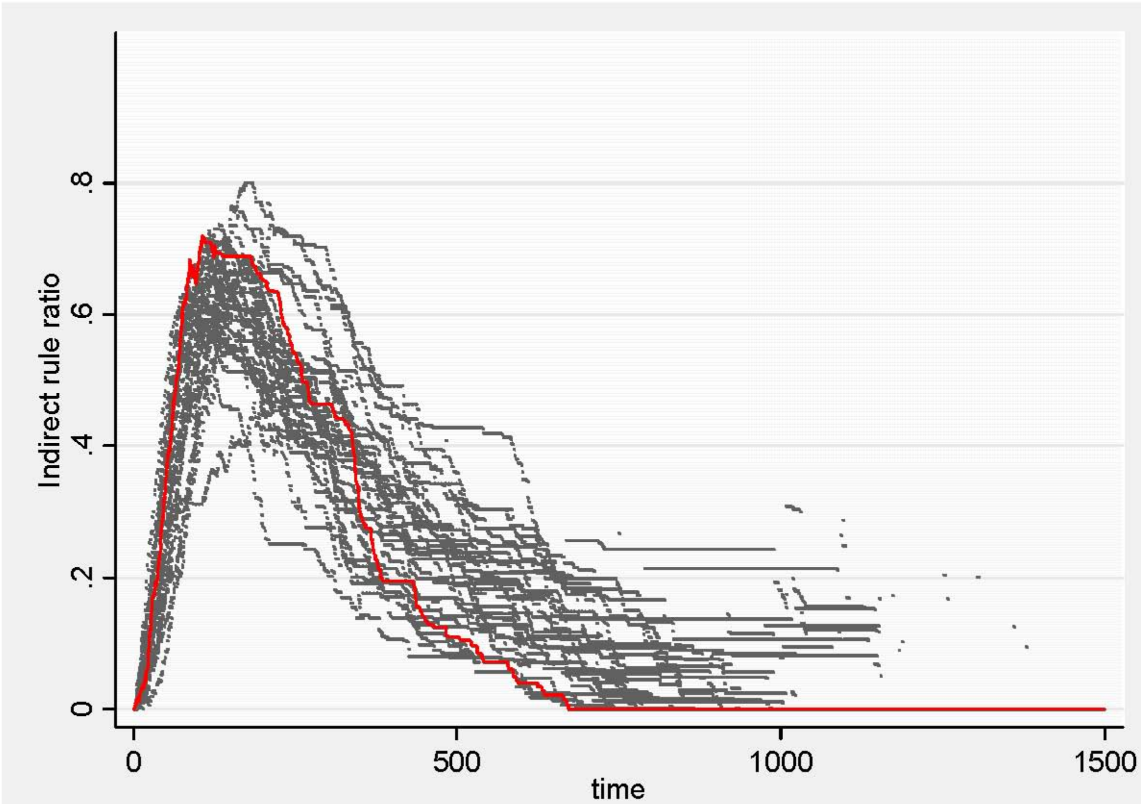

FIGURE 12 Share of indirect rule over time with sliding threshold and slope

this observation applies to the computational case, we reran the 30 runs with an exponential decay function that was shifted from $\delta = 0.8$ to 0.9 at $t = 1{,}000$. Here technological change was simulated through a stretching of the decay function, which improves geographic reach over time.

Figure 13 displays a radically different picture from the trend in Figure 12. In this case, indirect rule fails to take hold. In fact, the maximum share of indirect rule never exceeds 0.25, which is well below the peak in the previous set of runs. The majority of the trajectories with exponential decay do not even reach that level. These findings confirm the general conclusion of Proposition 1 in a more realistic setting.

Our final experiment investigates the pace of the organizational shift. Figure 11 traces a rather slow decline of indirect rule. What would it take for this transformation to unfold more suddenly? Figure 14 presents the evolution of indirect rule assuming a logistical distance function that changes its slope $c(t)$ over time from 10 to 0.95 while keeping the threshold value $x^*(t)$ constant at 3.

Under these conditions, the distance curve gradually develops into a decay function. The results indicate that while the modern world may well be best-described by an exponential loss-of-strength gradient, a more abrupt distance-dependence is initially necessary in order for the shift from feudal, multi-level hierarchies to occur in the first place.

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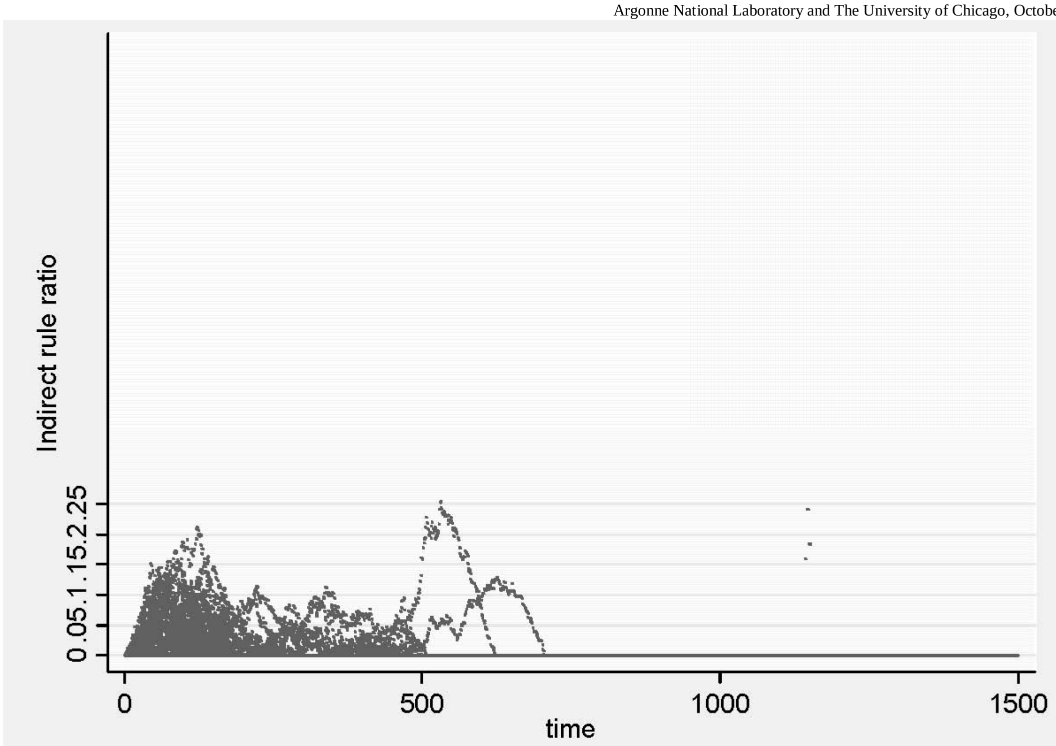

FIGURE 13 Share of indirect rule over time with an exponential decay function

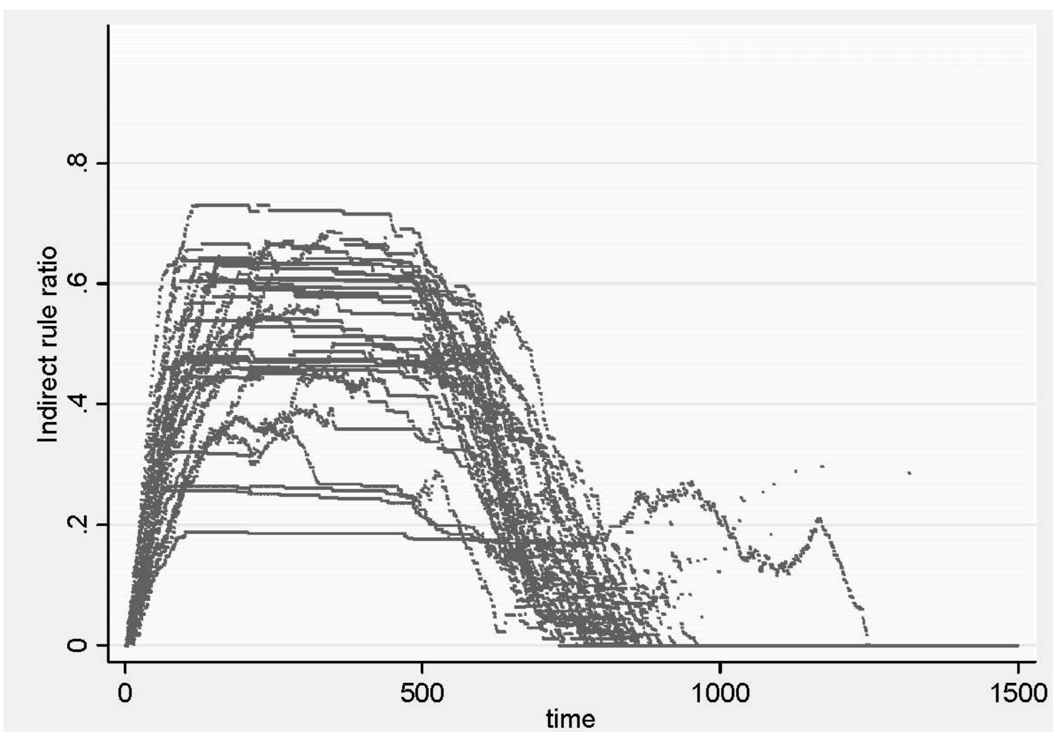

FIGURE 14 Share of indirect rule over time with a sliding slope only

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Obviously, the empirical validation of these trends remains a wide-open question. Still, in the absence of comprehensive data, our models offer some important hints that could help guide more careful, theoretically guided calibrations of functional forms. Previous work has focused entirely on exponential decay functions (e.g., Lemke 2002). To the extent that criticism has been directed at Boulding's (1963) initial formulation of the loss-of-strength gradient, it typically relates to the deviations imposed by weapons systems or geography (Wohlstetter 1968). Our findings add support to such critiques, suggesting that the reach of power centers may not always decline smoothly with increasing distance. The limitations of specific infrastructural technologies may thus explain deviations from the assumption of exponential decay.

Another empirical question concerns the speed of systems change. Our initial set of runs, summarized in Figure 12, exhibits a rather slow decline of indirect rule. With a slightly different assumption of technological change, we were able to generate a much more abrupt transformation (see Figure 14).

Moreover, abrupt change could also result from organizational imitation. World history contains many examples of technological transfer, which suggests that infrastructural and military innovations diffuse from successful states to other members of the system (Gilpin 1981). While the current version of our computational model relies entirely on natural selection, it could be extended to encompass strategic adaptation (cf. Cederman 1997, Chapter 5; Cederman and Gleditsch 2004). Such an extension would need to feature some transferable representation of organizational structures (i.e., an "organizational code"). On the basis of such a formalization, it would be possible to analyze the co-evolution of technological change and the ideological spread of sovereignty.

CONCLUSION

Traditional theories of IR assume that sovereignty operates as a constant. In contrast, we have shown how this assumption can be relaxed with respect to the internal dimension of sovereign governance. Building on the insights of historical sociologists, we have posited a coherent explanation for how technological change triggered a shift from indirect to direct rule. Our modeling framework allows us to specify how this dynamic process influences the organizational topology of the system.

It should be reiterated that this internal reorganization does not exhaust all aspects of territorial systems change. The emergence of sharp boundaries is at least as important, but it was set aside in this study in order to simplify the modeling effort. However, the Middle Ages exhibited many examples of overlapping and conflicting rules that deviated from the perfect hierarchies assumed in this paper. In future work, we hope to be able to endogenize the crystallization of sharp borders that exclude competing sovereignties, rather than postulating such a modern order from the outset.

Despite this simplification, we believe that the current paper represents significant theoretical progress. As far as we can tell, our computational framework is the first geopolitical model that incorporates variable-depth hierarchies. Our model of systems change demonstrates that structural changes and power extraction are two sides of the same coin. This is a general insight that applies to contemporary examples of power competition involving radically different actor types, such as networks of insurgents and terrorists.

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Thanks to its flexible ontology, computational modeling is ideally placed to assist historical research on such macro-transformations. With the current study of state formation in early modern Europe, we hope to inspire other researchers to rely on similar tools to explore complex transformations. Such a modeling effort promises to yield profound insights into the constantly changing realm of world politics.

APPENDIX

Proof of Proposition 1. Because the symmetric functional form of $p_{DR}(n) = 2\, f_{DR}(n) + k$ and $p_{IDR}(n) = 2\, f_{IDR}(n) + k$, it is enough to prove that $f_{DR}(n) > f_{IDR}(n)$. This is the same as proving that $f_{DR}(n) - f_{IDR}(n) > 0$.

$$f_{DR}(n) - f_{IDR}(n) = \sum_{i=1}^{n} k\delta^i - \sum_{i=1}^{n} k^i \delta^i = k\sum_{i=1}^{n}(1-k^{i-1})\delta^i \quad .$$

However, it is immediately clear that each term of the sum $(1 - k^{i-1})\delta^i$ is positive for $n > 1$ because $0 < k < 0$ and $0 < \delta < 1$, which means that the entire sum has to be positive too. Hence $p_{DR}(n) > p_{IDR}(n)$ for all $n > 1$.

QED.

Proof of Proposition 2. All comparisons can be made between $f_{DR}(n)$ and $f_{IDR}(n)$. We start by computing the latter, which holds for all values:

$$f_{IDR}(n) = \sum_{i=1}^{n} k^i \delta(i)^i = \sum_{i=1}^{n} k^i = \sum_{i=1}^{n} k^i = \frac{k}{1-k}(1-k^n) \quad .$$

For direct rule, it must be that for $n \le x^*$,

$$f_{DR}(n) = \sum_{i=1}^{n} k\delta(i) = \sum_{i=1}^{n} k = nk \quad .$$

It can be shown that for $n \le x^*$, direct rule is superior. This applies for $f_{DR}(n) - f_{IDR}(n) > 0$, which can be written

$$f_{DR}(n) - f_{IDR}(n) = \sum_{i=1}^{n} k - k^i = k\sum_{i=1}^{n} 1 - k^{i-1} \, .$$

However, we know that this expression has to be positive because the terms of the sum are positive for $(1 - k^{i-1}) > 0$ for $n > 1$.

For $n > x^*$, we compute

$$f_{DR}(n) = \sum_{i=1}^{x^*} k\delta(i) = x^* k \, .$$

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This quantity will always be greater than $f_{IDR}(n)$ where $x^* > 1/(1 - k)$ (Case 2):

$$f_{IDR}(n) \to \frac{k}{1-k} \text{ as } n \to \infty .$$

Clearly $f_{IDR}(n)$ cannot exceed this value.

Otherwise (Case 2), we need to find the point x' where indirect rule surpasses direct rule as $n \to \infty$: $f_{DR}(x') = f_{IDR}(x')$, or

$$x^* k = \frac{k}{1-k}(1-k^{x'}) \ ,$$

which implies that $n < x' = \dfrac{\log[1-(1-k)x^*]}{\log k}$.

QED.

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We would like to thank Alessandro Lomi for organizing the workshop “Forms, Functions and Organization,” in Bologna, Italy, on September 9 and 10, 2004, which stimulated the early phase of this project. We are also grateful to Kimberley Sims for her helpful linguistic advice.

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