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Hierarchy in Mixed Relation Networks: Warfare Advantage and Resource Distribution in Simulated World-Systems*

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Abstract

Building on world-systems theory, simulation models of 5-line intersocietal networks were generated in an effort to understand systemic power hierarchies. The societal nodes were exclusively connected by three types of interaction: migration, warfare, and unequal trade. These networks can be considered "mixed relation" networks due to the ways in which these types of ties combine positive and negative sanction flows. Insights from elementary theory were employed to understand how exclusion from these different types of ties might influence the resulting power distributions. Additionally, the resource carrying capacity of the nodes was varied by structural position in an effort to differentiate the influence of structural position and individual attributes on location in the hierarchy. It was determined that exclusion from interaction is likely a structural, scale invariant mechanism that helps to determine power distributions above and beyond the inherent attributes of network actors.

Keywords

World-systems, networks, elementary theory, exclusion, demographics, warfare, migration, trade, simulation

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World-systems theory (WST) and elementary theory (ET) both analyze power distributions in networks of actors engaging in different types of social relations. They are both network theories of interaction. WST focuses on intersocietal networks, where each node is a society, while ET focuses on interpersonal networks with nodes corresponding to individuals. Both theories analyze the types of connections between nodes. In WST, the ties linking nodes consist of warfare (the flow of force), migration (the flow of people), and trade (the flow of resources). ET takes a more general examination of social ties and argues that all ties fall into one of three categories: conflict, coercion, and exchange. Both theories look for and understand power in terms of the exploitation of some actors in the network by others as indicated by the flows and distribution of resources. Though the units of analyses are vastly divergent in scale, the goals and approaches of these theories are aligned. This paper attempts to demonstrate that micro-level insights used by social psychologists employing ET are applicable and useful for world-systems theorists.

Bridging these independent theories can advance both simultaneously. We build and analyze a series of simulation models containing interconnected societies. This allows us to apply micro-level theories regarding networks of individuals to macro-level actors. Though some world-systems researchers employ network analyses (Snyder and Kick 1979; Smith and White 1992; Alderson and Beckfield 2004), they do not explicitly explore the phenomenon of exclusion from interaction as a determinant of status in the global hierarchy. Our models also attempt to expand the scope of micro-level network theories by analyzing mixed networks of complex nonlinear nodes connected by multiple types of social relations. Additionally, we analyze heterogeneous networks composed of nodes with inherent differences in the attribute of resource capacity. Certain societal nodes are allowed to be more “resource rich” than others. This allows us to compare the influence of an actor’s network position vs. the actor’s attributes on their place in the power distribution.

Our simulation model examines how the connecting of nonlinear societal nodes by warfare, migration, and unequal trade influences the power distribution in an intersocietal network. We’ve borrowed the concepts of sanction flows and exclusion from ET to help interpret why and how stable hierarchies emerge. Introducing these micro-level theories of interaction to WST should advance future world-systems theorizing. Demonstrating that exclusion is a key determinant of power for complex nonlinear nodes that engage in mixed relation interaction (interaction containing different configurations of positive and negative sanction flows) should advance elementary theorizing as well. Ultimately, we conclude that exclusion from interaction is likely a structural, scale invariant mechanism that helps to determine power distributions above and beyond the inherent attributes of network actors.

Elementary Theory, Power, and Exclusion

Elementary theory views social structure as being made up of networks of actors connected by social relations. ET argues that there are three types of social relations based on the flow of sanctions between actors (Willer and Markovsky 1993). Sanctions are actions that influence the preference states of the actors, be it positively or negatively. When two actors that interact in a network both give and receive positive sanctions, this process is called exchange. When both actors give and receive negative sanctions, it is called conflict. Finally when one actor gives (or threatens) a negative sanction and receives a positive sanction, this is called coercion. Most of the theorizing and research based on ET focuses on exchange. There is an entire sub-discipline, network exchange theory (NET), devoted to pure exchange networks. However, all three of these processes occur in the social world and often simultaneously. A combination of these processes are present in our model, and our understanding of how these processes relate to the three types of intersocietal interaction (warfare, migration, trade) helps us to interpret model solutions.

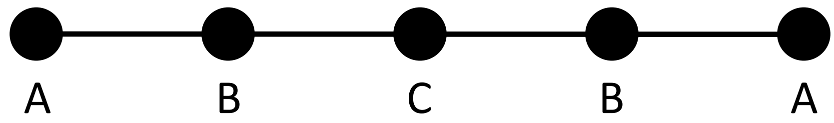

Figure 1. A 5-line Exchange Network Diagram

Work on power and exchange in social networks strongly suggests that the topology of the connections among social actors can determine the distribution of power and resources in a network (Willer 1999). For example, in exclusively connected 5-line exchange networks (Figure 1), the most central actor (C) and the most peripheral actors (A) may be exploited by the interstitial actors (B) who have the advantage of possessing exchange partners that are solely dependent on them (the As). This type of network is known as a strong power network where the power of the peripheral actors and the power of the central actor are equivalent and all three are less powerful than the interstitial actors. Cook et al. have demonstrated the existence of this 5-line power distribution experimentally (1983). However, it was Willer and Markovsky that recognized exclusion from exchange as the key determinant of power distribution in these types of networks.

Before discussing exclusion, it is necessary to explicitly define power. Markovsky et al. (1999: 92) define power as “an unobservable, structurally determined potential for obtaining relatively favorable resource levels.” To indirectly observe power in networks then, social scientists must measure “power use” which is indicated by resource flows and distributions. Willer and Markovsky (1993) criticize social exchange theorists for understanding power in network structures as a function of the “vulnerability” of the network to the removal of nodes (Cook et al. 1986). They instead focus on whether or not an actor’s structural position increases their probability of being excluded from exchange. Because actors with a greater number of potential exchange partners can play their partners off of each other to increase their payoffs in exchange, they are said to have high power positions. In the 5-line exchange network, where exchange is beneficial to actors, and the interstitial actors are never excluded from exchange, they will always gain the largest payoffs from exchange and therefore are classified as the high power actors. Their power is derived not from individual traits, but from their position in the network structure.

Intersocietal Interaction

World-systems theory attempts to understand hegemonic cycles and intersocietal power distributions using macrohistorical analyses (Chase-Dunn and Grimes 1995). It examines intersocietal linkages such as transference of people, resources, and conflict between societies that alter population, technology, and ultimately power levels throughout the system. The theory that guides the development of our formal model is Chase-Dunn and Hall’s iteration theory of world-systems evolution (Chase-Dunn 2001; Chase-Dunn and Hall 1997). The iteration theory identifies key dynamic processes at an abstract level, but does not deal explicitly with networks or complex dynamics. We have instantiated the iteration theory of world-systems evolution in a simple line network model. This approach applies evolutionary and ecological rules from received theory (see Fletcher et al. 2011a) in a minimally complex spatial topology of five sedentary hunter-gatherer societies.

After the last Ice Age ended approximately 12,000 years ago, early human sedentism and diversified foraging emerged. Settlements were more or less spatially fixed and constrained by those other settlements with which they had direct contact. Rather than studying societies in isolation, our model conceptualizes societies as self-contained nonlinear nodes coupled together into the unidimensional array of a 5-line network. Each single society within the network is a resource production and consumption model premised on theories of ecological predator-prey interaction that have been further modified to better characterize the special features of early human societies that existed at very small scale and with low levels of technology (Fletcher et al. 2011a). We first couple five such single-society systems together by the movement of people (migration), resources (trade), and force (warfare) and explore the resulting power distributions. Then, in an effort to emphasize and understand the importance of node attributes (vs. structural position) on the emergent hierarchies, we explore how a difference in enrichment levels across nodes affects the power dynamics of the network.

Different networks composed of different types of connections could have different power distributions, all else being equal. There is evidence in ecological theory that different types of interaction or relations (mutualistic, antagonistic) affect the stability of entire networks differently (Thébault and Fontaine 2010). Studies in ET largely focus on networks with a single type of relation present, yet networks containing multiple types of relations are important in understanding how power is distributed in real-world networks that likely contain varying combinations of conflict, exchange, and coercion. We propose that intersocietal relations must be understood as combinations of positive and negative sanction flows. By understanding how different types of relations influence the power and resource levels of simulated societal actors in a network, we can demonstrate that exclusion and network position are important factors for understanding intersocietal evolution.

Positive and Negative Sanctions

Our use of the term sanctions in the following discussion is different from that in ET. Being a micro-level theory, ET defines sanctions in terms of the "preference states" of individual actors (Willer 1999: 24). Actions that generate a positive alteration in the preference state of individuals are called positive sanctions and those that cause negative alterations are negative sanctions. In our model, the actors are societies and do not have preference states. Therefore our definition of sanctions must be slightly different than in ET.

To address this issue, we understand sanction flows in terms of whether they positively or negatively alter the relative levels of warfare advantage of the nodes rather than nodal preference states. It is argued by Willer (1999) that power can be derived from benefit as well as control. Power by benefit implies that those receiving more positive sanctions relative to others are powerful, whereas power by control implies those threatening more negative sanctions relative to others are powerful. In our model, both of these forms of power trace back to what we have termed "warfare advantage." Warfare advantage in our model is a function of a society's size and technology (these variables will be described in greater detail in the Model section). It dictates the society's terms of trade as well as its magnitude of deadly force when going to war. Societies that secure more resources in exchange (power by benefit) by threatening warfare and the devastation of another society's population (power by control) are those with the highest levels of warfare advantage.

We make the assumption that sanctions increasing the relative warfare advantage of a given society are beneficial to that society. Conversely, sanctions decreasing warfare advantage are detrimental. This is due to the fact that those societies with relatively high levels of warfare advantage secure higher amounts of resources and therefore higher population levels, which is an indicator of success in models of ecological competition. As a relatively greater number of resources are gained through trade, the population grows, and warfare advantage increases. This is analogous to receiving positive sanctions. The action of engaging in warfare, which devastates population levels at a faster rate than it promotes technological growth, reduces warfare advantage. This can be viewed as the transfer of negative sanctions. Though our actors do not have preference states, they do possess relative levels of warfare advantage, which provides them with the power to exploit and threaten (i.e. to benefit and control).

Sanctions are therefore related to the population and technology levels of societies. As was mentioned above, warfare advantage is directly proportional to levels of population and technology. Therefore, relations that increase population size or technological advancement are beneficial to actors and can be viewed as transmitting positive sanctions. Those that lower population levels (the level of technology is not allowed to decrease in our model) are then transmitting negative sanctions. We now analyze how each interaction process in our intersocietal model (migration, warfare, and trade) might influence power in the network.

Migration

Migration is the transference of individuals from one node in the network to another. In effect, one node loses a proportion of its population and the other gains in population size. Technology is not affected by migration in our model. The result is an increase in warfare advantage of the society gaining individuals and a decrease in the warfare advantage of the one losing individuals. This might be viewed as the transference of a positive sanction for a negative sanction, but it seems odd to call migration a coercive relation (like in ET) due to the lack of threat or force involved.

Warfare

When engaging in war, interacting societies suffer the losses of portions of their population in attempts to establish dominance and achieve power in the network. Though they experience technological growth in proportion to their losses, it occurs at a much slower rate than the reduction in population generating a net loss in warfare advantage. Because both parties transmit negative sanctions to each other, this type of relation resembles ET's relation of conflict.

Unequal Trade

In our model, trade does not resemble the exchange relation from ET as one might expect. Drawing from a WST perspective, we believe that trade is not necessarily purely beneficial to both parties involved. Often, though certain states acquire resources from and are dependent on other states via trade, the terms of trade can be viewed as exploitative whereby a net transfer of resources flows from the weaker, dependent state to the stronger one. In our model, stronger societies dictate the terms of trade leading to a net flow of resources to the stronger trade partner. Due to the fact that we've assumed homogenous, indistinguishable resources, and that the terms of trade are dictated by relative warfare advantage levels, trade in our model more closely resembles ET's coercive relation. The amount of resources each society gets from the other is a function of the warfare advantage ratio. So for example, if Society A's warfare advantage is greater, they might only have to trade 100 resource units for 200 of Society B's resource units. Because resources are indistinguishable, the net effect is a transfer of 100 resources from B to A. The threat of force by A is what drives this net transfer. This is very similar to the coercive relations described by elementary theory. The threat of a negative sanction from A causes the flow of a positive sanction from B. As Willer states, "in coercion, typically only one sanction flows" (1999: 27). The exploitation of one society by another due to unequal terms of trade enforced by threats of violence is commonplace in human history (Chase-Dunn and Hall 1997).

This paper attempts to demonstrate that micro-interactional network theories can inform theories of macro-historical evolution. We argue that the location of societal actors in global hierarchies is related to their structural position in intersocietal networks due to the phenomenon of exclusion from interaction. Though there is not a perfect one-to-one mapping of the dyadic forms of interaction posited by ET onto the intersocietal forms of interaction that we've modeled, they do provide us more generally with a theoretical tool for understanding how exclusion from the different flows of positive and negative sanctions influences the power structure of the network.

Agent heterogeneity is a fundamental factor influencing the interactions among multiple human populations existing in geographical space as well. One of the primary ways that actors might be differentiated in exchange networks is through their relative levels of the resources they produce and sustain. Some societal actors in a network may be embedded in highly productive resource rich zones, while others may not be as lucky. In most network exchange models, however, resource production and/or distribution is either exogenous or forced to be homogeneous across actors initially. We briefly explore the interplay between network topology and the effects of differentiating enrichment levels of societal nodes in the network.

The Model[1]

The systems modeling program STELLA 9.0.2 was used to simulate the power dynamics of our network model. Each node in the model consists of an early sedentary hunter-gatherer human population living and exploiting the resources of a catchment area of fixed size and potential productivity. These individual societal nodes are consumer-resource models built with coupled ordinary differential equations that regulate human and resource population flows. We've based our model on current ecological predator-prey models that have evolved from the seminal Lotka-Volterra equations. The general form of the equations governing the human and resource population dynamics in a single node are:

$$\frac{dR}{dt} = e(P) \cdot n_{Rb} \cdot R_0 \left(1 - \frac{R}{K}\right) - f(h(P,T) \cdot P, R) \pm \tau \qquad (1)$$

$$\frac{dP}{dt} = P\left(n_{Pb} \cdot b\left(\frac{R}{P}\right) - n_{Pd} \cdot c\left(\frac{R}{P}\right) \pm m\left(\frac{R}{P}\right) - w\right) \qquad (2)$$

In these equations, R is the resource population and P is the human population.

In the resource growth rate equation (1), environmental degradation (soil erosion, pollution, etc.) reduces the rate at which natural resources recover. This is assumed to be a function of population size and is captured in the resource growth rate equation by the fractional multiplier $e(P)$. All else being equal, resource populations (as well as human populations) are assumed to reproduce with a normal birth rate, which is a constant represented as n_{Rb} (or n_{Pb} for humans). R_0 is the initial resource population level set to twice the size of the initial population. The variable K is the carrying capacity of the resource population which cannot grow unbounded due to land constraints. The unmodified resource reproduction rate, $R_0\left(1 - \frac{R}{K}\right)$, corresponds with the environment's ability to "re-grow" or recover from the prior cycles of resource harvesting, a rate that is constant and asymptotically approaches the carrying capacity (Turchin 2003a). The function f is the amount of resources harvested for consumption. Individuals either harvest resources at a given rate $h(P,T)$ dependent on the current levels of technology, T, and population

[1] The entire mathematical model can be found in the Appendix: Simulation Model Code. Every equation is presented exactly as used by STELLA.

size, P, or when resources or scarce, harvest all available resources, R. Finally, τ represents the net resources gained or lost via unequal trade.

In the population growth rate equation (2), there are a series of multipliers modifying the growth and decline of the population level for a given societal node. When all else is equal, this model makes the Malthusian assumption that births will slightly exceed deaths (the normal birth rate constant n_{Pb} is greater than the normal death rate constant n_{Pd}), but that the realization of these processes is stochastic. The "predator functional responses" (Berryman 1992) that govern human births and deaths based on human-resource interaction, $b(R/P)$ and $c(R/P)$, are ratio dependent and a function of consumption levels within the society. Migration in and out of the society is a complex function of consumption levels and captured by the term $m(R/P)$. The last term, w, is the number of deaths due to warfare.

Technology in a single node grows over time as a function of starvation and warfare deaths. Technology also increases by diffusion. Evolutionary theories suggest that societies may adapt to selection pressures exerted either by the consequences of reaching carrying capacity in their environment, or by conflict with other societies (Spencer and Carneiro 1967). Adaptive responses may take the form of more complex and productive technologies of various sorts: human capital, material technologies, and social technologies, specifically hierarchy and solidarity that contribute to greater coordination of social agents (Chase-Dunn and Hall 1997). Additionally, technology can spread between societies that have frequent and systemic contact with one another, a process known as technological diffusion (Barro and Sala-i-Martin 1997). During this process, the society with a lower level of warfare advantage will be exposed to and begin to adopt the technology of the more powerful society. This is roughly equivalent to the semi-peripheral advantage discussed in world-systems theory, whereby weaker societies have access to the technological innovations of the stronger societies, especially as contact between the two societies increases (Chase-Dunn 2001). The initial value of the technology variable is set to zero for each node.

These assumptions about technological growth are limited but are kept simple to reduce the complexity of the simulation. Technology levels are only allowed to grow and societies always improve their technology as they adapt to starvation and losses in war. Without these assumptions, societies that did not adapt technologically would be wiped out or subsumed by their victors changing the network structure of the simulation.

Technology affects the relationship between a societal node and its resource base by increasing the productivity of resource extraction, $h(P,T)$. It also affects the relationship between each node and its neighbors by increasing the military force it can project. Societies that are able to project greater force are also more able to exploit their neighbors by threat of violence. Finally, technology also allows societies to "invent" resource storage. Once technology increases beyond a given threshold, a society is able to move any resources not necessary for subsistence into storage. Stored resources can be consumed if harvesting rates fall below subsistence levels, or can be "traded" with other societies.

Migration

The first process linking nodes in our network involves the movement of people between them. Migration raises population levels in one society while reducing them in the other. Migration from one societal node to another is driven by high levels of internal conflict, and by poor material conditions, both of which are results of low per capita consumption due to high population density.

Warfare

Warfare between adjacent nodes is proportional to the rates of contact between them, which is approximated by the product of the population sizes (as suggested by Peter Turchin via personal correspondence), and is modified by levels of circumscription. Circumscription results when natural increases in the size of a given node (internal population growth) and migration from a neighboring node combine to create high population densities and restricted life chances for all individuals in that societal node (Carneiro 1970). Consumption per capita is low and migration is no longer a viable outlet to release population pressure. Societies go to war with their neighbors to secure the resources needed to sustain existing population levels. Those adjacent nodes with higher levels of joint circumscription engage in battle first in a given iteration. Remaining resources can be used for any subsequent conflicts after the initial conflict has been accounted for. Once initiated, conflict decays exponentially as combatants are exhausted and/or grievances negotiated.

The warfare death value, w, is a function of a node's warfare advantage relative to its war partner's. Relative warfare advantage is determined by the product of two important ratios; the ratio of the given node's population level to that of its war partner, and the ratio of their respective levels of technology. A society can be especially effective on the battlefield if they can field a large army compared to their opponent. Also, a society can excel in warfare insofar as their technology (organizational, material, logistical, etc.) is superior to their opponent's (Collins 2010; Fletcher et al. 2011b). Each node's absolute warfare advantage is measured as the product of its population size and level of technology. This variable allows us to observe the distribution of power in the network.

Unequal Trade

Trade occurs when societies have stored resources that they are able to exchange with one another. Societal nodes will attempt to trade their stored resources with those they are not currently at war with. Using assumptions from WST, the terms of trade are determined by the relative warfare advantage between the two nodes. The more coercive force a society can apply to its neighbor, the more beneficial the trade relations with its neighbor will be. If the product of the population and technology ratios equals one (implying that the two nodes have equal military force), the trade relations between the two nodes are equal (i.e. one unit resource is traded for one unit resource). When warfare advantage is not equal, the node with greater advantage nets a larger amount of the combined resources. If a societal node has multiple trade partners, it trades with the more powerful partner first in a given iteration. Any remaining or additional resources after the first exchange can be used to trade with the other partner. We assume that powerful actors receive priority in trade relations. Again, the amount of net resources acquired in each iteration for a given societal node is denoted τ in equation (1) above.

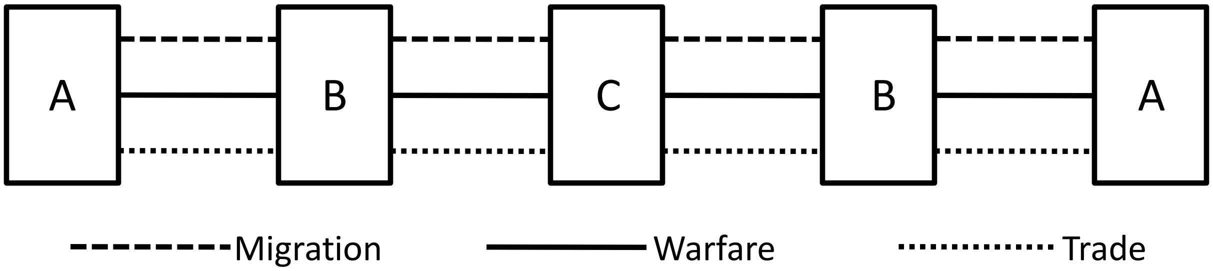

Figure 2. Intersocietal 5-Line Network Arrangement

Figure 2 is a diagram depicting the 5-line arrangement of societal nodes. The two nodes labeled A will be referred to as the edge societies, the nodes labeled B will be referred to as the interstitials, and the node labeled C will be referred to as the center society. Elementary theory does not distinguish between the two As or the two Bs because they share identical positions. All of the nodes are connected to neighboring nodes by migration, warfare, and trade.

In ET, networks can be exclusively, null, or inclusively connected (Willer 1999). Exclusively connected networks (also known as negatively connected networks by social exchange theorists; Cook et al. 1983) are those in which exchanging with one actor precludes exchanges with another in a given round of exchange. In other words, when an actor exchanges with one partner in a given round, it is excluding all other potential partners that round. Null connected networks are those in which exchanging with one actor does not impact exchange with another in a given round. In null connected networks, an actor "benefits independently in each relation" (Willer 1999: 51). Finally, inclusively connected networks (or positively connected networks) are those in which actors need to exchange with more than one partner in order to achieve successful exchange in a given round. Though our actors can exchange with more than one partner during a single iteration, we claim that our networks are exclusively connected due to the fact that an actor does not benefit independently in each relation. In our model, the amount of people, resources, and military projection for a given society are limited. Any and all transference of people, resources, and force is zero sum. If one of the interstitial societies trades all of its stored resources to the adjacent center society in a given iteration, there are no resources left that can be traded to the adjacent edge society in that iteration. The edge society is excluded from trade for that iteration. This is important because networks must be exclusively connected for exclusion to be a determinant of power distribution.[2]

The nodes are non-linear systems of differential equations that have been coupled by complex processes containing the transfer of both positive (i.e., increasing warfare advantage) and negative (i.e., decreasing warfare advantage) sanctions. These simulations allow us to explore the dynamics and power structure of linear topologies of mixed relation networks. Again, in our model, the way to secure a high level of resources relative to the other actors in the network (i.e. to achieve high payoffs or power in the network)

[2] Our definition of exclusively connected networks is clearly different from that in ET. Rather than a discrete form of exclusion, where ego's interaction with one partner completely excludes all of ego's other partners in a given round of exchange, this type of connection creates a graded form of exclusion. By allocating resources, force, or emigrants for an interaction with one partner, egos limit the amount of sanctions that can be transferred to the rest of their partners, thus excluding other partners to a certain degree and restricting the amount of benefit that can be gained in other interactions. Complete exclusion is allowed (e.g. ego can trade all of its stored resources to one partner therefore completely excluding its other partners), but not assumed. This is likely a better reflection of reality than the strict definition of exclusive exchange used in textbooks and laboratories. In our model, the benefit gained from one partner in a given iteration is not independent of the benefit gained from a different partner. Therefore, the type of connection is not null.

is to achieve a high warfare advantage. The distribution of warfare advantage (a proxy for power) will be the focus of analysis when examining solutions of the simulation models. Exploitation in trade (as measured by net resources gained in each iteration) will supplement this measure of power based on the assumption that the flow of resources through the network is an indicator of power use.

Results

The solution for a single society in isolation tends toward population equilibrium (Fletcher et al. 2011a). Equilibrium is maintained by a combination of fertility, productivity, and mortality regulation. Stability is also maintained by out-migration. Migration occurs because of pressure placed on the society due to increasing population density and the resultant internal conflicts over resources. In the single society model, emigrants simply disappear. But in real societies, emigrants move to adjacent niches, eventually filling all available space, and removing migration as a possible regulatory response. According to Chase-Dunn and Hall, in intersocietal networks, where circumscription comes into play, warfare emerges as the prominent demographic regulator.

Once additional societies are added, the stable solutions found in the single society model have the potential to transform into cyclical solutions oscillating between times of war and times of peace. The type of solution that emerges is dependent on the ratio of resource carrying capacity (K), or "enrichment" level, to the amount of land in each society (Fletcher et al. 2011a; Rosenzweig 1971). At low values of this ratio, which can be described as the potential resource density, the solutions have negligible levels of warfare and the population levels remain at equilibriums of equal value indefinitely. However, as the potential resource density is increased, a phase transition occurs and cycles of warfare appear. When the differentiation of warfare advantage becomes possible, the potential for hierarchy emerges. The primary outcomes of the single node in isolation model contrasted against a two node system are contained in Fletcher et al. (2011a).

The results of the 5-line intersocietal network model demonstrate this phase transition. For low levels of resource density, we see the population levels and warfare advantages of the five societies reach stable equilibriums of equal value and hierarchy is absent. However, for values larger than the critical resource density value, the threshold at which the transition occurs, the system starts in a destabilized state that after a brief transient period reaches a stable hierarchy. When the solution is in a stable state of hierarchy, the edge societies are indistinguishable and the interstitial societies are also indistinguishable (barring noise). The figures below only present one society from the pair of A and B nodes because in the stable regions of solution space, they behave identically as elementary theory predicts.

In the 5-line arrangement, upon reaching a stable hierarchy, the solutions always settle into the same configuration. This occurs regardless of the initial population levels. If the initial population levels are varied by structural position, the resulting hierarchy does not change.[3] Under certain conditions, it takes longer to reach the final configuration, but the same stable hierarchy is inevitable. Figure 3 displays the power levels for one of the A nodes, one of the B nodes, and the C node. This plot demonstrates the power hierarchy using standardized warfare advantage, which is the absolute warfare advantage level for each network position ($P \cdot T$) divided by the system wide technology level. The variable is standardized to eliminate the effect of constant technological growth. We have also averaged the variable over intervals of 500 iterations in order to remove some of the noise so that the hierarchy is clearly visible in the graph.

[3] This holds for initial population levels that lead to non-trivial solutions. For large initial population levels above a critical population density value, the solutions collapse and the populations are reduced to zero after a few iterations.

There is a slight positive slope in the curves for the two dominant positions (A and C) after the system has stabilized. This slight growth in warfare advantage is due to population growth. As their technology increases, they are able to raise their carrying capacity due to increased harvesting abilities. The dominated B positions however never reach their carrying capacity as they are forced to maintain low population levels due to trade exploitation and larger casualties of war.

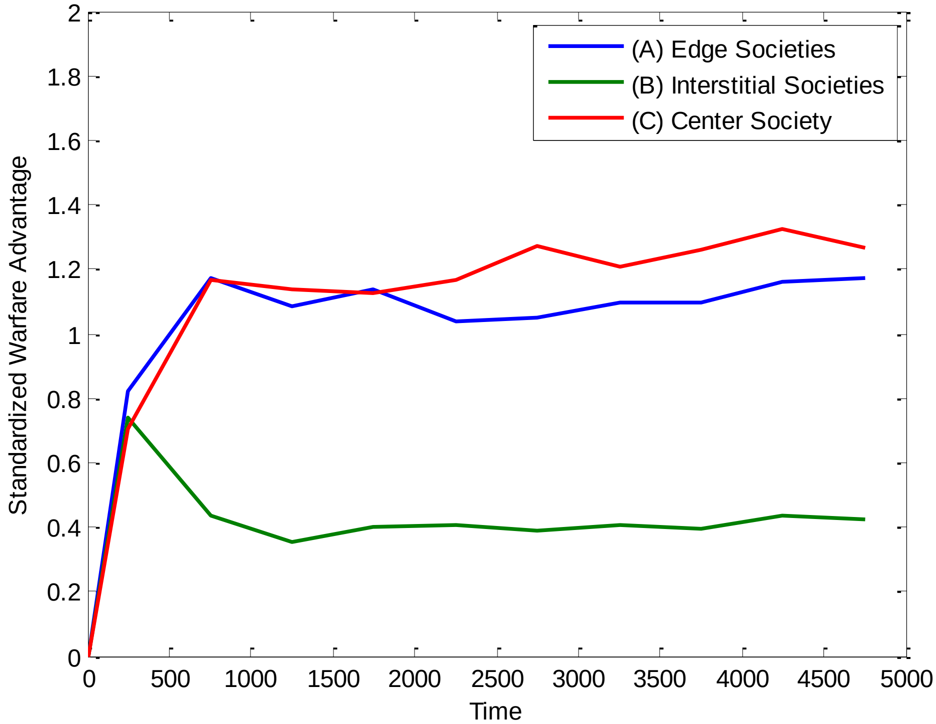

Figure 3. Standardized Warfare Advantage by Structural Position

The model can be viewed as a constant battle between two powers; a group containing societies A and C (the edges and the center) vs. a group containing only the two B societies (the interstitials). In the first few iterations (not visible in Figure 3 due to averaging), the interstitial societies, taking the brunt of warfare deaths due to the numbers disadvantage (two vs. three), rapidly decrease in population size. This allows their technology levels to grow at a much faster rate than their opponents' as they respond and adapt to the pressures of war. Early in the simulation, when system wide levels of technology are low, technological advantages are amplified. Simultaneously, migration and natural population growth allow the interstitials to maintain similar population growth rates as the other societies. Because the population growth rate of the edge and center societies is similar to the interstitials, it cannot compensate for the boost in interstitial technology during this time. The interstitials soon gain enough momentum to capture the overall warfare advantage (this occurs at around iteration 300). However, their time spent as the most powerful nodes is short lived. It is only a matter of time before the numbers catch up to them. Eventually the combined technology level of the edges and center recovers due to their numbers advantage and they overtake the interstitials. The final hierarchy with the edge and center societies at the top and the interstitials at the bottom remains indefinitely so long as the system is undisturbed.

The final steady state warfare advantage levels of the edge societies and the center society do not end up being equivalent. In fact, these two powerful structural positions tend to take turns acting as the dominant structural position. The reason this occurs is because when one of these two structural positions has the overall advantage, the less powerful of the two ends up fighting the bulk of the battles against the interstitial societies and the increased warfare deaths it experiences leads to a higher rate of technological growth. Eventually, the increased technology levels allow it to overtake the dominant structural position. This finding is in line with arguments claiming that a semi-peripheral advantage exists, whereby complacencies in core hegemonic states and improved social organizational technologies in semi-peripheral states lead to hegemonic transitions (Chase-Dunn 2001).

However, the center society always emerges as the most powerful actor on the average, followed closely by the edges. This is clear in Figure 3 and reflects the fact that the center society holds the overall advantage for considerably longer periods than the edge societies. Taking the average standardized warfare advantage for the final 4000 iterations (after the solution stabilizes) it's revealed that the center consistently ends up with about a 10 percent higher standardized warfare advantage. The final steady state warfare advantage of the interstitial societies are always much lower. Therefore, in our symmetric 5-line model, where the attributes are identical for all nodes, the center is the most powerful node, followed by the edges, and then the interstitials. Insights derived from ET that can help to explain why this particular power hierarchy emerges are discussed below.

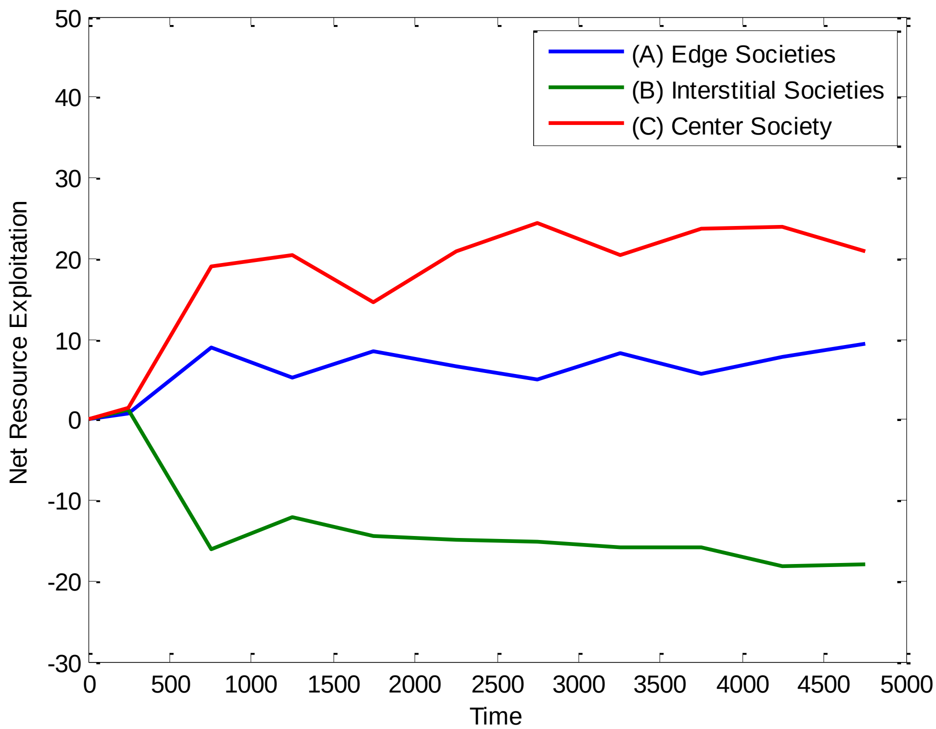

Figure 4. Net Resource Exploitation by Structural Position

To further support the interpretation of a C > A > B power hierarchy, Figure 4 displays the net number of resources gained by means of trade for each iteration. By examining the flow of resources throughout the network (power use), we can observe which actors receive the highest payoffs from trade and help to confirm our interpretation of the power distribution in the network. The same hierarchy that was found using the warfare advantage variable is evident.

Breaking Resource Symmetry

All nodes in the previously discussed model were built with identical enrichment levels (resource carrying capacity, K). While this limiting assumption allows for the implications of network structure on power distribution to be examined, it is likely not the case that real societies are privy to identical resource environments. By assigning different resource carrying capacities to the different structural positions in the existing models, we were able to highlight how heterogeneous enrichment levels interact with topology to produce stable hierarchies.

Though both attributes and position contribute to the relative power of an actor in a network, it was discovered that the level of influence of each mechanism depends on the position of the actor. For instance, no matter how much favorable enrichment bias the interstitials receive, they can never establish themselves as the powerful nodes in the network. Though higher levels of K than their opponents can prolong the early dominance by the interstitials, they can never maintain it. Once they lose power and drop to the bottom of the hierarchy, the potential for higher levels of production becomes irrelevant because their population never gets a chance to reach carrying capacity. Therefore, solutions in which the interstitials receive greater enrichment levels reach identical steady state outcomes to those in the symmetric resource model.

Increasing the K levels of the center society or the edge societies does impact the long term outcomes. As was discussed earlier, the inevitable hierarchy of the symmetric model has the center society just above the edges who are well above the interstitials. When the center society is given a higher K value, it remains the most powerful node, but its relative warfare advantage is greater in proportion to the increase in K. Similarly, the relative warfare advantages of the edge societies grow in proportion to the increase in K biases they receive. As K is increased, they catch up to the center in terms of warfare advantage, and eventually become the most powerful nodes in the system at high enough levels of K.

Discussion

Theories of societal evolution are often framed in terms of the endogenous dynamics of a single system (Parsons 1982), or the evolution of form by competition between a society and its fixed environment (Spencer and Carneiro 1967). While these are useful approaches at the most abstract level, empirical societies exist in the context of other societies that are also actively changing. That is, to varying degrees, societal evolution is really co-evolution. The exigencies that confront a single society will push that society to adapt to the problems it faces. The changes in a single society have implications for the network that society is embedded in, as this newly adapted society interacts with its neighbors through trade, migration, and warfare. These interactions are themselves driving forces in the societal evolution of the system. While it is true to state that societies and social forms evolve, it is also true to note that networks evolve, and it is difficult (if not impossible) to abstract the former from the latter. In some cases, the rise of one society is linked to the fall of others; in other cases, upward sweeps or collapse may occur in both (Chase-Dunn and Hall 1997).

Our model of a single, small scale, early sedentary human society in isolation enjoys a relatively stable existence. Most historical societies, however, do not exist in inert environments. Rather, they are embedded in world-systems, or intersocietal networks, occupying a geographical matrix that structures interactions among them. Our 5-line models explore simple world-system networks composed of multiple societies. Following Chase-Dunn and Hall, we suppose that three types of interaction exist between the societies: migration, warfare, and trade. Elementary theory suggests that these processes of societal interaction are forms of social relations that determine the flow of sanctions between the societal nodes. Ecological theory (Thébault and Fontaine 2010) suggests that antagonistic interactions (negative sanction flows) and mutualistic interactions (positive sanction flows) give rise to different characteristic degrees of hierarchy and clustering. When both forms of tie are operating in the same network however, the implications for the emergence and stability of hierarchy are not clear.

In ET, it is implicitly assumed that exchange (the mutual flow of positive sanctions) is beneficial to actors. The more exchange partners an actor has, the better payoffs the actor can accrue by avoiding exclusion from exchange. The amount of resources or profit that an actor has indicates their power in the network. However, in our intersocietal network model, where relations are not purely the flow of positive sanctions but include negative sanctions as well, we find different results. Though we have not produced an elegant mathematical predictor of power in our mixed relation network like Willer and Markovsky's "graph-theoretic power index," which uses structural information to quantify a node's absolute power in an exchange network (Willer 1999), we are able to examine how the types of interaction in our model influence the power of each position in the network.

In the single society model, devoid of intersocietal interaction, migration and starvation are the dominant demographic regulators. However, when societies are not free to expand, but instead encroach on adjacent societies as they compete for resources and space, war becomes the dominant demographic regulator (Chase-Dunn and Hall 1997; Fletcher et al. 2011a). Though migration is common in the intersocietal models, such a small proportion of population dynamics is governed by migration in our model that its effect on warfare advantage relative to the other types of relations (trade, warfare) is negligible. Though migration likely has some influence on the resultant power hierarchy we will focus our attention on the relations of warfare and coercive trade which dominate these dynamics.

Consistent with Chase-Dunn and Hall's iteration model, warfare drives the population dynamics in these intersocietal networks. Because warfare is more detrimental than beneficial to actors, a different argument parallel to the one made by ET about exchange networks should be true about the 5-line power distribution. The more warfare partners a societal actor has relative to others in a given network, the less likely it is to be excluded from negative sanctions at any given time, and therefore the less power it will have in the network. In the 5-line network, every tie in the network includes one of the B actors (which is not the case for the other structural positions). Therefore, the interstitial societies (B) are never excluded from warfare so they suffer the greatest detriment from these conflictual relations and are always the least powerful actors in the network once the system stabilizes. The other three societies stand to be excluded from warfare on occasion, and thus end up as the more powerful actors in the network. However, this exclusion from conflict argument adapted from ET predicts the inverse of the 5-line strong power exchange network in which the edge societies (A) and center society (C) are equally powerful. Though this is close to the findings in our symmetric resource model, the edge societies and center society are in fact differentiated. But warfare is not the only influential type of social relation in this network.

Unequal trade also plays an important role as the warfare advantage of the more powerful actors allows them to exploit their trade partners further enhancing their advantage. Upon reflection, it becomes clear that the relationship between coercive processes (trade in our model) and power in a network is not as simple as exchange and conflict. If an actor is less powerful than most of its trade partners in a given network, then the more trade partners it has, the more negative sanctions it receives from interaction (or threat of negative sanctions that leads to a loss of positive sanctions), and the less powerful it becomes. Therefore exclusion from unequal trade is beneficial to and relatively increases the power of weak actors. However, if an actor is more powerful than most of its trade partners in a given network, the opposite is true, and more trade partners implies even more power due to the exploitation of those partners. Thus, exclusion from unequal trade is detrimental to and relatively weakens the power of powerful actors. It appears from this logic that an interaction effect occurs, whereby the level of warfare advantage experienced by a node in an intersocietal network modifies the relationship between the level of exclusion from trade experienced by that node and the level of benefit (or detriment) such exclusion brings about. This argument is consistent with the results of our model.

The fact that the center and edge societies experience greater levels of exclusion from warfare allows them to establish themselves as more powerful than the interstitials. However, once they become the powerful nodes in the system, the more trade partners that they possess, the more resources they will be able to exploit, and the more powerful their position in the final hierarchy. Because the center society has the advantage of two possible trade partners (compared to one for each of the edge societies), and coercive trade is beneficial to these three powerful societies, the center society gains more from exploitation and establishes itself as the most powerful actor in the network. This is demonstrated by the significant advantage in net resource exploitation that the center has over the edges which is clearly displayed in Figure 4. The center society rides its exclusion from conflict to a powerful position and then adds to that power by avoiding exclusion from coercion.

Conclusion

This paper presents solutions of a simulated model of interconnected societies interacting via migration, warfare, and unequal trade. Simulations are not empirical tests and are limited by the assumptions of the theories they are exploring. They are however, excellent theoretical tools that allow for the exploration of emergent phenomena in complex systems. We consider this the first step in a larger study of how structural phenomena due to network constraints, such as exclusion from interaction, are important in determining the relative power of societies in world-systems.

This work contributes to network theories of mixed relation models that involve social relations with different combinations of positive and negative sanction flows. Considering the fact that most real world social networks likely contain different types of relations interacting simultaneously, more attention should be paid to the ways in which exclusion from different relations influences power distributions. Network exchange theory tells us that exclusion from exchange is detrimental, but we find that exclusion from conflict is beneficial. We also find that exclusion from coercive relations is likely a function of an actor's power in the network. Low power actors benefit by being excluded from coercive relations while high power actors suffer. Our minimal exploration of a simulated simple line network supports the ET finding that exclusion from social relations is fundamental in determining the power structure of a network. Though exclusion from each type of relation influences the power dynamics differently, it appears that the emergent hierarchy in a network is structured by exclusion from the types of relations that dominate the network (in our case, conflict and coercion).

The results of this model also demonstrate how important micro-level network theories can be when studying the macro social world. The relative power of societies in a system is likely influenced by the behavior of every other society in the system. Our simulation model demonstrates that under certain assumptions, it is clear that exclusion from positive and negative sanctions in an intersocietal network can have major implications for the relative power of a given society in the system hierarchy. Also, as was shown in the heterogeneous resource enrichment models, network structure can trump other predictors of power such as the enrichment levels of a society's environment for certain structural positions. Regardless of the relative value of K, the interstitial societies can never escape their weak network position. Macro historical researchers would be wise to incorporate explanations from ET and other micro-level network theories into their analyses of world power distributions and hierarchies.

A possible limitation of these models can be found in the assumptions we make about the structure and meaning of the ties between societies. Because we start from a world-systems perspective, we treat trade as unequal and coercive in our model where it is used as a tool by stronger societies to take advantage of weaker ones. One can just as easily conceive of a model in which trade is treated as purely beneficial to both societies and is isomorphic to the relation of exchange in ET where only positive sanctions are sent and received. Models employing this assumption would likely produce different solutions that reflect the fact that exclusion from exchange is always detrimental.

Another limitation of these models is that the network structure is rigid. Historically, relations between societies and empires shift and evolve (Turchin 2003b). Intersocietal ties of trade, warfare and migration often dissipate and are forged anew in different configurations. The vast international relations literature explores the important impact of aid and alliances between nations, which is ignored by our model as the nodes are bounded by the network structure and only allowed to interact with those they are adjacent to in restricted ways. In our future research, we plan to allow the network topology to evolve. Evolving exchange networks have been examined using agent based simulation models whereby actors are allowed to sever ties and search for better ones within a given space (Bonacich 2001). Our systems based simulation models would assume that ties are dependent on endogenous variables such as technology and circumscription and connections would change with these variables. As these variables evolve, so would the network structure. We hope to find further solutions where power dynamics that are in line with predictions of WST can be explained by structural factors such as exclusion from interaction.

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