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Permalink
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Publication Date
2014-12-01

Undergraduate

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Trade Networks in the Late Bronze Age

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Kopcke took a skeptical position on the evidence for interstate trade in the Late Bronze Age (LBA) Aegean when he observed that "none of the finds in the palaces themselves bear labels giving us specifics of the channels through which they passed they passed" (1987: 259). This may seem an unwieldy standard of evidence for establishing patterns of trade, and other scholars have taken more moderate positions by suggesting that artifacts, seals, ceramic and architectural styles, depictions of trade in art, and linear A/B Tablets compose a field of evidence from which we can understand LBA trade (see Cosmopoulos 1991; Cline 2009). This paper will explore the lower limit of evidentiary standards of proof in LBA trade. While one sherd may not tell us much about its role in the complex system of trade, a collection of pithoi is a chorus. From observed distributions of artifacts, this paper will attempt to fit a trade network between sites by simulating the behavior of individual agents. The aggregated decisions of agents in the system will trace a weighted, directional network between sites.

Once networks for the Minoan and Mycenaean periods are established, we can compare their structure. A number of metrics would be of interest (e.g. centrality measures, degrees of clustering) but efficiency, the net utility of a interactions across a network, will be the focus of this paper. Graph theory informs us that networks of links and nodes in which the links are established in a game strategic process may be pairwise stable (i.e. none of the nodes will benefit from forming or breaking a link) but have sub-optimal efficiency (Jackson & Watts 2001). It is possible, then, for stable networks of the same nodes to have different efficiencies. As it will be seen, the implications of a Minoan and Mycenaean period efficiency differential (hereafter MMED) are considerable. Minor differences in the efficacy of a system may aggregate over time, resulting in a substantial difference.

Introduction

Scholarship on LBA trade is diverse and profuse. Researchers have largely broken up into two camps divided on causal mechanisms. The scale of focus, decisions to address regions or local sites in the process of analysing archaeological evidence, is where scholars divide themselves. The relation between disparate scales of interaction in the Bronze Age are co-determinant as they might be in any complex system. Yet archaeologists have contended causality on either end of the scale, leaving third parties feeling as if they were trapped in an hermeneutic circle or stuck with choosing the chicken or the egg.

Macro-scale analysis of LBA trade is exemplified by World Systems Theory (WST). WST concerns long distance trade, the accumulation of capital, the relationship between core and peripheral powers, shifting hegemony, and the cyclical nature of economic development in analysing regional trends (Kardulias 2009). WST is useful in its ability to follow the effect of interacting cultures but is grounded on controversial assumptions: first, that all intersocietal interactions fit the core-periphery model, and second, that societies are represented as a regional space from which influence radiates uniformly (Knappett 2013: 5). On the opposite end of the spectrum lies political economic analysis of LBA sites. Driessen looks at the social organization of production through analysis of the size and function of housing units at Minoan sites (2010). Houses were a distinct political unit as they had "an intergenerational quality which made them socially relevant to a succession of people organized in a community with an internal hierarchical organization" (Driessen 2010: 40). Other scholars have looked at the construction of "elite culture" through a decentralized mode of production (Schoep 2010) or even developed political economies specific to individual sites (Shelton 2010).

Knappett provides a bridge between these camps by arguing that historical developments occur through the interaction of events on the micro, meso, macro and global scales (2012a: 395). Viewing the scale as a continuum is helpful, but problems arise when considering which forms of evidence are applicable at which levels. Parkinson and Galaty attempt a resolution by proposing a cartesian plane of time and spatial distance onto which regions are mapped representing acceptable uses of evidence by type (2012a: 12-15). This is a novel solution, but the size and locations of each region are open for debate, leaving want of a unified approach to archaeological evidence. Social Network Analysis (SNA) provides such a methodological link between disparate scales of analysis.

SNA in Archaeology

Archaeologists, "ever the magpies of the academic world," have found great use for the concepts and tools borrowed from graph theory (Isaksen 2013: 43). Recently, scholars have used SNA to map the development of Jewish ethnicity (Collar 2013), track the evolution of the prestige goods system in pre- and proto-historic Japan (Mizoguchi 2013), and understand the sociopolitical systems of the indigenous Caribbean (Mol & Mans 2013). Besides being a "handy metaphor for connectivity," networks bridge intersocietal and intrasocietal interactions, allow for but do not necessitate directionality, consider both spatial and relational distances, and can cross scales of analysis (Knappett 2013: 6). Though its products are not to be taken as archaeological "fact," SNA has served as "a set of exploratory techniques for data analysis" (Terrell 2013: 20). The extent to which networks can be used to make historical claims remains a point of contention. The range of claims made by this paper will be similar to that of Knappett, Evans,

and Rivers, who argued that the eruption of Thera caused a structural change in the Minoan trade network that would lead to the decline of Minoan influence (2011).

The first challenge in archaeological applications of SNA is the establishment of links within a network. As the data typically available to archaeologists are less consistent than data of other disciplines, the challenge is in reconstructing rather that analysing networks (Knappett 2013: 8). Attempts at network reconstruction have included manual reconstruction (e.g. Cosmopoulos 1991) or automated optimization such as the "gravity model" used to reconstruct an Aegean trade network (Knappett, Evans, & Rivers 2008). Manually generated networks, if dependent on archaeological evidence, may fail to represent the scale of interaction between sites. Optimization produces more realistic and intricate networks, but fails to capture the possibility of pairwise-stable, inefficient networks. Generation of networks through any means leads to a powerful representations of LBA trade, but we must be careful in constructing networks that they do not "become academic voodoo" (Isaksen 2013: 44). Isaksen thoughtfully observes that "all judgments of archaeological analysis must begin by asking why a given concept set—places, typologies, people, and so forth—was used for it inevitably determines the nature (if not the structure) of the results." (2013: 46). For this reason, and to avoid Isaksen's other "major bear traps," the elements of the model are listed and justified below (2013: 43).

Methodology and the Model

Models are useful inasmuch as they reflect reality. The process of network generation put forward in this paper is an attempt to generate models of Mediterranean LBA trade inductively, from observed distributions of artifacts. Unlike previous models, it will consist of two

components: sites, as we understand them, and agents, which will function as the medium

exchange between sites. Palaces, afterall, may only trade with each other through metonymy.

Further, the separation of sites and agents allows for more realistic paths of trade. Spatial

distance, site size, capacity to produce strategic goods, wind, and cultural allegiance are

considered in the generation of the model. In addition, the agents will fall into one of three

classes: palatial gift-exchange, merchant, and down-the-line. The selection of such factors should

not be trivial, though inclusion of a certain factor in the process does not unequivocally assert its

veracity. The model, as we can think of it as a non-linear regression, will help answer the

question of which factors are determinants of trade. Each of the chosen factors will be multiplied

by a parameter, and the value of the parameter will be initially randomized. If a factor is not an

element of trade in the LBA Aegean, or at least is not necessary to explain the distribution of

artifacts, successful networks will contain a wide range of values for the parameter, likely

including zero. In this way, the process of network generation will allow us to redact the

consideration of a potential determinant of trade. The intention of this paper is not to take a

position in these debates; instead, the establishment of an idea in scholarship will be taken as

sufficient grounds for inclusion in the model.

First, we look at the arguments for diverse agents in LBA trade. Knapp outlines a model

for disparate merchants including centralized, localized, entrepreneurial, and gift-exchange

traders (1993). The manifold nature of exchange has been noted in Homer : "there are indications

that the boundaries of transactional orders were negotiable. This presents itself in the *Odyssey*

where evaluations of Odysseus' exchange behavior depends on the status he adopts" (Reden

2003: 8). The proportion of trade that occurred through each type of transaction has also been

disputed, with some researchers proposing trade could have been executed primarily through

palatial gift exchange (Weiner 1990: 26). Even when assuming trade decisions are approximately

rational, the priorities and capabilities of disparate agents would have a significant effect on the

structure of a trade network. Indeed, scholars have called for agents with diverse aims, even

ideologies, in agent-based modeling (Costopoulos 2008).

Distance is a strong candidate to be a determinant of trade. Its level of importance in

making trade decisions, however, has been debated. Distance has been used as the sole

determinant of trade, linking each site with the next three closest sites in a process called

proximal point analysis (Broodbank 2000: 81-96). The question of the distance cost in a trade

venture quickly leads one to consider other factors involved in maritime travel such as wind,

depth of the water, and the type of boat used. Zerner and colleagues raised thoughtful questions

about each of these concerns (1993). Zerner posits the illegitimacy of the daily travel limit by

observing that night sailing was entirely possible; he also critiques the consideration of seasonal

wind patterns as "all winds can be expected at all seasons in the Aegean" (1993: 86).

Are all items of trade alike? Following various lines of reasoning a number of researchers

have responded definitely "no." Looking at miniature artifacts, Knappett argues that objects are

inextricably connected to those who utilize them through "semiotic networks" in which the

object is both a sign and a portion of the context of interaction (2012b). Other scholars look to

the strategic importance of the period's namesake, which was "of course essential to the

functioning of an advanced Bronze Age society" (Weiner 1990: 22) . Yet the incorporation of all of

the different functions and meanings of exchange into a unified model may not be feasible.

Instead, this paper will attempt a network of heterogeneous goods through the consideration of

"strategic goods" (i.e. copper and tin). In this model, strategic goods will be recorded as a proportion (S) of the total goods at a given site. Agents will consider the discrepancy of S between themselves and potential trade sites; in this way the mechanism somewhat reflects a demand curve which is then multiplied by the population of the site to give a "market size." We must also include a neutral factor that supplants the difference in S so that the proportion may be excluded from the model if it is irrelevant.

A more problematic element of trade is the effect of interacting cultures. The process of Minoanization, described by Wiener as the "Versailles effect," in which trade partners adopt Minoan cultural signs, may have had an impact on trade (see 2013). This model introduces one possible effect of interacting cultures: that agents at a site will experience a benefit, perhaps better understood as the lack of an additional cost, when trading at a site with similar cultural allegiance. This attempts to include the effect of processes such as Minonanization in the Cyclades. The cultural evidence (e.g. similar architecture, pottery style) that have been the basis for arguments of Minoan influence in the region are a sign, if nothing else, of frequent and consequently easy interaction (Branigan 1981).

Last, researchers have stressed the importance of the ability for networks to evolve over time. Social systems are complex, so that "the causal categories become intertwined in such a way that no dualistic language of state plus dynamic laws can completely describe it" (Rosen 1987: 324). As a result, some have turned to the concept of self generation in related biological systems, autopoiesis, to explain the behavior of complex systems in archaeology (Kohler 2012). Autopoietic systems are those made of:

> components which (i) through their interactions and transformations continuously
> regenerate and realize the network of processes that produce them; and (ii) constitute it

as a concrete unity in the space in which they exist by specifying the topological

domain of its realization as such a network (Maturana & Varela 1980: 79).

More simply put, autopoietic systems are self regenerative and capable of structural change. This

model attempts to address the problems of modeling a complex system by extending the

network across a time series and regenerating the links at each step. As populations change and

strategic goods circulate through the network, trade decisions may lose or gain utility, creating

the potential for structural change in the network.

The use of agents in the model helps mitigate the problem posed by fragmentary

archaeological records in establishing links. Researchers utilising SNA are often able to choose

objective measures (e.g. marriages, co-authorships, recorded transactions) as the basis for

establishing links in a network. As noted earlier, prehistorians are often less frequently gifted

reliable, comparable, and complete data sets. Sindbæk illustrates the problem with his concept

of "reconstructing black box circuits"(2013: 71). The challenge of SNA for archaeologists is in

deriving the inner circuitry of trade through analysis of the imperfectly recorded inputs and

outputs (Sindbæk 2013). This model guesses at the factors an actor may consider in the decision

to trade and constructs networks, the circuitry of trade, from the collective decisions of thousands

of agents over time. While the modeling process has been described as a non-linear regression, it

differs from regressive processes in that it does not rely on a large or consistent set of data.

Instead, networks will be generated through random parameterizations and checked against a

handful of data pulled from known patterns of artifact distribution. This approach looks at the

walk and listens to the quack but foregoes more rigorous anatomical inspection of the duck.

While the quality of the resultant network directly descends from the quality of the data

against which it is checked, a small number of checks quickly eliminates the majority of

generated networks and more comprehensive data sets are not panaceas as they are still subject

to confounding variance in the proportion of artifacts that survive to be found. Instead, the

strength of conclusions from analysis should be taken from the robustness of the observation.

This approach to SNA lends itself easily to measures of robustness. The criterion for accepting or

rejecting a generated network in this paper is its conformity to observed distributions of artifacts.

By expanding the width of the range of values considered acceptable (i.e. increasing the

acceptable error), one can increase the number and variety of networks accepted. The critical

metric, then, is a conclusion's ability to tolerate a range of networks varying about the

archaeological "mean."

Below are the utility functions developed from the consideration of the potential

determinants of trade discussed above.

$$U(\Omega, \Psi) = \alpha U^m(\Omega, \Psi) + \beta U^d(\Omega, \Psi) + \gamma U^p(\Omega, \Psi)$$

The net utility function $U(\Omega, \Psi)$ is composed of the sum of each of the types of actor in the

model: merchants are denoted with superscript m, down the line traders with d, and palatial

gift-exchange traders with p. The components of the merchant utility function are shown below:

$$U^m(\Omega, \Psi) = \sum_{i \in \Omega; j,h \in \Psi} M(i,j) + \eta C(i,j) - DC(i,j) - N(i,j,h)$$

$$M(i,j) = (\varepsilon P_j |S_i - S_j| + \zeta P_j)/(\delta A_j + 1)$$

$$DC(i,j) = \theta D_i(j) + \iota W_i(j)$$

$$N(i,h) = \mu D_i(h) + \nu T$$

Where Ω is the set of all merchants, Ψ is the set of all sites, $DC(i,j)$ is a function representing

the distance cost of an interaction, $M(i,j)$ is a function representing the market size, S is the

proportion of strategic goods, P is the population, A is the number of agents (merchants) at a given site, $C(i,j)$ a function of the allegiance of the agent and site, W is a function concerning wind direction, $N(i,h)$ is the "Nostos" which is an heuristic function forcing the agents to eventually return to the home site, T is the amount of time a merchant has spent away from its home site, and α through σ are parameters. The utility functions of the palatial gift-exchange and down-the-line agents differentiate from the merchant utility function in distance cost. Down-the-line agents are unique in their limited mobility, so the utility function will exponentiate the distance cost. Palatial gift-exchange agents, on the other hand, might be expected to defer the cost of sailing long distances to the prospect of interacting with another state, as shown in the Cretan exchange in Babylon (Weiner 1987). To reflect this in the model, the distance cost of a longer voyage will be mitigated by taking it's logarithm. The choice of exponential and logarithmic functions is somewhat arbitrary, as all that is needed to simulate the desired behavior is upward sloping concave up and concave down functions.

Table 1: List of parameters and corresponding elements of the utility function.

α	Merchant utility	η	Cultural function
β	Down-the-line utility	θ	Distance function
γ	Palatial utility	ι	Wind function
δ	Agent count at site	κ	Down-the-line distance based cost function
ε	Market considering the difference of the proportion of strategic goods	$\lambda\lambda$	Palatial distance based cost function
ζ	Market not considering the difference of the proportion of strategic goods	μ	distance in the Nostos function
-		ν	Time away from home-site

Before looking at the results of the model, it is necessary to observe some limitations of the model. First, the data taken as the basis for evaluating generated networks in this paper are weak. The data are collected from a number of sources (Orientalia, Cline 1994; Cypriot finds, Portugali & Knapp 1985; Central Cretan pottery, Moortel 2002; Cycladic finds, Cherry & davis 1982; Mycenaean finds in the Levant and Italy, Wijngaarden 2003; Dodecanese finds, Benzi 1988; site sizes, Knappett, Evans & Rivers 2013; distribution of copper and tin ore, Muhly 1973 and Gale & Stos-Gale 1986; wind patterns, Zecchetto & De Biasio 2006). From these data, only 28 "checks" are taken of the Minoan and Mycenaean period networks. There are, necessarily, limitations to the model. The list of sites included is far from complete; instead, the sites are clumped so that all regions may be represented. Lastly, there is no inclusion of certain factors (e.g. military) though they would may likely have played an important role in the nature of LBA trade. Ideally, generated networks run forward in time would map the transition from Minoan to Mycenaean periods, but the cause for such a shift is outside the scope of this model.

Results

The model as described was run repeatedly with a genetic algorithm to converge parameters to fitting networks. For each network, the parameters used, the utility of the network, the network structure, and whether the Minoan network was more efficient than its Mycenaean counterpart were recorded. As shown below in figure one, the majority of generated networks supported the MMED. Yet a conclusion from a particular network is not necessarily significant. As Isaksen asks "[h]ow much random corruption could occur to the data set before the analysis gave an entirely different result?" (2013: 47). Figure one is an attempt to answer this question

for the MMED. Error in the model, the width of ranges of acceptable values, was variable in the

model.

Figure 1: Proportion Successful over Error
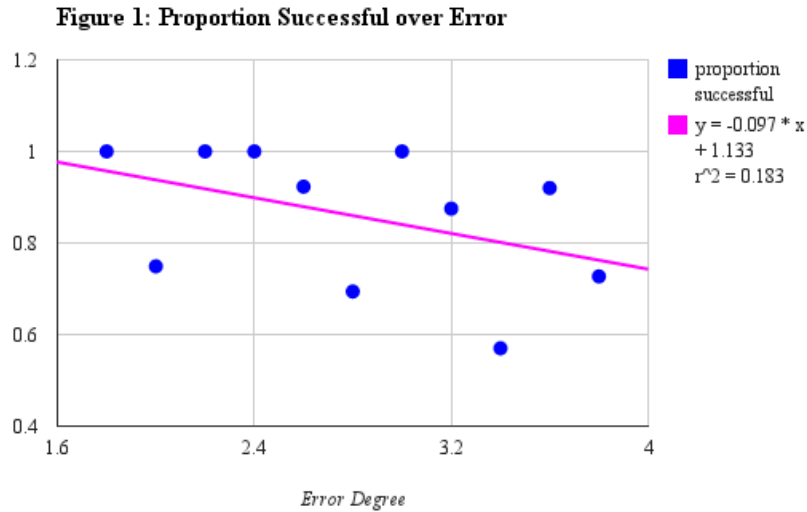
The overall trend of the graph shows a consistent conformity to the MMED argument at

lower levels of error, followed by essentially random success rates as a higher proportion of

generated networks are accepted. This pattern clearly illustrates the robustness of the MMED,

with the conclusion holding across a considerable degree of error before the results become

arbitrary. There is, however, one outlier at error degree 2.0 which detracts from the strength of

the trend. This should not be surprising when using a Monte Carlo method to find networks. The

parameterizations are random, so deviations in sampled values from the true value may occur.
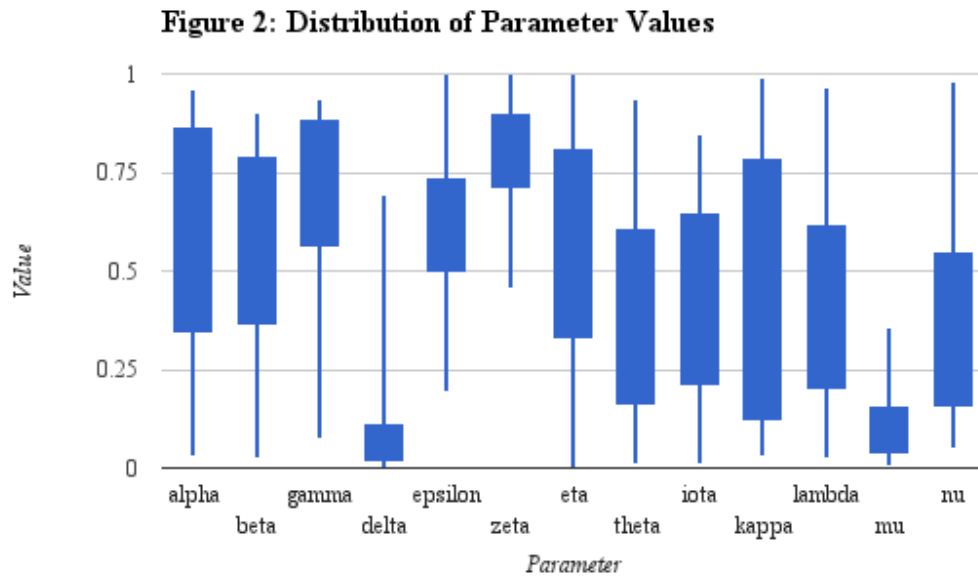
Figure 2: Distribution of Parameter Values

Figure 2 shows the distribution of parameter values of accepted networks with the highest

point representing the maximum value, followed by the third quartile, first quartile, and

minimum value. Tight spread of values near zero in parameters delta and mu strongly suggest

their insignificance in the model. Similarly, gamma, epsilon and zeta are clearly important to the

model. If wide ranges of accepted parameter values are indicative of an irrelevant factor in the

utility function, it might appear that the majority of considered factors are unimportant to the

determination of trade decisions. However, it may be that the relative as opposed to absolute

value of the parameter is important to the model. To check for this effect, we run linear

regressions between different parameters with strong correlations indicating that the ratio of the

pair is significant in the model. The strongest correlations are recorded in table two.

Interestingly, the high values of delta come from the same two networks that led to the unusually

low proportion of success at error 2.0 in figure one. This suggests a different network structure

than the majority of the generated networks and one that is less likely, as it was far less

frequently generated, to represent the true network.

Table 2: Parameter by Parameter Regressions

Parameters	β	R^2
eta/iota	0.438	0.157
iota/nu	0.523	0.268
lambda/eta	0.543	0.283
gamma/eta	0.608	0.285
kappa/nu	0.479	0.324
theta/iota	0.603	0.350

Considering the variation of parameter values relative to the variation of others we can

make conclusions about the relevancy of each factor considered in the model. All of the utility

function types were necessary in the model, though the gift-exchange function was the strongest.

It appears that both elements of the market size, whether or not considering strategic goods, were

important to the model. The number of transaction having occurred at a site was irrelevant to an

agent's decision to interact with the site. Distance and wind costs are relevant as they were

strongly correlated. The cultural function is a curious case: while it included zero in its spread, it

was correlated with three other parameters. There is also an interesting relationship between the

down-the-line distance cost and the nostos function.
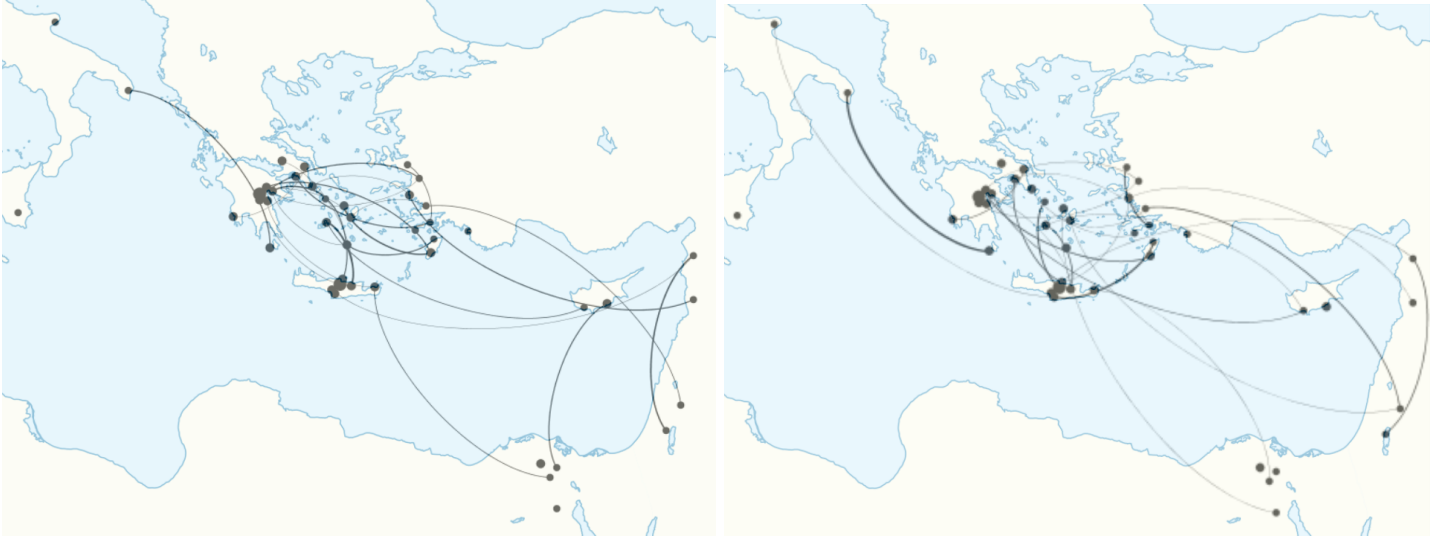
(Figures 3&4: Minoan p. network left, Mycenaean network right. Links weighted on a log scale. Sites locations are approximate. Networks produced with Gephi software. Map: Wikimedia.)

As Isaksen suggested, we must not be drawn into analysis of illustrations (2013: 44). The depictions allow us to visualize the output of the model, but they are singular examples in a plural field of networks. Several problems appear in these depictions of trade. First, there appear to be links that lack evidence in the archaeological record such as the connection of Memphis and Enkomi, or the complete lack of links between Egyptian and Syro-Palestinian sites. Second, one would expect, as was seen in Knappett's model of the Aegean during the Minoan Period, to see higher clustering within regions (2008). In addressing these concerns, it is important to remember the design and limitations of the model. Because the model is checked against portions of the Archaeological record, the network will generate a distributive structure instead of a network encompassing all trade. This effect is exacerbated as surviving artifacts are often exceptional in that they do not likely represent the most common items of exchange during the period. The circulation in trade of raw materials (e.g. wood, grain, wine), which may have accounted for the majority of exchange, is absent in this model. However, the aim of this paper is

to evaluate the efficiency of each network, which is, on a regional scale, likely more dependant on the distributive structure than local clustering.

Conclusion

The skeptical reader may have several reasonable objections at this point: doesn't expansion in Mediterranean during the Mycenaean period in the archaeological record debunk the MMED? Even if the MMED is accurate, isn't this minutiæ? First, the MMED could exist while the volume of trade in Mycenaean period exceeded its Minoan precedent. The key to this paradoxical result lies in this paper's methodology: the distribution of goods against which generated networks were checked was recorded in proportions instead of absolute counts. As a result, structural inefficiency is found irrespective of scale. Second, economist Thomas Piketty shows how minute change in growth rates can cause dramatic shifts as growth aggregates over time: for example, a one percent change in growth over a century is equivalent to multiplication by 2.7 (2014:76). The same principle applies in the case of MMED. The slight deficiency in the Mycenaean network, extant even though trade initially flourished, would aggregate through the 13th c. BCE, potentially contributing to the contraction in trade seen in the late 13th c. BCE (Jung 2012:172).

In constructing historical narratives, it is tempting to personify trends. For Gibbon, the loss of courage and genius during the prosperity of the Antonines was the injection of "the slow and secret poison into the vitals of the [Roman] empire" (1776: 83). Similarly, the "Sea Peoples" as a suggested proximate cause of Mycenaean decline provide a satisfying sense of corporeality (Jung 2012:177). Yet what is accurate and what is fitting in the study of history are not one in the

same. Certainly, archaeological evidence prevents us from dismissing this explanation. However, we cannot say the explanation, in combination with other natural forces such as earthquakes, suffices (Shelton 2012: 146). If the MMED is accurate, it is one example of a causal mechanism of an historical scale that is as arbitrary as a subtle variation in the formation of links across a network.

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