Miguel, Amblard, Barceló & Madella (eds.) Advances in Computational Social Science and Social Simulation
Barcelona: Autònoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

Roman Bazaar or Market Economy? An Agent-based Network Model of Tableware Trade and Distribution in the Roman East

Tom Brughmans
Sagalassos Archaeological Research Project,
University of Leuven
Department of Computer and Information Science,
Universität Konstanz
Email: Tom.Brughmans@uni-konstanz.de

Jeroen Poblome
Sagalassos Archaeological Research Project,
University of Leuven
Email: Jeroen.Poblome@arts.kuleuven.be

Abstract—**This paper aims to evaluate notions of two crucial studies on the Roman economy by Bang and Temin based on the study of distribution patterns of ceramic tablewares in the Roman East in the period 150BCE-200CE. It presents an agent-based network model simulating the social networks which represent the flow of information and goods between traders. Results of the simulation are subsequently compared to the tableware data collected in the ICRATES database. Preliminary results suggest, contrary to Bang's hypothesis, that limited availability of reliable commercial information from different markets is unlikely to give rise to the large differences in the wideness of product's distributions observed in the archaeological record.**

I. INTRODUCTION

Ceramic tableware is one of the most common find categories on Roman sites in the Eastern Mediterranean and therefore lends itself particularly well to quantification. It offers archaeologists a key tool for approaching aspects of the ancient economy. One of the most robust patterns observed in the collected tableware data is the variability of distribution patterns of different tablewares at consumption sites (products characterised by a distinct clay fabric and produced in different centres). Some wares such as Eastern Sigillata A (ESA) were distributed on a supra-regional scale for centuries, others were more of regional importance (Eastern Sigillatas B, C, and D), whilst yet other wares were produced for local consumption. What were the mechanisms that led to differences in the wideness of products' distribution patterns? A number of hypotheses have been published identifying, coupling and balancing particular combinations of possible contributing factors, such as state involvement, redistributive centres, consumption "pulling forces", commercial "piggy-back" trade, closeness to large-scale agricultural production, connectivity, etc. [1]-[4]. Most scholars seem to agree that a complex mix of mechanisms working on multiple levels was responsible for the considerable differences in tableware distribution patterns. Since there is evidently no lack of hypotheses, the main challenge becomes to recognise the mix of contributing factors that is best supported by the available evidence, and finding a more quantitative approach that allows one to distinguish between the archaeological "signatures" of different hypothetical scenarios. The development of such approaches has so far been limited in Roman studies [5]-[6].

This paper aims to contribute to this on-going discussion by evaluating two hypotheses of the role of social networks in tableware trade and distribution. It uses a combination of an exploratory analysis of the collected tableware data from the Roman East between 150BCE and 200CE (using the ICRATES database of tablewares) with computational modelling of hypothetical trade mechanisms.

In this paper we will focus our efforts on exploring the potential role of social networks as a driving force of the Roman trade system. The concept of social networks is here used as an abstraction of the commercial opportunities of traders, acting as a medium for the flow of information and products. We aim to formalise and evaluate aspects of two models of the Roman trade system in which such social networks play a key role: Peter Bang's *The Roman Bazaar* [7] and Peter Temin's *The Roman Market Economy* [8]. Bang considers three factors as crucial to understanding trade and markets in Roman Imperial times: bazaar-style markets, the tributary nature of the Roman Empire, and the agrarianate nature of ancient societies. The engine of the model, however, is clearly the concept of the bazaar: the existence of local markets characterised by a high uncertainty of information, and relative unpredictability of supply and demand. This limited availability of commercial information led to poorly integrated markets throughout the empire. Bang argues that different trajectories for the flow of goods could emerge as the result of different trajectories for the flow of information. In other words, the observed distribution patterns of tablewares and different workshops' products (when these can be identified) were at least in part a reflection of the structure and functioning of past social networks as defined above.

The ICRATES project was supported by the Belgian Programme on Interuniversity Poles of Attraction (IAP 07/09), the Research Fund of the University of Leuven (BOF-GOA 13/04), Project G.0562.11 of the Research Council-Flanders (FWO) and the Hercules Foundation (AKUL/09/16).

Temin agrees with Bang that the information available to individuals was limited and that local markets were structuring factors. However, contrary to Bang he believes that the Roman economy was a well-functioning integrated market where prices were determined by supply and demand. In Temin's model the structure of social networks allows for commercial information to be more reliably and widely available between markets than in Bang's model, resulting in more integrated markets across the Roman Empire.

II. THE MODEL

An agent-based network model was designed to test the above two hypotheses. In the model 2000 traders are located at 100 sites and are connected in a social network. Four products are produced at four different 'production sites', and are subsequently distributed through commercial transactions between pairs of traders that are connected in the social network.

Setup procedures: the model is initialised by arranging the sites along a circular layout and distributing the traders among the sites following an exponential frequency distribution, which represents observed differences in settlement sizes and the consumption demands of their populations, i.e. the existence of large urban centres with high demand. Four sites which are equally spaced along the circular layout are then selected as production sites of four different products (i.e. four different tablewares).

Traders are subsequently connected to each other to form a social network in three steps which results under different variable settings in the networks shown in Fig. 1:

1. Traders on the same site are connected following a *small-world* structure, with a high clustering coefficient and a low average shortest-path-length [9]. This is a suitable representation of the communities of traders in Bang's model who are more likely to only share commercial information to community members, since a feature of 'small-world' networks is the efficient spread of information within clusters whilst few intermediary traders will allow information to flow between clusters. The procedure to create a network with a *small-world* structure is inspired by the model for the growth of social networks by [10], previously applied in an archaeological model of exchange by [11].
2. We ensure that at least one pair of traders is connected between every pair of adjacent sites, and that the network consists of one connected component (the latter is done at the very end of the setup procedures), which guarantees that each trader can, in theory, obtain an item of each product. This step results in a high average shortest-path-length between traders at different sites.
3. A variable proportion (0% - 0.1%) of all pairs of traders are connected if they are located at different sites. The proportion is determined by the variable *proportion-inter-site-links*.

Distribution procedures: in every time step traders perform the following tasks in sequence:

- traders determine their demand;
- traders discard a small proportion of their stock (due to items going out of fashion or breaking). This proportion is

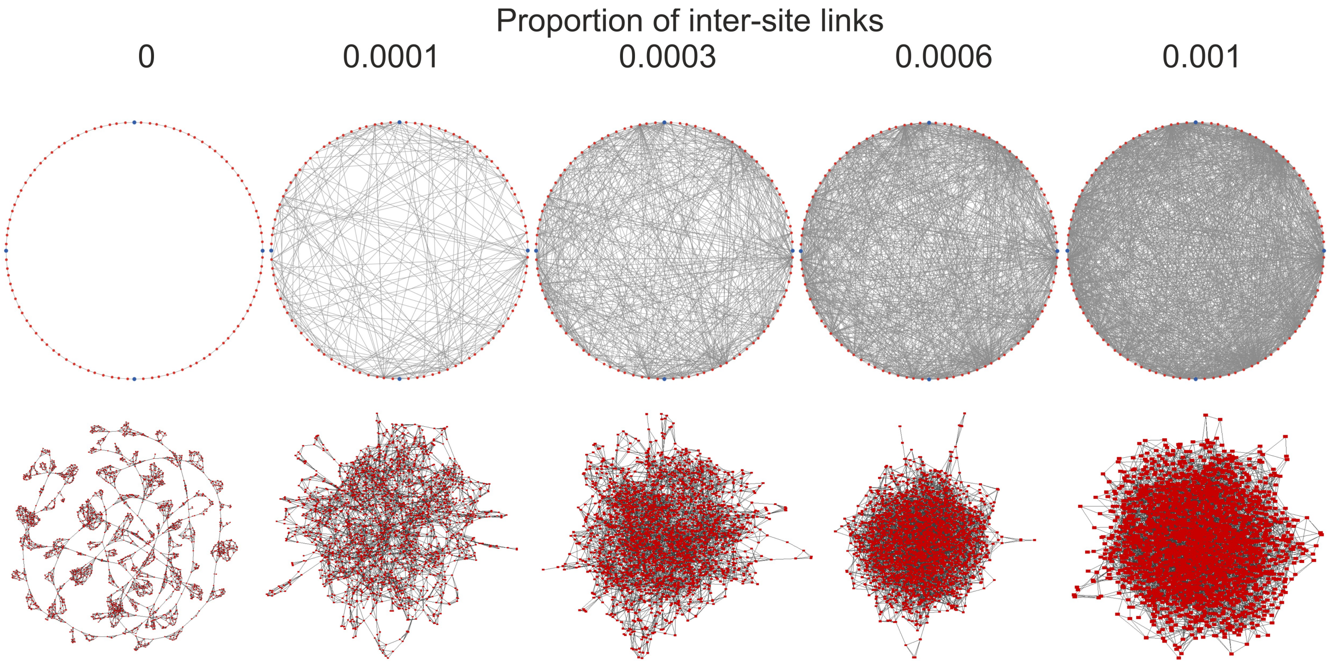

Fig 1: Example of the network structure generated in the setup procedure of the ABM for different values of the proportion-inter-site-links variable. At the top sites are layed out along a circle and traders are positioned at sites. At the botton sites are no longer included and the traders' social network is layed out using a force-directed layout algorithm (yFiles Organic layout in Cytoscape) to display its structure. Note the existence of clusters of traders on sites connected to few other clusters, a pattern which gradually disappears as traders receive more inter-site links and the sites become more integrated.

set to 14% following the model of the use-life of tableware by [12];

- traders on tableware production sites obtain new items if their current possession is below their demand;
- traders obtain commercial information from their neighbours in the network;
- traders determine what they believe to be the current price of an item using this commercial information;
- finally, all items owned by all traders in that turn are considered for trade.

Every time step each trader will only have commercial information available from a proportion (10% - 100%) of its link neighbours. This proportion is determined by the variable *local-knowledge*. The trader then calculates the average demand and average supply of this proportion of neighbours, including his own supply and demand. Using this information he calculates the price of a product as the average demand divided by the average supply (normalised so that the values fall between 0-1). When each product is considered in a transaction a seller will only agree to sell an item if the buyer's price is equal to or higher than this price.

Each item is considered for trade once per time step. An item is put in a trader's stock if he cannot make a profit or if none of his neighbours in the network requires an item (i.e. their demand equals 0). Items in stock can be redistributed in the next time step. An item is sold to a buyer if the buyer's price promises a profit or break-even for the seller. The buyer either places the obtained item in stock for redistribution if the average-demand is higher than his demand (i.e. redistribution holds the promise of a higher profit), or he sells it to a consumer. In the latter scenario the buyer's demand is decreased by 1, the item is taken out of the trade system, and it is deposited on the buyer's site.

III. Preliminary Results

A number of experiments were run to test Bang's and Temin's models by varying two variables: *proportion-inter-site-links* and *local-knowledge*. The experiments presented here were run 10 times each, with 10.000 time steps per experiment, and with parameter settings of the social network adopted from the model by [10]. When *proportion-inter-site-links* is increased traders will have a more diverse availability of information. Moreover, the average shortest-path-length will become shorter, which enables products to spread throughout the network in a lower number of steps, but the clustering coefficient will also decrease, reducing the community structure that is so prominent in Bang's model. When *local-knowledge* is increased traders will have more commercial information. High settings of either of these two variables therefore reflect Temin's hypothesis of a higher availability, diversity and reliability of information that allows for integrated markets across the Roman Empire.

The proportion-inter-site-links variable: setting this variable to 0 results in different products being deposited on a small but more or less equal number of sites, whilst high values result in strong differences between the number of sites different products are deposited on. A few examples are given: a proportion of 0% (0 random inter-site links) results in products being only deposited to the two neighbouring sites of the production centre, products have an equally wide distribution, and volumes of products deposited on sites decrease with distance away from the production centre. However, increasing this to a proportion of only 0.01% of all trader pairs (200 random inter-site links) will give rise to strong differences in the number of sites a given product is deposited on (the largest number of sites a given product is deposited on = 22 out of 100 sites; the maximum difference between product's distributions = 16 out of 100). Further increasing the proportion to 0.1% of all trader pairs (1999 random inter-site links) makes these differences even stronger (a single product is invariably distributed to up to 90 out of 100 sites; the maximum difference between products' distributions = 84 sites).

The local-knowledge variable: increasing this variable did not lead to differences in the wideness of products' distributions, but did have a strong impact on the proportion of failed and successful transactions. This is not surprising since in this model sellers aim to optimise their profits, and will not agree to lower a price which they know to be the correct price in their part of the network.

IV. Conclusion

Preliminary results suggest that the *local-knowledge* variable has a limited effect on the wideness of tableware distribution, whilst the *proportion-inter-site-links* variable has a strong effect. Limited commercial knowledge can still give rise to wide differences in distributions, but only in systems with highly integrated markets. This means that the *local-knowledge* variable is not instrumental in giving rise to the pattern of interest, whilst the *proportion-inter-site-links* variable is. Limited availability and high uncertainty of information, and a weak integration of different markets in an economy governed by supply and demand, is unlikely to give rise to large differences in the distribution patterns of tableware. Preliminary results of this model therefore reject Bang's claim that limited market integration, availability and reliability of commercial information can give rise to differences in the wideness of products' distributions. However, more experiments and a detailed comparison with the archaeological record are required to support these results and to evaluate other aspects of Bang's and Temin's interesting models. Indeed, the main contribution of this preliminary model is to illustrate how aspects of the many hypotheses surrounding the study of the Roman economy can be formalised and tested, an approach which we believe to be all too rare but valuable and necessary for Roman studies as a whole.

In future work a number of other experiments will be performed, including: a higher number of iterations per experiment proportional to the stochasticity in the model; experiments that add a transport cost for transactions between sites; experiments in which the traders are distributed uniformly and normally; and a comparison with random network structures rather than the *small-world*. Furthermore, a more detailed goodness of fit between experiments' results and the actual tableware record of the ICRATES database will be evaluated.

REFERENCES

[1] C. Abadie-Reynal, "Céramique et commerce dans le bassin Egéen du IVe au VIIe siecle". In: Kravari V, Lefort J, Morrisson C, editors. *Hommes et richesses dans l'empire byzantin Tome I, IVe-VIIe siècle*. Paris; 1989. p. 143–59.

[2] P. Bes, "A geographical and chronological study of the distribution and consumption of tablewares in the Roman East". PhD thesis. Leuven: K.U.Leuven; 2007.

[3] T. Lewit, "Dynamics of fineware production and trade: the puzzle of supra-regional exporters". *J Rom Archaeol.* 2011;24:313–32.

[4] P. Reynolds, *Trade in the Western Mediterranean, AD 400-700: the ceramic evidence. BAR international series* 604. Oxford: Archaeopress; 1995.

[5] J. K. Davies, "Linear and nonlinear flow models for ancient economies". In: Manning JG, Morris I, editors. *The ancient economy: evidence and models*. Stanford; 2005. p. 127–56.

[6] I. Morris, R. P. Saller, W. Scheidel, "Introduction". In: Scheidel W, Morris I, Saller RP, editors. *The Cambridge economic history of the Greco-Roman world*. Cambridge: Cambridge University Press; 2007. p. 1–12.

[7] P. F. Bang, *The Roman bazaar, a comparative study of trade and markets in a tributary empire*. Cambridge: Cambridge university press; 2008.

[8] P. Temin, *The Roman Market Economy*. Princeton: Princeton University Press; 2013.

[9] D. J. Watts, S. H. Strogatz, "Collective dynamics of "small-world" networks". *Nature*. 1998 Jun;393(6684):440–2.

[10] E. M. Jin, M. Girvan, M. E. Newman, "Structure of growing social networks". *Phys Rev E Stat Nonlin Soft Matter Phys*. 2001 Oct;64(4 Pt 2):046132.

[11] A. Bentley, M. Lake, S. Shennan, "Specialisation and wealth inequality in a model of a clustered economic network". *J Archaeol Sci.* 2005 Sep;32(9):1346–56.

[12] T. Peña, *Roman pottery in the archaeological record*. Cambridge: Cambridge University Press; 2007.