Analysing the Apprenticeship System in the Maghribi Traders Coalition

Christopher Frantz[1], Martin K. Purvis[1], Mariusz Nowostawski[2], and Bastin Tony Roy Savarimuthu[1]

[1] Department of Information Science, University of Otago, New Zealand
[2] Faculty of Computer Science and Media Technology, Gjøvik University College, Norway

Abstract. In this work we further the investigation into the functioning of the Maghribi Traders Coalition – a historically significant traders collective that operated along the North African coast between the 10th and 13th centuries. They acted as a closed group whose interactions were governed by informal institutions (i.e. norms). Historical accounts point to an apprenticeship system that was in force in this society. In this work we propose an agent-based model of the society with the apprenticeship mechanism and analyse the role the mechanism may have played in the removal of cheaters from their trade relationship networks.

Keywords: Maghribi Traders Coalition, Apprenticeship System, Institutions, Norms, Social Simulation, Agent-Based Modelling

1 Introduction

The area of New Institutional Economics [24], with its quest to delineate the extent to which institutions based on norms and rules, could have made the difference for the development of societies we observe today, is of increasing interest in the context of computational sociology and economics (e.g. [17]). Equilibria-based game-theoretic approaches, such as Greif [17], have shown compelling results and provide a structured formal backing that is felt to be desirable for comprehensive modelling. However, in order to explore the emergent characteristics of individual-based interactions in the context of an institutional setting, the wider scope of agent-based modelling offers an approach that does not limit the diversity of individuals, can reveal emerging social structures that supersede individuals' influences, and can allow relaxation of the rationality assumption associated with game-theoretical approaches.

In this work we review an important example from comparative historical analysis, namely the Maghribi Traders Coalition, a term coined by Greif [17] with respect to a traders collective that relied on informal enforcement of cooperation based on norms to facilitate the group's long-distance trade operations along the North African coast between the 10th and 13th centuries. Its importance for institutional research lies in its nature as an early documented example of multi-party long-distance trading, which offers us a useful source of empirical information concerning the rise of institutional mechanisms to govern networks of interacting agents.

Prior research [14,15,17] into the reasons for stable institutional equilibria that facilitated cooperation without relying on formal institutional instruments, such as contracts and commercial courts, has generally been based on the assumption of a closed group in which cultural bonds and the interlinked nature of the Maghribis' reciprocity relationships led to an environment of trust that would reassure proactive reporting of non-cooperators.[3] From the perspective of the social science domain of Institutional Analysis, the Maghribi Traders Coalition is a primary historic example of how cooperative behaviour could be achieved based on informal means, i.e. without the reliance of laws or other explicit rules, but merely based on normative principles.

In the present work we address some aspects of the coalition's activities that, though documented in historical records, have not been explored computationally to understand and relax some of the assumptions mentioned above, such as the cultural embeddedness of cooperative behaviour. In particular we are looking at the systematic grooming of new traders in an apprenticeship system in which established 'full' traders employed inexperienced young society members, often sons of fellow traders ('associates') [13], to train, and eventually mentor their progressive integration into the wider trader relationship network. The mentees eventually became established as full traders, or, if considered disloyal or ineffective, were permanently excluded from the network's trade operations.

Central contributions of this work include the conception of the Maghribi Traders Coalition in its entirety as a structure (aṣḥābunā) that emerged from interlinked elementary tightly knit groups (aṣḥābs) that still maintained some degree of openness in order to facilitate the shift of active traders over time (which is in contrast to the coalition's understanding as a unified well-defined and integrated entity). Based on this we analyse the impact of the apprenticeship concept on the collective's ability to identify and exclude non-cooperators.

In the following section (Section 2) we provide an overview of the characteristics of the Maghribi Traders Coalition that are of relevance to this work. Then, in Section 3, we carve out an agent-based model that captures the aspects of interest, namely the apprenticeship network, and explore results for given parameter sets (Section 4). We finish with a discussion of the results and their implications on the interpretation of the institution 'apprenticeship system', and finally reintegrate it with the literature context (Section 5).

2 Maghribi Traders Coalition

The 'Maghribis' (historically referred to as "Maghrebis" [9]), were named after their geographic situation with respect to the Fatimid Empire's world view centred in Fustat (nowadays: 'Old Cairo'), and largely derived from the Jewish communities of the two cities Qayrawān and al-Mahdiyya (both located in

[3] This would contrast with Southern European societies such as the Italian city states of Genoa and Venice that operated based on formal institutions.

what is nowadays Tunisia). This group had moved from Baghdad and settled in the Western part of the Mediterranean Basin, integrating into the Muslim environment by adopting a wide range of customs and norms, while maintaining their identity based on their own religion and descent as well as the shared experience of occasional discrimination. The Maghribis used this strong in-group bond to their advantage as it enabled them to assure cooperation by members based on possible social consequences of communicated misconduct (along with a strong emphasis on gossip) and family reputation within their tightly knit cultural group. As a consequence, they developed a trader network that spanned across and beyond the Northern African coast, expanding to al-Andalus (nowadays Spain) in the West and the Indian Ocean in the East. For their trade operations, traders relied on individual (personal) trader relationships that had formal rituals of initiation (face-to-face meetings) and termination (termination under witnesses).[4] Based on this institutional instrument[5] traders formed their personal network of associates, their 'aṣḥāb', upon which individual traders drew to extend their trading activities by means of delegation. This associate network created the backbone of a long-distance trader's success as it allowed one's economic presence at multiple widely distributed trading locations and to benefit from varying market prices, an aspect that would have not been achievable by personal travel. This system of associates inherently relied on a high level of trust between associates that performed trade-related services for each other (such as storing goods, selling them, etc.). To reassure trust and to monitor compliance with instructions Maghribi traders communicated extensively via letters whose delivery was often delegated to fellow traders, overlaying the trade network with a second, not necessarily symmetric information transmission network. The receipt of such letters can be considered guaranteed, both by sending those redundantly, but also by expecting the acknowledgement of their receipt in future correspondence [12]. As part of those letters, traders dealt with their business operations as well as more general gossip that included information about markets and prices as well as conduct of fellow traders.[6] Those letters are in fact the primary source of information historians such as Goitein [9], Udovitch [23], Greif [14,15,17], Ackerman-Lieberman [1] and Goldberg [10,11,13] used to reconstruct the lives of medieval Jews in the Fatimid Empire.

From the different individual aṣḥābs, i.e. the non-transitive personal relationship networks individual traders maintained, emerged the construct of the aṣḥābunā ('our colleagues'), which represented the Maghribi network in its totality. Performing agency services, i.e. selling each others' goods and returning incurred profits, occurred without direct remuneration, as payment was considered slave-like and would have questioned the courteous nature in which trade

[4] These rituals describe the suḥba relationship whose interpretation has been subject of more recent discussion (see [11,13] and [7]).

[5] A more in-depth overview of different institutional instruments available to and employed by the Maghribi traders can be found in [13] and [15].

[6] Goldberg's statistical analysis [11] allocates the fraction of gossip in letter content at around 20 percent.

was pursued [13]. Instead in suḥḅa relationships, services were 'paid' by gaining reciprocal favours against the other party. Furthermore, money was not handled on a transactional basis, but instead traders managed accounts for each other, increasing the mutual leverage should a party be observed to defect, or only be suspected of shirking profits. The practically closed nature of the group, the dependency on reciprocal favours and the delayed clearing of accounts all assured, or at least motivated, compliance throughout one's aṣḥāb.

As refined and integrated as the methods that assured compliance appear, the establishment of relationships did not simply occur at random but underlay a further filtering feature: an individual's *jāh*, his[7] 'standing' or 'reputation' [11]. Based on the perceived jāh differences (and obviously the trade interest in general, such as the traded goods) an individual could decide whether he would engage in long-lasting relationships.

To analyse the jāh's effect one can consider the jāh as a means to help traders consider whom to enter a trade relationship with, and whom to avoid. Agency services in the context of the suḥḅa were not monetarily rewarded. However, a merchant's gain (the one performing services on behalf of another) to his investor (the one that delegates the sales to a merchant) was proportional to the jāh difference of both parties, with one of higher jāh being able to demand more services such as multiple different operations or higher volume sales [11]. On the other hand, one could consider dealings with traders of lesser jāh to be unattractive, because of the impact their lower standing could have on one's own jāh. Even more importantly, considering that a trader with lower jāh faced lesser cost (i.e. loss in absolute reputation) when detected as a cheater, his incentives to engage in cheating could be considered higher. We thus believe that traders had an interest in concentrating their relationships on the traders that had not necessarily the same but similar jāh levels.[8] We make this assumption a central concern when modelling the aṣḥābunā network in an agent-based manner.

The second aspect central to this contribution is to investigate the extent to which the Maghribi apprenticeship system could have made a difference in removing potential cheaters from the trader network. Long-distance trading was considered to be a profession that required a carefully developed skill set and a mentor that would be an initial business partner for newcomers striving to become 'full traders'. Given the common sociocultural background, traders often inherited the profession from their parents, who sent their child to a fellow associate who was then considered responsible for their livelihood in exchange for unremunerated trade-related services by those young apprentices [13]. Over time,

[7] It is safe to use the male form. The trader community was of patriarchal nature, with men performing trade operations, while their (potentially multiple) wives managed their different homesteads and warehouses. The geographic spread of marriages in principle allowed the development of extensive trade operations across the Mediterranean. [1,13]

[8] Note that the proposition of partner choice based on status similarity is compatible with the principles proposed by Podolny [20] in the context of organisational studies. He suggests that in the face of market uncertainty organisations choose partners they had *previous experience* with and which are of *similar status*.

those apprentices' activities could expand beyond the dealings with their mentors and establish their own relationships. However, given their inferior standing, the apprentices' operations carried strict monitoring, not only to assure their loyalty (which could ultimately affect their own family's reputation) but also to assess their acquired ability before opening access to other trade connections. Those apprenticeships were by no means short-lasting as they could take more than a decade and bore the option for failure [13]. This refined mechanism existed in stark contrast to Southern European traders that (a) operated in one-off transactions, (b) applied strict role stratification into investors and merchants, and (c) potentially employed opportunists to manage one-off business dealings that were formally regulated based on contracts but also private-order enforcement [17].

This background presented here provides the grounds for our basic model for representing the development of the aṣḥābunā as an emergent property of 1:1 agent relationships established based on a conceptualisation of reputation grounded on jāh levels. Using this base model, we can examine the extent to which the Maghribi apprenticeship system could have restrained cheating levels. Both those aspects did not find consideration in previous research. Exploring those, we can relax the high-level assumption that cooperation based on informal means was intrinsic to the collectivistic culture. We do not challenge this assumption as such, but wish to offer a more refined analysis of previously neglected factors that may have contributed to the cooperative outcome.

3 Simulation Model

At this stage, we want to propose an agent-based model that incorporates selected aspects discussed above. Our model aims at increasing the level of understanding of the Maghribi trader collective, and does not aim at accurate reproduction, given that this is challenged by a lack of sufficiently detailed historical data. More importantly, we think it is important to develop an understanding of used institutional mechanisms, such as the jāh as a regulative artefact for the number of connections an agent would engage in and how this would affect the performance of the overall society. We thus use a generative model to represent the aṣḥābunā, as opposed to using global thresholds (e.g. for the setup and size of trader networks) to drive controlled emergence.

In the following we describe an agent's proactive execution cycle (Algorithm 1) as well as his reactions (Algorithm 2) to other agents' requests. During each execution round, each agent acts from the perspective of the merchant, i.e. the one seeking employment by an investor (who delegates its business dealings to merchants). It randomly picks another agent to offer oneself as a potential merchant. If the agent has not been previously employed it will need to offer its services as an apprentice looking for initial employment. If the apprenticeship employment request is accepted, the agent commits to its employer for a randomly picked number of rounds between $apprenticeshipDuration_{min}$ and $apprenticeshipDuration_{max}$. During this period the apprentice agent does not seek further employment relationships and only deals with 'its' mentoring investor. Alternatively, if the merchant had been previously employed, it checks whether the randomly picked agent's jāh lies within an acceptable range of its own jāh, the lower threshold being jāh - jāh * *lowerJahDifference* and the upper threshold being jāh + jāh * *upperJahDifference*, with *lowerJahDifference* and *upperJahDifference* being values between 0.0 and 1.0.

Following this, the agent trades with a fixed fraction (*tradeQ*) of agents it enjoys employment relationships with. Every successful trade results in an absolute jāh increase of *jahIncrement* for both participating traders. The announcement of cheaters likewise leads to a jāh increase for the announcing agent.

Beyond trading, agents involve themselves in the observation of other agents. To do so agents randomly pick a fraction of all agents (*observationQ*). The random choice of observation targets may appear unrealistic at first. However, note that agents did not necessarily need to maintain trade relationships with observed agents, but potentially operated in the same market places and thus be potential targets for the observation of conduct. Observers would inform their aṣḥāb not only about known but likewise about unknown peers as the individual aṣḥābs were a non-transitive private matter; observers could not make assumptions about their partners' other trade relationships, an uncertainty aspect that, we believe, motivated compliance in the first place. Likewise, the observer may not be able to observe its own trading-partner agents' conduct. However, for apprenticeship relationships we consider more frequent closed-loop interactions, such as small-scale deals or services, that would allow the determination of his conduct in any case.

To represent the proactive reporting norm of announcing trading-partner cheating, observing agents notify their entire network of trade relationships (their respective aṣḥābs) about any observation. We believe that this modelling intuition is realistic as traders used different means for letter exchange (such as land-based couriers in contrast to sea-based sending of goods), sent them redundantly, mutually acknowledged their receipt, and often read them in public to demonstrate compliance. [12]

Agents age and die with a probability of $p_{deathBelowExpectedAge}$ if $age \leq expectedAge$ at the end of each round. If older, they die with a probability of $p_{deathBeyondExpectedAge}$. This mechanism allows us to incorporate the unexpected death of agents. In order to keep the number of agents stable while modelling the change of traders over time, for each dying trader a new agent is introduced, who will need to pass the apprenticeship phase prior to full employment.

In our algorithms, an individual agent's jāh levels continuously increase as a reflection of 'standing' and experience in a society. The ageing mechanism provides a natural boundary to jāh levels. Also, when cheating, counter-intuitively, the jāh levels of the cheater are not adjusted (e.g. reduced). A more refined representation would use the notion of endorsements [2][9] in which the individual's jāh would be exogenous to the individual and derived from its social environment, i.e. what others think about the individual. However, we opted for a more primitive endogenous jāh model, primarily to isolate the effect of exclusion from

[9] This suggestion was raised by one of the anonymous reviewers.

employment based on announcement of cheaters from the effect of dropping jāh levels of cheaters. For this iteration the primary focus lies on cheater propagation as the institutional cornerstone, as opposed to preventing re-employment based on increasing jāh differences.

Beyond its own execution cycle an agent reacts to incoming requests, which include requests for engagement in trading relationships (employment) and receiving goods in order to realise the actual trade. As a final aspect agents react to incoming cheater notifications by remembering them as well as sharing cheater information with all agents they have trade relationships with (except the original sender). This models the cascading effect of cheater notifications in the Maghribi society.

Algorithm 1 and Algorithm 2 show the pseudocode representation of agents' execution cycle and reactions.

Algorithm 1: Agent Execution Cycle

```
Agent picks random other agent;
if unemployed and not previously employed then
    Offer oneself as apprentice;
    if accepted then
        Commit to apprenticeship for random duration between
            apprenticeshipDuration_min and apprenticeshipDuration_max rounds;
else
    if randomly picked agent is within acceptable range of own jāh then
        Offer oneself as employee;
end
Trade with tradeQ of employed agents;
Increase own jāh by jahIncrement for each trade;
Randomly choose observationQ number of agents from all agents (incl. eventual apprentice);
foreach agent in observed agents do
    Check if agent has cheated;
    if agent has cheated then
        Announce to other agents in own aṣḥāb;
        Increase own jāh by jahIncrement;
end
Increment age each round;
if age ≤ expectedAge then
    Check for death with probability p_deathBelowExpectedAge;
else
    Check for death with probability p_deathBeyondExpectedAge;
end
```

We parametrize agents with an initial unified jāh level and define whether an agent cheats, and if so, assign a fixed cheating probability ($p_{cheating}$). Table 1 summarizes the base parameter set used in our simulations, the intuitions of which we will discuss in more depth.

In the simulation we model 'rounds' in a rough equivalence to years, with one year being represented by 10 simulation rounds. As soon as traders enter the simulation they participate in trade, either entering an apprenticeship or (in the control case without the apprenticeship system) by directly engaging in trade relationships.[10] An expected trader lifespan is around 40 years, an assumption we build based on documented evidence of a long-lasting suḥba relationship between Nahray Ibn Nissīm and one of his associates [13]. Instead of removing

[10] We ignore any lifespan before or following active tradership.

Algorithm 2: Agent Reactions

```
if receiving employment request then
    if requester seeks initial employment and receiver has no other apprentice at current
    stage then
        Employ irrespective of jāh difference;
    else
        if requester within jāh range and not known as cheater then
            Employ requester;
        else
            Reject request;
        end
    end
if receiving trade request then
    if cheater then
        Decide whether to cheat or to trade fair;
    Trade;
    Increase own jāh by jahIncrement;
if receiving cheater notification by others then
    Share with own aṣḥāb (excluding agent who sent cheater announcement);
    Increase own jāh by jahIncrement;
```

Table 1. Simulation Parameters

Parameter	Value	Variation in Section
Number of agents	400	Section 4.4
Fraction of cheaters	0.4	
$p_{cheating}$	0.5	Section 4.2
expectedAge	400 rounds	
$apprenticeshipDuration_{min}$	50 rounds	
$apprenticeshipDuration_{max}$	100 rounds	
lowerJahDifference	0.2	Sections 4.1 - 4.4
upperJahDifference	1	Section 4.1
tradeQ	0.5	Section 4.4
jahIncrement	1	
observationQ	0.025	Section 4.3, 4.4
$p_{deathBelowExpectedAge}$	0.0001	
$p_{deathBeyondExpectedAge}$	0.001	

a trader at the expected end of his life, we introduce the more realistic notion of changing death probabilities ($p_{deathBelowExpectedAge}$ and $p_{deathBeyondExpectedAge}$) to smoothen the generational transition without total loss of cheater knowledge. As indicated in Section 2, apprenticeships last for up to a decade, with the minimal value being five years, the equivalence of which is represented in the round values for $apprenticeshipDuration_{min}$ and $apprenticeshipDuration_{max}$. We further assume six trade interactions with the apprentice during each year of apprenticeship. We will vary this value for the later set of simulations.

Initially, the number of agents is parametrised at 400. Historical evidence offers widely varying information, examples ranging from 330 [16], up to 550 [18]. However, note that those values are derived from subsets of the actual Geniza corpus, with future research likely to offer more realistic (possibly higher) values. In this light, the chosen value represents a rough middle ground between documented values, while being computationally tractable.[11] This aspect showcases an example of the problems when building models based on anecdotal

[11] A representative set of simulation runs for one parameter sweep takes about three weeks on current hardware (Intel i7 8-core with 12 GB RAM).

accounts, which we can balance with the flexibility of agent-based modelling. Instead of arguing precise values the central evaluation implication is to perform experimental parameter variation to analyse the impact on simulation results.

Most other parameter values (the ones related to cheating, jāh differences as well as trading and observation quotas) do not rely on specific evidence, which makes their experimental variation important, an aspect that is explored in the following section.

4 Results

To recall, our central question is whether the apprenticeship system employed by Maghribis could have had a filtering function by improving the society's resilience to cheaters. To measure this effect, we use *the number of cheating traders who maintain relationships with non-cheaters* as an indicator for the institution's performance. We operationalise this as the mean number of cheaters that maintain relationships with non-cheaters across all simulation rounds.[12] For this evaluation one simulation run consists of 20,000 rounds.

To evaluate the model with respect to the measure of interest we performed parameter sweeping based on the initial parameter set by systematically varying two parameters each for a given simulation run. Given the large amount of possible combinations, we focused on parameters of central interest, namely the ones related to the traders' jāh, and used those to guide further analysis.

4.1 Upper and Lower Jāh Differences

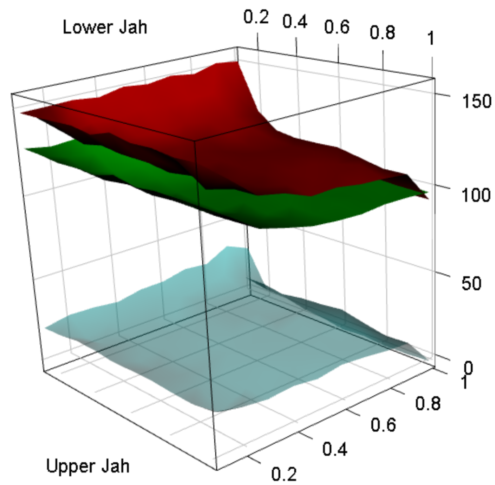
Given the importance of jāh differences to constrain partner choice, we initially concentrated on the interaction between permissible *lowerJahDifference* and *upperJahDifference* for trade partner choice – to recall, the maximum acceptable jāh difference for traders of lower status to engage with ones of higher status (*upperJahDifference*), and the maximum acceptable jāh difference for traders of higher status to engage with ones of lower status (*lowerJahDifference*).

We instantiated simulations covering the parameter range from 0.1 (implying a permissive relative difference of 10 percent) to 1 (implying any difference in jāh) in steps of 0.1. The results are shown in the form of a surface plot (see Figure 1). Simulation runs with enabled apprenticeship system are represented in green colour, the control variant without apprenticeship system is plotted in red colour. To provide a better overview of the relative differences in results of both configurations and to isolate those from trends, a further surface (in light blue colour) plots the inverted absolute value difference (i.e. reduction of cheaters by the apprenticeship system). Interactive versions of this and all further result charts, including variants that show the relative difference for each data point, are provided in [6].

[12] We use 'round' to describe a simulation step, as opposed to 'run' that describes a complete simulation execution over the parametrised number of rounds.

Looking at the overall effect of introducing the apprenticeship model, for nearly the entire parameter space (with the exception of trade-engagement acceptance for all jāh levels, i.e. lower jāh = 1.0), we can observe a significant drop in cheating levels. This is driven by the comprehensive observation of an apprentice by his mentor and the proactive exclusion from trade and notification of the mentor's aṣḥāb, should the mentee decide to cheat.

Fig. 1. Number of cheaters with relationship to non-cheater for varied upper and lower jāh differences (red surface: without apprenticeships; green surface: with apprenticeship system; blue surface: inverted absolute cheater reduction by apprenticeship)



The model displays very high numbers of cheaters with relationships to non-cheaters, which is based on our pessimistic parameter settings. However, this aspect is secondary, given that our interest lies in the understanding of the institution, as opposed to an accurate representation of historical reality.

For the specific jāh level-related parameter combinations we can observe the correlation of lower parameter values with larger numbers of socially embedded cheaters. The reason lies in the nature of jāh levels to control the establishment of new relationships. Limiting the access for newcomers and constraining their willingness to enter relationships with higher-status traders segregates the traders into groups of relatively homogeneous jāh levels. Overall, the apprenticeship system nearly consistently fares better at limiting cheater embeddedness with a relatively constant reduction of around 15 percent for lower jāh levels below 1.0. (max. reduction: 0.216, min: -0.056, mean: 0.127, σ: 0.054). However, for high lower jāh levels we can observe a performance breakdown of the apprenticeship system (it produces around 5.6 percent *more* economically embedded cheaters).

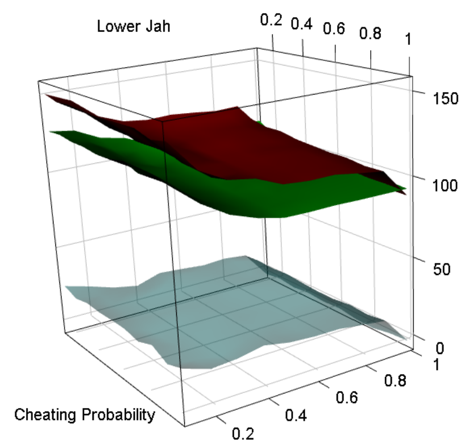
The reason for this lies in the interaction frequency. Immediate admission to full tradership without an initial apprenticeship phase results in a higher trade frequency and observation for those newcomers, which are then discovered more rapidly, which, in consequence, leads to a lower mean. In this case the apprenticeship-free system achieves around 5 percent fewer connections. This is an important finding, inasmuch as it reveals under which conditions the apprenticeship system achieves better results despite fewer interactions with cheaters (which, as apprentices, exclusively deal with their mentors).

Varying higher jāh differences, in contrast, hardly showed any effect on the relative performance (shown as blue surface). For further simulations, we thus fix it to the value of 1.0. Instead we consider the lower jāh difference as pivotal for the institution's performance as it determines how receptive established traders are towards newcomers, which affects the filtering effect of the apprenticeship system. The further exploration thus concentrates on the effect of *lowerJahDifference* in conjunction with the cheating probability of traders ($p_{cheating}$), and beyond this, the impact of the observation quota (*observationQ*).

4.2 Cheating Probability and Jāh Difference

A consequent choice is the analysis of the varying cheating probability, given its likeliness to affect detection of cheating. Figure 2 shows results for the parameter variation of $p_{cheating}$ in combination with *lowerJahDifference*. Both variables have been systematically varied across the range from 0.1 to 1.0 (step size: 0.1).

Fig. 2. Number of cheaters with relationship to non-cheater for different cheating probabilities and jāh differences

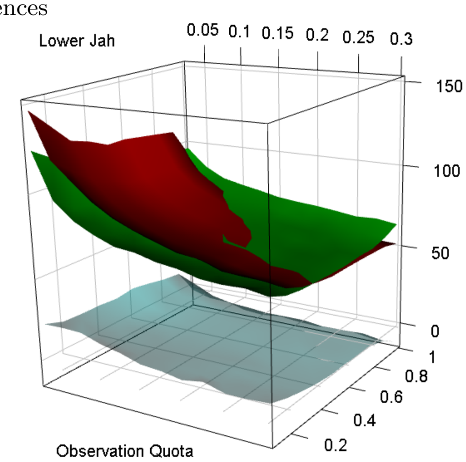


In absolute numbers, we can observe that the cheating probability has an impact on the number of potential cheaters with relationships to non-cheaters, which decreases with increasing cheating probability because of the earlier detection of cheaters (max. reduction: 0.186, min.: -0.082, mean: 0.119, σ: 0.062). However, the cheating probability has little impact on the performance of the apprenticeship system (in comparison to the apprenticeship-free variant). Again, the impact of lower jāh values is of greater significance as immediate admission of newcomers overrules the apprenticeship system's effect.

4.3 Observation Quota and Jāh Difference

Another interesting question is how much of a difference could the extent of observation, or monitoring, have made in maintaining a compliant trader society. To examine this, we fix the cheating probability at 0.5 and look at the impact of different observation quotas. For this purpose, we analyse the interaction between the lower jāh difference and the fraction of all traders an individual monitors (*observationQ*). We concentrate on a range from 0.025 to 0.3 (step size 0.025) for pragmatic reasons, as the assumption that agents could observe as much as 0.3 of all agents seems unrealistic. The results are shown in Figure 3. As is intuitively retraceable, an increasing observation quota leads to an increasing exclusion of cheaters, reaching the point of reducing cheaters with relationships to non-cheaters (in the apprenticeship variant) to around 60 agents for an observation quota of 0.3 (max. reduction: 0.203, min.: -0.257, mean: 0.023, σ: 0.097). As with the previous case, a more liberal attitude towards newcomers (i.e. greater acceptance of lower jāh values) leads to improved identification of cheaters. However, closer inspection of the simulation outcome for both configurations (i.e. with apprenticeship model and without an initial apprenticeship employment) reveals insights about the apprenticeship system's actual purpose as part of the informal institution employed by the Maghribis. For higher values of jāh difference and observation quota, one can observe a better performance for the model that operates *without* apprenticeship relationships (more than 20 percent fewer connections for an observation quota of 0.3 and lower jāh difference of 1.0 as compared to the apprenticeship-based model). Note the lower number of potential cheaters with relationships to non-cheaters shown by the red surface (no apprentices) in Figure 3, which dominates the apprenticeship-based model for lower jāh values $\geq$ 0.4 when paired with higher observation quota levels (especially for values ≥ 0.2); in such cases the apprenticeship model permits up to 26 percent more cheater connections. The reason for this lies in the greater probability of both attracting cheaters as employees (greater permissible jāh difference), and also a greater likelihood of identifying cheaters enabled by the greater observation coverage. At first one could conclude a limited or different purpose of an apprenticeship system under those circumstances. However, one should take into account the differentiated characteristic of the informal institution when considering higher acceptance of jāh differences and observation quota. For higher values, the function of identifying cheaters (and thus the cost in terms of lost profit associated with it) is born by the collective of all traders. Thus all traders have to expect potential cheating for trade encounters, which, if addressed, leads to fast identification of newly introduced cheaters. In contrast, relying on the apprenticeship system concentrates the uncertainty associated with introducing new traders into the system exclusively with the apprentices' mentors, who bear the full risk and cost of cheating (since all trade with newcomers concentrates on their mentors) but who may also benefit from unremunerated cheap services should the apprentice turn out to act reliably truthful. The apprenticeship system thus concentrated the risk of introducing cheaters and converted it into a potential investment on the part of established traders. In an environment with an explicit use of the apprenticeship system, the risk of cheating, which includes both the

Fig. 3. Number of cheaters with relationship to non-cheater for different observation quotas and jāh differences



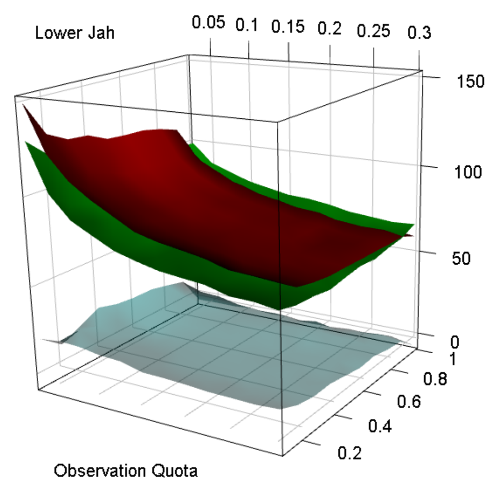
loss of profits associated with the individual transaction and the loss of trust in the institution, could be minimized for the collective, as cheaters could often be identified before becoming fully established members of the trader community. Beyond this, particularly for lower, and probably more realistic levels of observation quota and acceptance of lower jāh values, the apprenticeship system bears a clear benefit (more than 20 percent increase in undesirable connections for the apprenticeship-free system for observation quota of 0.05 and lower jāh difference of 0.1) in reducing cheater relationships, particularly if traders have limited interest in dealing with agents of lesser status (jāh differences < 0.4).

4.4 Reducing Interaction Frequency

To extend the argument that the apprenticeship system bears a clear benefit for scenarios in which monitoring opportunities are limited or costly, we explore the effect of reducing the interaction frequency.

We do so by reducing the trade frequency, which is indirectly represented in the trade quota (*tradeQ*), the fraction of all partners from his aṣḥāb a trader trades with during each round. Initially we set a high value of 0.5, which we reduced to 0.1. For the apprenticeships we reduced the assumed trade interactions from initial 6 per apprenticeship year to 1. In both cases, reducing the number of interactions likewise reduces the chance to observe and detect cheaters. Figure 4 shows the experimental results. Those show a significantly higher performance of the apprenticeship system, in particular for higher parameter settings[13] (max: 0.192, min: -0.121, mean: 0.079, σ: 0.069), which supports its purposefulness for cooperation scenarios in which observation opportunities are limited by fewer interactions.

Fig. 4. Number of cheaters with relationship to non-cheater for different observation quotas and jāh differences for low trade frequencies



To address a last concern, the model's robustness with respect to population variation, we tested the previous scenario against a variant with 200 agents. The results reveal a difference between the respective performance means of around 0.006.[14] This offers the suggestion that the trade network structure had a low sensitivity to changing trader numbers and strong scalability characteristics. However, this aspect demand further investigation in future research.

[13] This includes the borderline case of *lowerJahDifference* = 1.0, which nevertheless still performs worse compared to the apprenticeship-free variant.

[14] Max. difference: ∼0.042; min. diff.: ∼0.025; σ: 0.0067. See [6] for the resulting graphs.

5 Discussion

This work investigates an existing scenario from the area of comparative economics, the Maghribi Traders Coalition, and analyses the apprenticeship network Maghribi traders employed to establish a professional trader community by informal means.

The presented model analyses the function of a systematic apprenticeship mechanism on the functioning of the 'rather closed' trader society (highlighted by Greif [17]) but relaxes some of its more rigid assumptions and explores the potential function of the apprenticeship system, which has been described in more depth by historians such as Goldberg [13]. Exploring the apprenticeship system not only extends the detail of analysis, but more so, it can possibly be considered a necessary element to sustain trust in an institution that facilitated cooperation by informal means and lasted over multiple trader generations.[15] The closed system assumption used in previous approaches cannot capture this generational aspect.

Beyond the quantitative aspect (minimisation of cheaters with relationships to non-cheaters) the interpretation of the results offers us further insight into the apprenticeship system's institutional function of reducing uncertainty [19]. For the Maghribis, the apprenticeship system converted the task of identifying cheaters into a potentially profitable endeavour by diverting the uncertainty towards self-selected more risk-affine traders. Those could expect a benefit if they employed honest apprentices to further their trade operations for a considerable time. However, identifying a cheating newcomer comes at a cost for the risk-taking mentor, who would share this information gain with his community to maintain his reputation and thus save the collective from identifying the observed mentee as a cheater, but would bear the consequences incurred by his cheating apprentice. By effectively 'privatising' the uncertainty associated with cheater detection, risk-averse traders, in contrast, could rely on a comparatively cheater-free cooperative trader network. Furthermore, besides the increasing benefit of apprenticeship systems for 'more closed' societies, limiting monitoring opportunities (here represented by reduced trade interactions) contributed to (in our case consistently) better performance of the apprenticeship system, compared to the apprenticeship-free variant.

These results support the idea that, whether intentional or not, the Maghribian apprenticeship system could have been an important part of the overall informal institutional setup (beyond its obvious function to train newcomers) that allowed the Maghribis to operate compliantly over multiple centuries.

The model proposed here is by no means a complete or accurate model of the trader scenario, but extracts relevant aspects and concentrates on the extensive exploration of selected model properties. The approach taken is a prototypical example for the KIDS modelling approach [5], in which anecdotal or weak evidence is permissible to support a poor information base to reflect aspects

[15] The Geniza letters considered by Goldberg [13] cover the period from 990 until the early 13th century.

that would otherwise not find consideration at all. However, this increases the demand for a systematic exploration of the model's parameter space (jāh differences, etc.) and testing of parameter settings which are based on uncertain information (here: number of agents).

Beyond the concrete historical case, the principle of apprenticeship relationships is commonly adopted in the area of skilled labour but likewise in knowledge-based occupations, such as scientific research. Following the analogy of the Maghribian apprenticeship, emerging researchers are continuously tested for their compliance to scientific standards (e.g. plagiarism as cheating), but also the quality of their work (e.g. significance), while giving them the opportunity to develop their own standing. The risk of failure lies in part with the grooming institution and the supervisor, while promising the benefit of furthering one's research and consequently academic jāh.

Other characteristics of the historical trader society are also compatible with contemporary findings from the area of social control. This includes the central role of norm communication in conjunction with material sanctioning as explored by Andrighetto et al. [3]. Giardini and Conte [8] provide an overview of the related research field and offer a set of examples from the area of ethnography that showcase gossip as a means of social control.

As alluded to earlier, a potential refinement is a more realistic development of reputation, as done in Alam et al.'s work [2]. They apply the concept of endorsements as an exogenous determinant of reputation, which we avoided in this set of experiments as it would have challenged the differentiation of cheater exclusion based on notification and loss of jāh. However, including a refined representation of reputation, our approach would be more aligned with a systematic construction of network relationships by shifting from an initial random selection (as done here) to a trust-based partner selection (see e.g. [4,22]).

A further limitation concerns the assumption of perfect memory; in this model agents do not have a notion of 'forgetfulness' and retain all cheater information until their death.[16] Constraining the number of memory entries (as done in [7]) would reflect individuals' bounded rationality [21].[17]

Gaps in historical records restrict the establishment of a fully grounded model of the Maghribis' apprenticeship system as described by Goldberg [13]. However, we believe the model proposed here can foster the understanding of the function of the specific institution 'apprenticeship system' in the Maghribi Traders Coalition, a phenomenon not addressed elsewhere as far as we are aware.

References

1. P. I. Ackerman-Lieberman. *The Business of Identity.* Stanford University Press, Stanford (CA), 2014.
2. S. J. Alam, A. Geller, R. Meyer, and B. Werth. Modelling contextualized reasoning in complex societies with "endorsements". *Journal of Artificial Societies and Social Simulation*, 13(4):6, 2010.

[16] Note: This effectively represents intergenerational 'forgetfulness' on the social level.
[17] In this context we wish to thank the anonymous reviewers for their contribution.

3. G. Andrighetto, J. Brandts, R. Conte, J. Sabater-Mir, H. Solaz, and D. Villatoro. Punish and voice: Punishment enhances cooperation when combined with norm-signalling. *PLOS ONE*, June 2013.
4. G. Bravo, F. Squazzoni, and R. Boero. Trust and Partner Selection in Social Networks: An Experimentally Grounded Model. *Social Networks*, 34(4):481–492, 2012.
5. B. Edmonds and S. Moss. From KISS to KIDS: an 'anti-simplistic' modelling approach. *Lecture Notes in Artificial Intelligence*, 34(15):130–144, 2005.
6. C. Frantz. Interactive Versions of the Apprenticeship Model Result Plots. `http://papers.christopherfrantz.org`, 2014. Accessed on: 6th July 2014.
7. C. Frantz, M. K. Purvis, and M. Nowostawski. Agent-Based Modeling of Information Transmission in Early Historic Trading. *Social Science Computer Review*, 32(3):393–416, June 2014.
8. F. Giardini and R. Conte. Gossip for social control in natural and artificial societies. *Simulation*, 88(1):18–32, Jan. 2012.
9. S. D. Goitein. *A Mediterranean Society: The Jewish Communities of the Arab World as Portrayed in the Documents of the Cairo Geniza.* University of California Press, Berkeley (CA), 1967–2000. (6 Volumes).
10. J. L. Goldberg. On reading Goitein's A Mediterranean Society: a view from economic history. *Mediterranean Historical Review*, 26(2):171–186, 2011.
11. J. L. Goldberg. Choosing and Enforcing Business Relationships in the Eleventh Century Mediterranean: Reassessing the 'Maghribī Traders'. *Past & Present*, 216(1):3–40, August 2012.
12. J. L. Goldberg. The use and abuse of commercial letters from the Cairo Geniza. *Journal of Medieval History*, 38(2):127–154, 2012.
13. J. L. Goldberg. *Trade and Institutions in the Medieval Mediterranean: The Geniza Merchants and their Business World.* Cambridge University Press, 2012.
14. A. Greif. Reputation and Coalitions in Medieval Trade: Evidence on the Maghribi Traders. *The Journal of Economic History*, 49(4):857–882, 1989.
15. A. Greif. Contract Enforceability and Economic Institution in Early Trade: The Maghribi Traders' Coalition. *The American Economic Review*, 83(3):525–548, June 1993.
16. A. Greif. Cultural Beliefs and the Organization of Society: A historical and theoretical reflection on Collectivist and Individualist Societies. *The Journal of Political Economy*, 102(5):912–950, October 1994.
17. A. Greif. *Institutions and the Path to the Modern Economy.* Cambridge University Press, New York, 2006.
18. A. Greif. The Maghribi traders: a reappraisal? *The Economic History Review*, 65(2):445–469, May 2012.
19. D. C. North. Institutions. *Journal of Economic Perspectives*, 5(1):97–112, 1991.
20. J. M. Podolny. Market Uncertainty and the Social Character of Economic Exchange. *Administrative Science Quarterly*, 39(3), September 1994.
21. H. A. Simon. A Behavioral Model of Rational Choice. *The Quarterly Journal of Economics*, 69:99–118, 1955.
22. B. Skyrms and R. Pemantle. A Dynamic Model of Social Network Formation. *Proceedings of the National Academy of Sciences of the United States of America*, 97(16):9340–9346, August 2000.
23. A. Udovitch. At the origin of the Western commanda: Muslim, Israel, Byzantium. *Speculum*, 37:198–207, 1962.
24. O. Williamson. *The Economic Institutions of Capitalism.* Free Press, New York, 1975.