Finding changepoints in medieval European and Middle Eastern trade networks

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ABSTRACT

Trade networks reflect societal vitality and are thus essential tools to understand historical dynamics, including epochal events. In this paper we will be looking at the Mediterranean trade network reflected in the FLAME dataset, coin hoards found in the region which establish a link between the place the coins were minted and where they were found. We will use changepoint analysis to identify shift points in this trade network, mapping it to actual events (or conjunction of events), and then analyze the existing network prior and after the events. The trade network has regions (identified as current countries) as nodes, and the number of coins of one place found in another as edges. Changepoint analysis for the time series of the number of links in the network finds a statistically significant changepoint with average links before and after the changepoint plotted. Multiple sequence changepoint, including entropy and high-level network measures, will be also presented, and possible causes for these shifts, looking at historical events as well as changes in edge and node (region) betweenness, will be discussed.

0.1 Introduction

When researching history, there are few certainties and usually many questions. Even in basic matters, such as when an *age* starts or ends, there are as many results as methodologies to establish them; case in point the boundary between Antiquity and the Middle Ages in Europe and the Middle East. It is generally accepted that Antiquity finished when the last Western Roman emperor was ousted, that is, by the fall of the Roman Empire in 476 CE [6]. However, in his book "Mohammed and Charlemagne", Henri Pirenne [11] proposed a different, bold thesis: As Brown says [3]:

> ... It was only with the Arab conquests of the eastern and southern Mediterranean in the seventh century A.D. that this Mediterranean-wide economy was disrupted. Islam marks a breach in the continuum of ancient civilization incomparably deeper than that of the Germanic Invasions.

This thesis points to a different historiographical methodology, one that would be later called the "Annales" school [5] after the French journal that included most of the historians that pushed it forward; a methodology that considers not only sources that write about the fact that one "Big Man" succeeds another, and that signal big changes when a "Very Big Man" is substituted by many small ones, or very different ones, but also all kinds

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of other, non-written, sources, including all that is known about the *material culture* (all kind of artifacts found in archaeological digs) as well as any kind of geographical, environmental and climatic data that is known about a certain period.
Who is right? In general, history still follows Gibbon, but very recently Pirenne's hypothesis has been put to test in a paper [2] that looks at the rate of economic growth of different societies using data on found coin hoards, that is, data on literally treasure chests stashed all over the world. These treasure chests contains the aforementioned coins, and by establishing the origin of those coins, there can be certainty that there is some kind of trade links between origin and destination.
The dataset used in that paper is not available for the time being; however, part of the dataset, the so-called FLAMES database, which spans a smaller period, is available online at `https://coinage.princeton.edu/flame-database-last-version`. This is the database that we will use in this paper.
And we will also use a different methodology. We would need to find a point in time that implies a watershed change, an epochal shift with lasting effects that can effectively be set as the boundary, if not between two different ages, at least between two very different periods. The statistical tools that are used for that purpose are called changepoint analysis methods; while initially applied in the domain of physics to detect abrupt climate variations [1] it was soon adopted by history, for instance to analyze deaths in battle [4], the age of the elected Venetian doges [9] or how the time series of marriages in the same city reflects the fate of the Venetian Republic at large [10].
We will organize the rest of the paper as follows. First, we will present the methodology used to process the data and obtain the time series needed for changepoint analysis in Section 0.2. Then we will try to find the changepoint(s) present in the data in Section 0.3. By analyzing different data sources, we will try to identify different factors that might lead to that change point. Finally, we will present our conclusions and future lines of work in Section 0.4.

0.2 Methodology

As indicated, the dataset used is the FLAMES dataset in its September 2024 version. The dataset contains what are called *coin groups*, groups of coins minted in the same place and period, several of which form a *coin hoard*. Most mints and hoards are geolocated. Coin groups are identified also by the minting period.
From this database we have extracted four fields:

- Hoard, a unique identifier for the hoard; using an inverse geocoding service we have converted this also to a current territory when possible.

- Mint, every one of which has an unique identifier; when possible, this has been mapped to its current territory as above.

- Year. In most cases what it includes is a minting period. This has been converted to the year in the midpoint; in the case it was identified by a century we have used the year 50 in the century. Those pairs that have no identifiable year have been eliminated.

- Number of coins, the number of coins in the hoard minted in that specific place.

The dataset, which includes 84344 pairs, is publicly available at the GitHub repository `https://jj.github.io/medieval-trade` under a free license, together with the scripts used to create it.

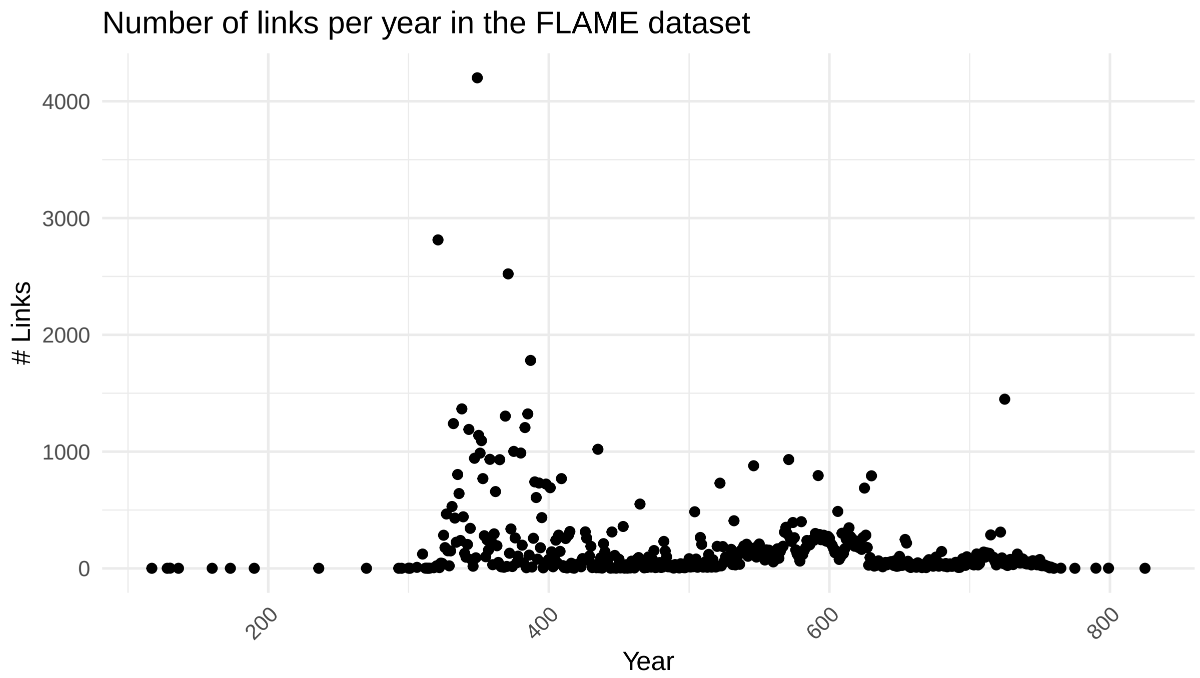

FIGURE 1. Initial datasets with links per year

From this initial dataset, a new dataset with the number of links per year has been created, by simply adding up the number of pairs of places that appear for every year. The resulting dataset is shown in Figure 1. As it can be seen, it spans from the 2nd century to the 9th century, although the data for both tips of the range is very sparse. This is the initial dataset we will explore right next.

0.3 Results

Some additional massaging is applied in order to get the changepoint analysis to work properly. Two additional processing steps have been performed:

- Years with missing values have been set to 0, so that we have a data point for every year, and years without links count as such.
- The dataset has been filtered to only include years between 300 and 775, as the data before and after that is very sparse.

We have applied the cpt.meanvar method in the changepoint package [8] to the time series, which gives a statistically significant change point. The reason why we have used a method that analyzes a changepoint in *mean* and *variance* is because the data seems to change in magnitude as well as variability, so we thought this one would find the change point with the highest precision. The result, of this algorithm is shown in Figure 2, which plots the average number of links before and after the change point in red. The found changepoint is at year 401, 775 CE.

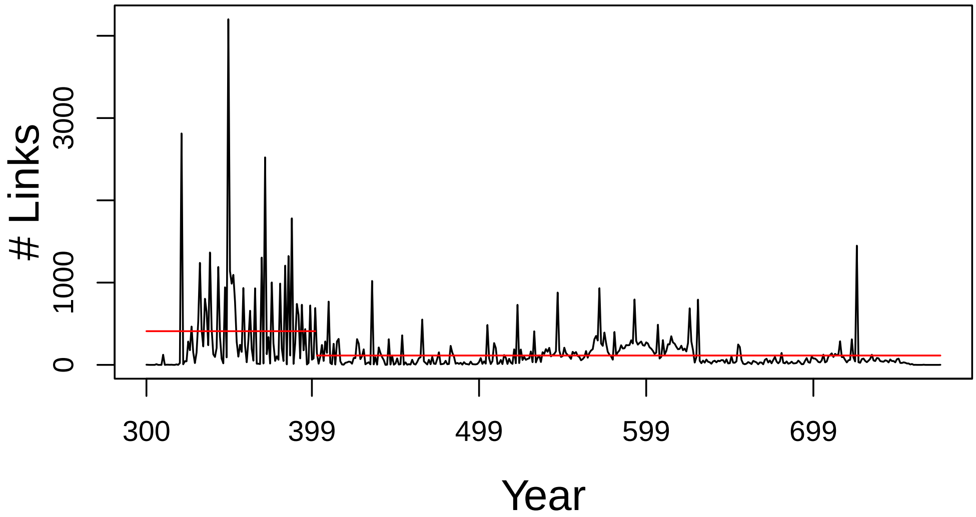

FIGURE 2. Number of links per year and mean before/after changepoint

This date is interesting, since it predates the fall of the Roman Empire by several decades; but it of course also predates the Islamic expansion, although there seems to be a brief "renaissance" in 500 CE, so researching additional changepoints might yield some insight on what happened. But at any rate we will need to understand why this is happening.

One of the angles we can explore is to take into account that we are, in fact, looking at a trade *network*, with vertices being the producers and consumers of coins, and edges the fact that a coin group contains coins created in a different place. In order to work with this network, we need to normalize the places so that they are mapped to a fixed vertex.

The original dataset contains information on the actual polities that produced and consumed the coins, with the specific kingdoms and even kings mentioned. However, this is not useful to research the network, since polities evolve and disappear and specific places would appear as different vertices depending on when the coin group was found or pressed. Since most coin hoards are geolocated, we will map the coordinates to *current* countries or territories, always considering that this is not the actual state or country that produced them. However, it will give us an idea of the relevance and centrality of the different territories back then. When necessary, we will map them back to the original locations, if it is relevant to our analysis.

Additionally, we have eliminated all vertices with an unknown location, and we have set as weights the number of coins in every specific coin group; that is, if Turkey is linked to Italy, the number of coins will indicate the strength of that particular link. The resulting network is shown in Figure 3. In this graph we also represent the betweenness centrality of the vertices, and use a layout that puts the most central vertex, that is Turkey, in the middle. We are clearly dealing here with the Eastern Roman empire, with its capital city in Constantinople, current Istanbul.

The main purpose of this graph is to show the overall connectivity, so that we can perceive the differences between and after the changepoint.

We have split the graph in a *before* and *after* the date, with the objective of trying to find

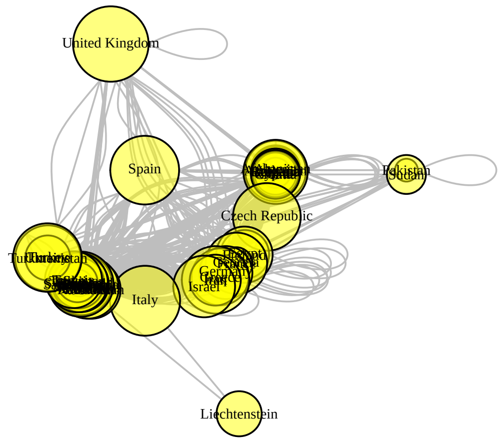

FIGURE 3. Trade network graph, with vertex size related to betweenness centrality

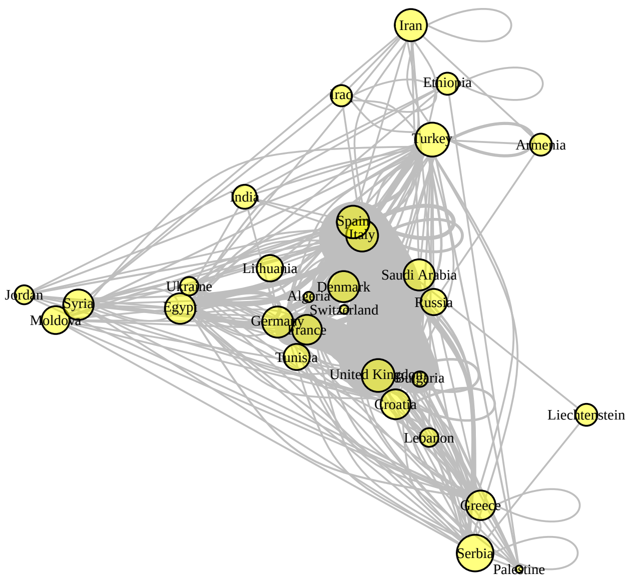

FIGURE 4. Trade network before the changepoint

out if the change in overall connectivity of the network can explain the change point. We have simply used the coin group date for the split. The graph before the changepoint date is shown in Figure 4, where vertex size is proportional to betweenness and edge width proportional to the number of coins, adding all coin groups with those two nodes as origin *or* destination.

We show in Table 1 the ten nodes with highest betweenness centrality before the changepoint. The fact that Serbia is in the top position is mildly surprising; at the time it was

Table 1. Betweenness centrality before changepoint

node	betweenness
Serbia	670.8690
Turkey	414.4226
United Kingdom	342.5583
Spain	326.4583
Iran	304.8369
Italy	290.3286
Saudi Arabia	254.3310
Germany	252.2000
Denmark	248.5786
Egypt	227.6321

part of the trade routes between Eastern and Western Roman empire, as well as including in its territory the all-important Danube River, trade route [7] as well as natural border between the Roman empire and the rest of Europe. Turkey is, of course, the Byzantine empire. What comes next is the United Kingdom and Spain which, as Figure 4 show, have a very strong connection between them. This is in part explained by the fact that the number of hoards found in these two current countries seems to be higher in the FLAMES database, but still those were territories that were an important part of the Roman empire with their mines (tin in the UK, iron, silver and mercury in Spain) and important ports. We need to see, anyway, what changed after the date found.

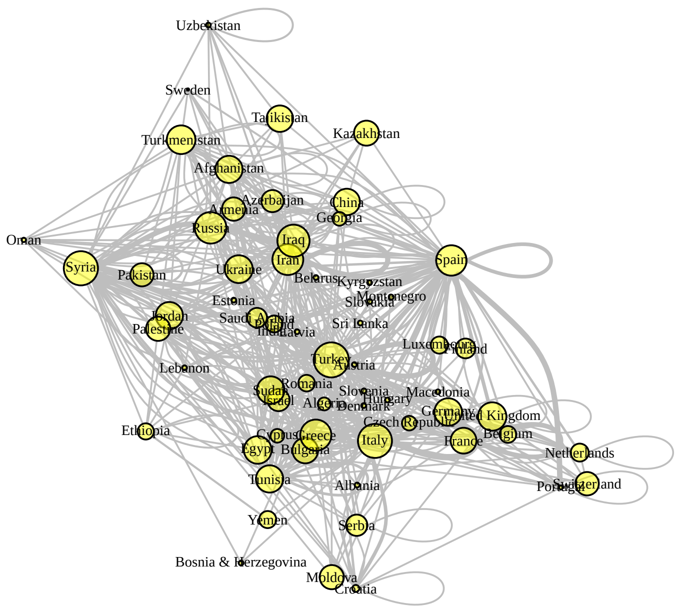

Figure 5. Trade network after the changepoint

The scenario drawn in Figure 5 is dramatically different, much more decentralized, with formerly central actors displaced to the periphery (like Italy or Spain), strong links (like the one between UK and Spain, and Italy and Bulgaria) vanished, and a bigger distribution of trade hubs among the continents; the importance of the Asian nodes, which were barely

Table 2. Betweenness centrality after changepoint

node	betweenness
Turkey	502.1175
Syria	430.0939
Italy	420.5795
Iraq	303.9644
Russia	268.5490
Greece	250.1615
Iran	239.4609
Spain	218.9250
Turkmenistan	160.8978
United Kingdom	152.8236

represented before, is quite evident.
The list of territories with the highest betweenness is shown in Figure 2. With Turkey and Syria, both part of the Byzantine empire, in the top positions, it clearly shows its importance in the world after the regime changed. But the trade network after the year 401, 775 has Italy, now capital of the Ostrogoth and after Lombard kingdom, as an important node. The presence of Russia and Greece again shows how the Byzantine empire was the most important kingdom in that era.

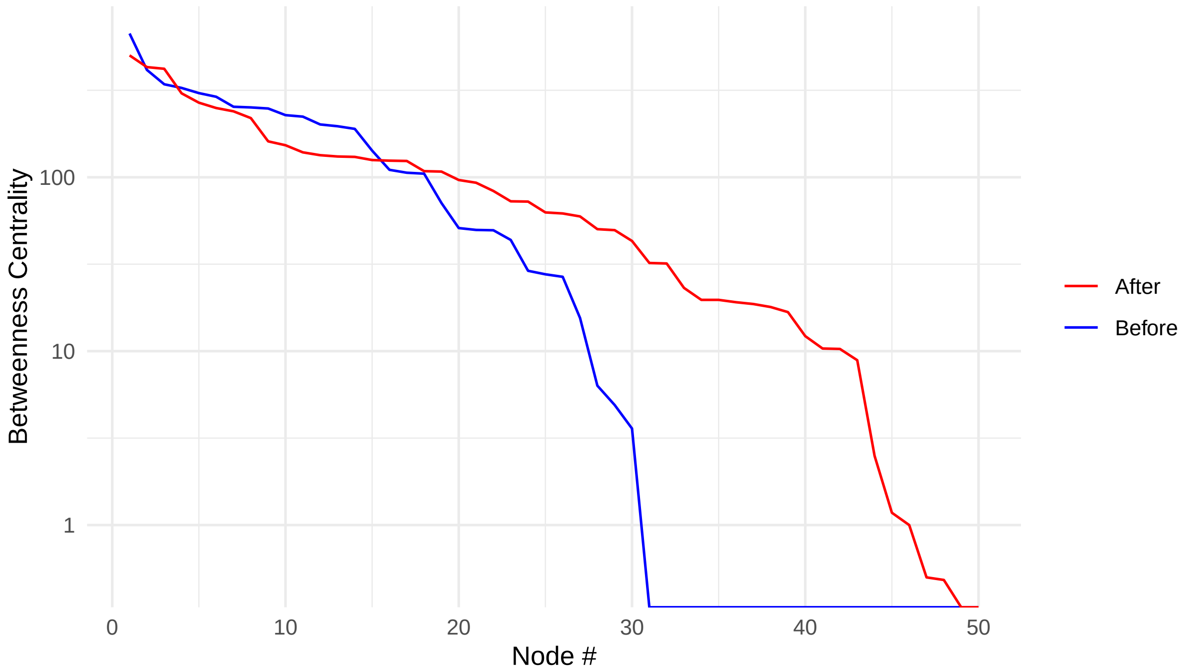

Figure 6. Betweenness centrality of the top nodes before and after the changepoint

What Figure 6 establishes is the stark change in trading patterns before and after the changepoint. The more centralized network before the changepoint has nodes with higher betweenness, but also less nodes with a high betweenness, descending very fast after the first few nodes. The subsequent network has lower betweenness overall, but the slope is also less steep, with many more nodes with a significant betweenness after the top 20.
At the end of the day, what this implies is that the change of regime has a high impact in

the trading patterns, but also that de demise of one of the nodes in that trading network in the Balkans or around the Danube River might have been one possible cause for that change.

0.4 Conclusions, discussion and future lines of work

History is characterized by abrupt changes brought by a variety of factors. In general, however, historiography has looked at singular events (battles, deaths of rulers) registered in the written record for those changes. The combination of available data on material culture and statistical methods, sometimes picked up from the physical deficiencies, can lend new insights not only on when the changes occur, but on the possible causes of those changes.

In this report, we have looked at coin hoard data from the FLAME dataset and created a timeline of trade links from late Antiquity to the Early Middle Ages. An analysis of that timeline has yielded a statistically significant changepoint in the year 401, 775 CE. Since this possible boundary between those two periods occurs earlier than previously predicted, we need to find possible causes, and we use the same dataset to establish them: by using those same links as a trade network with regions as nodes, we see that the period before the fall was characterized by a highly centralized network where the vertex with the highest betweenness was along the Danube River, in Serbia. The network after the changepoint is much more decentralized, with many more nodes in Asia, and with the most central node in Turkey, that is, the Byzantine Empire.

Since the date is very close to the battle of Adrianople [12], we can try and find if there is some relationship between the changepoint and the battle. This battle was fought in 378 CE between an Eastern Roman army and a coalition of Gothic groups that included what would later be called the Visigoths. Adrianople is in current Edirne, in the European part of Turkey, very close to the Greek and Bulgarian border. Besides destroying and rendering almost inoperative the Roman army, this battle took part south of the Danube, deleting the river as an effective border, but also as a trade route with signposts administered and manned by a central imperial power. After this event, more self-governing Gothic nations were allowed south of the Danube as *foederati*, and this probably implied the total loss of control of those territories south of the Danube.

In this paper we have established what we will call *the Danubian hypothesis* for the breakpoint that signaled the end of Antiquity and the start of a new era where Europe would have no central control and a new military and political order was established. This hypothesis states that Roman control of the Danube was primordial to keep this trade route open, essential for keeping communication between the two parts of the empire and to tap the riches of the territories both sides of the river, and that when that control decayed it almost immediately disrupted trade patterns and eventually led to the fall of the Western Roman Empire, widely considered the real end of Antiquity.

Proving this hypothesis can be a fruitful future line of work. We would need to look specifically at the coin hoards found in that area and how they evolved, as well as the presence elsewhere of coins minted in the Danube basin. As new data becomes available, it can be used to find the breakpoint with more precision and maybe find other factors or trends that, together, might have led to this specific turn of events.

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