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Jewish Networks in the Spread of Early Christianity: A Mathematical Model of Marcionite and Lukan Christianities

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The authors reconsider the dynamics of Jewish and non-Jewish networks in the spread of early Christianity. For mathematical modeling of complex processes like these, they apply Lukan and Marcionite Christianities as strictly coded test cases. Despite weak historical evidence, it is obvious that these two movements, which are newly assumed to be contemporaneous, maintained different attitudes to the Jewish background of Christianity and so they probably used Jewish and non-Jewish networks in a different way. While Lukan Christianity, which remained open to the Jewish tradition, may still have utilized Jewish Mediterranean networks, Marcionite Christianity, which rejected the Jewish heritage, probably ignored them. On this reduced historical basis, the authors constructed a mathematical model of temporal spreading on the network which was common for both of the hypothesized types of Christianity. The nodes of this network, representing big cities of the ancient Mediterranean, contain only two different kinds of diffusivity – Jewish and non-Jewish. At the level of the common network which remains stable, the model examines the importance of global centers for the spreading dynamics of early Christianity. On the other hand, the employment of the Jewish sub-network is manipulated over time according to the regular alteration of early Christian generations. This way, the necessity of the Jewish sub-network for the spread of early Christianity is tested.

Introduction

The purpose of this project is to build a formal, abstract, and tractable model of the spread of early Christianity in its formative period, i.e., during the 1st century and the first half of the 2nd century CE. Such macro-historical modeling can provide a useful tool to overcome a fatal gap in sources because, at least until ca. 180 CE, we

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are faced with a crucial lack of any archaeological evidence which might be directly connected with the emerging Christian religion (Snyder [1985] 2003: 2-3; Tabbernee 2014: 5-6; Caraher and Pettegrew 2019: 12-5). With the modeling approach, we try to answer the traditional question about the early parting of Judaism and Christianity (cf. Dunn [1991] 2006, 1992; Becker and Reed 2003; Shanks 2013) and reconsider the dynamics of Jewish and non-Jewish networks in the spread of early Christianity in a new way.

Historical background

The traditional conception of Christian origins locates the Passion story and Easter events in Jerusalem, where after Jesus' death, the primordial church was established. From this locative point, early Christianity was disseminated through the apostles' missionary efforts. This linear and monolithic understanding of Christian origins is based on Luke's canonical diptych of the *Gospel of Luke* and *Acts of the Apostles*. The Lukan harmonizing conception was later enforced in the Constantinian period, by its inclusion in Eusebius' *Ecclesiastical History*, and became a mythical core of Christianity (Smith 2004, 2009; cf. Vinzent 2023). Even Rodney Stark, who constructed one of the first quantitative models of the initial spread of Christianity (1996: 129-45; cf. Fousek et al. 2018), followed the tracks of the Lukan historiographical imagination and, without any criticism, placed the initial point of the spreading process to Jerusalem.

For a long time, the scholarly consensus dated *Luke-Acts* at ca. 85 CE. Nevertheless, Richard I. Pervo persuasively challenged this traditional consensus and shifted the date of Lukan writings to the decade 110–120 CE (Pervo 2006; cf. already Koester [1980] 1982: vol. 2, 310). His dating is based on two crucial findings: that Luke knew and used Paul's letters and Josephus' *Jewish Antiquities*. Following this later dating, *Luke-Acts* came closer to the chronological horizon of Marcion. Marcionite Christianity flourished during the first half of the 2nd century in the eastern part of the Roman Empire and probably also strongly influenced the development of Christian communities in Rome. Joseph B. Tyson, who recently elaborated on this possibility, speaks about a "defining struggle" between Marcion and the author of *Luke-Acts* (Tyson 2006).

Despite the fact that Marcion is ultimately known through the writings of his later opponents (most notably Irenaeus, Tertullian, and Epiphanius), it is evident that Marcionite Christianity rejected the Jewish heritage and probably did not utilize Jewish networks for its spread. Tyson, following certain propositions made by his teacher John Knox (1942), proposed that the author of *Luke-Acts* conceived his work in conscious opposition to Marcion, who refused the scriptures of the Hebrew Bible and created a new canon consisting of his own gospel (*Euangelion*) and ten letters of Paul (*Apostolikon*). Thus, in *Acts*, Luke tried to return Paul, usurped by Marcion, back to the Jewish context. For these reasons, he could not

probably use the “occupied” collection of Pauline letters directly but only as a background of his apologetic composition. Lukan Paul, firmly connected with the destiny of Jesus in the *Gospel*, stresses an intimate relationship with Judaism as well as the universalizing claim of the Christian mission.

Although Tyson’s hypothesis did not gain widespread approval, the shift in the dating of Lukan writings has strongly revitalized the debates concerning not only the earliest development of the Christian canon but also the mutual relationship between Lukan and Marcionite Christianities. Today, we are confronted with a real boom of Marcionite titles, be it attempts at the reconstruction of Marcion’s canon (BeDuhn 2013; Roth 2015; Klinghardt [2015] 2021; Gramaglia 2017; Gianotto and Nicolotti 2019) or at the textual and chronological relationship between the New Testament writings and Marcionite scriptural traditions (Moll 2010; Vinzent 2014, 2018; Lieu 2015).

While the recent discussions are mostly focused on the textual framework of Marcionite and Lukan Christianities and on historical reconstructions of their mutual relationship deduced from fragmentary written evidence (see esp. discussions in the *Journal of Ancient Christianity* [BeDuhn 2017a; Roth 2017; Schmidt 2017; Klinghardt 2017a; Lieu 2017a] and *New Testament Studies* [Klinghardt 2017b; BeDuhn 2017b; Lieu 2017b; cf. Roth 2022]), our project tries to reconsider these two movements in a broader context of the spreading dynamics of early Christianity. It steps back from the eventual history, aimed at intentional actors’ activities captured in texts, and rather follows the Braudelien long-term (*longue durée*) history (Braudel [1949] 1966; cf. Concannon and Mazurek 2016), using mathematical models and appropriate proxies.

Adopted simplifications

For a mathematical model, Lukan and Marcionite Christianities are applied as strictly coded test cases. In spite of weak historical evidence, it is obvious that these two movements, which are assumed to be contemporaneous, maintained different attitudes to the Jewish background of Christianity and so they probably used Jewish and non-Jewish networks in a different way. While Lukan Christianity, which remained open to the Jewish tradition, may still have utilized Jewish networks, Marcionite Christianity, which rejected the Jewish legacy, probably ignored them. At the time Christianity emerged, the Jewish networks had already been established and probably occupied the majority of the Mediterranean big cities (Gruen 2002; Lightstone 2011; Collar 2013: 146-223). In this connection, the tension between Marcionite and Lukan Christianities generates a more general question about the role of Jewish networks in the spreading process of early Christianity as a whole. On this reduced historical basis, two research questions can be stated:

- What was the role of big centers in the spreading dynamics of early Christianity?
- Was the Jewish sub-network necessary for spreading Christianity all over the considered time (31–150 CE)? – If not, when did its importance fade away?

Based on the urban character of early Christian communities (Meeks [1983] 2003; Still and Horrell 2009; Harrison and Welborn 2015), our model is conceived as a network of big cities throughout the ancient Mediterranean. Both pro-Jewish and non-Jewish Christian movements shared a common Mediterranean network created by cities with global or regional trade connections, which supported the spreading process. As a proxy for the global frame of the model, the current outcomes of the Oxford Roman Economy Project (OXREP 2018) were applied. The network was designed based on the minimum estimation of city sizes and urbanization for the 1st century and the first half of the 2nd century CE, made by Andrew Wilson. His study “City Sizes and Urbanization in the Roman Empire” (Wilson 2011), starting with the Augustan period and finishing before the Antonine Plague (165–180 CE), covers quite precisely the time period investigated in our project. We adopted Wilson’s presupposition that the urbanization rate correlates with economic and demographic growth (cf. Lo Cascio 2009) in the analogical sense that the urbanization rate correlates with the spreading dynamics of early Christianity. In his estimation of the Roman Empire, Wilson states 20 big cities having a population of 40,000 or more and ca 1,780 other cities population of 1,000 – 40,000. To the group of 20 big cities (see Tab. 1), we added Jerusalem, although Wilson estimates its population at only 22,000. The reason for its incorporation lies in its importance as a religious center (see Fig. 1).

The Jewish sub-network within the global Mediterranean model is represented by 200 cities with synagogues. Their number is derived from the catalog *The Ancient Synagogue from Its Origins to 200 C.E.*, compiled by Ander Runesson, Donald D. Binder, and Birger Olsson (2008). The catalog numbers 217 items; nevertheless, some of them cannot be individually coded because of their general character. We simulated the established Jewish network by the identification of “synagogal” cities with the group of 20 big cities and other 180 cities regularly distributed throughout the Roman world.

City	Population	City	Population
Rome (+ Ostia)	1,040,000	Arsinoe	45,000
Syracuse	90,000	Sardis	53,400
Akragas	50,000	Alexandria Troas	41,700

Carthage	300,000	Antioch	250,000
Leptis Magna	90,000	Caesarea Maritima	75,000
Thysdrus	45,000	Berytus	50,000
Iol Caesarea	63,000	Jerusalem	22,000
Alexandria	500,000	Corinth	80,000
Ptolemais	125,000	Athens	90,000
Memphis	125,000	Rhodes	40,000

Table 1. Roman cities having a population of 40,000 or more (Wilson 2011), Jerusalem added.



Figure 1. The geographic distribution of 20 big cities in the ancient Mediterranean (Wilson 2011; location after Hanson 2016). The size of the orange dots representing the big cities respects a level of city population; the red dot symbolizes Jerusalem. Dark ochre grey shows the territory of the Roman Empire to its greatest extent in 117 CE. The map was designed by Adam Mertel. The nodes of the modeled Mediterranean network can be summarized according to their different diffusivity (see Fig. 2):

Global nodes in the common Mediterranean network

- 20 big cities having a population of 40,000 or more (Wilson 2011);

- all these cities are directly interconnected;
- all these cities are incorporated into the Jewish sub-network.

Regional nodes in the common Mediterranean network

- 1780 other cities of population 1,000 – 40, 000 (Wilson 2011);
- every one of these cities is connected only to the nearest one.

Jewish sub-network within the common Mediterranean network

- 200 cities with a synagogue (Runesson, Binder, and Olsson 2008);
- regularly distributed within the global and regional nodes;
- the Jewish sub-network includes all 20 big cities.

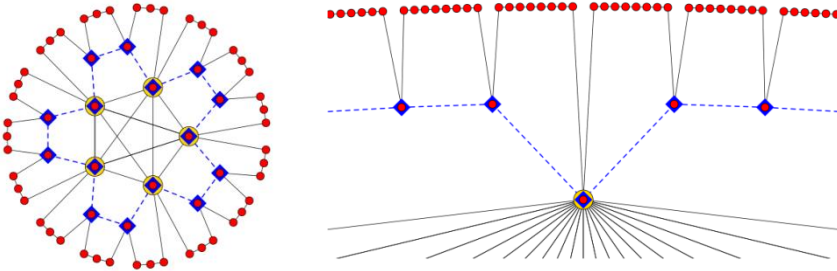


Figure 2. A schematic picture of the modeled Mediterranean network. The gold and the blue colors added to the red nodes represent the global nodes (big cities) and the Jewish ones, respectively. The lines represent edges (connections between nodes). The black edges depict connections between neighbor sites and the other within global centers, and the dashed blue lines represent the Jewish that may be “switched off.” Let us underscore that the length of the depicted edges has nothing to do with the actual distances between sites. Left: network with 90 nodes only, including 5 global and 15 Jewish ones. Right: part of the network utilized in the model (1800 nodes, 20 and 200 global and Jewish ones, respectively); a neighborhood of one global center is depicted.

Since the real historical connections between the sites may be subjected to a wide-ranging discussion, we suppose that the underlying network is the most entropic one, i.e., a regular graph.

While the common Mediterranean network is stable, the employment of the Jewish sub-network can be manipulated over time. The temporal changes of the Jewish sub-network follow the regular alteration of early Christian generations

(every 30 years), and in this mode, they can be disengaged or activated within the researched period of 31–150 CE. The individual aspects of the eventual history usually discussed as various key factors in separating processes between Judaism and Christianity (see Tab. 2), are intentionally sidelined in the model. Some of them will be considered in the final evaluation of the model “against the data.”

Generations	Historical context (evental history)
31 – 60 CE	<ul style="list-style-type: none"> • Central role of Jerusalem (pilgrimage, temple tax). • Synagogal networks in Palestine and the diaspora. • Beginnings of Christian mission to the gentiles (Paul).
61 – 90 CE	<ul style="list-style-type: none"> • Fall of Jerusalem (70 CE). • The increasing role of diaspora networks. • Jewish tax (<i>fiscus Iudaicus</i>).
91 – 120 CE	<ul style="list-style-type: none"> • Jewish tax (<i>fiscus Iudaicus</i>). • Roman restrictions against the Jews during the Parthian wars (115–117 CE). • Marcion started his career (supplying grain to the Roman army?). • Lukan writings.
121 – 150 CE	<ul style="list-style-type: none"> • Lukan writings. • Marcionite churches established. • Romans distinguished between Judaism and Christianity. • Jews forbidden from entering Jerusalem after the Bar Kokhba revolt (132–135 CE).

Table 2. Alteration of the early Christian generations against the eventual history.

The aim of the proposed mathematical model is not to provide a simulation of the spatial spreading of Christianity through the Roman Empire but only of its temporal features. The modeled space consists of nodes and their formalized connections without any direct reference to the historical map. The Christianity researched here is reduced to a singular phenomenon spreading on the network.

Mathematical model

From the first successful attempts to model history from a mathematical viewpoint, the dominant inspiration comes from mathematical population dynamics (Turchin 2003a; Turchin and Korotayev 2006). Our model aims to simulate time progress in Roman cities that came into contact with Christianity until the middle of the 2nd century CE. As was stated in the previous section, we do

not intend to localize these sites, we only want to estimate a proportion of sites affected by some type of early Christianity. Further, “early Christianity” is a rather vague concept, hence, an exact quantification of it is not attainable; it is only possible to describe it in a qualitative way. These considerations lead us to utilize models that are based on the qualitative theory of differential or difference equations. Fortunately, there is a considerable number of models developed during the history of mathematical seizing of biology, and models of population growth are well elaborated (cf. Bacaër 2011; Thieme 2007). The majority of the established models of the spatial aspects of population ecology deal with a continuous space (Kot 2001; cf. Cantrell, Cosner, and Ruan 2009), while models dealing with discrete space – networks or graphs, i.e., models appropriate for our purpose – are relatively rare (cf. Slavík and Stehlík 2015).

The abstract process of the spread of early Christianity may be considered as population dynamics in a discrete space, i.e., on the network of Mediterranean cities described in the previous section. Christians may occupy a city and mutually interact in it. In other words, we consider the spreading of early Christianity to be a reaction-diffusion process on a regular simple connected graph. Christianity grows in a node and may diffuse to a neighboring one. For the purpose of our model, we consider discrete time scale, the size of the time step corresponding to one year.

These suppositions lead to a random walk of a quantity interpreted as the “density of Christianity” on a graph; let us note that on regular graphs a random walk coincides with diffusion (Newman 2018: 142-7). We assume that such a quantity is measurable or observable, it may be the “proportion of Christians” in a site. At the same time, a “reaction” interpreted as the interaction between Christians in the site takes place in each node. The state variable denoted by $x_i(t)$ represents “the density” in node i , $i=1,2,\dots,N$. It is a non-negative real number ranging from zero (no Christianity in a site) to unity (a maximum intensity, not necessarily complete Christianization). This way, we obtain the general model in the following form (for details see Pospíšil 2020)

$$x_i(t + 1) = f(x_i(t)) - d \left[f(x_i(t)) - \sum_{j=1}^N \kappa_{ij} (x_j(t)) f(x_j(t)) \right].$$

Here d denotes diffusivity (probability that a “particle” or “propagule” leaves a node during a unit time interval), f represents the “reaction of particles” depending on their density, and κ_{ij} describes the connection between the nodes i and j . The sum operates through all nodes hence the last term expresses the total input to the node i from all of the neighboring nodes.

The connection κ_{ij} from the node j to the node i depends on the topology of the graph (network) and also on the density in the node j . In fact, we suppose that a phenomenon does not diffuse from a node where the density is too small; Christians were able to provide some missionary activities to their neighborhood only when a community had been established, i.e., when it was strong enough. In particular, we put $\kappa_{ij}(x)=0$ if $x \leq \theta$, where θ represents a threshold density, and $\kappa_{ij}(x)=a_{ij}/\sigma_j$ if $x > \theta$, where a_{ij} is the corresponding entry of the graph adjacency matrix and $\sigma_j = \sum_i a_{ij}$ is the degree of the node j .

The topology of the network was described in the previous section. It consists of $N=1800$ nodes while $k=20$ and $m=200$ nodes among them represent the aforementioned big cities and cities with synagogues, respectively. Since we assume a uniform distribution of big and “Jewish” cities, we consider the nodes denoted by i from the sets $B=\{1+90n: n=1,2,\dots,20\}$ and $J=\{1+9n: n=1,2,\dots,200\}$ to represent the big cities and the “Jewish” ones, respectively. Hence, the entries of the adjacency matrix are $a_{ij}=1$, if and only if $|i-j|$ is in the set $\{1,1799,9,1791\}$ or both i and j belong to the set B .

Finally, we need to adopt certain suppositions about the reaction term f . To keep things as simple as possible, we assume that the growth rate of Christianity in a node is proportional to its density (we assume that Christians proliferate on the basis of mutual service and support) but the growth is not unbounded (there are certain “social resources” necessary for a community growth). Further, we assume that an isolated Christian or a very small group of them cannot survive and proliferate since the attractivity of religion deeply depends on interpersonal relationships. In other words, we consider the “reactions” in nodes to be an analogy of population dynamics of a self-supporting population exhibiting the Allee effect (cf. Turchin 2003b: 51-4). In particular, we use the modified Ricker model $f(x)=x \exp[\alpha(x)]$, where $\alpha(x)=-c$ for $x \leq \eta$ and $r(1-x)$ for $x > \eta$; all of the parameters r, c are positive and they express the intrinsic growth rate, the death rate for an intensity less than the non-negative threshold η , respectively.

The main problem consists in the calibration of the model due to the lack of historical data and the abstract meaning of the state variable x . Hence, we adopt the values of growth and death rates to be $r=0.15$ and $c=0.007$; this option corresponds to common choices for population models. The value of the threshold parameter is more dubious. It should be non-zero but not too high; so, after some computational experiments, we set it to $\eta=0.01$. These parameter values give qualitatively reasonable results – monotone convergence to the growth limit scaled to unity and not a very high threshold for the growth of the modeled phenomenon (cf. Kot 2001: 43-69). The parameters of the “spatial part” of the model are diffusivity d and threshold θ . We suppose that one-half of the maximum possible “density of Christianity” is adequate for spreading, i.e., to provide “missionary activities”, and that one-quarter of this “density” would spread. That

is, we put $d=0.25$ and $\theta=0.5$. The parameters of the model are summarized in Tab. 3.

Symbol, parameter value	Description
$x_i=x_i(t)$	state variable, “intensity of Christianity” on the node i in time t
a_{ij}	adjacency of nodes j and i
σ_j	degree of the node j
$d=0.25$	diffusivity, rate of spreading of propagules along edges
$\theta=0.5$	threshold for intensity on a node for spreading it into neighbor nodes
$\kappa_{ij}=\kappa_{ij}(x)$	weight of connection, $\kappa_{ij}=0$ for $x \leq \theta$, a_{ij}/σ_j for $x > \theta$
$r=0.15$	logarithmic growth rate of intensity in a node
$c=0.007$	ratio of death rate to $\log r$, parameter describing the Allee effect
$\eta=0.01$	threshold intensity for survival and proliferation in a node
$f=f(x) = x \exp[\alpha(x)]$	growth function in a node, $\alpha(x)=-x$ for $x \leq \eta$, $r(1-x)$ for $x > \eta$

Table 3. Symbols used in the model.

The next decision concerns the initial value. We assume that Christianity *in statu nascendi* occupied the whole capacity of a node, that is $x_i(0)=1$ for some i which denotes the index of the site where Christianity originated, and that $x_j(0)=0$ for $j \neq i$. The last option is a choice of the index i , i.e., of a place of the commencement of Christianity. The time 0 means the year 31 CE.

We embrace the supposition that by 150 CE not more than one-half of the considered Roman cities had been affected by Christianity in some way (for the big cities see Stark 1996: 132-4, 2006: 70-2; Hopkins 1998; cf. Trombley 2006; Ehrman 2018: 160-77). We do not consider the introduced state variable $x_i(t)$ to be an accurate quantification of Christianity present in the node i at the time t , rather we interpret it to be a latent variable such that a positive value of it simply

represents the fact that the node i is at the time t affected by Christianity. Hence, we require the transient dynamic of the proposed model to fulfill the property that roughly 50% of the values x_i at the end of the simulation are positive.

Results of simulations

The described mathematical model was implemented in the R-language software (R Core Team 2015). The simulations start with the identification of the node where the initial value equals 1, that is, of the site where Christianity originated. The first choice was one of the global nodes in the common Mediterranean network. It yields too great number of Roman cities affected by Christianity, namely 67.3% in 150 CE. This result means that the origins of Christianity in a big center are unrealistic according to the proposed model because of too high dynamics of spreading (see Fig. 3a).

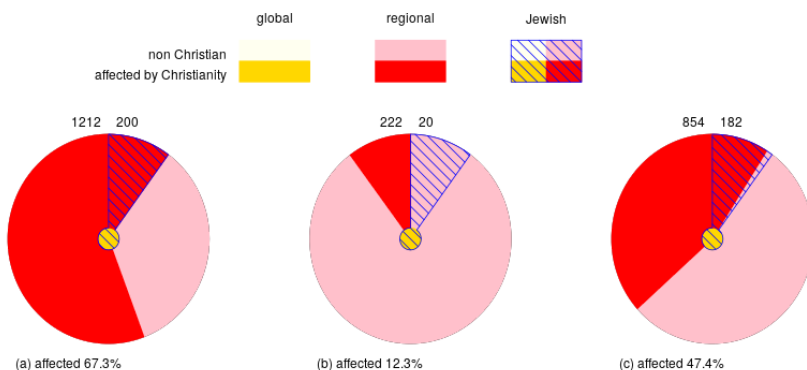


Figure 3. A calibration of the model of early Christianity spreading on the idealized Mediterranean networks; for details see the text. The plots depict the simulated affection of Roman cities by Christianity in 150 CE. The proportion of colored area to the total circle area equals the proportion of the global, regional, and “Jewish” sites. The numbers of affected cities are put above the diagrams; the left and the right numbers represent regional centers and the Jewish sites (both global and regional), respectively. The figures illustrate the three scenarios: (a) the beginning in a big center; (b) the beginning in a big center, the Jewish sub-network not in use; (c) the beginning in a “Jewish” city nearest to a big center.

The second simulation tested the possibility that Christianity originated in a big center but it spread independently of the Jewish sub-network. The number of cities affected by Christianity in 150 CE was too small, namely 12.3%. This result shows

that the Jewish sub-network was substantial for the spreading of early Christianity (see Fig. 3b).

Only the choice of the origins in the node of the Jewish sub-network nearest to a big city yielded the suitable proportion of 47.4% of cities affected by Christianity (see Fig. 3c). This finding allows us to turn to the main question – the timing of the separation between Christianity and Judaism.

The scenarios being considered were these three – the abandoning of the Jewish sub-network in the second (starting in 61 CE), the third (91 CE), and the fourth (121 CE) generation. The results of the simulations are depicted in Fig. 4.

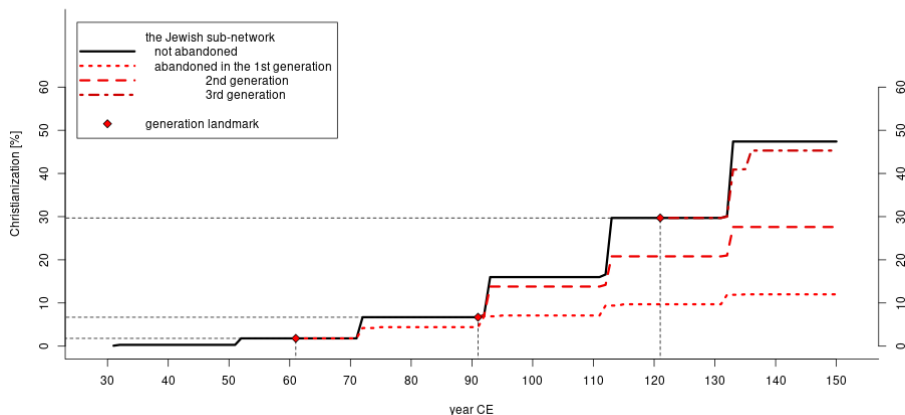


Figure 4. The simulated contact of Roman cities with Christianity. “Christianization” means the percentage of localities affected by Christianity. The solid black line denotes the spread of Christianity using the Jewish sub-network all the time until 150 CE. The dotted, dashed, and dot-dashed red lines denote the spread of Christianity that abandoned the Jewish sub-network within the second (61 CE), the third (91 CE), and the fourth (121 CE) generation, respectively. The stepwise character of the graphs is related to the thresholds of growth (parameter θ) – first the “density of Christianity” grows in nodes, and after reaching a value above the diffusion threshold, it spreads to the connected nodes until it gets to a sufficient value.

Since the line representing the third scenario follows the one of permanent employment of the Jewish sub-network, we can see that the abandoning of the Jewish sub-network in about 120 CE does not diminish the spreading dynamics of Christianity. Hence, we can conclude that the proposed model indicates that Christianity can leave the Jewish sub-network approximately by the end of the third Christian generation (120 CE).

Discussion

The model produces quantitatively plausible projections of the spread of early Christianity. A network of connected Mediterranean cities, designed according to Wilson's estimation (2011), proves to be sufficient for simulating the spreading dynamics of early Christianity. The calibration of the model has indicated that the spreading process originated outside a big center, but "not far" from it because of the decisive role of big centers in the global spread of Christianity.

While the Christian origins in a Galilean periphery might correspond to the course of the simulation, a big *religious* center was not necessary. The closest big center, crucial for the earliest spreading of Christianity, may have been Jerusalem as well as Antioch, Berytus, or Caesarea. In this connection, it is important to keep in mind that, for the model, Jerusalem was "elevated" to the big cities despite its lower population (22,000). Moreover, unlike the other mentioned cities, which had flourishing ports in those times, Jerusalem remained a landlocked area with decreasing importance. From the point of eventual history, the Roman conquest of Jerusalem and the destruction of the Jerusalem temple in 70 CE probably strongly reduced its diffusivity and eliminated it from the global nodes of the Mediterranean network. On the other hand, the closest big cities with ports show unbroken continuity and higher diffusivity than Jerusalem. The preserved Christian evidence is connected especially with Antioch, which was ten times bigger than Jerusalem and served as a base for Paul of Tarsus (Zetterholm 2003).

The fall of Jerusalem (70 CE) as a main historical factor in the parting of Judaism and Christianity seems to be overestimated (cf. Schwartz and Weiss 2012). The model has demonstrated that Christianity could not have spread without the Jewish sub-network for a long time and probably continued to use other Jewish nodes, established mainly in the diaspora. It was not until the third generation (91–120 CE) that Christians could renounce the Jewish sub-network without any significant loss to the Christianization level. More likely, Christian withdrawal from the Jewish sub-network was framed by the Parthian wars (115–117 CE) and the Bar Kokhba Revolt (132–135 CE), after which the Jews were forbidden from entering Jerusalem (Horbury 2014) and all known Christian teachers, including Marcion, arrived as displaced from the East in the city of Rome. The restrictions against the Jews embodied in the Jewish tax (*fiscus Iudaicus*) and its different administrations under Domitian (81–96 CE) and Nerva (96–98 CE) may have been an important factor in the following parting processes (Heemstra 2010). However, the fragmentary evidence of the Jewish tax collection limits its use in modeling.

Marcion came "just in time" to be successful. The broader dates of Marcion's life might be approximately 95–165 CE while his arrival in Rome in 144 CE remains the only certain date (BeDuhn 2013: 13). Marcion came from the Roman province of Pontus (the north coast of today's Turkey) and had his profession in the sea trade (May 1989; Wendt 2018), being a shipmaster or a shipowner (*nauclerus*,

nauklēros). He started his career at the time when the Pontic shipmasters played a crucial role in supplying grain to Roman armies during the Parthian wars (115–117 CE). Although no direct evidence is available, Marcion may have been involved in these activities and confronted with the Jewish resistance to the Roman occupation of Mesopotamia and its cruel suppression by the Roman emperor Trajan. At least, Marcion's early career fits well with the turning point of the model dated between the third (91–120 CE) and fourth (121–150 CE) Christian generation. At the same time, the Roman intellectual elites (Plinius the Younger, Tacit, Suetonius) recognized Christianity as a new religious phenomenon different from Judaism (Wilken [1983] 2003) and, from the opposite side, Luke for the first time referred to the fact that the followers of Jesus had been called “Christians” (*Christianoi*) in Antioch (*Acts* 11:26). The reasons for the later unsuccess of the Marcionate line probably consisted of other aspects. A crucial one was the absence of ancient (Jewish) tradition, which discredited the new Christian religion as a mere superstition in the Roman eyes (Ehrman 2003: 111).

Future prospects

The proposed mathematical model provides a formalized tool that – in an abstract way – tries to overcome the total lack of archaeological evidence. It suggests a new reconsideration of fundamental mechanisms that may have influenced the spreading dynamics of early Christianity. On this basis, the next step could be a projection of the abstract model onto a historical map, using a combination of fragmentary written sources and suitable archaeological proxies. While the limited reliability of written evidence primarily requires a detailed revision of available historical atlases, a promising archaeological proxy could be found in the contemporaneous Jewish synagogues (Runesson, Binder, and Olsson 2008) and their geographical networking. Another proxy might be Roman tableware (*terra sigillata*, red slip ware) and its distribution following trade networks throughout the ancient Mediterranean (cf. Bes 2015; Brughmans and Poblome 2016). This way the succeeding research could examine correlations between the shared trade routes and the spreading processes of early Christianity.

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Supplementary materials

Results of simulations in the form of animated pdfs. The source R-language scripts are available on request.

