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## The shape of the Roman world

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Walter Scheidel

Stanford University

Abstract: Ancient societies were shaped by logistical constraints that are almost unimaginable to modern observers. “ORBIS: The Stanford Geospatial Network Model of the Roman World” (<http://orbis.stanford.edu>) for the first time allows us to understand the true cost of distance in building and maintaining a huge empire with premodern technology. This paper explores various ways in which this novel Digital Humanities tool changes and enriches our understanding of ancient history.

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## Sizing up Enemy Number One

The Roman Empire was very large. At the peak of its power it extended 33 degrees of latitude from north to south and 34 degrees of longitude from east to west. The first of these accomplishments is by far the more remarkable, given that the inclination of the earth's axis favors longitudinal expansion within ecologically familiar terrain: of all the contiguous empires in premodern history, only those of the Mongols, Incas and Russian czars matched or exceeded the north-south range of Roman rule. And unlike those of any other major contiguous empires, the Roman territories were dramatically segmented, wrapped around an inner sea of two and a half million square kilometers. Mountains ranges such as the Alps and Taurus on occasion required travelers to climb above 2,000 meters to traverse passes. Within its borders, the Roman Empire was unprecedented and remains without successor, still the only state in history to have claimed all that space. Holding on to it and distributing the resources required to maintain the imperial superstructure must have been a formidable challenge. And yet, after generations of scholarship, we have only a vague sense of how this system was spatially configured and how strongly its constituent elements were connected. Conventional maps look at the Roman Empire from high above. By representing distance as the crow (or rather a plane) flies, they fail to give us a proper sense of how different hard and liquid surfaces, altitudes and climes shaped people's movement across this vast space. The real cost of travel, in terms of time and money, remains unknown. A pictorial itinerary such as the Peutinger Table might arguably do a better job than a modern map by focusing on connections, but does so in a way that likewise makes it impossible to understand spatial differentiation overall.<sup>1</sup>

Fernand Braudel noted this problem a long time ago, drawing our attention to the human struggle against distance, the ‘ennemi numéro 1’ of civilization.<sup>2</sup> He sought a way forward by developing what we might call cost contour maps in which isochronic lines superimposed on conventional maps represented the time it took couriered messages from all over Europe to reach Venice during the early modern period.<sup>3</sup> Inevitably, his pioneering efforts were narrowly circumscribed by the resources available at the time. A more comprehensive model of connectivity costs poses considerable challenges: it requires us to approximate the pace of movement across different terrains, by different means of transport, at different times of the year. A wide range of factors from geomorphology and climate to technology and infrastructure affect this equation, to say nothing of institutions and tastes. And time is only one variable, critical in the transmission of information and perhaps also the projection of military power but less crucial for economic exchange that tends to be more sensitive to price. For all these reasons, even a highly simplified and optimized reconstruction of the costs of connectivity across an entity of several million square kilometers requires not merely substantial inputs of data but also their computerized processing.

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The findings presented in this paper were derived from a computer model of the Roman Empire funded by a Digital Humanities grant of Stanford University for 2011/12. I am greatly indebted to Elijah Meeks for building the model and more specifically for generating the cost maps and cartograms used here. For information on this project, see below, n.4. I also wish to thank Peter Bol, Pau de Soto Cañamares and Carlos Noreña for sending me unpublished work, and Greg Woolf and several anonymous readers for valuable feedback. In keeping with the programmatic and exploratory character of this paper, I have kept referencing to a minimum and sought to give electronic publications their due.

<sup>1</sup> The best conventional map resource is of course R. J. A. Talbert (ed.), *Barrington Atlas of the Greek and Roman World* (2000), and the best study of the Peutinger Map is his *Rome's World: The Peutinger Map Reconsidered* (2010), with the splendid online resources at <http://peutinger.atlantides.org/>. For ancient maps in general, see now the references in Talbert's ‘Maps’, *Oxford Bibliographies*, June 26, 2012, DOI: 10.1093/OBO/97801953896610075.

<sup>2</sup> F. Braudel, *La Méditerranée et le monde méditerranéen à l'époque de Philippe II* (1966), 326 (poorly rendered as the ‘first enemy’ in the English translation of 1972).

<sup>3</sup> *Ibid.* 331-9, drawing on P. Sardella, *Nouvelles et spéculations à Venise au début du XVIe siècle* (1948).

Geospatial modeling is now sufficiently advanced for Roman historians to take on this challenge. After sketching out the model's parameters (in the following section), this paper focuses on two issues that are fundamental to our understanding of the Roman world. First, I revisit the trajectory of imperial expansion and decline, demonstrating that Roman expansion proceeded in accordance with connectivity cost constraints and that the eventual segmentation and separation of the empire was likewise shaped by the same factor (in the third and fourth sections). Second, I argue that the model allows us to address key questions about the nature of the Roman economy, namely the relative significance of market forces and state intervention and the degree of economic integration (in the fifth section). I finish with a call for more complex multi-layered modeling that holds great promise for our future understanding of historical causation in the ancient past (in the final section). In all this, my emphasis lies on identifying promising avenues for further research in Roman archaeology and history: my principal goal is to illustrate the use of geospatial modeling and to encourage more in-depth investigation, which is necessarily beyond the scope of a single paper.

### **Modeling Roman connectivity**

'ORBIS: The Stanford Geospatial Network Model of the Roman World' simulates the time and price costs of travel by land, river and sea across the mature imperial transportation network, notionally approximating conditions around 200 CE.<sup>4</sup> In the version used for this paper, the model links some 750 sites (mostly cities but also some landmarks such as passes and promontories) by means of c.85,000 kilometers of Roman roads selected to represent the principal arterial connections throughout the empire (supplemented by a few caravan tracks in the desert), c.28,000 kilometers of navigable rivers and canals, and 900 sea routes (that is, 450 individual routes in both directions) whose simulated length varies by season but averages c.180,000 kilometers. The model supports movement across this network, which extends across close to ten million square kilometers of land and sea, using a wide range of means of transportation: fourteen different ways of traveling by road, from walking and ox carts to fast carriages and horse relays; civilian and military river boats; and two types of sail ship with slightly different navigational capabilities which may travel across the open sea (in keeping with attested routes), along the coast, and either around the clock or by daylight only. Information on terrestrial and riverine travel speed was gathered from ancient and later premodern sources, while mean sailing speed was computed with the help of a novel algorithm devised by my collaborator Scott Arcenas that enables us to simulate movement of Roman-style sail ships across the seascape in response to winds and, in specific cases, currents.<sup>5</sup> Sailing paths and speeds take account of monthly variation in meteorological conditions reported by standard nautical manuals. The speed of road travel was adjusted for significant changes in altitude, and for certain vehicles constraints were added to mountain passages in the winter. The information and assumptions that were incorporated into the model are described in considerable detail on the web site and need not to be repeated here.<sup>6</sup> Only a few variables that are critical for the specific simulations presented below are explained there.

Certain model simulations are publicly accessible via the project web site. However, the site only offers path-finding functions (that allow users to simulate travel between any two points) but cannot currently support the more complex and computationally demanding manipulations that are required to generate the simulations used in this paper. These systemic simulations are a first attempt to deploy the

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<sup>4</sup> W. Scheidel and E. Meeks, 'ORBIS: The Stanford Geospatial Network Model of the Roman World', Version 1.0 launched May 2, 2012, at <http://orbis.stanford.edu>. For other collaborators, see the 'Credits' page on that site.

<sup>5</sup> See the preliminary exposition by S. Arcenas, 'ORBIS and the sea: a model for maritime transportation under the Roman empire', ORBIS/Applying ORBIS, at <http://orbis.stanford.edu>.

<sup>6</sup> The relevant sections are ORBIS/Understanding ORBIS/Introduction and ORBIS/Building ORBIS/Historical evidence and .../Geospatial technology, at <http://orbis.stanford.edu> (with full bibliography). The technical details will be dealt with more extensively in a forthcoming publication on travel speed in the Roman world.

model in search of the structural properties of Roman communication and transportation networks. The model simulations work best in the aggregate and on a large spatial scale.<sup>7</sup> Computed travel costs do not (and inevitably cannot) capture the experience of any given trip but instead seek to approximate mean outcomes for an infinite number of trips taken on a given route with a given mode of transport in a given month, under the simplifying assumption that these trips used the best available path and were continuous. In so doing, the results reflect structural conditions in two ways, by providing orders of magnitude for actual time and price cost and by allowing us to relate them in a consistent manner to those for other routes. The ultimate goal is to establish the real cost involved in connecting imperial centers to particular regions.

This goal may seem especially difficult to reach when it comes to transportation expenses. Faute de mieux, the model relies on the price ceilings ordained by Diocletian's Prices Edict of 301 CE, which alone yields concurrent information regarding road, river and sea travel. We may leave aside the question whether this text documents realistic price levels: only price *ratios* between different modes of transport are of relevance to our model. All that is required is that these price ceilings are not *both* massively *and* inconsistently wrong. Comparative evidence suggests that this modest condition is indeed met by this set of data. With the help of ORBIS, it is now possible to determine that the envisaged price ratio for moving a given unit of cargo over a given unit of distance is 1 (sea) to 5 (downriver)/10 (upriver) to 52 (wagon).<sup>8</sup> This compares reasonably well to sea/river/road ratios of 1 to 5 to 23 in early eighteenth-century England, a ratio 1 to 7 for river compared to wagon in both Song China (c.1160) and late medieval France, and, once again, of 1 to 5 for river versus road in eighteenth-century England. The match with ratios of 1 to 3.3 (upriver vs land) and 1 to 10 (downriver vs land) attested for China in 1202 is particularly close.<sup>9</sup> These examples make Roman road transport look costlier than elsewhere without making the Edict's values seem downright fantastic.<sup>10</sup> As I have shown in an earlier paper, the maritime freight charges for specific routes stipulated in the Edict do on average very closely correlate with simulated sailing times, which indicates that they are based on extrapolation from empirical observations.<sup>11</sup> While this does not strictly speaking show that the actual prices are likewise credible, it supports a more favorable view of these data than that advanced in recent scholarship.<sup>12</sup> Expressed in wheat equivalent, the Edict's riverine shipping costs are comparable to some real-life charges attested in Roman Egypt.<sup>13</sup> The biggest source for concern

<sup>7</sup> For more detail, see ORBIS/Understanding ORBIS, at <http://orbis.stanford.edu>.

<sup>8</sup> Total allowable charges per *modius kastrensis* are 698 *denarii communes* for 55 sea routes specified in the Price Edict for which ORBIS computes a total length of 104,403 kilometers in July. This yields a mean of 0.00067 *denarii* per kilogram of wheat per kilometer. River travel is priced at 1 *denarius* per *modius* (?*kastrensis*) for 20 miles downriver and 2 *denarii* upriver, or 0.0034 and 0.0068 *denarii* per kilogram of wheat and kilometer. (The cost of provisions for the crew, which were also included, can be estimated to have been comparatively trivial.) Land transport by wagon is priced at 20 *denarii* for 1,200 Roman pounds per Roman mile, or 0.035 *denarii* per kilogram of wheat per kilometer. Earlier calculations sometimes lacked access to more recently discovered information regarding river transportation and were generally unable to establish average maritime charges per kilometer, relying instead on supposedly representative routes: e.g., R. Duncan-Jones, *The Economy of the Roman Empire* (2<sup>nd</sup> ed. 1982), 368; K. Hopkins, 'Models, ships and staples', in P. Garnsey and C. R. Whittaker (eds.), *Trade and Famine in Classical Antiquity* (1983), 104; J. DeLaine, *The Baths of Caracalla* (1997), \*\*.

<sup>9</sup> Duncan-Jones, op. cit. 368; H. Dubois, 'Techniques et coûts des transports terrestres en France aux XIV<sup>e</sup> et XV<sup>e</sup> siècles', in A. V. Marx (ed.), *Trasporti e sviluppo economico, secoli XIII-XVIII* (1986), 290; J. Masschaele, 'Transport costs in medieval England', *Economic History Review* 46 (1993), 277; P. Bol, 'Transportation costs in the Song: ChinaX Project Report 2012', with references (I am indebted to Peter Bol for sharing this unpublished survey with me.) Significantly lower ratios attested for Tang China and inferred for medieval England (Masschaele, op. cit; Bol, op cit.) are hard to explain.

<sup>10</sup> For positive assessments of (earlier) ratios, cf. Hopkins op. cit. 104; R. Laurence, *The Roads of Roman Italy* (1999), 99.

<sup>11</sup> W. Scheidel, 'Explaining the maritime freight charges in Diocletian's prices edict', *JRA* 26 (2013).

<sup>12</sup> *Contra*, e.g., Hopkins op. cit. 103-4 and esp. P. Arnaud, 'Diocletian's prices edict: the prices of seaborne transport and the average duration of maritime travel', *JRA* 20 (2007), 334.

<sup>13</sup> See A. C. Johnson, *Roman Egypt to the reign of Diocletian (ESAR II)* (1936), 400-24.

may be the implied high ratio for sea and land transport, especially considering the high quality of many Roman roads.<sup>14</sup> Here it is important to appreciate that, as I have argued elsewhere, Roman-era sea travel was probably exceptionally cheap by premodern standards for the simple reason that maritime freight charges have historically been to a large extent determined by security rather than shipping technology.<sup>15</sup> Even allowing for residual piracy and corrupt customs officials, we may expect *pax Romana* and diminished toll predation greatly to have pushed down real costs. Most importantly, the price differences between road and sea travel are so large that even if the ratio were cut in half, this would not much change the overall picture (see below).

ORBIS represents the first attempt to model connectivity by time and price cost for the Roman Empire as a whole. A few earlier studies have mostly focused on particular regions: pride of place belongs to Cèsar Carreras Monfort and Pau de Soto Cañamares with their pioneering studies of Roman trade connections in Britain and especially on the Iberian peninsula.<sup>16</sup> Their work, however, was undertaken without the benefit of a means to reconstruct travel time as opposed to price, with no means of simulating sailing routes, and with a limited range of transportation options. Most recently, Justin Leidwanger has tried to model Roman sailing speed in the northeastern Mediterranean.<sup>17</sup> By simultaneously covering all surfaces and accommodating an unprecedented range of variables, the ORBIS model puts this approach on a new footing by enabling complex simulations for the empire as a whole. In its current format, the model works at a fairly high degree of resolution. Thousands of sites and tens of thousands of kilometers of road could be added, resulting in a more fine-grained representation of connectivity in the Roman world. More sophisticated adjustments for slope and sea currents and the introduction of probabilistic parameters might allow a closer approximation of the real costs of movement. Such fine-tuning would primarily improve simulations on a regional scale without altering the basic properties of the imperial network as a whole. Consequently, I focus on the ‘big picture’.

The Roman world encompassed or was part of different kinds of networks. Some world-systems theorists think in terms of four types: in roughly ascending order of scale, bulk-goods networks, political/military networks, information networks, and prestige-goods networks.<sup>18</sup> Premodern bulk-goods networks were necessarily relatively small, as the transfer of low-value goods was constrained by transportation costs, but represented an unusually intense kind of integration. Political/military networks coincide with multiple-state systems or, as in the Roman case, individual empires and the peripheries

<sup>14</sup> It is unclear whether this high ratio can be blamed on Roman-era harnessing, which used to be considered inadequate but has now found defenders: see M. Polfer, ‘Der Transport über den Landweg – ein Hemmschuh für die Wirtschaft der römischen Kaiserzeit?’, *Helinium* 31 (1991), 275 and esp. G. Raepsaet, *Attelages et techniques de transport dans le monde gréco-romain* (2002).

<sup>15</sup> W. Scheidel, ‘A comparative perspective on the determinants of the scale and productivity of maritime trade in the Roman Mediterranean’, in W. V. Harris and K. Iara (eds.), *Maritime Technology in the Ancient Economy* (2011), 21-37, with discussion of medieval and early modern comparanda.

<sup>16</sup> For Britain, see A. Carreras, *Una reconstrucción del comercio en cerámicas: la red de transportes en Britannia* (1994); *La economía de la Britannia romana: la importación de alimentos* (2000). The most detailed study, for part of the Iberian peninsula, is P. de Soto, ‘Anàlisi de la xarxa de comunicacions i del transport a la Catalunya romana: estudis de distribució i mobilitat’ (PhD thesis Universitat Autònoma de Barcelona 2010). See also C. Carreras and P. De Soto, *Historia de la movilidad en la península ibérica: redes de transporte en SIG* (2000); P. De Soto and Carreras, ‘La movilidad en época romana en Hispania: aplicaciones de redes de análisis (SIG) para el estudio diacrónico de las infraestructuras de transporte’, *Habis* 40 (2009), 303-24; P. de Soto, ‘Transportation costs in NW Hispania’, in C. Carreras and R. Morais (eds.), *The Western Roman Atlantic Façade: A Study of the Economy and Trade in the Mar Exterior from the Republic to the Principate* (2010), 31-43; C. Carreras and P. de Soto, ‘The Roman transport network: a precedent for the integration of the European mobility’, *Historical Methods* forthcoming. For the entire empire, see now C. Carreras, ‘An archaeological perspective’, in Carreras and Morais, op. cit. 7-19.

<sup>17</sup> J. Leidwanger, ‘Maritime archaeology as economic history: long-term trends of Roman commerce in the northeast Mediterranean’ (PhD thesis University of Pennsylvania 2011), 90-121.

<sup>18</sup> The classic exposition is C. Chase-Dunn and T. D. Hall, *Rise and Demise: Comparing World-Systems* (1997), esp. 52-5.

beyond their frontiers. Large states may encompass several bulk-goods networks. The other two types are more expansive but also much more ephemeral: Roman consumption of Chinese silk or the spread of Manichaeism to China are suitable examples. In dealing with the Roman Empire, I focus on bulk-goods and political/military networks centered on the political centers, and especially on the tensions arising from their respective differences in scope. (High-value goods traveled more freely and are therefore less susceptible to transport cost analysis.) I also add a third kind of network for information flow, not in the broad continental-scale sense in which this concept is used in world-systems theory but more narrowly as a variant of political/military connectivity: the goal is to model the flow of information between imperial centers and subject territories. Although this kind of network may have been less significant than the other two, it nevertheless reflects constraints on the empire's ability to command and control that are worth considering. Viewed side by side, these three networks reveal the effective costs of connectivity throughout the empire.

### From expansion to segmentation

The speed of military power projection is a critical variable in structuring political/military networks. In the Republican period, time distance from Rome and later Italy to subject territories mattered most. Under the monarchy, the direction of connectivity was reversed as the time it took for frontier armies to reach the center assumed greater political significance, given their vital role in power politics. The Roman military primarily relied on land routes.<sup>19</sup> This raises the question of how troop movements by sea are to be integrated in a general model of military connectivity. Within the Mediterranean, maritime transfers were necessary to attach North Africa to Roman rule and would more generally always have been an option, regardless of how frequently it was exercised. My simulations adopt a conservative approach by merely ruling out routine seaborne troop movements along the Atlantic coast, which seem to have been unknown on a significant scale, except for crossings of the English Channel.<sup>20</sup> The model also disregards rivers which, notwithstanding Julian's advance down the Danube in 361 CE, do not appear to have been a common conduit for the Roman military, at least not on a large scale.<sup>21</sup> Within these basic constraints, several configurations are possible. One option is to optimize the time cost of both land and sea connections. This is achieved by applying a mean daily marching distance of 20 Roman miles or 30 kilometers, a figure that might be on the high side for longer expeditions but need not have been unfeasible.<sup>22</sup> Sailing speeds are simulated by allowing movement on all available routes, both coastal and

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<sup>19</sup> Aside from classic sea routes for military transfers such as from Sicily to Africa or across the Strait of Otranto, most references are to the maritime movement of supplies, not of the troops themselves: e.g., J. P. Roth, *The Logistics of the Roman Army at War* (264 BC – AD 235) (1999), 189-95; and cf. also C. G. Starr, *The Roman Imperial Navy 31 B.C. – A.D. 324* (1941), 167-208; M. Reddé, *Mare Nostrum* (1986), 370-99. Except for the abovementioned routes, explicit references to longer-range maritime troop transfers for campaigns under the monarchy are extremely rare: Starr, op. cit. 186-7, 192; Reddé, op. cit. 373 (who however tries to infer a larger number of such operations indirectly from epigraphic records such as dedications by naval personnel).

<sup>20</sup> Roman sea routes in the Atlantic are generally poorly known: for recent scholarship, see Carreras and Morais, op. cit. For sea ports on rivers in Britain, cf. S. Rippon, 'Coastal trade in Roman Britain: the investigation of Crandon Bridge, Somerset, a Romano-British transshipment port beside the Severn estuary', *Britannia* 39 (2008), esp. 85-9.

<sup>21</sup> For this episode, see Zosimus 2.10.2-3 (3,000 soldiers reached Sirmium from Raetia in eleven days, followed by 20,000 troops on foot), with F. Himmler, H. Konen and J. Löffl, *Exploratio Danubiae: ein rekonstruiertes spätantikes Flusskriegsschiff auf den Spuren Kaiser Julian Apostatas* (2009). Other instances are limited to the German campaign of 16 CE (Tac. *Ann.* 2.5) and a few campaigns along the Euphrates: Reddé, op. cit. 357-8, 362. The most detailed study of Roman riverine military assets is H. C. Konen, *Classis Germanica: die römische Rheinflotte im 1.-3. Jahrhundert n. Chr.* (2000). See now more generally B. Campbell, *Rivers and the power of ancient Rome* (2012), 160-99.

<sup>22</sup> For discussion, see most recently A. Kolb, *Transport und Nachrichtentransfer im Römischen Reich* (2000), 310-11. Vegetius 1.9 prescribes a training march for recruits of 20 miles in full gear that was to be completed within five

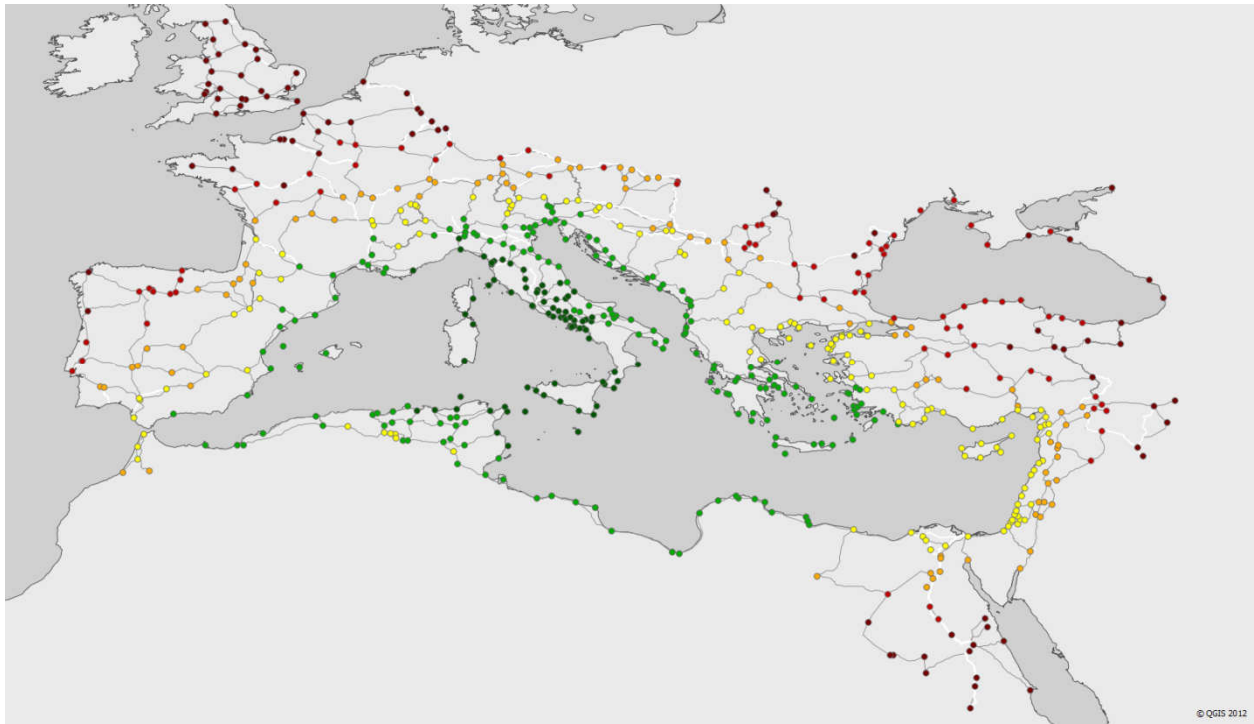
open sea, 24 hours a day. These starting assumptions necessarily produce a ‘fast’ network that systematically tends to underestimate actual transfer times but does so in a consistent fashion, without upsetting the balance between terrestrial and maritime speeds. An alternative option is to minimize both as far as the model parameters allow, by reducing mean daily marching distance to 20 kilometers (perhaps a more realistic value for multi-week marches) and sailing speed by limiting movement to coastal routes during daytime. This results in a ‘slow’ system that in terms of regional differentiation looks only slightly different overall but likewise seeks to maintain a balance between different transportation modes. Together, these two scenarios may be thought to circumscribe the limits of the plausible.

These assumptions allow us to produce simple time cost maps centered on the city of Rome (Maps 1-2). (The inverse – from the outside in – would look very similar, except for a few adjustments to account for different wind conditions.)

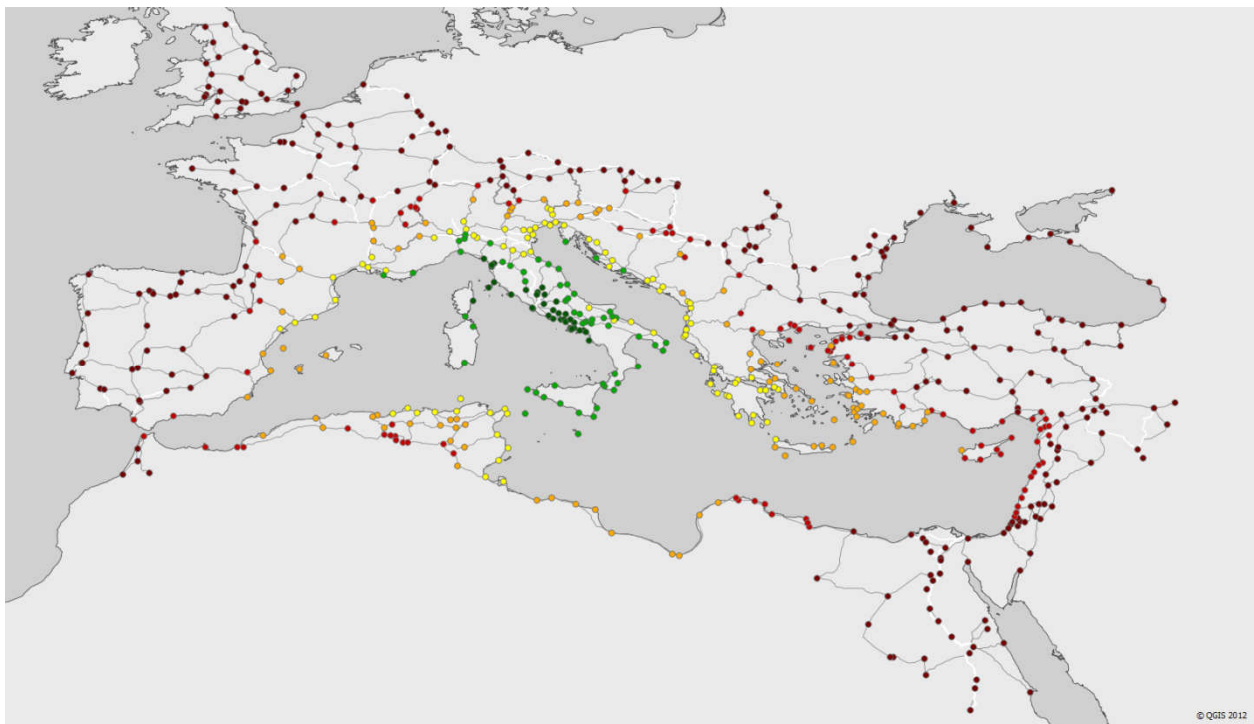
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summer hours, which may reflect contemporary expectations of what constituted a reasonable daily effort. Cf. also P. Vigneron, *Le cheval dans l'antiquité gréco-romaine* (1968), 158; A. J. Silverstein, *Postal systems in the pre-modern Islamic world* (2007), 12-13. This speed could be matched by moderately loaded mules: B. Cotterell and J. Kamminga, *Mechanics of Pre-industrial Technology* (1990), 194. 20 kilometers per day is certainly feasible as a longer-term average (Kolb op. cit. 311) and also works for heavily loaded mules (Cotterell and Kamminga op. cit. 194). Cf. also D. W. Engels, *Alexander the Great and the Logistics of the Macedonian Army* (1978), 16 (15 kilometers/day for Alexander the Great); F. Ludwig, *Untersuchungen über die Reise- und Marschgeschwindigkeit im XII. und XIII. Jahrhundert* (1897), 182-3 and M. McCormick, *Origins of the European Economy: Communications and Commerce, A.D. 300-900* (2001), 477, for daily marches of 20 to 30 kilometers; R. Chevallier, *Roman Roads* (1976), 194. Ancient sources tend to privilege particularly rapid marches (for which see W. Riepl, *Das Nachrichtenwesen des Altertums* (1913), 129-36) that cannot reflect routine standards and longer-distance performance (*pace* Laurence op. cit. 82).

For determining distances, ORBIS relies on road lengths measured by GIS. Comparison between measured distances and those reported in various Roman itineraries has revealed substantial incongruities that cast doubt on the latter's accuracy. Thus, the matches between measured distances and itinerary data for northwestern Spain observed by J. L. V. González, ‘GIS and Roman ways research in Hispania’, paper presented at the ESRI European User Conference 2011, Madrid (Spain), October 26-28, 2011, could not be replicated for the system as a whole: see D.-E. Padilla Peralta, ‘ORBIS and the ancient itineraries: preliminary observations’, ORBIS/Applying ORBIS, at <http://orbis.stanford.edu>. Cf. also M. Pazarli, E. Livieratos and C. Boutoura, ‘Road network of Crete in Tabula Peutingeriana’, *e-Perimtron* 2 (2007), 245-60.



Map 1 Time cost from Rome, at high military speed (summer)



Map 2 Time cost from Rome, at low military speed (summer)

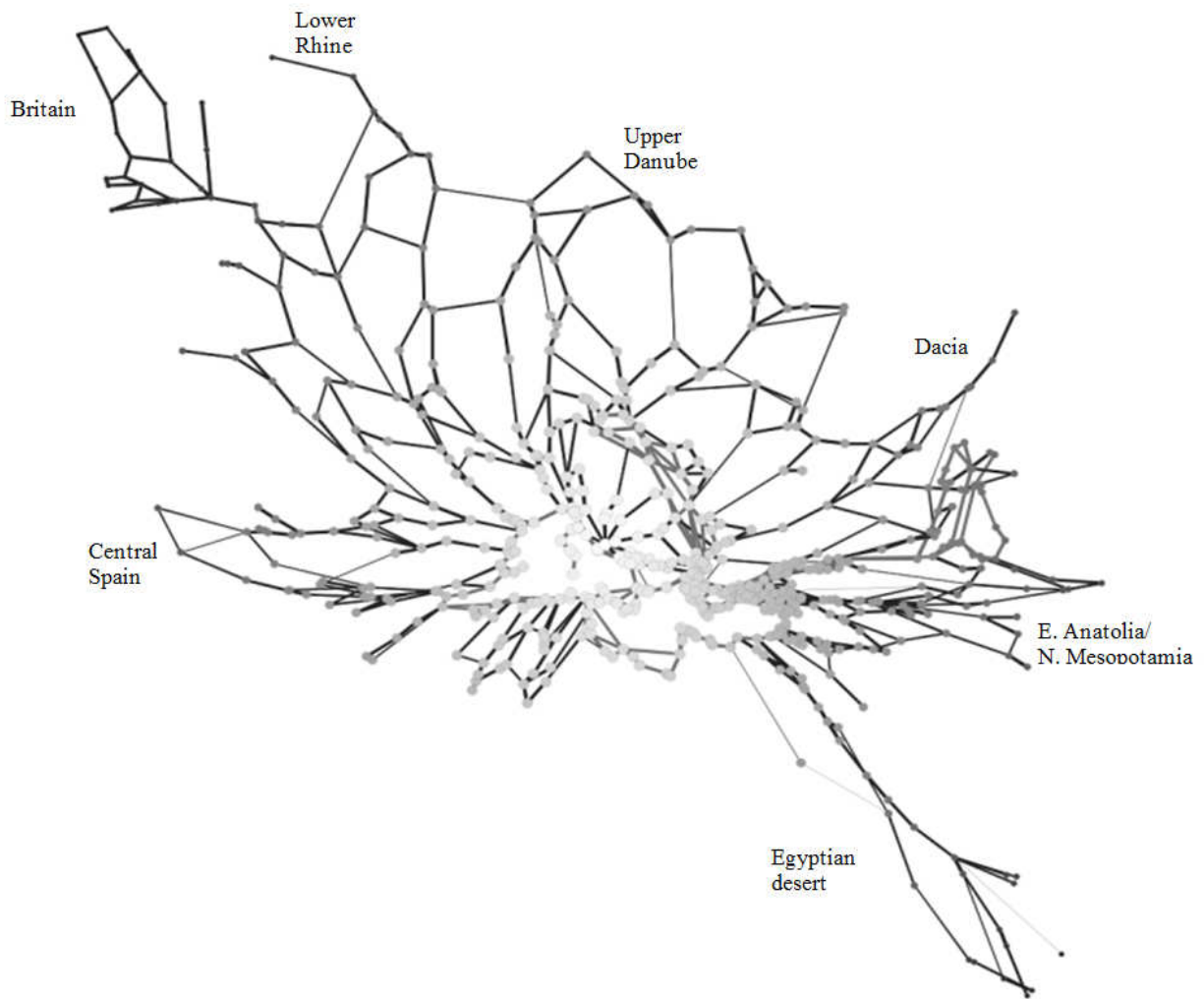


The ‘fast’ version (Map 1) shows (in dark green) a core area that reflects Roman military reach up to the third century BCE, centered on Italy, the islands and North Africa. Sicily, Sardinia and Corsica and even Carthage appear closer to Rome than eastern Italy or the Po Valley, a configuration that meshes well with the fact that Rome’s first military engagements beyond the Italian peninsula took place in that region: Rome’s ‘natural backyard’ is the sea to the west and south, and excludes northern and eastern Italy. This highlights the fragility of traditional regionalization that conceives of units based on geomorphology (where a peninsula bordered by the Alps is thought to form a region) or later developments (such as the emergence of ‘Italy’ as a geographically demarcated concept) rather than on actual connectivity costs. The light green-colored sites track much of Roman expansion until the late second century BCE, into coastal Spain, Provence, the Aegean and North Africa. The main exception is the historically deeper penetration of the Iberian peninsula in this period, a development that did not only impose comparatively greater logistical costs but also, and perhaps at least in part as a consequence, turned into a difficult and protracted affair. Moreover, as we will see below, this exception may have been facilitated by ecological proximity, as indicated by the feasibility of ‘Mediterranean’ olive cultivation (see below, Map 6). By contrast, the most remote areas in terms of time cost, here marked in red and brown, were mostly the last ones to be brought under Roman rule: northern Gaul, northwestern Spain, eastern Anatolia and northern Mesopotamia, Egypt, Britain, Dacia, and parts of the Danube basin (whose effective proximity to Rome might well be overstated due to the model’s very conservative cost adjustment for Alpine crossings). Map 1 shows that radial distance from Rome is a much poorer predictor of the spatial spread of Roman power than time cost distance. Much the same is true of the ‘slow’ version in Map 2, where the green, yellow and orange markers largely coincide with the reach of Roman rule by the late second century BCE, again with the partial – and costly – exception of parts of the Iberian peninsula.

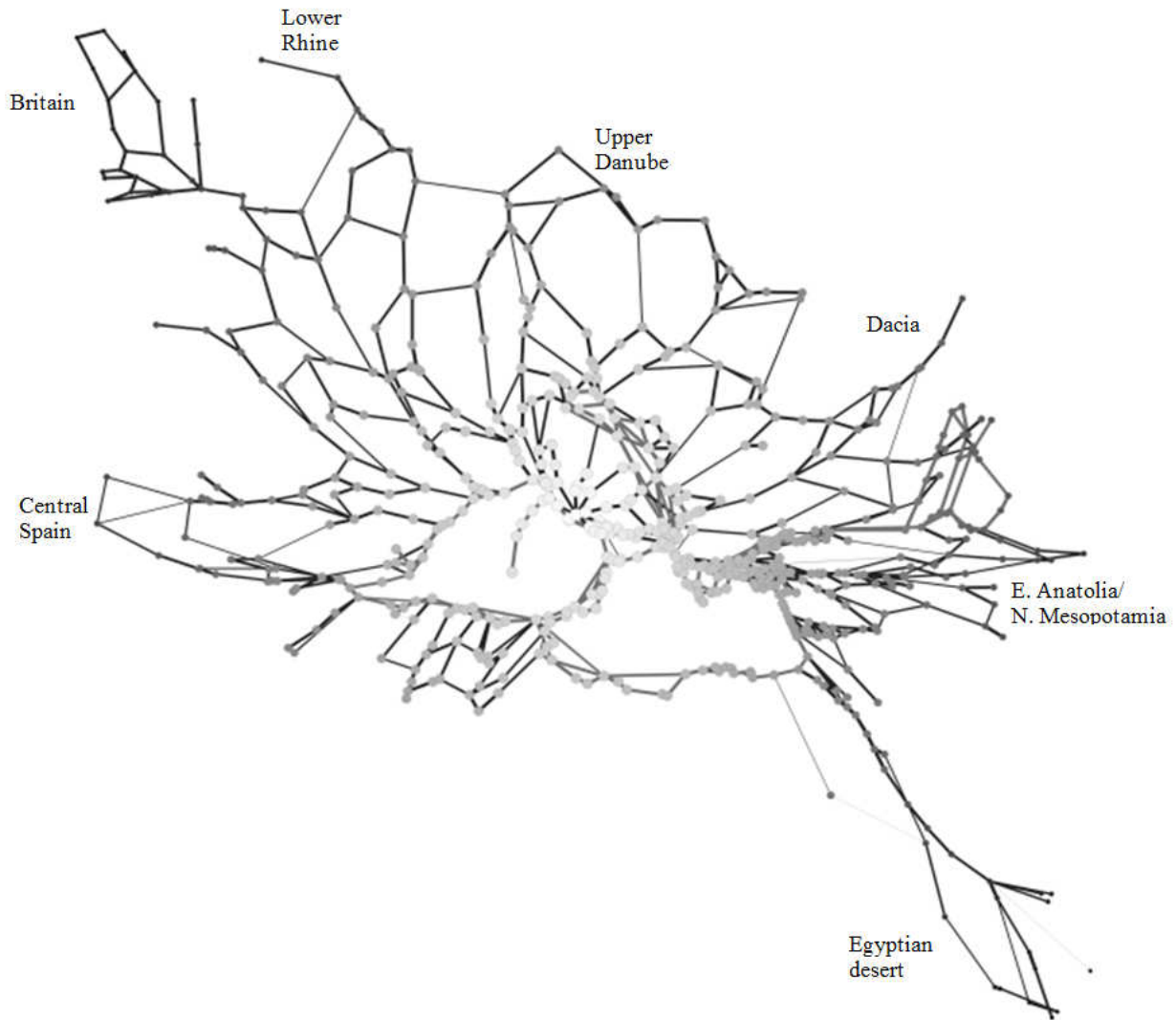
These patterns can be more clearly visualized with the help of distance cartograms which express cost – in this case travel time – as physical distance (Cartograms 1-2).<sup>23</sup>

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<sup>23</sup> For an interactive ‘proof-of-concept’ version, see ORBIS/Mapping ORBIS/Interactive Distance Cartogram, <http://orbis.stanford.edu/#fn4>. The substantial computational requirements involved in creating complex cartograms currently prevent their ad hoc generation on the website.



Cartogram 1 Time cost from Rome, at high military speed (summer)

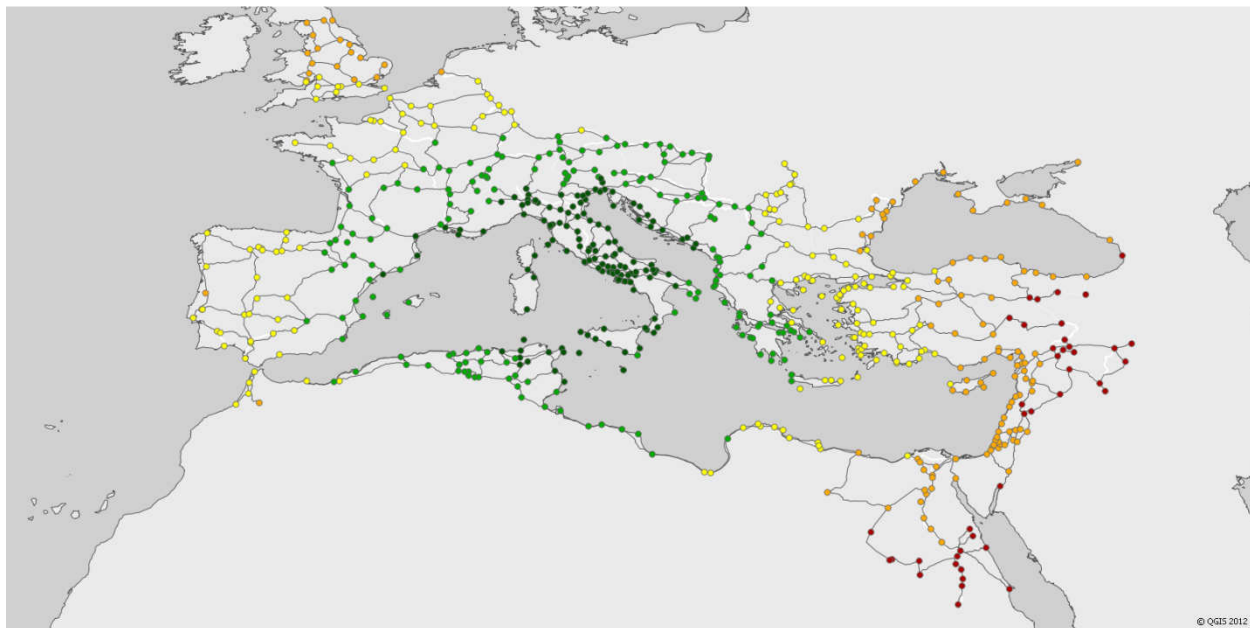


Cartogram 2 Time cost from Rome, at low military speed (summer)

The higher speed of maritime transport compresses the sea relative to its terrestrial hinterlands, especially in the ‘fast’ version. Britain, the upper Danube basin and Dacia can be shown to be particularly remote from the center in terms of travel time, as were eastern Anatolia, northern Mesopotamia, and Egypt outside the Nile valley.

Similar outcomes can be observed for the speed of communication, measured between Rome and all other sites in the imperial network. The simulations are based on a daily mean distance of 67 kilometers by road covered by couriers of the *cursus publicus*, the use of fast rowed boats where available, and the use of sail ships with access to all lanes 24 hours a day (Map 3).<sup>24</sup>

<sup>24</sup> The literature on the speed of Roman messengers is large: the most substantial discussions are A. M. Ramsay, ‘The speed of the Roman imperial post’, *JRS* 15 (1925), 60-74; P. Stoffel, *Über die Staatspost, die Ochsengespanne und die requirierten Ochsengespanne* (1994), 161-5, and now esp. Kolb, op. cit. 321-32. Normal messenger speeds gathered by these studies fall in a range from the 50s to the 80s kilometers per day, for a median value of 67 kilometers (45 Roman miles). Cf. also McCormick op. cit. 476-7 (45-78 kilometers/day); Y. Renouard, ‘Routes,



Map 3 Time cost from Rome, at courier speed (summer)

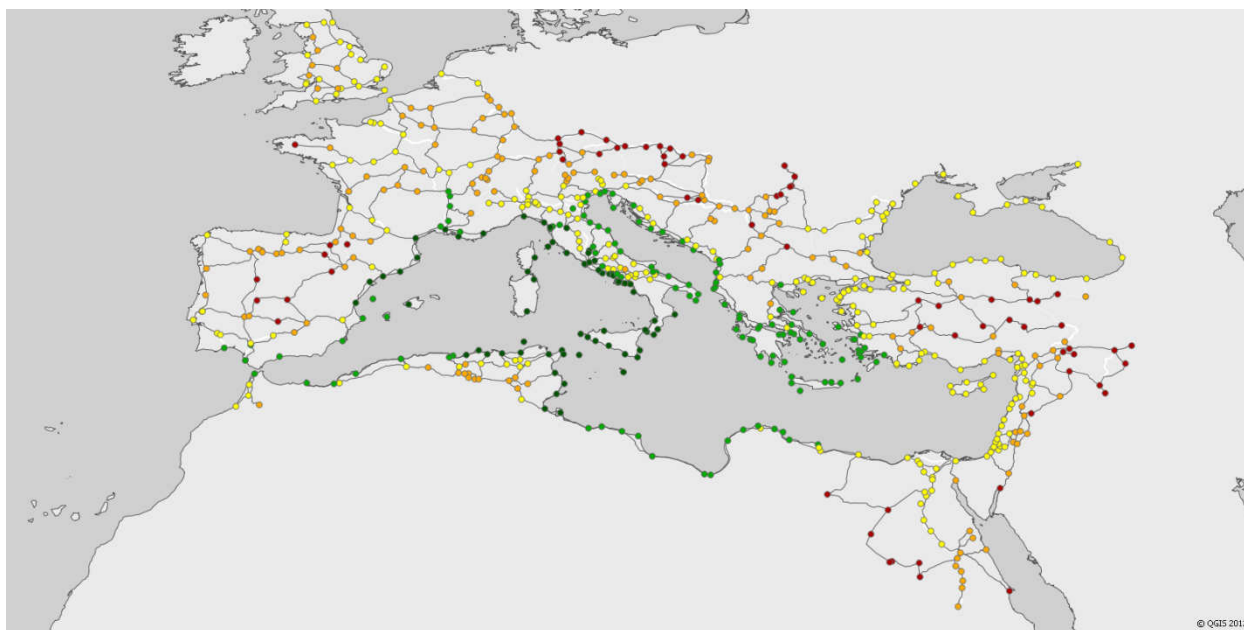
The most striking feature is the imbalance between the eastern and western peripheries of the mature empire. With the small exception of central and northern Britain, much of what was later to become the Eastern Empire was farther removed from Rome than any of the peripheries of the future Western Empire: the Black Sea coast, much of Asia Minor, and the entire Levant. This reflects a fundamental east-west segmentation that is documented in greater detail in the section on segmentation and disintegration.

Spatial differentiation according to transport price is patterned differently. The simulation measures the expense of moving one kilogram of wheat by wagon, boat, and sail ship (Map 4).<sup>25</sup>

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étapes et vitesses de marche de France à Rome au XIIIe et au XIVe siècles d'après les itinéraires d'Eudes Rigaud (1254) et de Barthélemy Bonis (1350)', in *Studi in onore di Amintore Fanfani, III* (1962), 113 (50-80 kilometers/day in fifteenth-century Europe). Again, higher speeds are documented (Kolb op. cit. 322) but were not the standard (*pace* Laurence, op. cit. 81, who generally seeks to maximize Roman travel performance). I use 67 kilometers per day as an approximation of the mean speed of the *cursus publicus* (Scheidel, op. cit., n.12). For military row boats, I draw on Zosimus 2.10.2-3 and the experimental recreation by Himmeler, Konen and Löffel op. cit. (see above, n.22), for a daily speed of 120 kilometers downriver and 50 kilometers upriver. The extent to which sea ships were used by the *cursus publicus* remains highly uncertain: cf. Reddé, op. cit. 447-51.

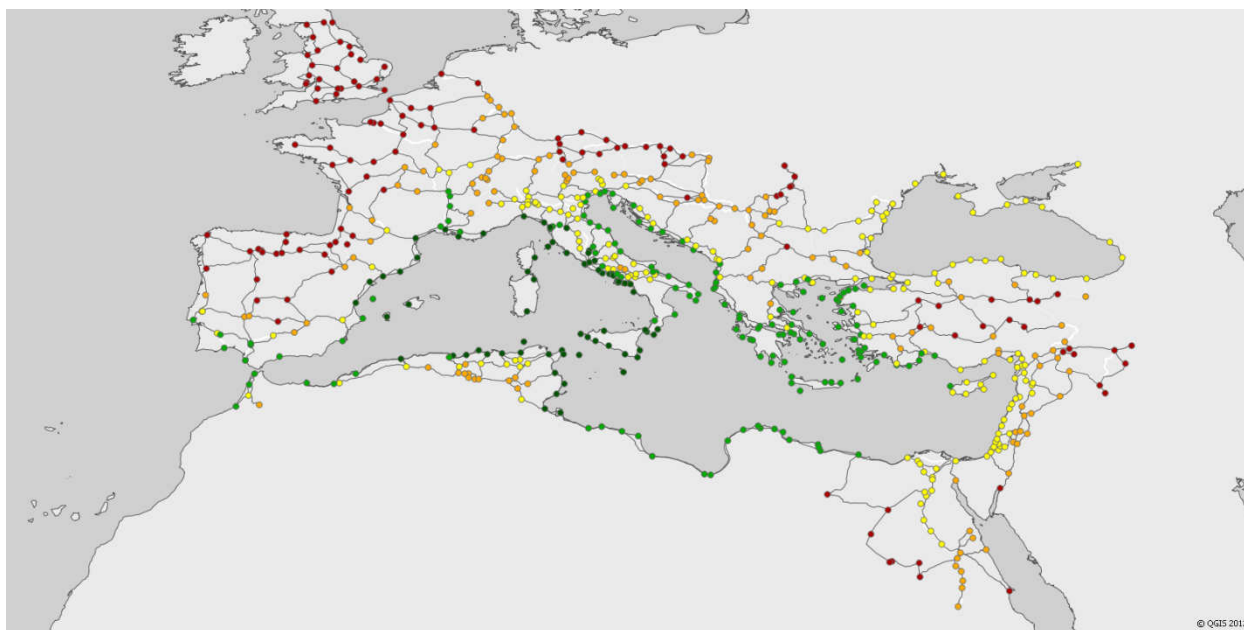
<sup>25</sup> For the underlying price rates, see above, n.8.



Map 4 Price cost to Rome (summer)

The low price cost of sea transport increased the potential for economic integration in coastal areas. A core zone (marked in green) centered on Rome extends along much of the Mediterranean seaboard from southern Spain to Provence, around Italy, the Adriatic, the western islands, Greece, and what is now Tunisia and Libya. The extent of this region broadly corresponds to the inner tier of political/military proximity (the green sites) in Map 1 and the inner and intermediate tiers (green, yellow and orange) in Map 2. Thanks to the efficiency of maritime transport, it would have been less expensive to reach Rome from Britain than from the central Iberian peninsula or the upper Danube basin (and *vice versa*). It must be stressed that the model can only reveal the *potential* for connections with Britain, and not whether they were properly realized. Even so, this observation may help account for the arrival in Britain of assorted import goods from afar. This potential was severely curtailed in the winter months, when the likely interruption of Atlantic shipping would have turned the northwestern periphery into the effectively most remote part of the empire (Map 5).<sup>26</sup> This suggests that Atlantic shipping may have played a more significant role in the overall integration of the empire than existing scholarship would lead one to expect.

<sup>26</sup> The simulations in ORBIS assume that regular sailing was not feasible in parts of the ocean where wave heights of at least 12 feet are encountered for at least 10 percent of the time in a given month, a condition that serves as a proxy of stormy weather: National Imagery and Mapping Agency, *Atlas of Pilot Charts: North Atlantic Ocean* (2002). In the Roman world, such weather events were limited to the Atlantic and, in the winter, the northwestern Mediterranean south of France.



Map 5 Price cost to Rome (winter)

The extent of seasonal variation in transport costs is an important issue in its own right. While Mediterranean shipping undoubtedly abated in the winter there is no good reason to assume that the sea was in any meaningful sense ‘closed’ during that period.<sup>27</sup> For now, by simulating all connections that were possible at a given time, our model cannot take account of seasonal fluctuations in the likelihood of travel, by sea or other media. Map 5 only applies to travel that was actually undertaken, no matter how rare it may have been in real life. Whether winter conditions distorted actual travel costs by privileging certain types of routes over others remains an open question. Although it is possible that sea travel was disproportionately affected by winter weather, terrestrial movement in much of Europe and Asia Minor was likewise susceptible to restrictions.<sup>28</sup>

Owing to these uncertainties, our simulations generally focus on the summer when different modes of transportation (except for some rivers) all reached their maximum potential. On the assumption that most transport and communications took place between spring and fall, this limitation does not greatly affect the representative value of the resultant simulations. For that part of the year, the case of Britain serves to illustrate the relative isolation of the Po valley, from which it was as expensive to reach Rome as from the British coast or, perhaps more realistically, from Middle Egypt. This observation reinforces the impression gained from the previous political/military time cost simulations that Italy was

<sup>27</sup> W. M. Ramsay, ‘Roads and travel’, in J. Hastings (ed.), *A Dictionary of the Bible, Extra volume* (1904), 376; S. D. Goitein, *A Mediterranean Society: The Jewish Communities of the World as Portrayed in the Documents of the Cairo Geniza, I* (1967), 316-7; A. C. Leighton, *Transport and communication in early medieval Europe AD 500-1100* (1972), 132; F. J. Meijer, ‘Mare clausum aut mare apertum: een beschouwing over zeevaart in de winter’, *Hermeneus* 55 (1983), 2-20; Ohler, op. cit. 11; G. Jehel, *Les Génois en Méditerranée occidentale (fin XI-début du XIV siècle)* (1993), 315-6; Braudel, op. cit. 227-32; Horden and Purcell, op. cit. 137-43; McCormick, op. cit. 444-68.

<sup>28</sup> Sweeping claims about winter closures of roads (albeit mostly in the mountains: W. M. Ramsay, op. cit. 377; Vigneron, op. cit. 174-5) conflict with comparative historical data for speedy Alpine crossings and even fairs in the depths of winter. See Renouard, op. cit. 411-20; J. F. Bergier, ‘Le trafic à travers les Alpes et les liaisons transalpines du haut Moyen Âge aux XVIIe siècle’, in *Le Alpi et l'Europe*, 3 (1975), 37; G. Castelnovo, ‘Tempi, distanze e percorsi in montagna nel basso medioevo’, in *Spazi, tempi, misure e percorsi nell'Europa del bassomedioevo* (1996), 226-7.

not a coherent unit. The effective hinterland of the city of Rome was both larger and smaller than Italy: it encompassed the coastal western Mediterranean across two continents but excluded much of northern Italy.<sup>29</sup> This has significant repercussions for existing debates: once we accept that Italy, as whole, cannot be conceptualized as Rome's immediate hinterland, it becomes rather meaningless to estimate an Italian urbanization rate, to name just one popular academic exercise.<sup>30</sup>

In terms of the potential for economic integration, the most remote regions were the Danube basin, which except for its lowest reaches was far from the sea, the interior of Anatolia, northern Mesopotamia, and the Egyptian oases. The Rhine region benefited only somewhat from proximity to the Rhone and access to the Atlantic. Due to its strong current, the Rhone in particular was considerably more useful for southward movement than for strategically more desirable upriver transfers.<sup>31</sup>

The extreme degree of price cost differentiation is thrown into sharp relief by a distance cartogram that expresses transport expenses as physical distance from Rome. Here we observe a tiny Mediterranean core and far-flung peripheries (Cartogram 3).

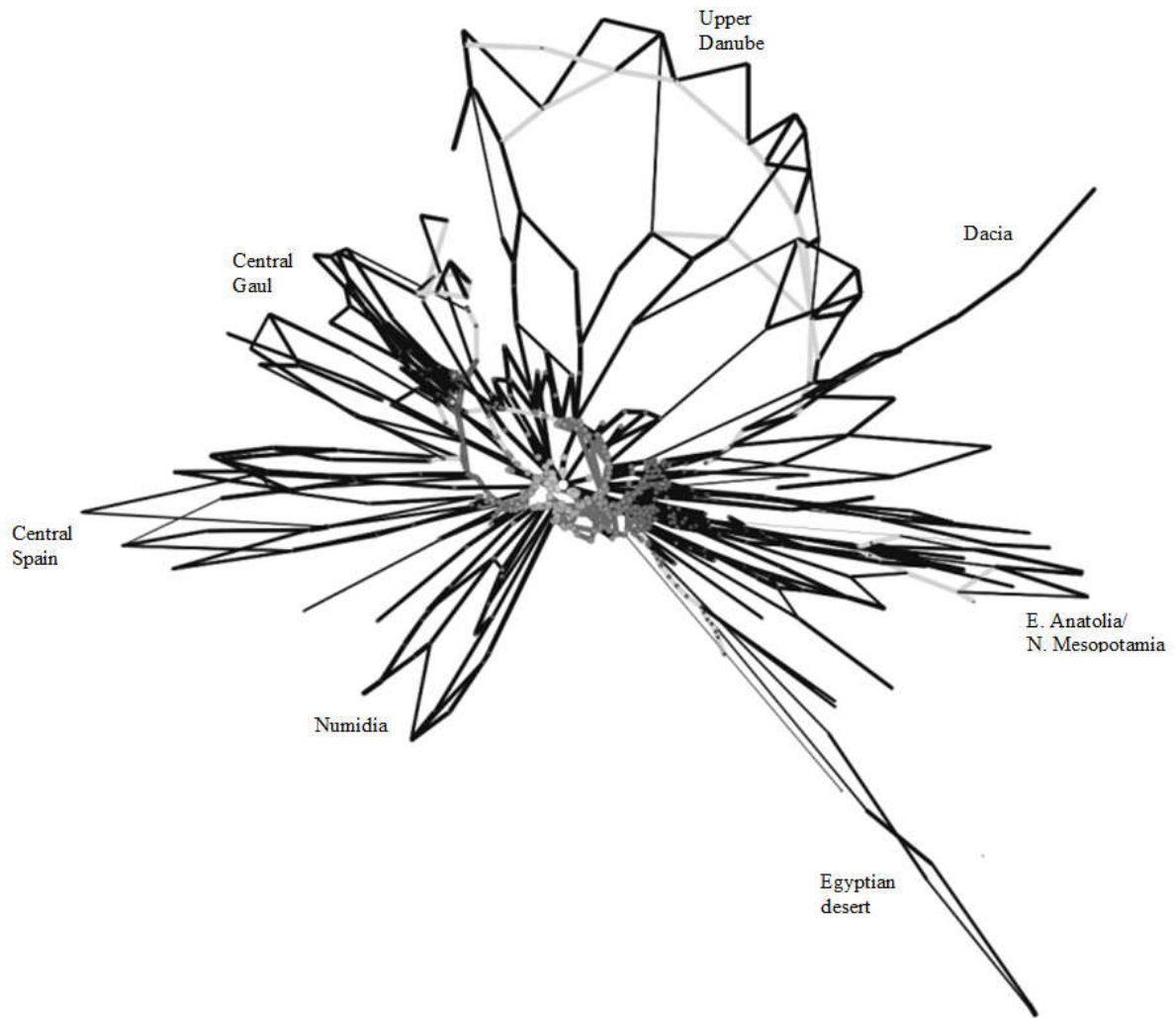
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<sup>29</sup> The classic discussions of the Po Valley all to varying degrees stress its isolation: P. A. Brunt, *Italian Manpower 225 B.C. – A.D. 14* (1971), 172-84; P. Garnsey, *Cities, Peasants and Food in Classical Antiquity*, ed. W. Scheidel (1998), 45-62; W. V. Harris, *Rome's Imperial Economy* (2011), 188-97. Cf. also P. Horden and N. Purcell, *The Corrupting Sea: A Study of Mediterranean History* (2000), 115-22 for 'dispersed hinterlands' more generally.

<sup>30</sup> *Contra*, e.g., K. Hopkins, *Conquerors and Slaves* (1978), 68-9; E. Lo Cascio, 'The size of the Italian population: Beloch and the meaning of the Italian census figures', *JRS* 84 (1994), 39; N. Morley, *Metropolis and Hinterland* (1996), 182; E. Lo Cascio, 'The population of Roman Italy in town and country', in J. Bintliff and K. Sbonias (eds.), *Reconstructing Past Population Trends in Mediterranean Europe* (1999), 164-5; see already W. Scheidel, 'Roman population size: the logic of the debate', in L. de Ligt and S. Northwood (ed.), *People, Land, and Politics* (2008), 32.

<sup>31</sup> Its current was stronger than those of other major rivers in the empire (e.g., N. Beardmore, *Manual of Hydrology* (1872), 158) and could be reinforced by the Mistral, which blows roughly from the north. In the Middle Ages, a flat barge could reach Avignon from Lyon in two to five days but might take a month to be towed back upriver: N. Ohler, *The Medieval Traveler* (1989), 34. In addition, the river ran low for part of the year: D. Brewster, 'Inland navigation', in *The Edinburgh Encyclopaedia*, vol. 14 (1832), 265; F. Denel, 'La navigation sur le Rhone au XVe siècle d'après les registres de péage de Baix', *Annales du Midi* 82 (1970), 289-90.





Cartogram 3 Price cost to Rome (summer)

Although a reduction of the ratio of the costs of land transport to that of sea transport (see above, in the previous section) would somewhat compress the hinterland, the imbalance is so massive that this would fail to change the overall picture. Cartogram 4 highlights the crucial importance of maritime transport by blocking out roads, thereby clarifying the picture.

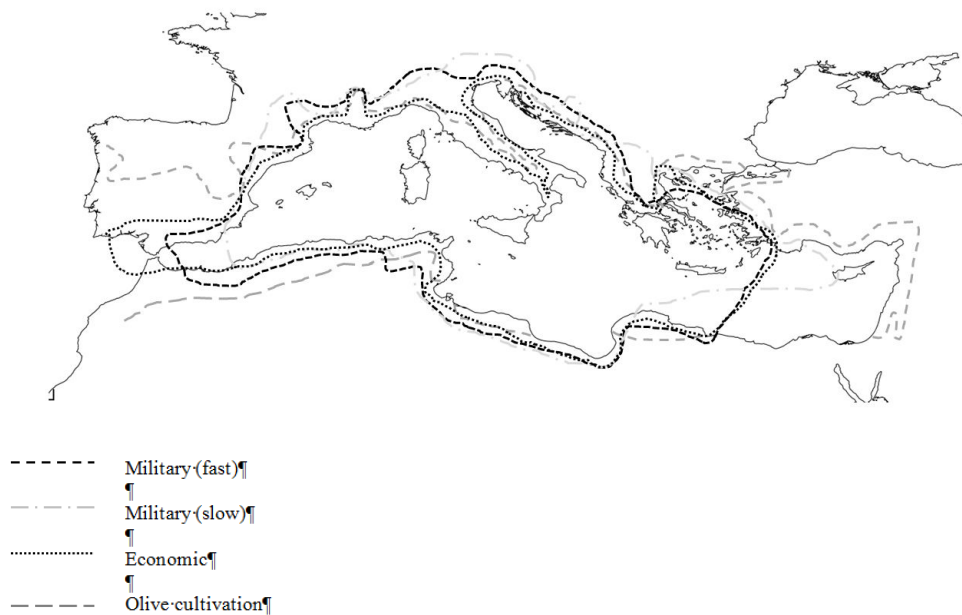




Cartogram 4 Price cost to Rome (summer), disaggregated by medium (dark grey lines: sea routes; light grey lines: river routes; no lines: road routes)

The maps and cartograms presented so far reveal a fundamental mismatch between military and economic reach. The mature empire consisted of three distinct zones. The first was what we might define as the core empire, represented by the inner or inner and intermediate tiers of political/military proximity (in Maps 1-2, as defined above) and the first tier of economic accessibility (the green-colored sites in Map 4), which broadly overlap. With the exception of the Levant and part of the interior of the Iberian peninsula, they, in turn, closely overlap with the area in which olive cultivation was feasible and which constituted the Mediterranean in a narrow ecological sense (Map 6).<sup>32</sup>

<sup>32</sup> For the boundaries of olive cultivation, see Horden and Purcell, *op. cit.*, 14; for its importance in the Roman world, most recently G. Woolf, *Rome: an empire's story* (2012), 51. With W. V. Harris, 'The Mediterranean and ancient history', in Harris (ed.), *Rethinking the Mediterranean* (2005), I think of the Mediterranean in terms of a construct "with something of a natural basis" (4) represented by climate, certain crops and styles of animal husbandry, and relatively easy maritime navigability (21-23), notwithstanding Horden and Purcell's emphasis on micro-ecological fragmentation.



Map 6 The Mediterranean core of the Roman Empire

This congruence of ready military reach, economic proximity, and ecological affinity provided favorable preconditions for political control and the transfer of goods. From the mid-first century BCE onward, however, this Mediterranean core zone was suddenly and comparatively rapidly augmented by two more peripheral zones. What was to become the larger of those two was the result of Caesarian-Augustan expansion into Gaul, Germany and the Danube basin, whereas the other, eastward one ultimately stemmed from the Pompeian campaigns in eastern Anatolia and Syria. While both of these movements were soon checked – by the Parthians in the 50s and 30s BCE and the Germans after 9 CE –, they continued on a diminished scale through the incorporation of Britain, Dacia, and the hinterland of the Greater Syria region.<sup>33</sup> In terms of time and price costs, these developments produced two giant protuberances to the northwest and east of the original core.

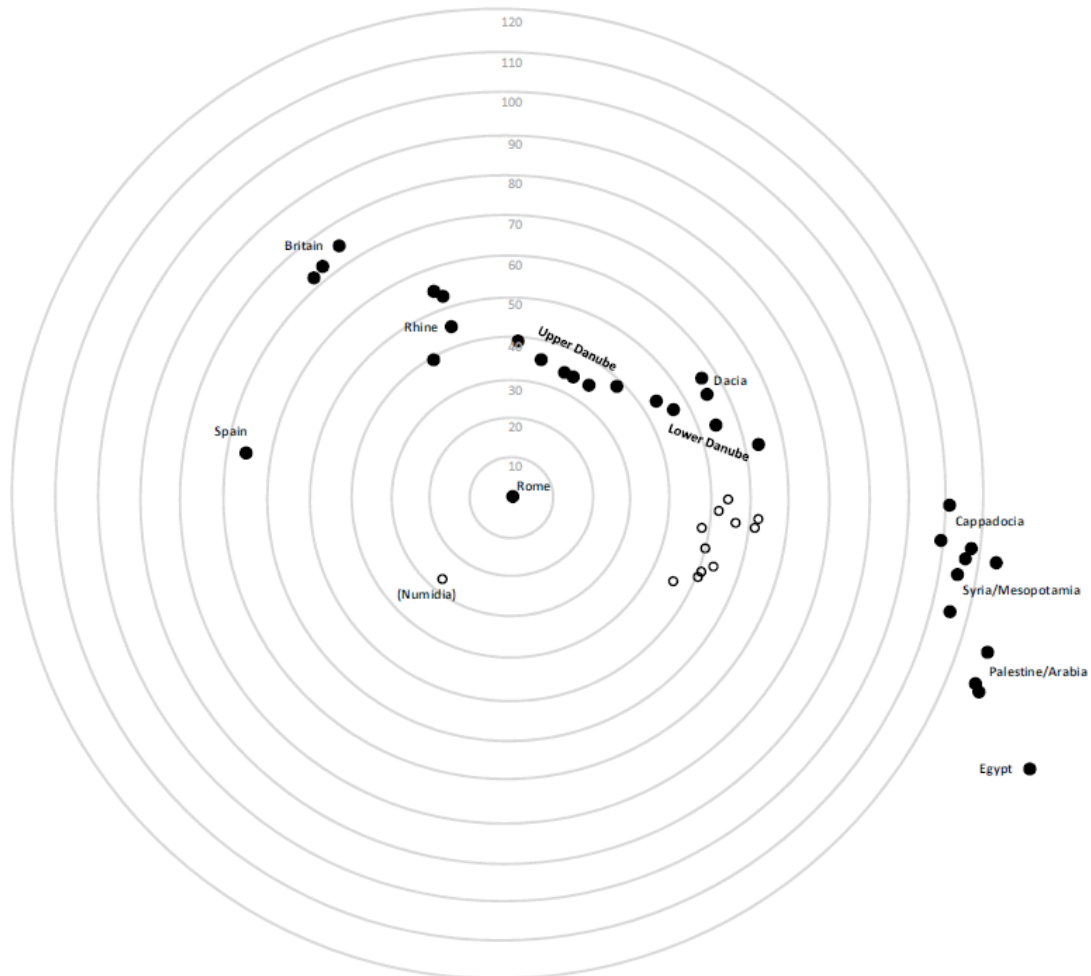
### From segmentation to disintegration

These dramatic moves beyond the Mediterranean core had tremendous long-term consequences that were arguably the most important legacy of the extraordinary commands and warlordism of the failing Republic that encouraged extravagant military ventures for domestic political reasons. One outcome was the spatial peripherization of military power that prepared the ground for the eventual peripherization of political power when officers from the northern Balkans came to furnish a large majority of all emperors for almost four centuries and the political centers – Trier, Milan, Sirmium,

<sup>33</sup> It is worth noting that the attempted conquest of Germany (12 BCE – 9/16 CE), Trajan's invasion of Armenia and Mesopotamia (114-117 CE) and Roman campaigning in Bohemia, Moravia, Slovakia and the Hungarian plain (which may or may not have aimed for conquest; 172-180 CE) took place at exceptionally remote locations as defined by connectivity costs relative to the imperial capital and that the odds for successful incorporation were small by that standard alone. Dacia, shielded by the Carpathians, remained the sole exception, and was the first established Roman province to be abandoned.

Constantinople – were pulled into or towards the Danubian periphery, a region which had started out as the largest of the militarily and logistically remote peripheries of the empire but, at least in terms of state formation, gradually turned into its center of gravity. Our model simulations give us a sense of the likely scale of friction generated by this gradual yet ultimately profound reorientation of political and military power away from the closely interconnected Mediterranean core.

Another parallel but distinct outcome was the inexorable separation of the empire into western and eastern halves. As shown in Map 4, the coastal regions of the East were more remote from Rome than those of the West. At the most basic level of cost constraints, this diminished the potential for economic integration. Rome's tributary reach into Egypt was therefore something of an anomaly that was eventually erased. In terms of political/military connectivity, the time costs of negotiating the distance between Rome and its legions reveal a striking east-west segmentation of the empire that goes back to the beginning of the monarchy (Cartogram 5).



Cartogram 5 Military time distance to Rome (summer), by medium (solid circles: land routes; hollow circles: land routes + coastal daytime routes)

By 200 CE, the legionary troop deployments closest to Rome (excluding metropolitan garrisons) were along the Upper Danube (6 legions 36-39 days away, assuming a daily marching distance of 30 kilometers – a slower pace would increase the values without changing the overall ratios) followed by the Rhine armies (4 legions 40-56 days away), Moesia and Dacia (6 legions 43-64 days away) and Britain (3 legions 72-75 days away). Despite intervening forward deployments, this situation already dates back to 14 CE, when the closest troop concentrations were in Pannonia and Dalmatia (5 legions 24-33 days away), followed by Moesia (2 legions 41-43 days away), the Rhine armies (8 legions 40-56 days away) and Spain (3 legions 64-68 days away). The mean time cost was virtually the same at 47 days in 14 CE and 51 days in 200 CE.

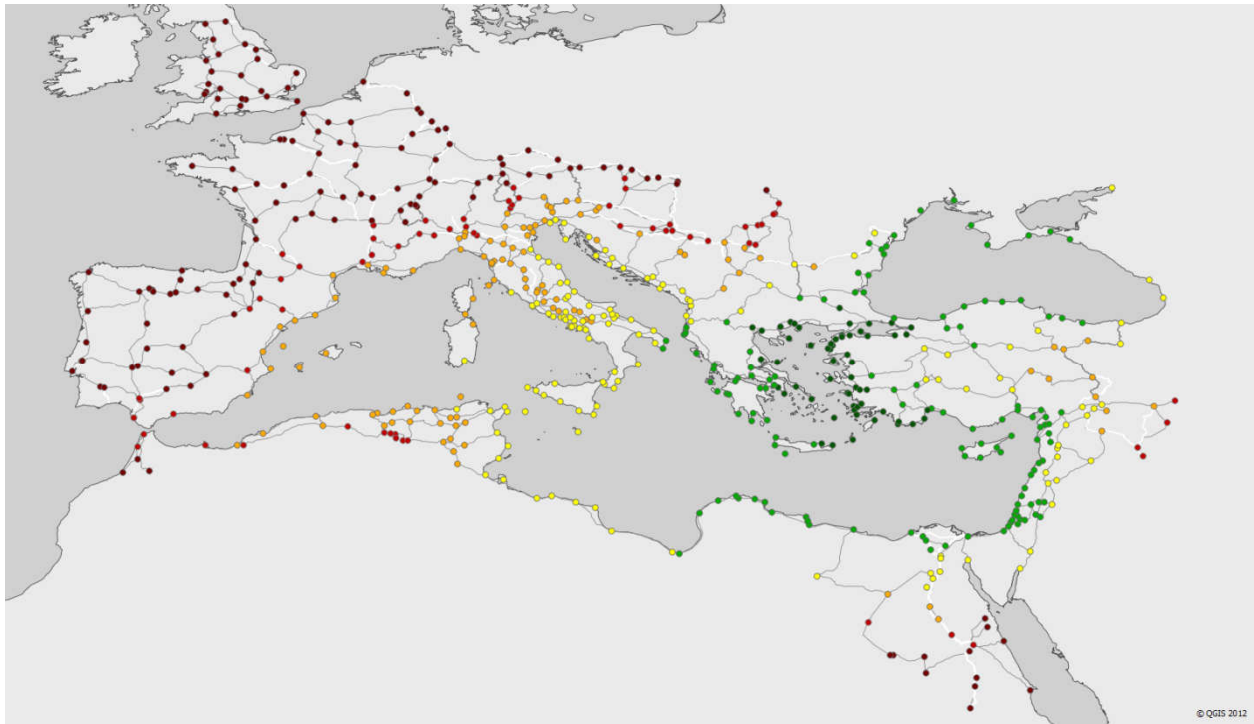
By contrast, the effective time distance from Rome for troops stationed outside Europe depends entirely on the medium of transport. If legions primarily relied on roads in projecting power domestically, there were two distinct imperial zones in relation to Rome itself, one in Europe and one in Asia and Africa. Excluding metropolitan garrisons, European camps were between five and eleven weeks away from the capital, compared to sixteen to nineteen weeks for those in Asia and even more for Africa. Troops deployed outside Europe were only in comparable proximity to the European garrisons if we assume travel by sea whenever possible (indicated by the hollow circles in Cartogram 5). However, given the absence of naval invasions of the center by frontier troops, non-European troops were *de facto* much more isolated.<sup>34</sup> Later separations, briefly foreshadowed in the 30s BCE, were therefore already anticipated by the military system of the Principate.

Both the time cost and price cost simulations suggest that the emergence of a second center in the East was not a historical contingency but the result of deep-seated imbalances, as was the subsequent effective division of the empire. The model even helps assess the formalization of this process. Path simulations show that the 395 CE boundary between the western and eastern halves of the empire is uncannily precise in being perfectly equidistant from Mediolanum and Constantinople. With respect to military time costs, an equidistant border should be located between Singidunum and Viminacium, which is where it was. Similarly, pathfinding for information costs predicts that Narona, Domavium and Lepcis Magna should belong to the Western Empire and Ulpiana and Cyrene to the Eastern Empire, with Dyrrhachium and Singidunum positioned right at the border, all of which was the case. The principle of equidistance even largely holds for price costs (with Rome, as the leading consumption center, replacing Milan as the western focal point): of all the eastern territories, only the west coast of Greece and the western Cyrenaica were slightly closer to Rome than to Constantinople. The formal division thus very closely followed the structure of the various networks.

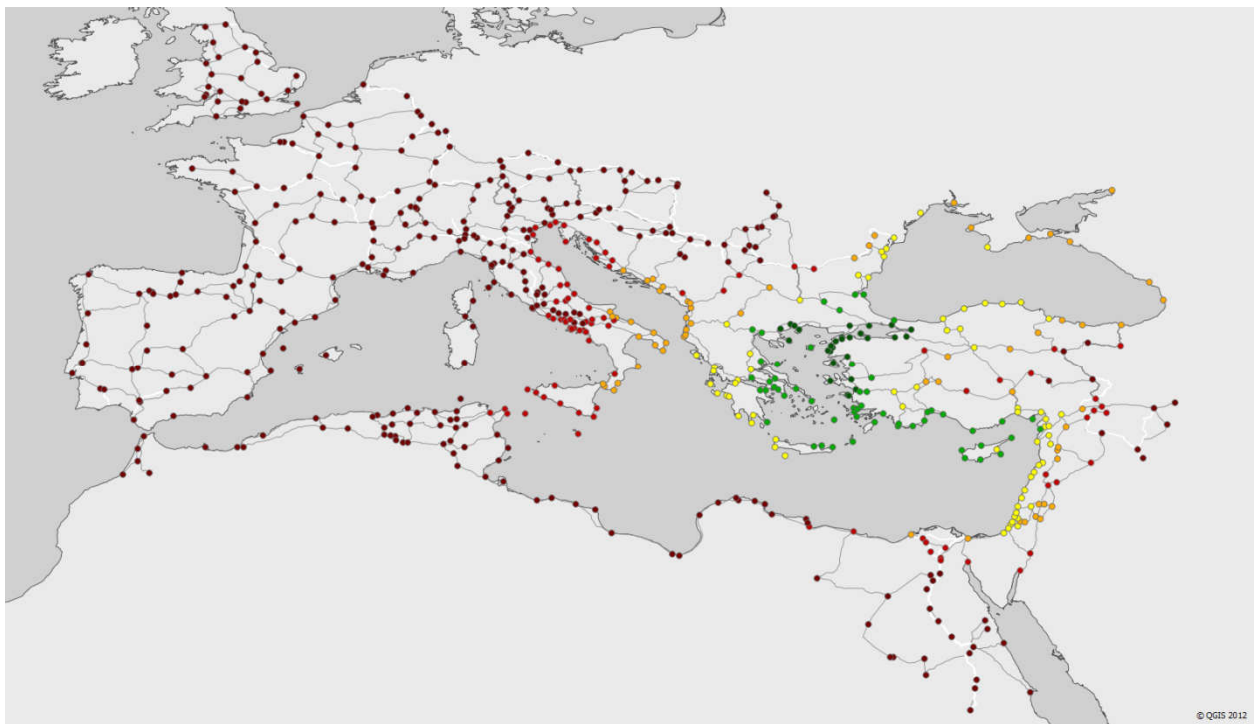
Later developments may be put in context by re-centering the entire network on Constantinople, beginning with political/military reach (Maps 7-8).

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<sup>34</sup> Aside from isolated instances of naval support for military crossings of the Strait of Otranto or the Bosphorus/Dardanelles and even rarer operations involving North Africa, significant maritime troop transfers seem virtually unknown in civil war contexts of the monarchical period: cf. Starr, *op. cit.* 182-3, 190; Reddé, *op. cit.* 373.

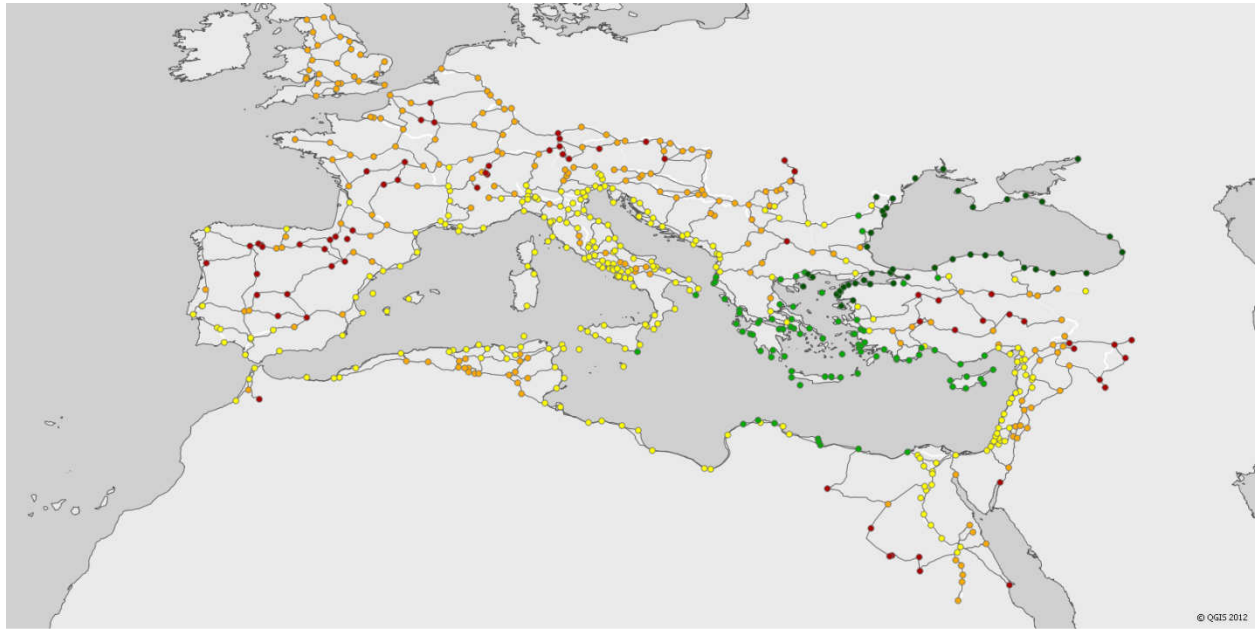


Map 7 Time cost from Constantinople, at high military speed (summer)



Map 8 Time cost from Constantinople, at low military speed (summer)

These simulations create a new core in the Aegean. In the ‘fast’ version (Map 7), the green, yellow and orange sites coincide almost perfectly with the maximum extent of Roman re-conquests in the reign of Justinian. Logistical costs suggest that further expansion to the west and northwest would have been an arduous undertaking. This map also points to the disproportionate exposure of Roman positions in northern Mesopotamia. In the ‘slow’ version in Map 8, the same colors foreshadow most of the effective reach of Byzantine power in the late first millennium.



Map 9 Price cost to Constantinople (summer)

Map 9 reviews price costs to Constantinople. The Black Sea coast, rather than the Aegean, turns out to have been the most accessible hinterland for Constantinople.<sup>35</sup> In the west, much of continental Europe was remote. This latter pattern matches that for military reach established in Map 7, reinforcing the logistical constraints on western re-conquest. The high degree of isolation of the interior even of western Asia Minor also deserves attention, which belies its close physical proximity to the capital emphasized by conventional maps.

Cost simulations allow us to address the question of whether the Western Empire was more overstretched than its eastern counterpart, which might help account for the former’s more rapid disintegration. This does not appear to have been the case: by land as well as by land and sea, Gades was as far from Mediolanum or Ravenna as Alexandria was from Constantinople. Nisibis was as far from Constantinople as Eburacum was from northern Italy, and Satala as remote as Castra Vetera. That said, in the fifth and seventh centuries CE, both polities first lost those territories that were the most remote in terms of connection cost.<sup>36</sup>

<sup>35</sup> Though not to the rest of the empire, a result of the high time costs of negotiating entry into the Black Sea which a more realistic model would have to factor into price simulations as well: see E. Taitbout de Marigny, *New Sailing Directions of the Dardanelles, Marmara Sea, Bosphorus, Black Sea, and the Sea of Azov* (1847) and esp. B. W. Labaree, ‘How the Greeks sailed into the Black Sea’, *AJA* 26 (1957), 32. Weaker effects in the Dardanelles made the Aegean more ‘distant’ than it would seem from a conventional map.

<sup>36</sup> This is consistent with the parabolical trajectory of the growth and decline of empires: A. J. Motyl, *Imperial Ends: The Decay, Collapse, and Revival of Empires* (2001), 7.

Cost simulations may also be applied to power segmentation on a somewhat smaller scale. For instance, the effective boundaries of the ‘Gallic empire’ of the 260s and early 270s CE neatly coincide with relative cost distance to the rival centers of Cologne or Trier and Milan.<sup>37</sup> In terms of military time costs, Argentorate on the lower Rhine, Mediolanum Santonum in northern Aquitania, Augustodunum in central Gaul and Cabilonnum on the upper Rhone were closer to Cologne, whereas southern Aquitania, the lower Rhone, Aventicum and Genava were closer to Mediolanum and Raurica Augusta was equidistant from both, a division that broadly reflects the limits of the core zone of the separatist entity. Any site on the Iberian peninsula was much closer to Mediolanum, which meshes well with the Rhine army’s failure to hold on to it.

It catches the eye that such convergences between cost contours and political divisions only occur in the case of effective power structures but not for artificial administrative creations. Thus, the centers of the four fourth-century CE Roman prefectures were all spatially eccentric relative to their designated catchment areas and the borders between them are not related to relative cost distance from these centers. *Ceteris paribus*, this diminished their capacity to develop into separate states and, unlike the western and eastern halves of the Empire or the Gallic empire before them, they never did. The impact of cost constraints becomes apparent only in the most fundamental processes of state formation: expansion and disintegration.

### Connectivity costs, trade and economic integration

The relationship between simulated price costs of transport and the archaeologically observable or textually documented flow of goods sheds new light on one of the most fundamental questions of Roman economic history, the nature of trade.<sup>38</sup> The old debate about formalist/modernist and primitivist/substantivist modes has been replaced by, or perhaps merely recast as, disagreement about the importance of market-driven and predation-driven transfers. The former position assigns the state an indirect economic role as provider of a favorable (i.e., relatively more secure and predictable) environment for exchange sustained by private enterprise that capitalized on comparative advantage, whereas the latter considers state and elite demands for tax and rent as the engine of large-scale trade in bulk goods.<sup>39</sup> Geospatial modeling improves our understanding of the relative weight of these factors. The notion that market forces underpinned observed transfers can be tested by relating the distribution of provenanced trade goods to their points of origin. Thus, the extent to which the distribution patterns of such goods matched cost contours might be read as a proxy for the prevalence of market exchange, which would arguably have been more sensitive to costs than coerced transfers. The more distribution patterns deviate from the outcomes predicted by cost contours, the more likely it is that these transfers involved

<sup>37</sup> On this entity, see J. F. Drinkwater, *The Gallic Empire* (1987), esp. 19 fig. 1.1 on its southwestern frontier.

<sup>38</sup> For the problem, see, e.g., N. Morley, ‘The early Roman empire: distribution’, in W. Scheidel, I. Morris and R. Saller (eds.), *The Cambridge economic history of the Greco-Roman world* (2007), 580-7, and for the current state of the debate, see the ‘forum on Roman trade’ in W. Scheidel (ed.), *The Cambridge Companion to the Roman Economy* (2012), 287-317.

<sup>39</sup> For a somewhat more detailed summary, see W. Scheidel, ‘Approaching the Roman economy’, in Scheidel (ed.) (op. cit. [n.38]), 8-9. For the former view, which dates back to Ed. Meyer and M. Rostovtzeff, see esp. H.-U. von Freyberg, *Kapitalverkehr und Handel im römischen Kaiserreich* (27 v. Chr. – 235 n. Chr.) (1989); M. Silver, ‘Roman economic growth and living standards: perceptions versus evidence’, *AncSoc* 37 (2007), 191-252, ‘Historical otherness, the Roman bazaar, and primitivism: P. F. Bang on the Roman economy’, *JRA* 22 (2009), 421-43; P. Temin, *The Roman market economy* (2013); for the latter, K. Hopkins, ‘Taxes and trade in the Roman empire (200 B.C. – A.D. 400)’, *JRS* 70 (1980), 101-25, ‘Rome, taxes, rents and trade’, *Kodai* 6/7 (1995/6), 41-75 (repr. in W. Scheidel and S. von Reden [eds.], *The ancient economy* [2002], 190-230); C. Wickham, *Framing the early Middle Ages: Europe and the Mediterranean, 400-800* (2005); P. F. Bang, ‘Trade and empire – in search of organizing concepts for the Roman economy’, *P&P* 195 (2007), 3-54, *The Roman bazaar: a comparative study of trade and markets in a tributary empire* (2008).



intervention in the market, as in the form of coerced or subsidized deliveries. This approach that has already borne fruit in earlier work that relies on more basic cost simulations and seeks to relate distribution of ceramic items to cost contours.<sup>40</sup>

Moreover, cost simulations allows us to address a related question, that of the extent to which the Roman Empire was economically integrated. This goes back to Moses Finley's famous observation that "ancient society did not have an economic system which was an enormous conglomeration of interdependent markets", countered by Peter Temin's repeated claim that the Roman Mediterranean did indeed form a single integrated market for goods and labor.<sup>41</sup> This bold proposition rests in part on his observation that grain prices reported for six sites across the empire varied in relation to those sites' distance from the city of Rome.<sup>42</sup> Temin interprets this as evidence in support of the existence of an integrated market economy centered on the capital. Given the paucity and uneven quality of the available local price data, it is easy to find fault both with the underlying premise and the practical execution of Temin's analysis. After carefully exposing these problems in great detail, Gilles Bransbourg has repeated this exercise with a revised and expanded sample of local grain prices from twelve different sites. He argues that a Rome-centered grain market was confined to coastal Italy and to specific areas outside Italy – namely Sicily, North Africa and Egypt – that are reliably known to have exported grain to that city. In this zone, distance from Rome explains 86 percent of variance in local grain prices, a result that would indicate close integration overall, whereas for the entire sample of twelve sites, distance accounts for little over half of price variance, which suggests that sites elsewhere were little affected by price-setting mechanisms driven by demand in the capital.<sup>43</sup>

Our model shows that local variation in grain prices was not a function of distance from the center. Replacing distance-based calculations with more meaningful price simulations, we find that distance from Rome accounts for 62 percent in variance of grain prices at those seven sites in Bransbourg's sample that can legitimately be defined as coastal Mediterranean – that is, locations with low-cost access to the metropolitan market – but for 75 percent of variance in grain prices at five more remote sites in the hinterland (Fig.1).<sup>44</sup>

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<sup>40</sup> See Carreras, *La economía* (op. cit., n.16) and 'An archaeological perspective' (op. cit., n.16).

<sup>41</sup> M. I. Finley, *The ancient economy* (updated ed. 1999), 22; P. Temin, 'A market economy in the early Roman empire', *JRS* 91 (2001), 169-81, and cf. also 'The economy of the early Roman empire', *Journal of Economic Perspectives* 20 (2006), 133-51.

<sup>42</sup> D. Kessler and P. Temin, 'Money and prices in the early Roman empire', in W. V. Harris (ed.), *The Monetary Systems of the Greeks and Romans* (2008), 137-59, re-iterated in Temin, op. cit. (n.39), 29-52. The sites are Sicily, the Po Valley, Lusitania, Pisidian Antioch, the Fayyum, and Palestine. In this scenario, physical distance from Rome accounts for 79 percent of variance in local grain prices.

<sup>43</sup> G. Bransbourg, 'Rome and the economic integration of empire', ISAW Working Papers 3, <http://dlib.nyu.edu/awdl/isaw/isaw-papers/3>.

<sup>44</sup> Sites from Bransbourg, op. cit. table 3, for which see prices and estimated period-specific price differentials to Rome. Coastal Mediterranean sites: Sicily (0.84 from Syracuse), Pompeii (0.43), Fayyum (3.59 via Nile), Palestine (2.78 from Ascalon), Forum Sempronii (1.54 via Fanum Fortunae), Lanuvium (1.2), Tarracina (0.31). Others: Lusitania (2.2 from Olisipo), Po valley (2.67 from Placentia), Antioch in Pisidia (6.6), Veleia (3.44), Sicca Veneria (3.93 routed by road to the nearest port of Thabraca unlike via Carthage as in ORBIS).



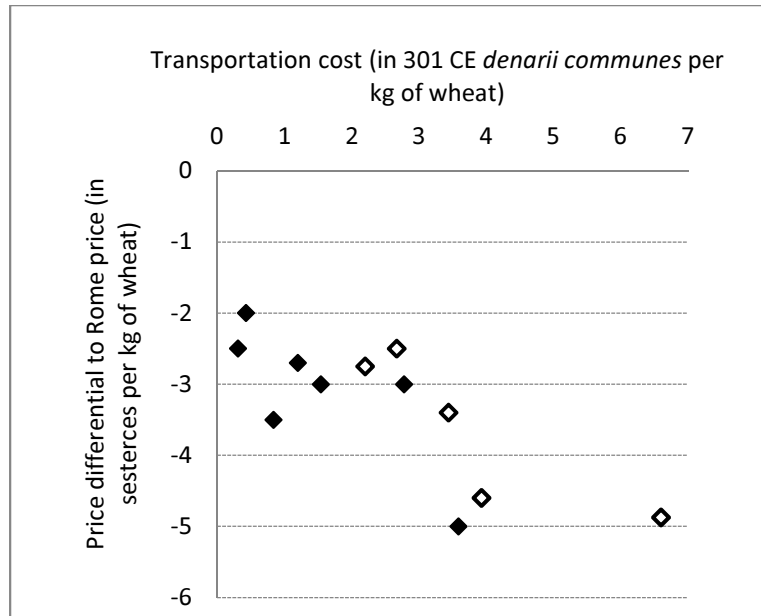


Fig. 1 Correlation between local grain price and transport cost to the city of Rome for 12 Roman sites (solid: coastal or near-coastal Mediterranean sites; hollow: inland sites)

This result is incompatible with Temin's notion that local grain prices were a function of proximity to Rome: it would have been paradoxical for more isolated areas to exhibit a higher degree of price integration than coastal Mediterranean ones. The paradox is heightened by the observation – clearly visible in Fig.1 – that for those eight sites whose transport cost to Rome was less than half the highest of the twelve values, relative transport costs to Rome account for merely 5 percent of variance in local grain prices. This demonstrates the complete lack within this bracket of any meaningful correlation between effective distance from Rome and local grain prices *even though* the projected transportation costs to Rome from these eight sites vary by an entire order of magnitude.<sup>45</sup> Taken together, these findings cast grave doubt on Temin's contention that Roman grain markets were integrated to such an extent that distance from Rome was a principal determinant of local prices. On the contrary, the metropolitan grain supply was a special case precisely because import flows were not governed by transport costs *per se* but by regional variation in factor endowments and, most importantly, by imperial institutions: tributary mobilization of surplus was more important than comparative advantage.

This is not to say that costs were somehow irrelevant to the flow of goods. If economic connections were the result of historically contingent (and therefore changing) factors, costs were instrumental in determining the potential for economic integration. What the model does is highlight the costs associated with observed outcomes. The higher these costs, the higher the strains on the system, and the greater the effort required to maintain it. The historical evidence shows that it was perfectly possible for the Roman state to tap into the Egyptian grain market, or to drag North African grain from fertile valleys to the coast, or to funnel supplies to distant military frontiers: But all that came at a cost, and existing arrangements became more vulnerable to these costs as coercive capacities weakened.<sup>46</sup> Rome's

<sup>45</sup> This new finding is important not least because Bransbourg's results allowed Temin, *op. cit.* (n.39), 52 to interpret them as support for his own thesis, contrary to Bransbourg's overall argument.

<sup>46</sup> It is important to realize that it in this context it does not matter who bore these costs: even in the case of coerced transfers, the state could not make them disappear simply by unloading them onto subjects liable to transportation liturgies. Connectivity cost put strain on the system regardless of whether it raised state expenditure (if it was

armies may have managed to seize a fundamentally disconnected region such as the Danube basin, but as noted above, the long-term repercussions in terms of economic cost and political transformation were very considerable indeed. This is what Braudel meant by the struggle against distance, what made distance – or rather, the cost of bridging distance – the ‘Enemy Number One’ of civilization, most notably of far-flung entities such as imperial powers. Geospatial modeling allows us to identify and measure the hidden but ever-present costs of connectivity as a variable in the equations of historical change. The resultant simulations cannot predict what happened, but they illuminate the constraints within which events unfolded. This, in turns, enables us to weigh the importance of these constraints relative to those of other factors, and to flesh out our understanding of historical outcomes.

## **Toward multi-layered modeling**

Geospatial modeling is a new means to a resolutely old-fashioned but vitally important end, to reconstruct the Roman world *as it was*. Cost simulations help us appreciate the constraints that shaped interaction within it, in the aggregate and in the long run. This project was inspired by a comparatively basic application that spatially reconfigures the London underground network in a way that expresses anticipated travel time as physical distance.<sup>47</sup> It is a vastly greater challenge to attempt the same for the entire Roman world for both time and price cost: yet this is not merely desirable but necessary if we wish to gain a systematic understanding of Roman connectivity. I say ‘systematic’ because it is of course perfectly well-known that waterborne transport was (and even today remains) cheaper than terrestrial alternatives, or that mountains are more difficult to negotiate than the plain. What geospatial modeling alone can offer is a better sense of how all the different variables interacted in structuring space and movement, and of the orders of magnitude this structuring entailed. Without this information, we cannot hope to explore the relationship between cost constraints and historical outcomes.

The costs of connectivity were but one factor that shaped these outcomes. In the political-military sphere, conventional historiography might privilege a different type of causes in accounting for the specific patterning of Roman expansion and contraction, most notably the geographical position of other polities and the nature of their interactions with the Roman state: from this perspective, what mattered most were the Mamertines in Messana, Carthaginian expansion in Spain, Carthage’s alliance with Philip V, Antiochus’s III foray into Greece, and so on for many centuries. Yet even my very rapid survey has illustrated how developments on the largest scale of resolution – the formation and eventual partitioning and disintegration of the Roman Empire – were broadly consistent with cost constraints. This suggests that these constraints merit serious consideration as one of the ultimate determinants of change: underneath multiple layers of historical contingencies that accounted for the location of conflicts and the spatial direction of expansion and contraction, connectivity costs created friction that helped shape outcomes in the long run.

This is not to say that other variables were not similarly important and can be omitted from attempts to model past realities. Economic transfers and processes of integration would have been associated with features such as urbanization, population density, cultivation, and mineral resources. Geospatial modeling readily accommodates all of these variables for the purpose of producing more sophisticated approximations of the past. At least some of the necessary resources are already available or under development. For example, the ‘Atlas of Urbanization in the Roman Empire’ project directed by Carlos Noreña maps over 3,000 Roman cities, disaggregated by rank. Although the resultant visualization cannot be reproduced here because it still awaits formal publication, it is clear that the majority of all Roman cities above the level of very small towns were located within the core region identified above

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directly covered by the state) or whether it raised enforcement costs and reduced overall output (if it was borne by taxpayers).

<sup>47</sup> [http://www.tom-carden.co.uk/p5/tube\\_map\\_travel\\_times/applet/](http://www.tom-carden.co.uk/p5/tube_map_travel_times/applet/).

(see Map 6).<sup>48</sup> Population densities and cultivation patterns are more difficult to reconstruct (or, when it comes to demography, estimate) for the empire as a whole but new tools will support at least rough attempts.<sup>49</sup> The Ancient World Mapping Center's new project 'Benthos: A Digital Atlas of Ancient Waters' that seeks to map the sea adds another vital component to a more comprehensive model by locating shipwrecks. And archaeologists and numismatists have of course produced numerous distribution maps of amphoras or coins that can be incorporated into geospatial models.

Analysis of the intrinsic properties of the network represented by a geospatial model will have to complement the addition of more data. Community detection algorithms can be of help in identifying distinct areas of connectivity within large systems such as the Roman empire. They enable us to assess modularity by considering faster or cheaper routes as stronger connections, a strategy that allows us to delineate clusters of routes that particularly well interconnected, and also to predict communities by determining the likelihood of random walks of set duration to remain within a given cluster of routes.<sup>50</sup> Preliminary experiments with these techniques are already yielding promising results for the Roman world. At the very least, they provide an alternative to our current reliance on Roman-era itineraries to track networks.<sup>51</sup>

In all of this, two things are clear. One is that even basic forms of geospatial modeling push against the limits of what is possible on the printed page: a multi-layered model as outlined above would be easy enough to set up and manipulate on a screen but very hard to replicate here. (Even the single-variable maps in this paper require color to be at all intelligible.) The other one is that given ongoing advances in technology and increasing commitment to Digital Humanities approaches at academic institutions and funding agencies, this kind of computerized modeling is bound to play a growing role in the study of the Roman world.<sup>52</sup> While such models cannot directly explain specific outcomes, they help us understand them by casting light on otherwise obscure or invisible framing conditions that render some outcomes more likely, or more sustainable, than others. In so doing, they will not merely reveal the 'real' shape of the Roman world but also re-shape the way we study that world.

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<sup>48</sup> Pleiades (<http://pleiades.stoa.org/>) already allows us to locate over 34,000 ancient sites.

<sup>49</sup> E.g., <http://themasites.pbl.nl/tridion/en/themasites/hyde/>, <http://themasites.pbl.nl/tridion/en/themasites/image/>.

<sup>50</sup> See V. D. Blondel, J.-L. Guillaume, R. Lambiotte and E. Lefebvre, 'Fast unfolding of communities in large networks', *Journal of Statistical Mechanics: Theory and Experiment* 10 (2008), P10008, doi:10.1088/1742-5468/2008/10/P10008; R. Lambiotte, J.-C. Delvenne and M. Barahona, 'Laplacian dynamics and multiscale modular structure in networks', *arXiv:0812.1170v3 [physics-soc.ph]* (2009). I owe these references to Elijah Meeks.

<sup>51</sup> For network analysis based on the *itineraria*, see S. Graham, 'Networks, agent-based models and the Antonine itineraries: implications for Roman archaeology', *Journal of Mediterranean Archaeology* 19 (2006), 45-64; L. Isaksen, 'The application of network analysis to ancient transport geography: a case study of Roman Baetica', *Digital Medievalist* 4 (2008), <http://www.digitalmedievalist.org/journal/4/isaksen/>.

<sup>52</sup> 'Modeling points the way to a computing that is *of as well as in* the humanities: a continual process of coming to know by manipulating representations': W. McCarthy, 'Modeling: a study in words and meanings', in S. Schreibman, R. Siemens and J. Unsworth (eds.), *A Companion to Digital Humanities* (2004), <http://www.digitalhumanities.org/companion>. Note its potential to tie in with larger concerns such as the Digital Earth movement: e.g., M. Craglia et al., 'Digital Earth 2020: towards the vision for the next decade', *International Journal of Digital Earth* 5, 1 (2012), 4-21, esp. 13-14.