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THE LONG-TERM EFFECTS OF THE HISTORICAL ROMAN ROAD NETWORK: TRADE COSTS OF ITALIAN PROVINCES

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The long-term effects of the historical Roman road network: trade costs of Italian provinces*

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Abstract
The paper provides evidence of the causal effect of infrastructure on trade costs, for the 107 Italian provinces (NUTS3), testing whether current differences in trade costs among provinces can be traced back to the structure of the historical Roman road network. By constructing a specific measure of the extent of the Roman road network for each Italian province and relying on an instrumental variables approach, the empirical analysis shows that having an integrated road system, as the one built during the Roman Empire, plays an important role in current international trade. The study confirms not only the importance of history for contemporary economic development, but also the significant role played by the historical infrastructure in shaping geography and in determining current trade patterns via the influence on today's infrastructure.

Keywords: Trade costs, Roman roads, Long-term effects of history, Italy, Provinces.
Jel Classification: F10, F14.

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"*And what was said by Homer, 'The Earth was common to all', you (Rome) have made a reality, by surveying the whole inhabited world, by bridging rivers, by cutting carriage roads through the mountains, by filling deserts with stationes, and by civilising everything with your way of life and good order*" Aelius Aristides Orat.26.101

1 Introduction

Trade costs are of major importance (Anderson and van Wincoop, 2004), as they are considered to be the single factor that discriminates among countries and regions in the participation in global markets.[1]

In the attempt to reduce the burden of high trade costs, economic analysis and economic policy have often called upon the need to promote sustained investment in infrastructure. However, the evidence on the relationship between infrastructure capital and economic outcomes (such as GDP, economic growth, trade openness) is mixed and still controversial (see Esfahani and Ramírez, 2003). The main issue in examining the literature findings on infrastructure returns is the endogeneity bias resulting from the potential reverse causality between infrastructure and the economic outcome of interest, due to richer, more open and more productive regions investing in infrastructure rather than the other way around.

This paper offers a new contribution on this very point, estimating the causal effect of infrastructure on trade costs, relying on an empirical instrumental variable strategy based on the long-term effect of historical events on economic development (Nunn, 2009). In particular, in order to exploit the spatial variation in infrastructure in the greatest possible territorial detail, the paper focuses on a single country (Italy), instead of taking a cross-country approach, using existing information on one of the largest infrastructure investments in history: the construction of the road network during the Roman Empire. Therefore, the empirical analysis provides combined evidence on three dimensions: the causal effect of infrastructure on trade costs, the persistent effect of history, the role that Roman roads have on current transport infrastructure. Along these lines, the paper also presents one of the first investigations on the long-lasting eco-

[1] Trade costs are considered the main common cause of the six major puzzles in international macroeconomics (Obstfeld and Rogoff, 2000); their reduction accounts for one third of the trade expansion that occurred in the second half of the twentieth century and for two thirds in the nineteenth century (Jacks et al., 2008) and they largely shape the patterns of trade worldwide and the asymmetric gains associated with their evolution (Pascali, 2017); lastly, they are largely responsible for the uneven spatial distribution of economic activity (Redding and Rossi-Hansberg, 2017).

nomic effect of the Roman Empire and its road network (see Temin, 2013, and the recent paper by Michaels and Rauch, 2018). Furthermore, the inference analysis provides new insights into the appropriateness of instrumental variables based on geography and those related to major historical events. Results suggest that the complementary use of geography and history allows, when the two are uncorrelated, to address the common issue associated with the collinearity of instruments based on geography, which imposes a just-identified empirical model. The combined use of geophysical and historical instrumental variables contributes to overcome model identification problems. Moreover, the instrumental variable based on historical events seems to identify transport infrastructure in a more accurate way, suggesting that historical, more than geographical variables perform better as instrumental variables.

The Roman road network started to expand simultaneously with the military conquests of the Roman armies. The main reason for constructing paved suburban roads was purely military: the need to rapidly deploy troops to the insecure borders of the Empire.[2] The earliest strategic Roman road was the Via Appia (the Appian Way), constructed in 312 B.C. in a south-easterly direction from Rome to Capua (close to Naples), to guarantee fresh troops for the war against the Samnites. It was constructed as an assembly of straight segments, not for the purpose of linking existing cities or villages along the way, but simply as the easiest and most convenient way to move troops and supplies. Subsequently, the Appian Way, the *regina viarum*, was extended to reach Beneventum, and Tarentum and finally Brundisium, on the Adriatic coast. Expansion to the regions of southern Italy was again dictated by military necessity (e.g. the campaign against the Greeks) and not with a view to connecting existing towns.

After the Via Appia, miles and miles of roads were built.[3] In Italy, the network of Roman roads covers the entire peninsula, including the two main islands (Sicily and Sardinia). At the regional level of disaggregation (NUTS2), the Roman roads touch every region in Italy, while at the provincial level (NUTS3), they are present in 108 out of the 110 Italian provinces.

The existence of the Roman road network modified the habits of Romans,[4] and its influence

[2] Consular roads were not built either for trade purposes, largely managed by navigation across the Mediterranean Sea, or for civilian transportation. The cost of mobility was high and Romans were very superstitious. Moreover, moving required a great deal of effort to be realized (Chevallier, 1976).

[3] Starting from the city of Rome, the expansion of the road network covered six centuries and three continents (Europe, Africa, Asia), covering at its peak the territories of almost forty of today's nations.

[4] The development of land transportation determined a dramatic cultural change: from a society based on the city state, as prevailed in ancient Greece, to a political entity that was associated with the notion of spatially dispersed citizenship, like that of the Roman Empire. Over time, this led to a change in the very notions of space and time, radically changing the way the spatial extension of a territory and the time required to travel across

persisted far beyond the collapse of the Roman Empire. After World War II the modern Italian road network, that altered and renovated the one partially destroyed during the conflict, followed in many cases the route traced by Roman roads. In this paper, this correlation is exploited to deal with the endogeneity issue in the relation between infrastructure and trade costs adopting an instrumental variable strategy.

The paper is organized as follows. Before addressing the issue of the causal effect of infrastructure on trade costs and its quantification, the next four sections constitute the *mise en place* of the single elements of the problem. Section 2 places the analysis in the 'new economic history' strand of literature (Michalopoulos and Papaioannou, 2017). Section 3 illustrates the available data on Roman roads and how they have been transformed, organised and used in the subsequent analysis. Section 4 discusses the reverse causality problem that may arise when investigating the effects of infrastructure on economic outcomes. Section 5 is devoted to the definition and measurement of a general indirect trade costs factor (Novy, 2013; Chen and Novy, 2012) for Italian provinces. Section 6 illustrates the two empirical approaches adopted to investigate the effects of Roman roads on modern infrastructure and trade costs, and discusses the results. Section 7 extends the analysis and illustrates three sets of robustness checks. Section 8 concludes.

2 The persistent effect of history and historical infrastructures

In the last twenty years a new strand of economic literature has emerged, focusing on the influence of history on various aspects of the economy today. As nicely summarised by Nunn (2009) and by the three volumes edited by Michalopoulos and Papaioannou (2017), the 'new economic history' literature (as referred to in Michalopoulos and Papaioannou (2017, p.ix)) - that started by collecting data on specific historical episodes (e.g. colonialism in Engerman and Sokoloff (1997, 2002), La Porta *et al.* (1997, 1998), and Acemoglu *et al.* (2001, 2002)) and providing evidence of the long-lasting effect of those historical episodes on modern economic development – rapidly evolved in several directions. The historical epochs under scrutiny - from

it were considered (Laurence, 1999). From being a population of superstitous motionless individuals, Romans started to enjoy traveling, for business and for amusement, and mobility started to become a trait of the Roman culture and society (Chevallier, 1976). Accordingly, von Hagen (1967) argues that, through its roadways, Rome was able to wield systematic control over the known world, making the Romans a mobile civilisation, that exerted its influence for centuries.

the Neolithic to Nazi Germany – and the geographical expansion were one of the first directions investigated;[5] in a second stage, the focus of the research "... moved from asking whether history matters to asking why history matters" (Nunn, 2009, p.66); and several studies focused on the mechanism linking the past to contemporary outcomes, exploring the channels of causality in identification-based empirical analyses.

Over the last few years, some contributions have started to give an account of the long-lasting impact of shocks in ancient or modern history, from environmental shocks (Hornbeck, 2012; Hornbeck and Naidu, 2014), to social and political events (Becker and Woessmann, 2009), to technological shocks, which are also dealt with in this paper.

Pascali (2016) documents and explores the creation and the development of local banks. He tests the conjecture according to which the Jewish community in the early Renaissance played an important role in the development of local banking, and this positive effect lasted until today, driving current economic performance of a large number of Italian cities. Pascali (2017) explores the role of the steamship in advancing international trade and institutions, finding that the growth benefits of innovation were particularly significant in countries with modern and effective institutions. De Benedictis and Pinna (2015), using the same data as Pascali (2017) (all the available archival information on navigation, for the period 1750 to 1850, coming from British, Dutch, French and Spanish archives on ships' logbook records), place their work midway in the economic growth debate between 'geography matters' and 'institution matters', looking at the long-term consequences of being involved in historical navigation routes on contemporary trade costs, using islands as natural experiments, as in Feyrer and Sacerdote (2009). De Benedictis and Pinna (2015) show that, once geographical features and other covariates typically associated with trade costs have been controlled for, including spatial connectedness with trade partners, colonial origin and ocean dummies, the factor that explains the variability of current trade costs, among otherwise comparable islands, can be attributed to the largely casual involvement in historical navigation routes. The work of Valencia Caicedo (2014), instead, looks at the Jesuit Missions of the seventeenth and eighteenth centuries in South America as the explanation for the current income and education level in Argentina, Brazil and Paraguay. Differently from other missions (such as the Franciscan Missions), the Jesuit Missions had an important role in terms of education externalities and instruction for children, promoting human capital spillovers

[5] The three volumes edited by Michalopoulos and Papaioannou (2017) include works with a global view point, in volume 1, on Africa and Asia, in volume 2, and on Europe and the Americas, in volume 3.

and labour training for adults. The long-term effects of history on today's economic incomes in South America is also examined by Dell (2010). In her work, Dell explores the case of the *mita*, a forced mining labor system in Peru and Bolivia between 1573 and 1812, providing evidence that the *mita* system negatively affected current economic development, household consumption and increased stunting in children.

Moving to a topic closely related with the present paper, the focus on historical infrastructures accounts for a large share of the entire literature on the persistent nature of history. Recent literature has shown an interest in the effect of great historical transportation infrastructure projects on reducing trade costs, on enhancing productivity and on increasing the level of real income in the trading regions involved.

Starting from the seminal work of Aschauer (1990), the contributions of Donaldson (2015), Donaldson and Hornbeck (2016), Jedwab et al. (2017), Berger and Enflo (2015) add novel insights into understanding of the effects of large transportation infrastructure projects and their expansion. The first two papers address railway expansion in colonial India and the U.S. respectively, the first also providing a measure of the share of total welfare gains. The other two papers provide similar evidence for Kenya and Sweden. In particular, Jedwab et al. (2017), exploiting the variability in railways constructed by colonizers in Kenya, show how the location of major urban centres is characterised by path-dependence. Although, colonial benefits in terms of physical (i.e. transport infrastructure) and human capital vanished after independence, railway cities kept their developed status until today.[6]

Some recent studies focus on the positive effect attributable to the Roman domination (Bosker and Buringh, 2017; Buringh et al., 2012; Bosker et al., 2013; Greif and Tabellini, 2010; Michaels and Rauch, 2018). Recently, one specific aspect of the Roman Empire has attracted the attention of researchers: the Roman road infrastructure. In the paper by Wahl (2017), the presence of ancient Roman roads is instrumental in dividing the area that corresponds to contemporary Germany into a Roman and a non-Roman part. The *Limes Germanicus wall*

[6] Other works address other means of transport. Wantchekon and Stanig (2017) provide causal evidence of the importance of transportation costs showing that in African districts with poor infrastructure, the poverty rate increases as soil quality gets better, not worse! They instrument current transportation costs with least-cost paths from mining areas to ports and colonial road networks. Fajgelbaum and Redding (2014) look at Argentina and at the reduction of international transport costs generated in the late nineteenth century by the introduction of large steamships. Volpe Martincus et al. (2014) analyse the case of Peru, to assess the effect of the new road infrastructure on firms' exports and employment and to investigate whether public policies supporting transportation infrastructure projects positively affect firms' global trade. On these bases, they use the Inca road network (built by the Inca Empire before 1530) as an instrument for the current road infrastructure in Peru.

is used as a geographical discontinuity in a regression discontinuity design framework to test whether the formerly Roman part of Germany shows greater nighttime luminosity than the non-Roman part. The transmission mechanism, that links the past to the present, is attributed to the enduring effect of the Roman road network, fostering city growth and denser infrastructure. Together with this paper, the one by Wahl (2017) represents the first attempt entirely devoted to understanding whether the Roman road system left a mark on the modern economy through its persistent effect. Although similar in intention, the study by Wahl (2017) differs from the present one in the dependent variable used, in the way Roman roads are collapsed into a synthetic indicator, in the countries it looks at and in the empirical methodology adopted.

3 The Roman road network

The raw data on the Roman road network, used throughout the analysis, was digitalised by McCormick et al. (2013) on the basis of the Barrington Atlas of the Greek and Roman World (2000).[7] The Digital Atlas of Roman and Medieval Civilizations (DARMC) includes 7,154 segments of ancient Roman roads existing at the peak of the Empire, corresponding with the death of Trajan (117 A.D.). Each segment is uniquely identified and roads are composed of many segments.[8] The network covers 36 countries[9] over Europe, Africa and Asia; and road segments are classified according to their class of importance (e.g. major and minor) and certainty (e.g. certain and uncertain).[10] Figures 1 and 2 provide a representation of Roman roads according to importance and certainty. As can be seen from Figure 2, there is a reasonable balance between certain (purple lines) and uncertain (orange lines) roads.[11] This is less the case when considering the class of importance of the road: Figure 1 shows a prevalence of blue (minor roads) over red

[7] The data, in shapefile format, allows spatial analysis for the Roman and medieval worlds using a Geographic Information System (GIS) coding. The level of geographical accuracy and detail and the geo-referenced data facilitate investigations. Moreover, the close connection with the work of Talbert (2000) confirms the reliability and correctness of the information included.

[8] As an example, the Via Appia is composed of 67 different segments. Roads are not classified as such and have to be reconstructed assembling the different segments. For brevity, from now on the terms 'road' and 'road segment' will be used interchangeably.

[9] Albania, Algeria, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Egypt, France, Germany, Greece, Hungary, Israel, Italy, Jordan, Lebanon, Libya, Liechtenstein, Luxembourg, Macedonia, Montenegro, Morocco, Netherlands, Palestine, Portugal, Romania, Saudi Arabia, Serbia, Slovenia, Spain, Switzerland, Syria, the U.K., Tunisia, Turkey.

[10] Certainty refers to the path followed by the road segment. The segment is certain in its existence and in the Roman origin, it is uncertain in the route followed.

[11] For the majority of Roman roads in Greece and Turkey no information is available in terms of certainty.

lines (major roads). Moreover, considering just the major roads, many modern nations' borders are readily recognizable as well as the outline of the Mediterranean Sea, since a large number of roads were constructed along the coast.

The Roman road network covers a total length of 192,861 kilometres. The information on the length of each segment of the Roman road network is the third trait extracted and included in the dataset used in the following analysis. These data give a good idea of the extent and coverage of the entire Roman infrastructure, although its geo-coding does not make any explicit reference to current political boundaries of the geographical territories. To obtain that information Licio (2017) uses the DARMC's shapefile along with GIS tools to create two new datasets: a shapefile of the Roman road infrastructure for the Italian territory alone (excluding segments outside Italy's borders) and a measure of Roman roads in kilometres for every Italian province. In particular, 108 layers have been created for each Italian province where Roman roads are present. Figure 3 shows the newly created layer of the Roman road system for Italy, which comprises 25 percent of the entire network: 1,817 out of 7,154 segments. 108 of the 110 Italian provinces have Roman roads,[12] 94 have major roads, 85 certain roads, 77 both certain and major Roman roads.

Exploiting the information about importance and certainty, Licio (2017) computes five different measures of Roman road coverage for all Italian provinces: i) all roads (in km), including all segments regardless of their classification; ii) certain roads (in km); iii) major roads (in km); iv) major and certain roads (in km); and v) a binary variable that takes the value of 1 if Roman roads are present in the province. To obtain a general picture of the density of the Roman road system, the first four measures have been weighted by the area of the province, in square kilometres (Source: Italian National Statistical Institute, Istat). These measures represent the main original variables used in the empirical analysis.

Figure 4 shows the cartograms of Roman roads in the Italian peninsula. When considering all roads (certain and uncertain, major and minor), it is clear how Romans devoted more effort to building roads in the South rather than in the North of the Italian territory. This depends on the way the Roman Empire expanded: firstly towards the southern regions, then to the North. When looking simply at certain or major roads, this spatial correlation becomes less evident.

[12] The two Italian provinces where there are no Roman roads are the province of Pordenone (in the North-East) and the province of Verbano-Cusio-Ossola (in the North-West).

4 Issues about endogeneity

As recalled in the Introduction, any inference analysis on the effects of infrastructure investments on economic outcomes is plagued by issues of endogeneity. Higher investment in infrastructure and higher economic output do not necessarily reflect the fact that infrastructure is boosting economic development. It may well indicate that in wealthier areas there is an increasing demand for infrastructure or that new infrastructure projects are located in higher income regions. And if richer areas attract new investment in infrastructure and poorer areas do not, then the direction of causality between income and infrastructure is hard to determine.

The endogeneity drawback behind the use of infrastructure in empirical models has been widely discussed in the literature, in conjunction with the econometric solutions that help to deal with the problem. As highlighted by Brooks and Hummels (2009), a considerable amount of time elapses between planning a road and its actual completion. From this perspective, road infrastructure can be construed as an exogenous variable. The case of old infrastructure would appear to be different. Donaldson (2015) argues that the effect of historical transportation infrastructure is characterised by a potential simultaneity problem: roads and railways are often constructed to connect regions already active in trade, while inter-regional trade relations are often forged after the construction of infrastructure or road improvements. Taking this further, it could be argued that the relation between the existence of Roman roads and a higher propensity to trade today may suffer from an endogeneity bias, too. Roman roads might have been constructed to reach economically prosperous and flourishing territories, and these conditions could well have lasted up to the present day in those provinces with a more lively trade. To analyze in greater depth the possible endogeneity stemming from simultaneity issues, the research effort of this paper is to gain an insight into in understanding why and how Roman roads were built. As a preview: Roman roads were constructed for *military purposes* and they were straight, preferring to *engineer solutions* to obstacles rather than circumvent them. The 'military reason' and the 'engineering reason' both suggest that the decision to construct roads was not merely economically motivated: there was no intention to connect wealthy regions.[13]

[13] Chevallier (1976, p. 116) points out that "*As a rule, earlier sites were avoided by Roman roads, especially the great Imperial highways, which were unconcerned with local interests and small settlements. [...] The road often attracted the village, but when the ancient road itineraries name a civitas, it does not mean that the route went through the town itself: occasionally it simply skirts its territory*". Moreover, Bosker et al. (2013) support the view that the reverse causality issue is not present in the case of Roman roads, since they favoured the subsequent expansion of urban centres in those territories where roads passed through, rather than being constructed for

4.1 Why did Romans build roads? The 'military reason'

As reported in the Dictionary of Greek and Roman Antiquities, "*The public road-system of the Romans was thoroughly military in its aims and spirit: it was designed to unite and consolidate the conquests of the Roman people, whether within or without the limits of Italy proper*" (Smith, 1890). Even after construction, it had no significant immediate economic impact, since the cheaper modes of goods' transport in that historical epoch were by river or sea (Finley, 1973). More specifically, as Laurence (1999) clearly explains, roads were planned and designed to provide troops with the essential means in terms of subsistence and support, to guarantee an efficient repositioning and to facilitate armies' movements. Because of this original purpose, roads were straight, as level as possible, often stone paved, cambered for drainage, equipped with safe stops along the way.[14] During the fourth, third and second centuries B.C., the Roman road network played a central role in guaranteeing Roman supremacy in the world. At the peak of the Roman Empire, not fewer than 29 great military highways radiated from the city of Rome, and the late Empire's 113 provinces were interconnected by 372 main roads. Expansion of the Roman road network and the foundation of colonies had the same purpose: to establish Roman military control and to avoid revolts in newly conquered territories. On this point, Patterson (2006, p. 608) remarks that "*Hand in hand with the establishment of colonies went the construction and the extension of the Roman road network. Sometimes following preexisting routes and sometimes adopting new ones, the roads had an overtly military purpose - in this case to allow Roman armies to travel swiftly Italy and to provide links with the colonies. [...] The building of the Via Valeria in 307, extending the Via Tiburtina eastward into the Apennines, likewise appears to be the precursor of the military campaigns against the Aequi in 304 and the foundation of the colonies at Alba Fucens and Carseoli*".

already existing settlements.

[14] The 'military reason' is also strongly supported by the Latin literature. "*After having pacified Liguria, Aemelius had his army build a road from Piacenza to Rimini to join the via Flaminia*" (Livy, 59 B.C.-17 A.D.). In his 'Encyclopedia of antiquities, and elements of archaeology, classical and medieval,' Fosbroke (1843) reports that the Anglo-Saxon ancestors named the Roman roads 'military ways' and that they thought the construction of small roads had more military utility than large ones. Chevallier emphasizes the importance of the army's role in the case of main roads. He remarks that "*[...] the majority of main roads were pioneered by military operations. For example, on its return from the first Samnite war (343-40), the Roman army did not come back along the via Latina, but followed the coast through the territory of Aurunci, thus blazing the trail of the Appia on a line that had already been known to traders, at least since the hegemony of Etruria. In the early third century, operations against the Umbrians of Mevania and Narnia and against the Senones took into account the route that became the Flaminia. Great strategic roads were built by the military in Gaul under Agrippa from BC 16-13 in Dalmatia and Pannonia under Tiberius from AD 6-9, in the Rhineland and the Danube valley under Claudius, and in Asia Minor under Flavians*" (Chevallier, 1976, p. 85).

The construction of the Via Appia over the centuries is a clear and concrete example of its military purpose and how the ultimate aim to reach some strategic territories resulted in a long road that passed through areas of absolutely no interest to Romans, but that, nonetheless, benefited from the presence of the road. The case of the Via Appia is not isolated, but is rather the norm for Roman roads.

4.1.1 The case of the Via Appia and the Greek target

As recalled in the Introduction, the Via Appia was the first large strategic consular road. It connected Rome to Brundisium (modern Brindisi, Apulia). Started in 312 B.C, the road had the original tactical purpose to allow troops to be deployed outside the region of Rome during the Samnite Wars.[15] It was constructed in segments, following the progress of military campaigns, and was completed in 191 B.C., when it reached Brindisi.

During that time, the Roman Empire was comprised, as shown in the upper part of Figure 5, in those territories belonging to the Latine League[16] and corresponding, today, to the provinces of Rome and Latina. Between 500 and 400 B.C. the Romans had already defeated their neighbors in central Italy (the Etruscans, Latins, Sabines, Lavinii, Tusculi, Aequi, Volsci, Aurunci and the Veientes), where a small area was under their control. At the end of the fifth century B.C. the Italian peninsula was under the control of the Celts and the Gauls in the North, the Romans in the central-western part, the Samnites and the Greek colonies (Magna Graecia) in the South. It was precisely at that time, that the Romans decided to build the first section of the Via Appia (lower part of Figure 5) and started to show an interest in the southern part of Italy. But, they were not the only ones. The Samnites were an Italic population living in southern-central Italy, in territories corresponding today to north-eastern Campania, northern Apulia, Molise and southern Abruzzo, who were in conflict with the Romans, due to the aggressive expansionistic policy of both. At first, the Romans and the Samnites concluded a non-aggression pact, agreeing to expand their possessions in different directions, but this treaty was irremediably broken when these directions clashed. On the one hand, the Samnites intended to extend their area in the western part of Campania. On the other, the Romans' intention was, first, to expand their

[15] Chambers's Encyclopedia, Vol. 1, p. 490.

[16] The Latine League is a term coined by modern historians, that identifies a coalition of villages and tribes settled in central Italy, surrounding Rome and that had the primary role in guaranteeing the mutual protection against external enemies (Cornell, 1995; De Francisci, 1968).

territories in southern Italy (upper part of Figure 6), to obtain new lands for the growing Roman population and to enter into commercial relationships with the Greek merchants (Musti, 1990), but, later, the ultimate challenge was the conquest of the Magna Graecia and to extend their control over the Mediterranean Sea, where most of the trade occurred (Figure 7).

In 238 B.C., the situation of Roman supremacy was as shown in the upper part of Figure 6. The Romans controlled the entire central and southern parts of the Italian peninsula, including the three main Mediterranean islands (Sicily, Sardinia and Corsica); at the same time, the Via Appia (lower part of Figure 6) was extended southeastwards, reaching Brindisi. As shown in the upper part of Figure 7, the Romans aimed to expand northwards (in those territories under the control of the Celts), into Gaul, Spain, North Africa and into Greece. The construction of the Via Appia, and its stepwise extension to Brindisi, meant that the troops could sail from this port when they later conquested Epirus, landing on the Macedonian coast thanks to ally ports along the opposite coastline, like Durres. The lower part of Figure 7 shows how the Via Appia facilitated the conquest of Greece.

An interesting and nontrivial point has to do, however, with the direction followed by the Via Appia. Between 400 and 300 B.C. (i.e. before the construction of the first segment of the Via Appia) the major economic centres were located in the southwestern part of Italy, in those territories corresponding today to the NUTS2 regions Campania, Calabria and Sicily. Rhegium, Messana, Panormus, Syracusae, Catana, Agrigentum and Pompeii were thriving cities in the fourth century B.C and were all located in the regions of Campania (Pompeii), Calabria (Rhegium) and Sicily (Messana, Panormus, Syracusae, Catana, Agrigentum). Rhegium (modern Reggio Calabria) was one of the oldest Greek colonies in southern Italy, founded in 3000 B.C. by the Ausones, an Italic people inhabiting the southern and central regions of Italy. During 500 B.C. Rhegium gained, under Greek rule, incredible political and economic significance. Messana (modern Messina) too was a Greek colony, founded in the eighth century B.C. During the seventh and sixth centuries B.C., Messina was a flourishing port and played a central role in Mediterranean trade. Panormus (modern Palermo) was founded by the Phoenicians between the seventh and sixth century B.C. Thanks to its geographical position, Palermo was an important commercial hub. Like Messina and Palermo, Syracusae (modern Siracusa), Catana (modern Catania) and Agrigentum (modern Agrigento) were all Greek *polis* established between the eighth and sixth century B.C. and played a key role in the economy and trade of ancient times. Pompeii (modern Pompei) was founded by the Osci, an ancient Italic population, in the ninth century B.C., important for its port and market. These seven urban centres are the most important testimony to pre-Roman colonisation and confirm that, although economic development was basically concentrated in the southwestern part of the peninsula and in Sicily, the Romans' first major road took another direction, confirming that the first main reason for their construction was military.

Three facts emerge from the above description: 1) the instrumental role of roads in the military conquest of new territories; 2) the development and expansion of roads started from strategic points: the Romans built new road segments starting from tactical cities or outposts (*Stationes*); 3) the stepwise construction of roads, with a view to future expansion. These facts suggest that some territories were crossed by Roman roads although the Romans themselves had no economic, military or tactical interest in those areas. In other terms, those territories benefited from the presence of Roman roads merely by chance, because they were situated midway between the origin of a road's segment and its strategic destination.

4.1.2 The case of the Via Annia and the Magna Graecia

Further and clear evidence that roads served as a means to exercise military control over the territory, and that they were designed in successive sections, is the Via Annia.

The Via Annia, also known as Via Popilia or Via Popilia Lenate or Via Capua-Regium,[17] was the most important road in southern Italy. Built in 132 B.C. (200 years after the Via Appia) at the request of the Roman judiciary and, with its 475 kilometres in length, it had the precise function of connecting Capua to Regium (modern Reggio Calabria) so as to guarantee military power in the *Civitas foederata Regium*. In the second century B.C., Romans had already secured the entire South of Italy and they needed a road that easily connected Rome with the foot of the peninsula.

The Via Annia covered a tortuous path. As shown in Figure 8, to reach Regium, the road ran along the western coastline of Campania and Calabria. Starting from Capua, it arrived at Salernum (modern Salerno) first and then at Regium. Along its route, the Via Annia touched several Roman *Stationes*: Nuceria (modern Nocera), Moranum (modern Morano), Cosentia (modern Cosenza), Valentia (modern Vibo Valentia). These stations were all located to the

[17] The name is still being debated since it is not certain which Roman consul was responsible for the construction of the road.

West. However, at that time, economic development and urbanisation was concentrated along the eastern Calabrian coastline, where the former Greek colonies were located. Sibari, Crotone and Locri were large and important centres for trade, but were all concentrated eastwards. Figure 8 clearly shows that the route followed by the Via Annia was not intended to connect all those municipalities and though, as in the case of Sibari, the colony lay very close to the road, the Roman constructors designed and built paths that had the primary function of being safe and convenient in terms of repositioning and defence.

Two main indications emerge from the construction of the Via Annia: 1) the Roman concept behind road construction is closely related with creating a system of roads that connects strategic military points rather than a network among the major urban centres, and this is true of both major and minor roads; 2) roads were conceived as the assembly of linear segments, the easiest and fastest way to join two strategic points. This second issue will be further discussed in the following subsection.

4.2 How did Romans build their roads? The 'engineering reason'

One remarkable engineering feature of the Roman network was its straight roads: the Romans drew straight lines between two strategic locations and built the road as segments connected to one another. In fact, Cornell and Matthews (1982) point out that the first step in road construction consisted of marking as straight as possible a path with stakes and furrows, employing sightlines as measuring tools.[18]

The rule that guided Romans in building roads is clearly explained by Lopez (1956, p. 17) who describes "*That the network of roads should be convenient and economic was none of their*[19] *business. That is why the Romans built narrow, precipitous roads along the mountain crests rather than the valley bottoms, sometimes driving straight for their goal over gradients of one in five*". Also Margary (1973) remarks that, in order to achieve as straight a line as possible, Romans built roads with steep slopes or passing through mountainous terrains. Bishop (2014), referring to Britain, quoting Hindle (1998) and Welfare and Swan (1995), emphasizes

[18] The Romans preferred direct and straight roads, because with this outline it was easier to avoid ambuscades and human settlements. Moreover, straight roads were easier to secure (Gleason, 2013). As suggested by Poulter (2010) and as remarked by Bishop (2014), the Romans often did guard the beginning and end of the road; garrisons were typically placed at the top of a hill, and the road came along as the segment of paved route connecting two garrisons. Von Hagen (1967), on the constitution of a mobile civilisation throughout the continent, argues how this has been possible thanks to well-engineered and straight roads.

[19] Lopez (1956) refers to the Romans.

that long straight sections were a typical feature of the major Roman roads. However, even where variations in terrain morphology existed, the roads were still built in straight lines. Most of the non-major Roman roads exhibit some deviations from the main path. These variations in the course of the road were typically short and, rather than being curvy, they were subject to a change in the degree of the layout. This represents the typical feature that distinguishes Roman infrastructure from modern infrastructure.[20] Giving credit to historians' arguments, it is possible to test the proposition that the straightness of the roads[21] is the best rule for drawing an old historical infrastructure by looking at how the presence of Roman roads is linked with the geographical characteristics of the territory it traverses. The following subsection discusses the point.

4.3 Roman roads and geography

The relation between Roman roads and geography may provide important information on why Roman roads are located in given areas and not in others, and on whether and how geography ruled the Roman road network. This adds another level of complexity to the endogeneity issue discussed before. Omitted variables are one of the main sources of endogeneity, and to control for them avoids the drawbacks and weaknesses of inferential analysis. In an insightful paper, Ramcharan (2009) argues that landform can shape both the within-country spatial distribution of road infrastructure and economic activity, and, if so, it represents a potential unobserved factor that is correlated with both road building and economic performance.[22]

[20] In light of this, Bishop refers to the Roman roads as '*surveyed roads*' which origin from a geometric-linear perspective in conceiving the network. Current roads are, instead, in the words of Bishop, more linked to the '*line of desire,*' since there is not a geometric outline behind the planning of the network, but rather a preference to follow the shape of nature.

[21] The straightness of the road and, more specifically, the lines connecting two points in space, such as two main cities, are the focal point of the identification strategy of a strand of economic literature that started with the work of Banerjee et al. (2012) and continued with the main contributions of Atack et al. (2010) and Faber (2014). According to Banerjee et al. (2012) straight lines capture the way the first modern transportation infrastructure was constructed, which by definition cannot be influenced by the actual level of development, whereas the infrastructure developed afterwards was built along historical routes. According to this reasoning, straight lines can be used as the optimal tool for guaranteeing access to infrastructure and to disentangle the areas that benefited from the infrastructure, due to their proximity to the line (treated areas), from those that did not, because of the distance (non-treated areas). On these bases, the empirical strategy examines the correlation between the distance to the nearest straight line and economic performance.

[22] Moreover, Ramcharan (2009, pp. 559-560) argues that "*[...]countries with rougher surfaces also have less dense surface transport networks: a 1% increase in roughness is associated with about a 1% decline in the number of kilometres of roadway within a country*". This evidence is consistent with the road construction literature (important contributions include Aw (1981) and Tsunokawa (1983) who point out that the shape and structure of the territory strongly determine the cost and the time required to construct and maintain roads and railways).

The Romans only resorted to deviations in roads when major obstacles could not be overcome by building structures such as bridges. Whenever possible, the Romans built road supports, like embankments or dykes, bridges, or tunnels to cross hills, mountains, and marshlands (Richard, 2010).[23]

Following this line of reasoning, note that 35 percent of the Italian territory is made up of mountains, 42 percent of hills and 23 percent of plains. Also, Italy was the first region where the Romans built roads, adopting their primordial engineering techniques, hence the focus on the Italian territory is particularly suitable. The investigation on the relationship between Roman roads and geography, intended as the topographical features of the territory (percentage of mountainous territory and elevation), has been conducted adopting two complementary approaches.

The first approach consists in identifying in which territories Roman roads were constructed. Data provided by Istat on the elevation at the Italian municipality level have been geo-coded and mapped using the polygon layer of the Italian territory. The average altitude of each spatial unit has been classified according to five ordered equiproportional classes: [0 - 407 meters); [407 - 814); [814 - 1221); [1221 - 1628); [1628 - 2035). The Italian map was completed with the information on lakes and rivers using Corine Land Cover (CLC) data in order to control for watercourses and basins. The raster of the Roman road network at the Italian level was then superimposed on the polygon one and the Roman roads were divided into certain and uncertain, since the course of the road identifies where the road was constructed. The result is shown in Figure 9. As can be seen, the distribution of Roman roads among the different elevation classes is fairly homogeneous. Roman infrastructure is not absent in the darker areas, where elevation is higher.[24] In central-southern Italy, there is a high concentration of Roman roads in the Apennines, the second mountain range in Italy. Nevertheless, in the North the highest concentration of Roman roads is along the Po Valley, where, clearly, average elevation is lower.[25]

[23] In Italy, their roads in the Alps and the Apennines had steep slopes and can be defined as ancient motorways since they allowed the movement of pedestrians, horses and wagons.

[24] The right part of Figure 9 zooms in on an exemplificative area of North-East Italy (i.e. the delimited rectangular area in the left part of the figure). The chosen area includes four different elevation zones, lakes and a stretch of Roman road that is certain and a second one that is uncertain. It is possible to observe how the course of the Roman road passes through lowlands and more elevated areas. The road does not circumnavigate the lake where the altitude is lower, but crosses a more elevated area.

[25] A first preliminary conclusion is that Roman roads are unrelated with geography. Integrating the map with information on urbanisation and settlements during old Roman times gives a better and more complete view of the relationship between geography and Roman roads.

The second approach relies on the simple information provided by regression coefficients and R-squared, in order to assess whether and how much the Roman infrastructure is explained by the orography of the territory. Ramcharan (2009) argues that rougher territories have less kilometres of roads. This view implies that in rougher territories roads are sparse. However, more kilometres of roads are needed to reach those territories. From this perspective, the relationship between kilometres of roads and geography of the territory is an open question. Also, it is needed to consider which measure of Roman roads (levels or density) is more suitable to be used in the regression analysis at the provincial level. A measure of the density of Roman roads can potentially say something about the nature of the territory, since it controls for the size of the province and measures the degree to which the kilometres of road occupy a given land area. In geographical terms, landforms can be measured by elevation or by the percentage of mountainous territory.[26]

Selecting the most appropriate geographical measure is not trivial. For instance, elevation does not distinguish territories that are mainly mountainous from territories that are mostly hilly but with some mountainous peaks. Table 1 shows the regression coefficients and the R-squared resulting from a simple OLS regression where the dependent variable is represented by the Roman road measure (in kilometres or as density) and where the covariates are the two main geographical features of the territory (elevation and percentage of mountainous territory).

The second and third columns of Table 1, where the β coefficients for both geographical variables are reported, show, in the majority of cases, that both elevation and percentage of mountainous territory are significantly correlated with Roman roads. For certain and for certain and major Roman roads, however, the percentage of mountainous territory, when calculated on the basis of kilometres, does not produce a significant coefficient. When the dependent variable is measured as density, coefficients of elevation are smaller and do not seem to affect the construction of certain and of certain and major roads, once the percentage of mountains is controlled for. The elevation index has (in the majority of cases) a positive sign, suggesting that more kilometres of Roman roads are needed to reach more challenging territories. However, the sign of parameters associated with the percentage of mountainous terrain is always

[26] The data on altitude is considered as a continuous variable rather than as a categorical one as in Figure 9. Data on the percentage of mountainous territory at the provincial level are provided by the Istituto Tagliacarne, which provides three statistics: percentage of mountainous, hilly and flat terrain. The sum of these three percentages gives the total provincial land, 100. Data on elevation by municipality is drawn from Istat. The information by province has been obtained as the average elevation of all its municipalities.

negative, confirming that Roman roads are sparser in more impervious areas. The findings of this multivariate analysis are in line with the evidence provided by the literature. Roman roads, like modern roads, are fewer in those areas where the costs and energy required for building and maintaining transport infrastructure are higher. However, the last column of Table 1 shows that geography explains very little of the Roman infrastructure, suggesting that it is not a key determinant of the road network construction.

Analysis of the literature and the results of the graphical and econometric analyses lead to identical conclusions. The Roman road network covers the entire Italian peninsula in a homogenous manner, covering both low-lying and mountainous areas. More challenging terrains were not avoided by the Romans, though fewer roads were built. The Romans' approach to road construction was thoughtful, circumventing geographical obstacles only when it was not possible to surmount them using clever technical solutions, enabling them to reach the most impenetrable terrains.

5 Trade costs at the provincial level

With regard to the measure of trade costs used as the dependent variable in the subsequent analysis, this is measured for every Italian province, using the indirect approach proposed by Novy (2013), and applied in Jacks et al. (2008), Chen and Novy (2011) and Chen and Novy (2012). The indirect approach to computing trade costs is based on the insights provided by the structural gravity model of Anderson and van Wincoop (2003) and by additional contributions from Anderson and Yotov (2010, 2012), Fally (2015), Head and Mayer (2014) and De Benedictis and Taglioni (2011). The trade cost factor - that is the tariff equivalent of all possible bilateral costs associated with international trade – is obtained inverting the gravity equation as in Novy (2013, p.105). The result is a comprehensive aggregate measure of bilateral trade costs, $\mathcal{T}_{i,j}$, in the form of the geometric average of international trade costs, $t_{i,j}$ and $t_{j,i}$ between the spatial unit i and the spatial unit j, relative to domestic trade costs within each spatial unit, $t_{i,i}$ and $t_{j,j}$.[27] Accordingly, the measure of $\mathcal{T}_{i,j}$ for the Italian provinces has been calculated for every

[27] As stated by Novy (2013) "The intuition behind $\mathcal{T}_{i,j}$ is straightforward. If bilateral trade flows $X_{i,j}$ $X_{j,i}$ increase relative to domestic trade flows $X_{i,i}$ $X_{j,j}$, it must have become easier for the two countries to trade with each other relative to trading domestically. This is captured by a decrease in $\mathcal{T}_{i,j}$, and vice versa. The measure thus captures trade costs in an indirect way by inferring them from observable trade flows. Since these trade flows vary over time, trade costs $\mathcal{T}_{i,j}$ can be computed not only for cross-sectional data but also for time series and panel data."

year in the time interval 2003-2010 as the geometric average of the bilateral trade costs between an Italian province i and a foreign country j. Four variables have been used to calculate the trade costs following an indirect approach: exports from province i to country j, $X_{i,j}$; exports from country j to province i (imports to province i from country j), $X_{j,i}$; intra-provincial trade of province i, calculated as GDP minus province i's total exports, $X_{i,i}$; intra-national trade of country j, computed as GDP minus country j's total exports, $X_{j,j}$,

$$\mathcal{T}_{i,j} \equiv \left(\frac{t_{i,j}t_{j,i}}{t_{i,i}t_{j,j}}\right)^{\frac{1}{2}} - 1 \equiv \left(\frac{X_{i,i}X_{j,j}}{X_{i,j}X_{j,i}}\right)^{\frac{1}{2(\sigma-1)}} - 1 \equiv \left(\frac{(GDP_i - X_i)(GDP_j - X_j)}{X_{i,j}\ X_{j,i}}\right)^{\frac{1}{2(\sigma-1)}} - 1 \quad (1)$$

and the elasticity of substitution, σ, used in Equation 1, has been taken from the literature: $\sigma = 8$.[28] To be as agnostic as possible, the analysis has been replicated for values of σ of 7 and 11. Results are discussed in Section 7 and are summarised in the Appendix.

Data on imports and exports at the provincial level are from Istat.[29] Trade flows refer to 192 countries from 2003 to 2010. Since the original data are expressed in euro, the conversion in US dollars has been done using the ECB reference exchange rate US$/€ from the European Central Bank (ECB). To preserve the implicit information contained in absent trade flows (i.e. relatively too high international trade costs), zero trade flows have been replaced with a unit of the metric in use.[30]

Calculating domestic trade by province requires GDP and total exports at the provincial level. Total exports have been computed adding up all exports to international trade partners,

[28] Anderson and van Wincoop (2004) conclude that σ is likely to range from 5 to 10 and that, for goods that are differentiated and less substitutable, estimates are around 7 or 8.

[29] Data are available for an 8 year period (2003-2010) for 107 of the 110 provinces. The provinces of Barletta-Andria-Trani (in southeastern Italy, Apulia), Fermo (in eastern-central Italy, Marche) and Monza (in northwestern Italy, Lombardy) were established in 2004, but became operative in 2009; therefore, they are not included in the dataset. The same applies for the four 'new' Sardinian provinces (Carbonia-Iglesias, Medio-Campidano, Ogliastra, Olbia-Tempio) established in 2001, but went into operation in 2005: data are available from 2007 to 2010. Moreover, for the four historical Sardinian provinces (Cagliari, Oristano, Nuoro, Sassari) data for 2006 are missing.

[30] This approach is the one proposed by McCallum (1995) and Raballand (2003), who suggest replacing the zeros with small positive numbers. In the gravity model framework the case of zero trade flows is serious, since usually the dependent variable is expressed in logarithms and the logarithm of zero is undefined. As highlighted by Haq et al. (2011), besides the method suggested by McCallum (1995) and Raballand (2003), researchers have adopted different strategies to deal with this problem. McCallum (1995) and Frankel (1997) suggest deleting zeros, but the omission of zeros generates sample selection bias. Rose (2000) proposes estimating a Tobit model and censoring the zeros at the left tail. Helpman et al. (2008), Emlinger et al. (2008), Disdier and Marette (2010), Jayasinghe et al. (2010) use a Heckman selection model. The advantages and weaknesses behind each approach are amply discussed in the literature. The one selected in this paper is the most common in empirical research.

converting euro to US dollars. To obtain the provincial GDP, the Italian GDP from World Bank WDI database and the provincial value added (VA) data from Istat have been used. The GDP from World Bank has been decomposed using the weights derived from the VA. In other terms, for each province the information on the provincial VA has been exploited to compute the share that each Italian province has on the total Italian VA, and these shares have been applied to decompose the total Italian GDP into provincial GDP. Finally, the provincial internal trade has been obtained subtracting the total value of exports from the provincial GDP. Moreover, we separate the foreign market of reference into two nested clusters, one that comprises the early members of the European Union (i.e. j refers only to countries in the EU15) and the other that includes all countries in the world including the EU15 group (i.e. j refers to all countries in the world), to differentiate 'short distance' trade from 'total' international trade.[31]

Intra-national trade has been computed using the values for GDP reported in the World Bank WDI database and subtracting the total value of exports, obtained adding up bilateral trade data from the BACI-CEPII dataset revision of the Comtrade UN database.[32]

Descriptive statistics of the average $\mathcal{T}_{i,j}$[33] - that can be indicated as $\mathcal{T}_i$ – allow to assess three dimensions: the relevance and distance of the export market (world and EU15), the duality of the Italian territory, and the changes that occurred after the 2008 international economic crisis.

As clearly emerges from Figure 10, world market's average trade costs are considerably higher than those associated with the EU15 market, suggesting that shorter bilateral distance, being part of the same customs union, and sharing the same currency, similar culture and institutions play a significant role in making trade less costly. When Italian provinces trade with other

[31] Here lies the main concern about the inaccuracy in the computation of provinces' internal trade, since it includes 'exports' from each province to regions outside the provincial boundaries but within Italy itself. Unfortunately, this information is not currently available. However, robustness checks in Section 7 try to overcome this constraint, computing a measure of indirect trade costs corrected for intra-national trade by decomposing intra-national regional exports data obtained from the EU Joint Research Center (http://s3platform.jrc.ec.europa.eu/s3-trade-tool). The great advantage of an indirect measure of trade costs à la Novy is the general information it gives at the provincial level: the indirect measurement of all tangible and intangible obstacles that separate the domestic provincial market from the international one, allowing to focus on different foreign markets of reference (such as the EU15 market or the world market, in the case of this work).

[32] The data from the World Bank World Development Indicators has been obtained from https://data.worldbank.org/data-catalog/world-development-indicators, while the data on international trade flows from Cepii has been obtained from http://www.cepii.fr/cepii/en/bdd_modele/presentation.asp?id=1. Detailed information on the data used, the definition of variables, and the original sources is summarised in Table 3.

[33] $\mathcal{T}_{i,j}$, the annual value of trade cost for every province i with respect to all its trade partners j, has been averaged along the j dimension, obtaining a single value for every province for any given year and any cluster of trade partners. The time subscript and the cluster superscript will be avoided for the moment and the former will be explicitly indicated in Equation 2.

countries around the world, average trade costs are around 10; in the EU15 market this value is approximately 2.[34] The differences between years before and after the 2008 crisis can be better appreciated looking at Table 2. In spite of the global reduction in international trade costs due to technological innovation in transportation and to liberal trade policies, Table 2 shows how the crisis is associated with an increase in trade costs in Italian provinces: average values in 2010 are higher than those of 2003 in both panels of Figure 10 and in the respective columns in Table 2. This demonstrates that $\mathcal{T}_i$ varies both in time and space, and that this variability can be fruitfully exploited in the empirical analysis.

Figure 10 and Table 2 also reveal the noteworthy differences across the Italian territory. For explanatory purposes, Italy has been divided according to the NUTS1 classification, collapsing provinces (NUTS3) according to the macro-region of reference, and aggregating the southern regions with the insular ones.[35] Figure 10 and Table 2 clearly show that northern Italy has the lowest average trade costs; provinces in the centre are halfway between an internationally open North and a less-open South, and the economic backwardness of the southern provinces is reflected in higher average trade costs. Within northern Italy, the North-East macro-region performs better than the North-West, the latter ranking slightly higher in terms of average trade costs.

The well-known Italian duality is confirmed and newly assessed by the map of provincial average trade costs distribution, depicted in Figure 11. In 2010, average world market trade costs (left panel) present a spatial distribution that is strongly consistent with that of per capita income. On the one hand, there is a macroscopic gap between the northern and southern provinces; on the other, average trade costs are higher in provinces near the northern Italian border, where connectivity is strongly influenced by geography (i.e. the mountainous Alpine area). Moreover, Figure 11 highlights that this clear dichotomy between the North and South of the country is accentuated when considering world markets, rather than the EU15 market (right panel).[36]

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[34] Since $\mathcal{T}_{i,j}$ is a tariff equivalent, a value of $\mathcal{T}_{i,j}$=10 implies that $p_{i,j} = p_i \ (1 + \mathcal{T}_{i,j})$. The price of a good produced in province i is on average more than ten times higher when sold on the market of country j, that belongs to the world cluster. An identical reasoning applies to the EU15 market were the average $\mathcal{T}_{i,j}$=2.

[35] The North-West NUTS1 aggregation includes the following Italian NUTS2 regions: Piedmont, Aosta Valley, Liguria and Lombardy. The North-East NUTS1 aggregation comprises: Trentino-South Tyrol, Veneto, Friuli-Venezia Giulia, Emilia Romagna. The center NUTS1 level includes: Tuscany, Umbria, Marche, Lazio. NUTS2 regions belonging to the South NUTS1 aggregation are: Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria. The insular NUTS1 level includes the two main Italian islands: Sicily and Sardinia.

[36] Average world market trade costs (e.g. for every province the trade cost with respect to all j trade partners

6 Empirical model and estimation results

After this *mise en place*, it is now time to focus on the channel through which historical infrastructure can affect current trade costs.

Determinants of trade costs have been extensively researched by the empirical literature (Anderson and van Wincoop, 2004) and include several classes of factors: geographical, institutional and policy measures. Some of these factors do not vary over time (e.g. geographical features), others are time-variant (e.g. infrastructures), others are unobserved (e.g. local culture) or unavailable. Also in the present case, the effect of Roman roads on trade costs will be assessed in a model that includes both time-variant and time-invariant determinants at the province (NUTS3) level. The model allows to control for the unobserved heterogeneity within the Italian territory, using regional (NUTS2) fixed effects, and over time, using time fixed effects, so to minimise the omitted variable bias.

The endogeneity bias, arising from the possibility that well connected provinces (those with lower trade costs) are also the richest ones, that can afford to invest in infrastructure, enhancing productivity and further reducing trade costs, will be tackled using an instrumental variables approach, instrumenting infrastructure with a measure of Roman roads intensity.

6.1 The direct effect: OLS estimates

The estimated linear model is written as:

$$\tau_{i,t} = \alpha_0 + \mathbf{X}_{i,t}\ \alpha_1 + \mathbf{H}_i \alpha_2 + \alpha_3 \mathcal{RR}_i + \mathbf{G}_i \alpha_4 + \phi_r + \phi_t + \epsilon_{i,t} \tag{2}$$

where $\tau_{i,t}$ denotes the dependent variable, the log transformed average trade cost ($\tau_{i,t} \equiv \log(\mathcal{T}_{i,t})$) at the province level, for the years from 2003 to 2010; $\mathbf{X}_{i,t}$ denotes a matrix of time-invariant measures, including current infrastructure, $\mathbf{I}_i$, and time-variant measures, including productivity, $\mathcal{D}_{i,t}$, at the province (NUTS3) level;[37] $\mathbf{H}_i$ denotes a matrix of count variables referring to the

has been averaged along the j dimension) range from a minimum of 3.64 to a maximum of 22.91; in the case of the EU15 market they range between 1.19 and 30.09. The latter, surprisingly high, value corresponds to a single province; for the remaining 106 provinces, EU15 average trade costs span up to the level of 9.17. In the case of world markets, more than half of the provinces (58 out of 107) have an average trade cost of more than 9.17, and more than a quarter higher than 13, revealing that average trade costs for the world market are higher than for the EU15 market.

[37] All regressions have also been run without controlling for $\mathcal{D}_{i,t}$. In all cases, results are strongly confirmed. Moreover, as a further control, the distance of the province from Rome has been included in all specifications. Once again, results are confirmed.

number of years the province was ruled by past dominations; $\mathcal{RR}_i$ denotes the measure of Roman roads, by province; $\mathbf{G}_i$ denotes a matrix of geographical measures, by province; ϕ_r denotes regional (NUTS2) fixed effects; ϕ_t denotes year fixed effects; and $\epsilon_{i,t}$ denotes the error term, clustered at the province level.

According to Kessides (1993), current infrastructure affects economic development and performance in a large number of ways, acting through different channels, including externalities, spillover effects and indirect mechanisms.[38] In Equation (2), $\mathbf{I}_i$ is included considering two different means of transport and the physical infrastructure related thereto: railways and roads. Within current roads, both motorways and all roads are examined.[39] The $\mathbf{X}_{i,t}$ matrix also includes a control for total productivity, $\mathcal{D}_{i,t}$, which has been computed dividing the total value added by the total number of workers, at the province level. Both data are from Istat and refer to the eight years between 2003 and 2010.[40]

Since the seminal contribution of Guiso, Sapienza and Zingales (2011), it has become evident that when investigating the causes of the variability in income and productivity for Italian provinces, it is necessary to control for differences in the civic capital endowment within the Italian territory. Di Liberto and Sideri (2015) trace it back to past foreign realms and dominations. The need to control for civic capital and trust, in order to deal with omitted variable bias, also applies to the present study. Therefore, the data collected and examined in Di Liberto and Sideri (2015) is included in the matrix $\mathbf{H}_i$, referring to the length of the dominations that ruled Italy between the twelfth and eighteenth century.[41]

[38] As discussed in Section 2, the influence of infrastructure on trade costs has recently been reported and documented by Donaldson (2015).

[39] Data on kilometres of railways by province are from Istat and refer to 2005. The information is provided for 103 out of 110 provinces, since the missing provinces were established or became operational after 2005. Data on the current road network are from Automobile Club d'Italia (ACI) and are updated to 2011. Until 2011 there was a lack of data on the provision of road infrastructure in the different and comprehensive territorial levels. ACI fulfilled the need for more detailed data, collecting information from different sources. Data on motorways comes from AISCAT (`http://www.aiscat.it`) and ANAS (`http://stradeanas.it/it`). ANAS also provided data on national roads of interest.

[40] As no information was available about the number of workers in 2003, 2004 data were also used for 2003 checking for any significant variations in the number of workers in the following years.

[41] Di Liberto and Sideri (2015) follow two approaches to measure past dominations. On the one hand, they use a set of binary variables that identify, for each province, the administration that ruled from the mid sixteenth century to the mid seventeenth century, namely, the period from 1560 to 1659. In that period, the Italian peninsula had five different governments and one independent area, thus generating six binary variables: the Spanish Kingdom, the Republic of Venice, the Duchy of Savoy, the Papal State, the Austrians, the independent area. On the other hand, they measure the different administrations that governed Italy over seven centuries before the creation of the unified Italian State (1861), namely, the period from about 1100 to 1700, assigning to each province the number of years during which each regime ruled. During these 700 years, nine dominations

The matrix $\mathbf{G}_i$ accounts for surface morphology, as there is a strong correlation between rougher surfaces and ease of moving goods. The geographical variables included in the analysis are those already introduced in Section 4.3: the percentage of mountainous territory and elevation. Table 3 summarises the data and the sources used to construct all the variables.

The regression of $\tau_{i,t}$ on $\mathcal{RR}_i$ - excluding $\mathbf{I}_i$ – is the 'reduced form' of Equation (2). The results of this 'reduced form' are presented in Table 4. Comparing them with the results of Equation (2) shows whether the correlation between historical infrastructure and current trade costs reflects the influence that the Roman road network had on the development of current infrastructure. This comparison conveys information on the validity of $\mathcal{RR}_i$ to be used as an instrument for $\mathbf{I}_i$, i.e. the exclusion restriction: an instrument is valid if it does not influence the dependent variable when the potentially endogenous variable is included.[42]

From Ramcharan (2009) and Del Bo and Florio (2012), it is known that geographical variables can be used as instruments for current infrastructure, since landforms are closely correlated with the development of infrastructure, but they are expected to be uncorrelated with current economic development, once infrastructure is controlled for. Estimating the model in Equation (2) and its 'reduced form' provide a test on whether the historical infrastructure has similar characteristics (the correlation between the historical network and current trade costs being null, $cov(\mathcal{RR}_i, \tau_{i,t}) = 0$), when potentially endogenous variables in $\mathbf{X}_{i,t}$ are also included.

In the 'reduced form' equation both sets of potential instruments - $\mathcal{RR}_i$ and $\mathbf{G}_i$ – are included. Results are presented in Table 4. The coefficient of Roman roads (the measure considered is certain Roman roads, in kilometres, and log transformed) is always highly significant and with the expected negative sign: it shows the direct effect that Roman roads have on trade costs when excluding current transport infrastructure from the model. The effect is robust to the inclusion of controls, such as past dominations, and also when controlling for current productivity, as in column 4. The R-squared values indicate satisfactory goodness-of-fit. The 'reduced form' coefficients of past dominations are interesting in their own right. Over and above the North-South dichotomous economic structures, captured by the regional fixed effect, ϕ_r, the Bourbon domination is positively correlated with $\tau_{i,t}$, while the Norman rule shows a negative coefficient of similar size.

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occurred: the Normans, the Swabians, the Anjou, the Spanish, the Bourbons, the Papal State, the Savoy, the Austrians and the Republic of Venice. This second set of variables is included in Equation 2 as $\mathbf{H}_i$.

[42] For details on this see Angrist and Pischke (2008, pp. 85-91).

Including current infrastructure, as in Equation (2), produces the results summarised in Table 5. In the first three columns, kilometres of railways are considered. Columns 4, 5 and 6 look at motorways. In columns 7, 8 and 9 the kilometres of all existing roads are used. In the last three columns total current roads are divided into kilometres of motorways and kilometres of other roads in order to disentangle the effect of major roads from that of minor roads. As above, standard errors have been clustered at the provincial level. At a significance level of 5%, when motorways or railways are included, the standard errors of the relevant coefficients show the absence of any direct effect of Roman roads on trade costs. On the other hand, significance and negative sign of the coefficient associated with the current infrastructure measure persists in all the specifications, regardless of whether both geographical and Roman road measures are included, confirming that lower trade costs are negatively correlated with current infrastructure.

In columns 7, 8 and 9 both current and historical (Roman) infrastructure are highly significant and have the correct negative sign. The explanation for this mixed effect of Roman roads is to be found in the last three columns. As shown in specifications 10, 11 and 12, when distinguishing all current roads between motorways and other roads, the effect of the minor roads disappears and only motorways have an impact on current trade costs. Moreover, the direct effect of Roman roads vanishes.

Comparing these results with Table 4, the fulfilment of the exclusion restriction is verified from a statistical point of view (at 5% significance level): the direct effect of Roman roads on current development derives from its connection with current infrastructure. Testing the contribution of the historical road network to current roads and railways, $cov(\mathcal{RR}_i, \mathbf{I}_i)$, will be the next step of the analysis.

6.2 The indirect effect: 2SLS estimates

When OLS estimates are performed regressing $\tau_{i,t}$ on $\mathbf{I}_i$, this raises a quest against the possible effect of endogeneity and omitted variable issues on the bias and consistency of the estimated coefficients. These issues are closely related with questioning the channel of transmission from the historical road network to current trade costs. In other words, investigating whether and how strongly Roman roads left their mark on current roads and railways. This second phase of the empirical analysis will therefore adopt an instrumental variables (IV) approach, using a two-stage least square (2SLS) estimator, for assessing how deeply Roman infrastructure has influenced the presence and articulation of current infrastructure in the Italian provinces. Following Del Bo and Florio (2012), the historical measure will be tested along with geographical variables, using both sets of variables as instruments for current infrastructure. Issues related to the possible risk of using weak instruments when the potentially endogenous variable is over-identified will also be investigated.

If, on the one hand, the IV methodology offers several advantages in terms of addressing omitted variable bias, measurement error or reverse causality problems, on the other, the main challenge lies in two important conditions that need to be fulfilled: the correlation between the instrumental variable and the instrumented variable should be different from zero, something that will be tested in a 'first stage' equation, and the correlation between the instrumental variable and the error term should be zero, which is related to the exclusion restriction tested above, but that will be further investigated. These two conditions, that are unavoidable when using instrumental variable methods, and that define the validity of an instrument, are the key steps to assess the effects of the Roman road network on current trade costs through current roads and railways.

Moving to the model, the 'first' (Equation (3)) and 'second stage' (Equation (4)) of the IV approach, where $\mathcal{RR}_i$ and $\mathbf{G}_i$ represent the instrumental variables and $\mathcal{I}_i$ represents the variables to be instrumented, can be written as follows:

$$\mathcal{I}_i = \delta_0 + \delta_1 \mathcal{RR}_i + \mathbf{G}_i\ \delta_2 + \mathbf{H}_i\ \delta_3 + \delta_4 \mathcal{D}_i + \phi_r + \nu_i \tag{3}$$

$$\tau_{i,t} = \alpha_0 + \alpha_1 \hat{\mathcal{I}}_i + \alpha_2 \mathbf{H}_i + \alpha_3 \mathcal{D}_{i,t} + \phi_r + \phi_t + \epsilon_{i,t} \tag{4}$$

where the productivity measure $\mathcal{D}_i$, in the 'first stage' equation, and $\mathcal{D}_{i,t}$, in the 'second stage' equation, are made explicit with respect to Equation (2) in which productivity has been included in matrix $\mathbf{X}_{i,t}$.

The validity of the Roman road instrument requires the following two conditions to hold: $corr(\mathcal{RR}_i, \mathcal{I}_i) \neq 0$ in the 'first stage' equation; and $corr(\mathcal{RR}_i, \epsilon_{i,t}) = 0$ in the 'second stage' equation. The first condition refers to the correlation between Roman roads and current infrastructure and is easily verifiable through the 'first stage' statistics in Table 6. The key idea behind the positive correlation between $\mathcal{RR}_i$ and $\mathcal{I}_i$ is that areas with denser Roman road infrastructure are more likely to have a denser present road and railway infrastructure, since

Roman roads shaped the Italian landscape making the construction of later roads less costly as they simply followed the same route traced by the Romans. The second condition requires the instrument to be uncorrelated with any other determinant of the dependent variable. While it is possible to test whether the first condition is satisfied, the second condition cannot be tested when the model is exactly identified (number of instruments equal to the number of endogenous regressors). Over-identified models - such as the one used here – allow, instead, instrument exogeneity to be tested.[43] However, tests on the exogeneity of instruments are necessary, but not sufficient.

Results of the IV regression are shown in Table 6. Since from Table 5 it emerged that current minor roads have a negligible impact on trade costs, the analysis, summarised in Table 6, takes into account motorways and railways as measures for current infrastructure. The coefficients for both current infrastructure measures are highly significant and with the expected negative sign, confirming that the transport infrastructure has a positive effect in reducing trade costs and, consequently, that provinces with a more developed infrastructure network should be more advantaged in trading internationally than domestically, taking advantage of larger market size. The bottom part of Table 6 includes post-estimation tests on heteroskedasticity, relevance and exogeneity (i.e. validity) of instruments and endogenous regressors.

Since the potential collinearity between geographical variables (that warns about the joint use of geophysical instruments), elevation, together with the Roman road measure, have been adopted to instrument railways, while the percentage of mountainous terrain and the Roman roads have been exploited to identify motorways.[44] 'First stage' estimates of Table 6, namely the effect of $\mathbf{G}_i$ and $\mathcal{RR}_i$ on $\mathcal{I}_i$, confirm the relevance of the Roman road measure, whereas geographical instruments appear to be weak.[45] On the other hand, the effect of Roman roads on

[43] The exogeneity of the Roman road instrument is confirmed by Garcia-López et al. (2015) and by De La Roca and Puga (2017) in two studies on urbanisation and agglomeration economies in Spain. Garcia-López et al. (2015) exploit the Roman road measure in kilometres as an instrument for modern motorways to explore the sub-urbanisation of 123 metropolitan Spanish cities. De La Roca and Puga (2017) adopt the number of Roman road rays located within 25 km from each urban centre as an instrument for current city size.

[44] The choice of two different geographical variables for instrumenting current infrastructure is not trivial. Literature suggests that a 1 percent increase in elevation is associated with a 1 percent decline in the number of kilometres of the current infrastructure. However, it is also true that landforms matter: more kilometres of transport networks may be present in mountainous territories, given the orography. An additional point has to do with the chronology of construction. Since rail predates road infrastructure, it might be argued that the elevation of the territory influenced railway construction first. On these bases, elevation has been used for railways, and percentage of mountainous territory for motorways.

[45] Appropriateness of geographical instruments is better confirmed when exploiting robust rather than clustered standard errors.

current infrastructure, is always positive, as expected, and highly significant. These results are confirmed when testing the relevance condition. 'First stage' F-statistics prove the correlation with the included endogenous variable: results are more impressive when Roman roads are used as a single instrument.[46] According to the indications coming from the F-test of the 'first-stage' equation, the Hansen's J statistic of overidentifying restrictions suggests that the use of $\mathbf{G}_i$ and $\mathcal{RR}_i$ guarantees the validity of the exclusion restriction. As a further proof, relaxing the IV validity assumption (i.e. $corr(\mathcal{RR}_i, \epsilon_{i,t}) = 0$) and following Conley et al. (2012), bounds, rather than point values, are estimated. Results reported in Table 7 strongly confirm the instruments' validity.[47]

An additional check refers to the suitability of the IV method. The Durbin-Wu-Hausman (DWH) test concludes that the variables being instrumented are endogenous, confirming that the IV approach is needed. In regressions 2 and 4 the use of the IV estimator is questioned, since the null hypothesis that the instrumented variable is exogenous is not rejected, but is confirmed by the Hausman test. However, the detected heteroskedasticity (Pagan-Hall test) in all specifications may impact on the consistency of tests' results.

7 Robustness checks

The main conclusion that emerges from the empirical analysis is the persistent and negative effect of the historical Roman road network on Italian provincial trade costs, which resists different types of controls.

Robustness checks have been performed with a threefold purpose. First, to further explore the appropriateness of the indirect measure of trade costs, for capturing trade frictions and, therefore, to be used in studies aimed at exploring the effects of historical events on contemporary

[46] At 5% significance level, the null hypothesis that the instruments do not suffer from the specified bias (i.e. instruments are not weak) can be rejected tolerating a 20% maximal size distortion when both geographical and historical instruments are used. The first-stage F-statistic exceeds, instead, all weak identification critical values proposed by Stock and Yogo (2005) for the maximal IV size when the Roman road instrument alone is adopted. With robust standard errors the absence of a weak instruments problem is strongly confirmed, also when exploiting both geographical and Roman road instruments.

[47] The plausible exogeneity test by Conley et al. (2012) relaxes the standard IV validity assumption, allowing non-zero values of instruments' coefficients. One of the approaches they propose consists in assuming a minimum and maximum value for the parameter of the instrumental variable. They call this method "Union of Confidence Intervals" (UCI). The larger the interval, the weaker the plausibility of exogeneity. Throughout the analysis, the traditional exogenous restriction assumption is relaxed slightly, since a quite narrow interval for the Roman road measure is assumed: [-0.01; 0]. Results for all specifications adopting solely the Roman road instrumental variable demonstrate the validity of the instrument used.

outcomes. Second, to confirm the relevance and significance of the Roman road measure and its remarkable role in influencing current economic outcomes. Third, to provide further validation of the exogeneity of the Roman road network expansion. On these bases, robustness checks can been divided into three groups: controls referring to the dependent variable, $\tau_{i,t}$; controls referring to the main independent variable of the analysis, $\mathcal{RR}_i$; and controls referring to the exogeneity of the Roman road measure.

7.1 Dependent variable

The first set of robustness checks considers, for further validation, three different issues linked to the indirect measure of trade costs: the value of the elasticity of substitution, σ, considered, the reference export market, and the correction of the original Novy (2013) measure, when applied to sub-country spatial units of analysis.

Table 8 - included in the Appendix – replicates the structure of Table 6. The IV regression is exactly the same, apart from the dependent variable $\tau_{i,t}$ that, in the first four columns, is calculated using a higher elasticity of substitution (σ=11) in Equation (1),[48] while, in the last four columns, it is calculated considering a lower elasticity of substitution than the benchmark case ($\sigma = 7$). In Table 9 - also included in the Appendix – σ is fixed at the benchmark; what changes is the export market of reference, which in this case is the EU15. Trade costs, therefore, refer to 'short distance' trade.

As is evident from Tables 8 and 9, the benchmark results remain unchanged. Roman roads are confirmed to be a valid instrument for current infrastructure, which plays a negative role in determining trade costs, invariantly with respect to the level of substitutability of the goods traded and the export market of reference.

A further check has to do with the application of the indirect measure of trade costs at the Italian provincial level. The original measure, as described in Equation (1), simply derives trade costs from the formula proposed by Novy (2013) for international exchanges between nations, using generally available data on export flows and GDP at the country level. The application of the indirect approach to computing trade costs at the provincial level requires correcting the original measure, including in the calculation of $\tau_{i,j}$ export flows originating from province i and 'exported' to other Italian provinces, $X_{i,-i}$. In other words, at the province level, the value

[48] Eaton and Kortum (2002), Jacks et al. (2010) and Anderson and Yotov (2012) adopt the value σ=11.

of production that remains to local consumers needs to be computed omitting from local GDP the value of export flows to foreign countries and the one sold in other Italian provinces, as in Equation 5:

$$X_{i,i} = GDP_i - X_i - X_{i,-i}. \tag{5}$$

Data on inter-provincial trade is however not available. Recently, the EU Joint Research Center published data on inter-regional trade, for 256 European regions (NUTS2) for the three years 2000, 2005, and 2010. Therefore, the data on inter-regional trade have been used to obtain a proxy for $X_{i,-i}$, adopting provincial value added data as weights. The results - available on request - show no significant or substantial differences between calculating $\tau_{i,j}$ as in Equation (1) and adopting the inter-provincial trade correction.

7.2 Different measures of Roman roads

The second set of robustness checks concerns the use of different measures of Roman roads infrastructure. On the one hand, major and all Roman roads have been tested to confirm the robustness of the measure. On the other, the density measure takes into account the size of the provincial area.

Table 10 presents the estimation results when alternative measures of the Roman road infrastructure are used. In previous OLS and IV regressions, $\mathcal{RR}_i$ was defined taking into account only certain Roman roads. Table 10 shows the results of IV regressions when the Roman road instrument includes either major or all Roman roads, confirming the results obtained in the main empirical analysis: both major and all Roman roads are valid instruments for railways and motorways, substantiating the hypothesis that transport infrastructure causes a reduction in trade costs. However, as opposed to Table 6, both geographical variables perform well as instruments for predicting current infrastructure: the positive sign of the parameters linked to the geographical instruments suggests that more inaccessible territories require more infrastructure.

Even if, using fixed effects at the region level, ϕ_r, the effect of size is controlled for in the main IV regression, a finer control for the size of the province can be included in the analysis measuring $\mathcal{RR}_i$ as density (kilometres of roads per 100 square kilometres of land area) instead of in levels. Table 11 summarizes the results. Once again, the main outcomes of the analysis are confirmed in all dimensions: coefficients' sign, magnitude and significance.[49]

[49] The first-stage F-statistic exceeds the critical value for 20% or 25% of maximal IV size only in specifications

7.3 Historical dynamics of Roman roads

The last set of robustness checks concerns the historical evolution of the Roman Empire and the dynamics of the Roman road network construction. This issue is relevant since it further qualifies the point on the endogeneity of Roman roads discussed in Section 4. Segments of a transportation and mobility network are not created at random and the process of network formation follows a preferential attachment rule requiring that new segments be connected to previously existing ones (Barthélemy, 2011). The existence of a given segment and its length are, therefore, not independent of the existence and length of previously existing ones. This sequentiality in network formation implies that the location of new segments is endogenous, and this has to be taken into account in identification.

In order to account for this effect, the development of the Roman road network has been decomposed into nine historical periods, from 800 B.C. to 1 A.D. The Roman Empire expansion and the construction of the corresponding Roman road network has been subdivided and mapped using GIS techniques.[50] Figure 12 maps the expansion of both Roman Empire and Roman road network for the nine periods in a single map. Figure 13 shows separate maps. For each of the nine historical periods the measures of Roman roads at the province level have been computed.

Spatial path dependency has been modeled in two ways. The first is a simple model where Roman roads at their maximum expansion, $\mathcal{RR}_9$, are a function of the previous stages of the development of the network:

$$\mathcal{RR}_9 = \alpha_0 + \alpha_1\mathcal{RR}_8 + \alpha_2\mathcal{RR}_7 + \alpha_3\mathcal{RR}_6 + \alpha_4\mathcal{RR}_5 + \alpha_5\mathcal{RR}_4 + \alpha_6\mathcal{RR}_3 + \alpha_7\mathcal{RR}_2 + \alpha_8\mathcal{RR}_1 + \epsilon_i \tag{6}$$

The second is a recursive model where, except for the initial step, every step is dependent on the fitted value of the previous one:

$$\mathcal{RR}_2 = \alpha_0 + \alpha_1\mathcal{RR}_1 + \epsilon_i \tag{7}$$

where the Roman road instrument alone is adopted. However, with robust standard errors the fulfilment of the relevance condition is strongly confirmed.

[50] The analysis has been facilitated by the use of the digital history repository and desktop app Running Reality (`http://www.runningreality.org`), which is freely available online. The division into nine periods is the default one in Running Reality.

$$\mathcal{R}\mathcal{R}_3 = \alpha_0 + \alpha_1 \hat{\mathcal{R}\mathcal{R}}_2 + \epsilon_i \quad (8)$$

$$\mathcal{R}\mathcal{R}_4 = \alpha_0 + \alpha_1 \hat{\mathcal{R}\mathcal{R}}_3 + \epsilon_i \quad (9)$$

$$\mathcal{R}\mathcal{R}_5 = \alpha_0 + \alpha_1 \hat{\mathcal{R}\mathcal{R}}_4 + \epsilon_i \quad (10)$$

$$\mathcal{R}\mathcal{R}_6 = \alpha_0 + \alpha_1 \hat{\mathcal{R}\mathcal{R}}_5 + \epsilon_i \quad (11)$$

$$\mathcal{R}\mathcal{R}_7 = \alpha_0 + \alpha_1 \hat{\mathcal{R}\mathcal{R}}_6 + \epsilon_i \quad (12)$$

$$\mathcal{R}\mathcal{R}_8 = \alpha_0 + \alpha_1 \hat{\mathcal{R}\mathcal{R}}_7 + \epsilon_i \quad (13)$$

$$\mathcal{R}\mathcal{R}_9 = \alpha_0 + \alpha_1 \hat{\mathcal{R}\mathcal{R}}_8 + \epsilon_i \quad (14)$$

Table 12 - included in the Appendix – replicates the structure of Table 6, using the two new versions of $\mathcal{R}\mathcal{R}_i$. The first four columns summarise the results obtained when $\mathcal{R}\mathcal{R}_i$ is measured as a time series process as in Equation 6; the last four columns summarise the results obtained when $\mathcal{R}\mathcal{R}_i$ is measured as a recursive process. Coefficients' signs, magnitude and significance of current infrastructure are confirmed in all specifications. The Roman roads measure, its effect on current infrastructure and its goodness as an instrumental variable, is corroborated by 'first stage' statistics and coefficients.

8 Concluding remarks

The Roman Empire, with its ambitions of expansion, development and growth and characterised by superior engineering skills and military might, well-structured organisation and advanced knowledge, has recently been found to have had a deep and long-lasting effect on economic outcomes. German regions that were once part of the Roman Empire are more developed than those that were not (Wahl, 2017). This paper provides novel evidence on the long-term effect of the Roman Empire. It shows how the Roman road network has had a persistent effect on the present day road and railway system in Italy and, through this mechanism, it has been possible to identify an exogenous channel of influence from transport infrastructure to trade costs. The case of Italian provinces is interesting for several reasons: historically Italy is characterised by a duality between the developed North-Centre and a less developed South. Italian provinces seem to perform differently in terms of international trade costs, although central government is responsible for the maintenance of the current infrastructure. In all but two Italian provinces (NUTS3) there exist roads built during the Roman Empire. At the same time however, the measure of Roman roads, both in absolute or size-adjusted values, shows a remarkable variability, being the result of the needs of the military campaigns conducted by the Romans during the expansion of the Empire.

This paper presents a detailed investigation of historical sources, narrations and facts in order to understand why and how Roman roads were constructed. The reason was military: paved roads facilitated the movement of the army and enabled the transportation of supplies to the troops. Furthermore, wherever possible, Roman roads were built as straight lines between two strategic military points; an engineering feature which supports the exogeneity of infrastructure construction with respect to economic development in Roman times. Following this line, the paper also discusses the weak relationship between geography (landforms) and extent of the Roman road infrastructure.

The mark left by Roman roads on current infrastructure has been investigated adopting an IV approach. Following Ramcharan (2009), geographical variables have also been included as instrumental variables. This analysis tests Roman roads as a stronger and robust instrumental variable for current infrastructure. The econometric analysis reveals a meaningful and significant positive effect of the integrated ancient Roman road network on current infrastructure, whereas its direct effect on trade costs disappears when current infrastructure controls are included, supporting the validity of the exclusion restriction. Final results suggest that current infrastructure has the effect of reducing actual trade costs respectively by 20 - 23 percent (motorways - railways) when instrumented by the Roman road network. Roman Roads have had a highly significant influence on modern infrastructure measured by a coefficient of 0.30 on railways and 0.35 on motorways. This complements the qualitative information provided by the fact that still today some motorways in Italy are named after the Roman road that was constructed nearby.

Summarizing, the contribution of this research to the economic literature is twofold: it presents novel results on the persistent effect of history on contemporary economic outcomes and it provides a novel instrument for the quantification of the causal effect of current infrastructure on trade costs. On the one hand, Roman roads act as a complement, rather than as a substitute, of geographical instruments, allowing to use an over-identified model. On the other, the Roman road measure is a strong instrument for modern infrastructure.

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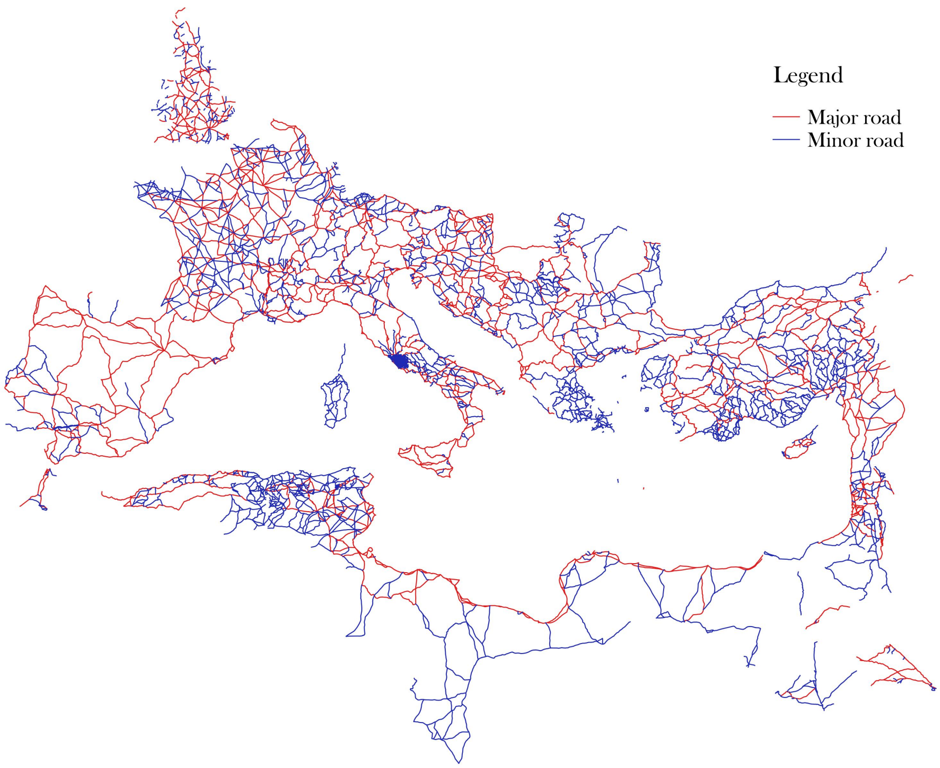
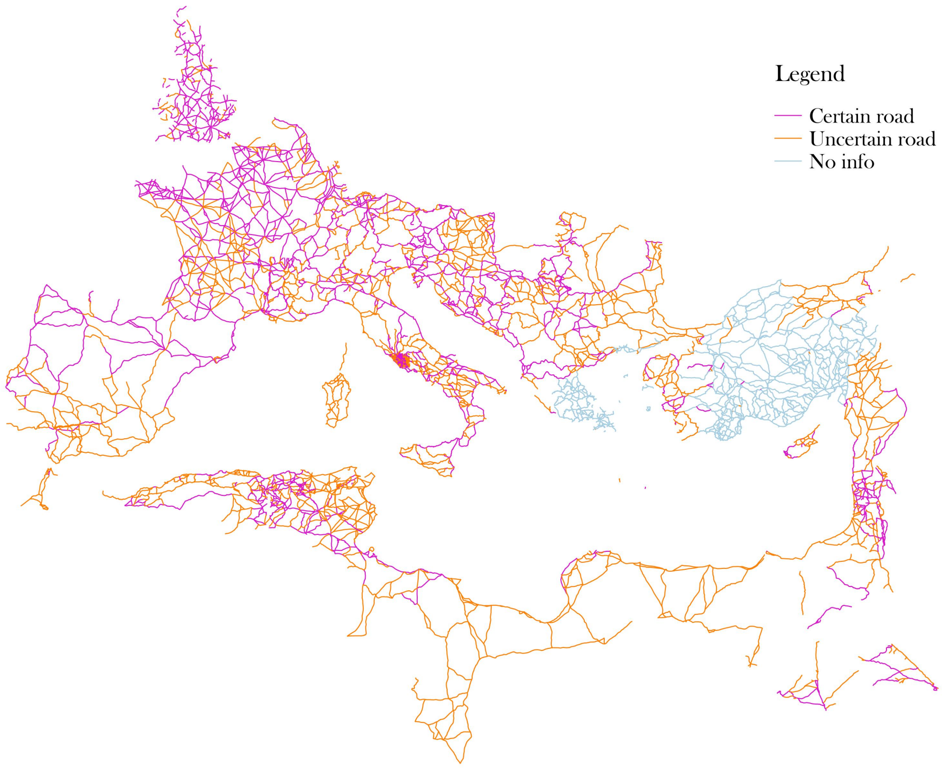
Tables and figures

Figure 1: Roman roads by importance: major and minor roads



Source: Authors' elaboration from McCormick, M. et al. 2013. "Roman Road Network (version 2008)," DARMC Scholarly Data Series 2013-5

Figure 2: Roman roads by certainty: certain and uncertain roads

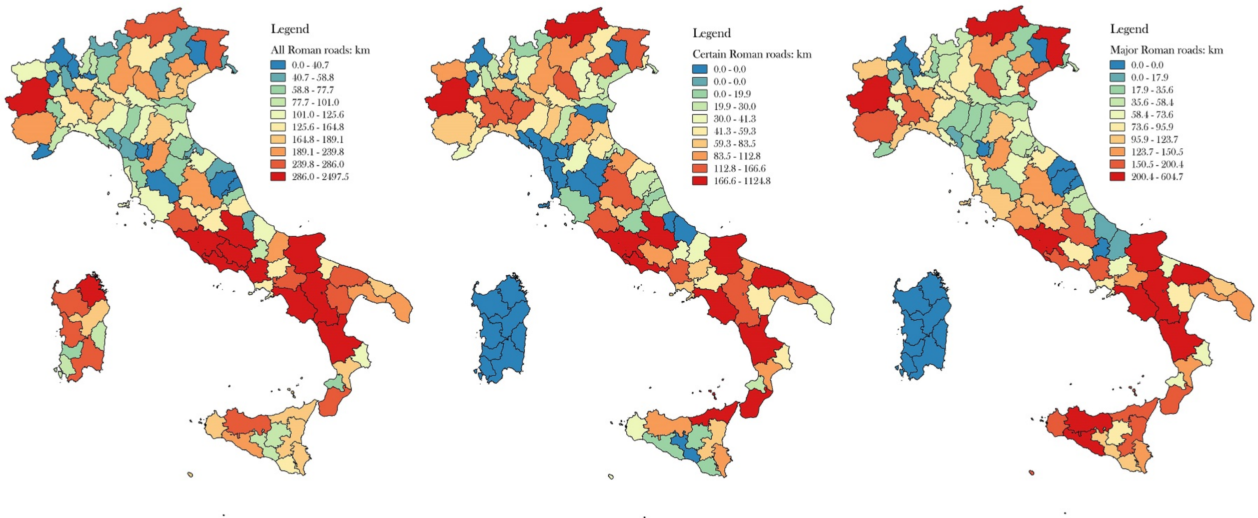


Source: Authors' elaboration from McCormick, M. et al. 2013. "Roman Road Network (version 2008),"
DARMC Scholarly Data Series 2013-5

Figure 3: Roman road layer and Italian provinces

Source: Authors' elaboration from McCormick, M. et al. 2013. "Roman Road Network (version 2008)," DARMC Scholarly Data Series 2013-5 and from Istat data (2011)

Figure 4: Roman roads in length by Italian province



Source: Authors' elaboration from McCormick, M. et al. 2013. "Roman Road Network (version 2008)," DARMC Scholarly Data Series 2013-5 and from Istat (2011)

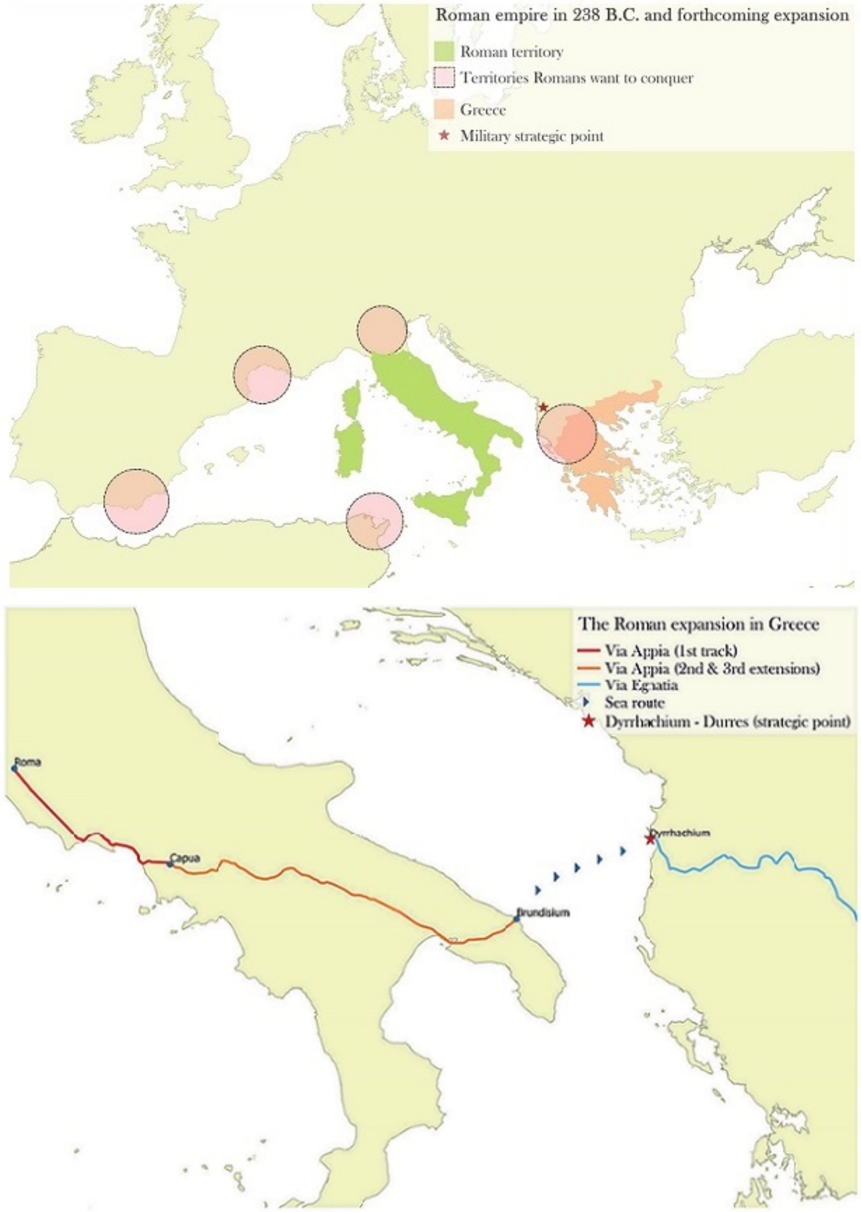
Figure 5: Roman Empire and Via Appia in 312 B.C.

Source: Authors' drawing

Figure 6: Roman Empire and Via Appia in 238 B.C.

Source: Authors' drawing

Figure 7: Romans' expansionist objectives and the conquest of Greece

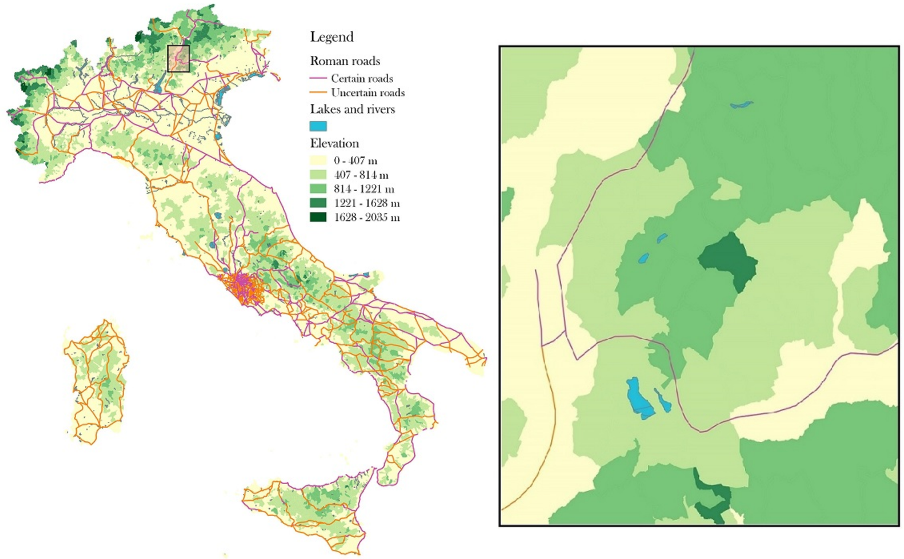


Source: Authors' drawing

Figure 8: The Via Annia

Source: Authors' drawing

Figure 9:   Roman roads and geography: locationing by elevation area



Source: Authors' drawing from Istat data, Corine Land Cover data, McCormick, M. et al. 2013. "Roman Road Network (version 2008)," DARMC Scholarly Data Series 2013-5

Table 1: Roman roads and geographical features of territory: Regression coefficients and R^2

	Roman road measures	*Elevation (m)*	*Mountain (%)*	R^2
	All	0.181***	-0.098***	0.02
		(0.034)	(0.021)	
km	Major	0.255***	-0.127***	0.04
		(0.043)	(0.025)	
	Certain	0.094*	-0.008	0.01
		(0.051)	(0.033)	
	Certain & major	0.164***	-0.019	0.02
		(0.049)	(0.032)	
	All	0.044*	-0.146***	0.12
		(0.026)	(0.014)	
	Major	0.135***	-0.199***	0.14
km per 100 km^2		(0.033)	(0.018)	
	Certain	-0.007	-0.103***	0.04
		(0.056)	(0.031)	
	Certain & major	0.044	-0.122***	0.04
		(0.053)	(0.031)	

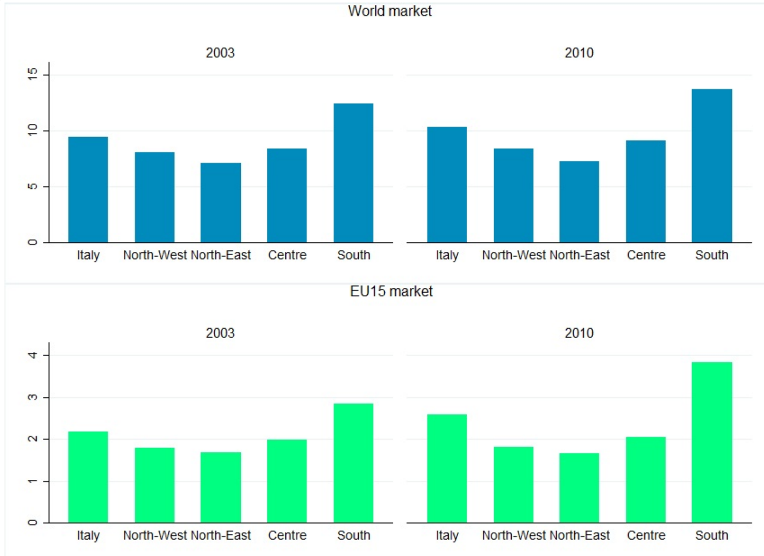
Note: Regressions are at the provincial level. Robust standard errors in parentheses

Table 2: Trade costs by export market, initial and final year. Italy and NUTS1 Italian macro-regions

Italy and Italian macro-regions (NUTS1)	*World market*		*EU15 market*	
	2003	**2010**	**2003**	**2010**
Italy	9.48	10.34	2.18	2.58
North-West	8.09	8.43	1.79	1.81
North-East	7.16	7.31	1.68	1.67
Center	8.40	9.16	1.99	2.04
South	12.45	13.77	2.85	3.84

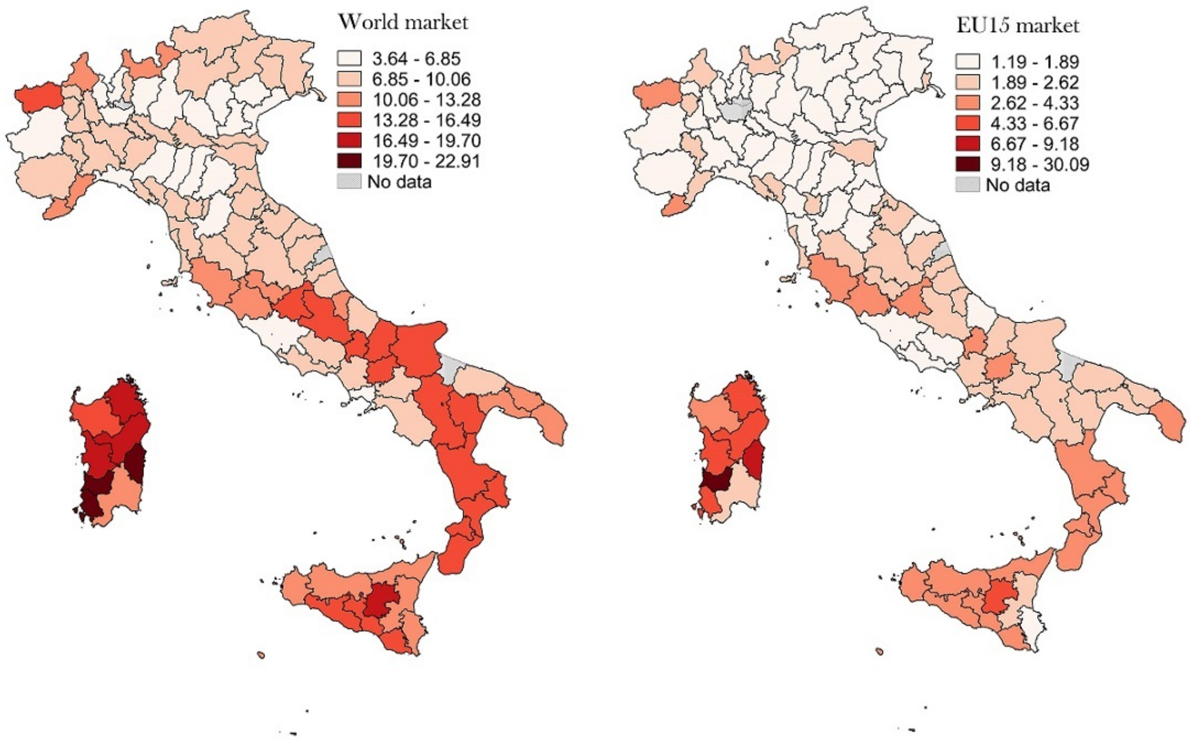
Source: Authors' elaborations from Istat data, BACI-CEPII data and World Bank WDI database

Figure 10: Average trade costs by export market, initial and final year. Italy and NUTS1 Italian macro-regions



Source: Authors' elaborations from Istat data, BACI-CEPII data and World Bank WDI database

Figure 11: Average trade costs by Italian province in 2010, world and EU15 market



Source: Authors' elaborations from Istat data, BACI-CEPII data and World Bank WDI database

Table 3: Data and sources

Variables	*Definition*	*Years*	*Source*	*Available for*
Trade costs	Yearly average at the Italian provincial level of the geometric average of international trade costs between Italian province i and country j relative to domestic trade costs within each province	2003-2010	Istat, BACI-CEPII and WDI	107 provinces
Trade costs (corrected for inter-provincial trade)	Yearly average at the Italian provincial level of the geometric average of international trade costs between Italian province i and country j relative to domestic trade costs within each province	2000, 2005, 2010	Istat, BACI-CEPII, WDI and EU Joint Research Center	107 provinces
All Roman roads (km)	kilometres of all Roman roads	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
Certain Roman roads (km)	kilometres of certain Roman roads	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
Major Roman roads (km)	kilometres of major Roman roads	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
Certain and major Roman roads (km)	kilometres of certain and major Roman roads	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
All Roman roads (density)	kilometres of all Roman roads per 100 square kilometres of land area	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
Certain Roman roads (density)	kilometres of certain Roman roads per 100 square kilometres of land area	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
Major Roman roads (density)	kilometres of major Roman roads per 100 square kilometres of land area	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
Certain and major Roman roads (density)	kilometres of certain and major Roman roads per 100 square kilometres of land area	117 A.D.	Licio's (2017) creation from McCormick et al. (2013) shape file	110 provinces
Certain Roman roads simple historical dynamic	certain Roman roads as a simple result of Roman Empire enlargement in 9 periods/steps	117 A.D.	Authors' creation from McCormick et al. (2013) shape file and from Running Reality	110 provinces
Certain Roman roads cumulative historical dynamic	certain Roman roads as a cumulative result of Roman Empire enlargement in 9 periods/steps	117 A.D.	Authors' creation from McCormick et al. (2013) shape file and from Running Reality	110 provinces
Normans	Number of years of the Norman domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Swabians	Number of years of the Swabian domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Anjou	Number of years of the Anjou domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Spain	Number of years of the Spanish domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Bourbons	Number of years of the Bourbon domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Papal State	Number of years of the Papal domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Venice	Number of years of the Venetian domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Austria	Number of years of the Austrian domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Savoy	Number of years of the Savoy domination	1100-1700	Di Liberto and Sideri (2015)	110 provinces
Mountain	Percentage of mountainous territory	time invariant	Istituto Tagliacarne	110 provinces
Elevation	Elevation in metres	time invariant	Istat	110 provinces
Land area	Land area in square kilometres	time invariant	Istat	110 provinces
Lakes and rivers	Watercourses and basins	time invariant	Corine Land Cover	Italy
Railways (km)	Kilometres of current railways	2005	Istat	110 provinces
Motorways (km)	Kilometres of current motorways	2011	Automobile Club d'Italia (ACI)	110 provinces
All current roads (km)	Kilometres of all current roads	2011	Automobile Club d'Italia (ACI)	110 provinces
Other roads (km)	Kilometres of all roads that are not motorways	2011	Automobile Club d'Italia (ACI)	110 provinces
Productivity	Total value added / total workers	2003-2010	Istat	110 provinces

Source: Authors' elaborations

Table 4: OLS 'reduced form' model

Dependent variable: *Average trade costs (log)* $\sigma = 8$	*(1)*	*(2)*	*(3)*	*(4)*
Certain Roman roads in km (log)	-0.109***	-0.109***	-0.108***	-0.069***
	(0.022)	(0.022)	(0.022)	(0.019)
Elevation (log)		-0.002	-0.040	-0.034
		(0.038)	(0.050)	(0.041)
% of mountainous territory (log)			0.027	0.024
			(0.028)	(0.021)
Total productivity (log)				-0.871**
				(0.273)
Normans	-0.009***	-0.009***	-0.010***	-0.008***
	(0.001)	(0.001)	(0.001)	(0.001)
Swabians	0.001	0.001	0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Anjou	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Spain	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.009***	0.009***	0.010***	0.007***
	(0.001)	(0.001)	(0.002)	(0.002)
Papal State	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Venice	-0.000	-0.000	-0.001*	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Austria	-0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Savoy	-0.000	-0.000	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)
Intercept	3.449***	3.460***	3.675***	1.048
	(0.379)	(0.422)	(0.519)	(0.925)
Regional fixed effects	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	664	664	664	664
R-squared	0.749	0.749	0.753	0.801

Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=8; Roman roads are considered only if they were certain, and they are measured in km. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Standard errors are reported in parentheses and clustered at the province (NUTS3) level.

Table 5: OLS complete model (with the current infrastructure)

Dependent variable:	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*
Average trade costs (log)												
σ=8		**Railways**			**Motorways**			**Total roads**			**Other roads**	
Railways in km (log)	-0.117**	-0.131***	-0.114**									
	(0.053)	(0.035)	(0.052)									
Motorways in km (log)				-0.185***	-0.157***	-0.177***				-0.186***	-0.166***	-0.178***
				(0.036)	(0.025)	(0.035)				(0.036)	(0.029)	(0.036)
Total roads in km (log)							-0.139**	-0.135***	-0.115**			
							(0.057)	(0.039)	(0.056)			
Other roads in km (log)										0.003	0.028	0.006
										(0.066)	(0.041)	(0.065)
Certain Roman roads in km (log)	-0.034*		-0.035*	-0.002		-0.007	-0.045**		-0.049***	-0.003		-0.008
	(0.018)		(0.018)	(0.023)		(0.023)	(0.018)		(0.017)	(0.024)		(0.022)
Elevation (log)	-0.032	-0.000		-0.060**	-0.043*		-0.037	-0.004		-0.060**	-0.048**	
	(0.038)	(0.028)		(0.024)	(0.022)		(0.038)	(0.029)		(0.024)	(0.023)	
% of mountain (log)	0.025	-0.002		0.028*	0.012		0.033	0.006		0.027**	0.013	
	(0.019)	(0.015)		(0.014)	(0.012)		(0.021)	(0.016)		(0.014)	(0.012)	
Total productivity (log)	-0.781***	-0.646***	-0.788***	-0.754***	-0.769***	-0.770***	-0.863***	-0.811***	-0.870***	-0.753***	-0.759***	-0.769***
	(0.251)	(0.174)	(0.258)	(0.210)	(0.179)	(0.221)	(0.281)	(0.197)	(0.288)	(0.211)	(0.175)	(0.222)
Normans	-0.009***	-0.006***	-0.009***	-0.036***	-0.032***	-0.036***	-0.010***	-0.007***	-0.009***	-0.036***	-0.032***	-0.036***
	(0.001)	(0.002)	(0.001)	(0.009)	(0.009)	(0.009)	(0.002)	(0.002)	(0.001)	(0.009)	(0.009)	(0.009)
Swabians	-0.000	0.000	0.000	-0.000	-0.000	0.000	-0.000	-0.000	-0.000	-0.000	-0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Anjou	-0.000	-0.000	-0.000	-0.001	-0.001	-0.001	0.000	0.000	0.000	-0.001	-0.001	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Spain	-0.000	-0.000	-0.000	0.000	0.000	0.000	-0.000	-0.000	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.007***	0.008***	0.007***	0.055***	0.052***	0.056***	0.008***	0.009***	0.007***	0.055***	0.053***	0.056***
	(0.002)	(0.001)	(0.001)	(0.015)	(0.015)	(0.016)	(0.002)	(0.001)	(0.001)	(0.015)	(0.015)	(0.016)
Papal State	0.000*	0.000**	0.000*	0.000**	0.000**	0.000**	0.000	0.000	0.000	0.000**	0.001**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Venice	-0.000	-0.000	-0.000	0.000	-0.000	0.000	-0.000	-0.000	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Austria	0.000	-0.000	0.000	0.000	0.000	0.000	-0.000	-0.000	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Savoy	-0.001	-0.001*	-0.000	0.000	0.000	0.000	-0.000	-0.001	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	1.705*	1.915***	1.501*	1.263*	1.536**	0.874	1.747*	1.665**	1.408	1.243	1.473**	0.837
	(0.921)	(0.648)	(0.860)	(0.757)	(0.607)	(0.753)	(0.990)	(0.708)	(0.953)	(0.818)	(0.570)	(0.823)
Regional fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	656	796	656	576	696	576	664	820	664	576	696	576
R-squared	0.818	0.796	0.815	0.861	0.838	0.856	0.811	0.782	0.805	0.861	0.839	0.856

Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=8; Roman roads are considered only if they were certain, and they are measured in km. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Standard errors are reported in parentheses and clustered at the province (NUTS3) level.

Table 6: IV estimates for current infrastructure

Dependent variable: Average trade costs (log) σ=8	*(1)*	*(2)*	*(3)*	*(4)*
Railways in km (log)	-0.226***		-0.229***	
	(0.070)		(0.069)	
Motorways in km (log)		-0.197***		-0.198***
		(0.060)		(0.058)
Total productivity (log)	-0.705***	-0.752***	-0.699***	-0.749***
	(0.258)	(0.226)	(0.254)	(0.224)
Normans	-0.011***	-0.038***	-0.011***	-0.038***
	(0.001)	(0.010)	(0.001)	(0.010)
Swabians	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Anjou	0.000	-0.001	0.000	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)
Spain	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.007***	0.058***	0.007***	0.058***
	(0.001)	(0.017)	(0.001)	(0.016)
Papal State	0.001**	0.001**	0.001**	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Venice	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Austria	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Savoy	-0.001**	0.000	-0.001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	2.252**	0.953	2.289**	0.966
	(1.076)	(0.812)	(1.055)	(0.833)
Regional fixed effects	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Observations	656	576	656	576
First-stage R-squared	0.592	0.542	0.590	0.539
First-stage instrument 1 (certain Roman roads) coefficient	0.301***	0.347***	0.302***	0.347***
First-stage instrument 2 (elevation) coefficient	0.046	-	-	-
First-stage instrument 3 (% mountain) coefficient	-	0.030	-	-
First-stage F-statistic (Kleibergen-Paap Wald F-statistic)	9.470	9.841	17.565	17.633
Hansen's J statistic P-value	0.788	0.867	-	-
Durbin-Wu-Hausman P-value	0.082	0.784	0.063	0.753
Hausman P-value	0.000	0.000	0.000	0.000
Pagan-Hall P-value	0.000	0.000	0.000	0.000
Instruments	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$

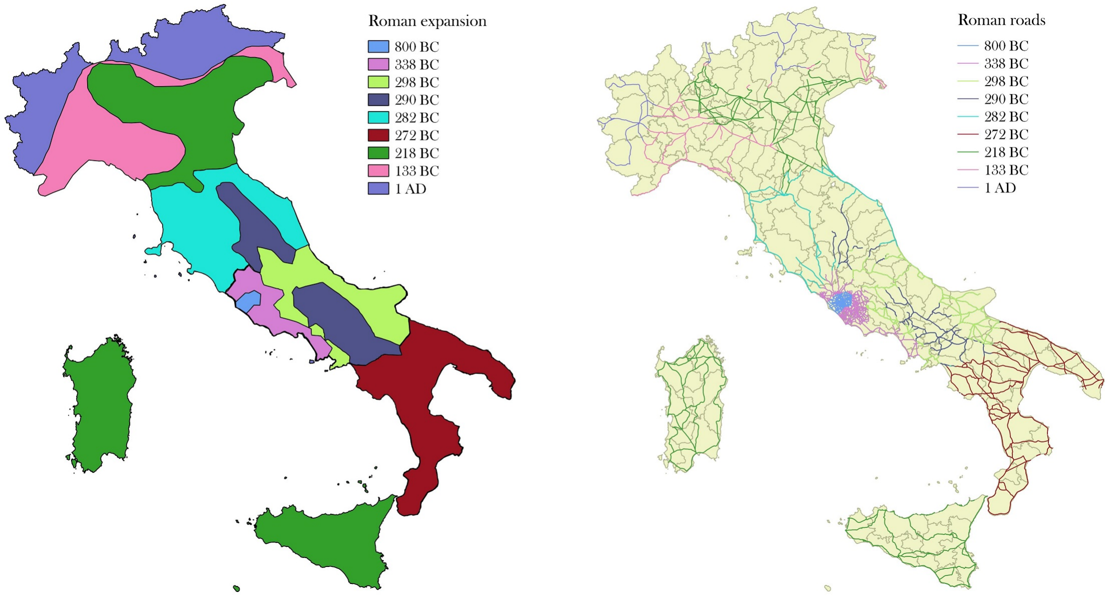
Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=8; Roman roads are considered only if they were certain, and they are measured in km. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Standard errors are reported in parentheses and clustered at the province (NUTS3) level. The first-stage F-statistic (Kleibergen-Paap Wald F-statistic) exceeds all weak identification critical values proposed by Stock and Yogo (2005) for the maximal IV size in specifications (3) and (4), and 20% of maximal IV size in specifications (1) and (2). The plausible exogeneity test of Conley et al. (2012) has been performed for all specifications where the sole Roman road instrument is adopted. Assuming the 95% confidence interval of [-0.01; 0] of the impact of Roman roads, the test confirms the validity of the exclusion restriction. Bounds estimates are reported in Table 7.

Table 7: Conley et al (2012)'s UCI results on specifications (3) and (4) of Table 6

Dependent variable:	*(3)*		*(4)*	
Average trade costs (log) σ=8	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
Railways in km (log)	-0.281	-0.145		
Motorways in km (log)			-0.242	-0.126
Total productivity (log)	-0.879	-0.543	-0.923	-0.604
Normans	-0.014	-0.007	-0.048	-0.025
Swabians	-0.000	0.001	-0.000	0.001
Anjou	-0.001	0.001	-0.002	0.000
Spain	-0.000	0.000	0.000	0.000
Bourbons	0.004	0.010	0.037	0.076
Papal State	0.000	0.001	0.000	0.001
Venice	-0.000	0.000	-0.000	0.000
Austria	-0.000	0.000	-0.000	0.000
Savoy	-0.001	-0.000	-0.000	0.000
Intercept	1.355	3.003	0.260	1.545

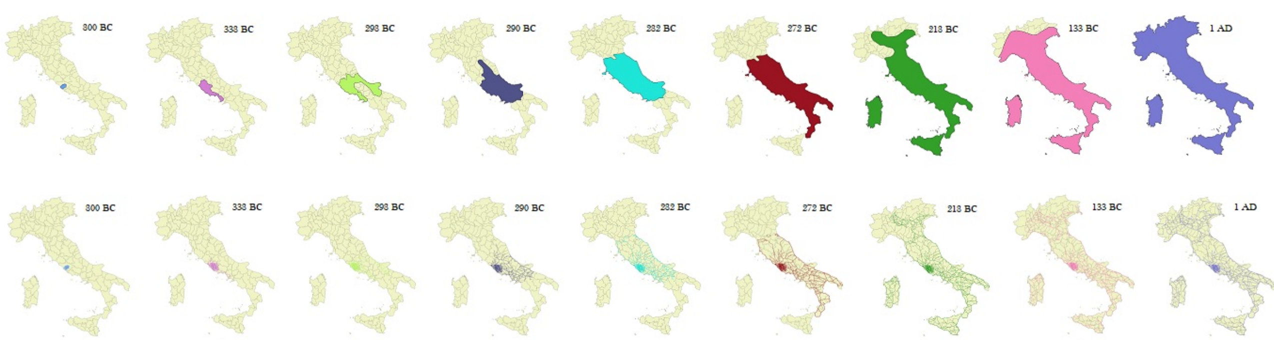
Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=8; Roman roads are considered only if they were certain, and they are measured in km. All log transformed variables are indicated with (log). All point estimates of specifications (3) and (4) of Table 6 are included within the displayed bounds.

Figure 12: Roman Empire and road network expansion: jointly view



Source: Authors' elaborations

Figure 13: Roman Empire and road network expansion: by period view



Source: Authors' elaborations

Appendix

Table 8: Estimation results IV approach for current infrastructure: world market, σ=11 or σ=7, certain Roman roads in km

Dependent variable:	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Average trade costs (log)		**σ=11**				**σ=7**		
Railways in km (log)	-0.193***		-0.197***		-0.243***		-0.246***	
	(0.059)		(0.058)		(0.076)		(0.074)	
Motorways in km (log)		-0.167***		-0.169***		-0.212***		-0.213***
		(0.050)		(0.049)		(0.065)		(0.063)
Total productivity (log)	-0.568***	-0.607***	-0.562***	-0.604***	-0.784***	-0.835***	-0.778***	-0.831***
	(0.213)	(0.185)	(0.209)	(0.184)	(0.283)	(0.248)	(0.279)	(0.246)
Normans	-0.009***	-0.030***	-0.009***	-0.030***	-0.012***	-0.042***	-0.012***	-0.042***
	(0.001)	(0.008)	(0.001)	(0.008)	(0.002)	(0.011)	(0.002)	(0.011)
Swabians	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Anjou	0.000	-0.001	0.000	-0.001	0.000	-0.001	0.000	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Spain	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.006***	0.047***	0.006***	0.047***	0.008***	0.064***	0.008***	0.064***
	(0.001)	(0.013)	(0.001)	(0.013)	(0.002)	(0.018)	(0.002)	(0.018)
Papal State	0.000**	0.000**	0.000**	0.000**	0.001**	0.001***	0.001**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Venice	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Austria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Savoy	-0.000**	0.000	-0.000**	0.000	-0.001**	0.000	-0.001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	1.443	0.358	1.480*	0.372	2.669**	1.251	2.703**	1.264
	(0.893)	(0.669)	(0.876)	(0.662)	(1.175)	(0.892)	(1.152)	(0.882)
Regional fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	656	576	656	576	656	576	656	576
First-stage R-squared	0.592	0.542	0.590	0.539	0.592	0.542	0.590	0.539
First-stage instrument 1 (certain Roman roads) coefficient	0.301***	0.347***	0.302***	0.347***	0.301***	0.347***	0.302***	0.347***
First-stage instrument 2 (elevation) coefficient	0.046	-	-	-	0.046	-	-	-
First-stage instrument 3 (% mountain) coefficient	-	0.030	-	-	-	0.030	-	-
First-stage F-statistic (Kleibergen-Paap Wald F-statistic)	9.470	9.841	17.565	17.633	9.470	9.841	17.565	17.633
Hansen's J statistic P-value	0.740	0.837	-	-	0.817	0.884	-	-
Durbin-Wu-Hausman P-value	0.064	0.709	0.045	0.671	0.095	0.829	0.075	0.802
Hausman P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pagan-Hall P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Instruments	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$

Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=11 or, alternatively, using σ=7 ; Roman roads are considered only if they were certain, and they are measured in km. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Standard errors are reported in parentheses and clustered at the province (NUTS3) level. The first-stage F-statistic (Kleibergen-Paap Wald F-statistic) exceeds all weak identification critical values proposed by Stock and Yogo (2005) for the maximal IV size in specifications (3), (4), (7) and (8), and 20% of maximal IV size in specifications (1), (2), (5) and (6). The plausible exogeneity test of Conley et al. (2012) has been performed for all specifications where the sole Roman road instrument is adopted. Assuming the 95% confidence interval of [-0.01; 0] of the impact of Roman roads, the test confirms the validity of the exclusion restriction.

Table 9: Estimation results IV approach for current infrastructure: EU15 market, σ=8, certain Roman roads in km

Dependent variable: *Average trade costs (log)* *σ=8*	*(1)*	*(2)*	*(3)*	*(4)*
Railways in km (log)	-0.311***		-0.325***	
	(0.094)		(0.097)	
Motorways in km (log)		-0.269***		-0.276***
		(0.089)		(0.092)
Total productivity (log)	-0.165	-0.193	-0.140	-0.178
	(0.203)	(0.197)	(0.208)	(0.200)
Normans	-0.008***	-0.032***	-0.008***	-0.033***
	(0.002)	(0.012)	(0.002)	(0.013)
Swabians	0.001**	0.001	0.001**	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Anjou	0.000	-0.001***	0.000	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Spain	0.000	0.000**	0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.005***	0.054**	0.005***	0.054**
	(0.001)	(0.021)	(0.001)	(0.021)
Papal State	0.001**	0.000	0.001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Venice	0.000	0.001**	0.000	0.001*
	(0.000)	(0.000)	(0.000)	(0.000)
Austria	0.000	0.000*	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Savoy	-0.000*	0.001**	-0.000*	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	2.506**	1.099	2.666**	1.162
	(1.072)	(0.882)	(1.103)	(0.895)
Regional fixed effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
Observations	656	576	656	576
First-stage R-squared	0.592	0.542	0.590	0.539
First-stage instrument 1 (certain Roman roads) coefficient	0.301***	0.347***	0.302***	0.347***
First-stage instrument 2 (elevation) coefficient	0.046	-	-	-
First-stage instrument 3 (% mountain) coefficient	-	0.030	-	-
First-stage F-statistic (Kleibergen-Paap Wald F-statistic)	9.470	9.841	17.565	17.633
Hansen's J statistic P-value	0.137	0.544	-	-
Durbin-Wu-Hausman P-value	0.004	0.042	0.002	0.040
Hausman P-value	0.000	0.000	0.000	0.000
Pagan-Hall P-value	0.000	0.000	0.000	0.000
Instruments	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$

Note: $\tau_{i,j}$ refers to EU15 market and is calculated using the value σ=8; Roman roads are considered only if they were certain, and they are measured in km. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Standard errors are reported in parentheses and clustered at the province (NUTS3) level. The first-stage F-statistic (Kleibergen-Paap Wald F-statistic) exceeds all weak identification critical values proposed by Stock and Yogo (2005) for the maximal IV size in specifications (3) and (4), and 20% of maximal IV size in specifications (1) and (2). The plausible exogeneity test of Conley et al. (2012) has been performed for all specifications where the sole Roman road instrument is adopted. Assuming the 95% confidence interval of [-0.01; 0] of the impact of Roman roads, the test confirms the validity of the exclusion restriction.

Table 10: Estimation results IV approach for current infrastructure: world market, σ=8, major or all Roman roads in km

Dependent variable:	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Average trade costs (log) *σ=8*		**Major Roman Roads**				**All Roman roads**		
Railways in km (log)	-0.098**		-0.102**		-0.155***		-0.155***	
	(0.044)		(0.044)		(0.051)		(0.054)	
Motorways in km (log)		-0.091***		-0.087***		-0.111***		-0.108***
		(0.025)		(0.028)		(0.031)		(0.034)
Total productivity (log)	-1.046***	-1.077***	-1.039***	-1.086***	-0.615***	-0.912***	-0.615***	-0.919***
	(0.206)	(0.193)	(0.201)	(0.195)	(0.191)	(0.215)	(0.188)	(0.218)
Normans	-0.005***	-0.021**	-0.005***	-0.021**	-0.007***	-0.027***	-0.007***	-0.027***
	(0.002)	(0.010)	(0.002)	(0.010)	(0.002)	(0.009)	(0.002)	(0.009)
Swabians	-0.001	-0.000	-0.001	-0.000	0.000	-0.000	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Anjou	-0.000	-0.000	-0.000	-0.000	-0.000	-0.001	-0.000	-0.001
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
Spain	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.006***	0.034**	0.006***	0.034**	0.008***	0.044***	0.008***	0.044***
	(0.001)	(0.017)	(0.001)	(0.017)	(0.001)	(0.015)	(0.001)	(0.015)
Papal State	0.000	0.000	0.000	0.000	0.001**	0.000**	0.001**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Venice	-0.000	0.000	-0.000	-0.000	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Austria	0.000	0.000**	0.000	0.000*	-0.000	0.000*	-0.000	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Savoy	-0.000*	-0.000	-0.000*	-0.000	-0.001**	-0.000	-0.001**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	0.255	-0.393	0.298	-0.428	1.641**	0.055	1.641**	0.023
	(0.774)	(0.674)	(0.756)	(0.680)	(0.754)	(0.754)	(0.757)	(0.767)
Regional fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	720	648	720	648	788	680	788	680
First-stage R-squared	0.602	0.563	0.593	0.531	0.621	0.622	0.605	0.602
First-stage instrument 1 (Roman roads) coefficient	0.430***	0.574***	0.426***	0.537***	0.555***	0.720***	0.534***	0.700***
First-stage instrument 2 (elevation) coefficient	0.084*	-	-	-	0.117**	-	-	-
First-stage instrument 3 (% mountain) coefficient	-	0.100*	-	-	-	0.078	-	-
First-stage F-statistic (Kleibergen-Paap Wald F-statistic)	32.212	26.793	59.520	38.534	36.137	24.696	44.861	45.352
Hansen's J statistic P-value	0.807	0.784	-	-	0.998	0.669	-	-
Durbin-Wu-Hausman P-value	0.455	0.003	0.523	0.006	0.583	0.070	0.616	0.057
Hausman P-value	0.000	0.000	0.000	0.000	0.351	0.000	0.371	0.000
Pagan-Hall P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Instruments	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$

Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=8; Roman roads are considered only if they were major roads or, alternatively as all roads; they are measured in km. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Standard errors are reported in parentheses and clustered at the province (NUTS3) level. The first-stage F-statistic (Kleibergen-Paap Wald F-statistic) exceeds all weak identification critical values proposed by Stock and Yogo (2005) for the maximal IV size. The plausible exogeneity test of Conley et al. (2012) has been performed for all specifications where the sole Roman road instrument is adopted. Assuming the 95% confidence interval of [-0.01; 0] of the impact of Roman roads, the test confirms the validity of the exclusion restriction.

Table 11: Estimation results IV approach for current infrastructure: world market, σ=8, certain Roman roads in density

Dependent variable: Average trade costs (log) σ=8	*(1)*	*(2)*	*(3)*	*(4)*
Railways in density (ln)	-0.289***		-0.398***	
	(0.111)		(0.135)	
Motorways in density (ln)		-0.163**		-0.306***
		(0.084)		(0.110)
Total productivity (ln)	-0.773***	-0.937***	-0.644***	-0.720***
	(0.221)	(0.245)	(0.201)	(0.202)
Normans	-0.005***	-0.026**	-0.004**	-0.029**
	(0.001)	(0.011)	(0.002)	(0.013)
Swabians	0.000	-0.000	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Anjou	-0.002**	-0.002	-0.002***	-0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
Spain	-0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.005***	0.045**	0.003	0.054**
	(0.002)	(0.019)	(0.002)	(0.024)
Papal State	0.001***	0.001**	0.001***	0.001***
	(0.000)	(0.000)	(0.001)	(0.000)
Venice	-0.001	-0.000	-0.001*	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Austria	0.001**	0.001***	0.001**	0.001**
	(0.000)	(0.000)	(0.001)	(0.000)
Savoy	-0.001***	-0.000	-0.002***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	1.157	-0.319	1.713**	0.176
	(0.774)	(0.714)	(0.757)	(0.558)
Regional fixed effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
Observations	656	576	656	576
R-squared	0.637	0.537	0.626	0.522
First-stage instrument 1 (certain Roman roads in density) coefficient	0.176**	0.183*	0.189***	0.221**
First-stage instrument 2 (elevation) coefficient	-0.097	-	-	-
First-stage instrument 3 (% mountain) coefficient	-	-0.071	-	-
First-stage F-statistic (Kleibergen-Paap Wald F-statistic)	6.258	2.749	7.659	5.714
Hansen's J statistic P-value	0.151	0.039	-	-
Durbin-Wu-Hausman P-value	0.127	0.930	0.004	0.178
Hausman P-value	0.000	0.000	0.000	0.012
Pagan-Hall P-value	0.000	0.000	0.004	0.000
Instruments	$\mathcal{RR}_i$ density elevation	$\mathcal{RR}_i$ density % mountain	$\mathcal{RR}_i$ density	$\mathcal{RR}_i$ density

Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=8; Roman roads are considered only if they were certain and included as a density. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Standard errors are reported in parentheses and clustered at the province (NUTS3) level. The first-stage F-statistic (Kleibergen-Paap Wald F-statistic) does not exceed all weak identification critical values proposed by Stock and Yogo (2005) for the maximal IV size in specifications (1) and (2), but exceeds the critical value for 20% and 25% of maximal IV size in specifications (3) and (4), respectively. The plausible exogeneity test of Conley et al. (2012) has been performed for all specifications where the sole Roman road instrument is adopted. Assuming the 95% confidence interval of [-0.01; 0] of the impact of Roman roads, the test confirms the validity of the exclusion restriction.

Table 12: Estimation results IV approach for current infrastructure: world market, σ=8, historical dynamic of the Roman road network

Dependent variable:	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Average trade costs (log) *σ=8*	**Simple historical dynamic**				**Cumulative historical dynamic**			
Railways in km (log)	-0.309***		-0.316***		-0.392**		-0.483***	
	(0.039)		(0.041)		(0.083)		(0.066)	
Motorways in km (log)		-0.143***		-0.140***		-0.231***		-0.223***
		(0.019)		(0.020)		(0.024)		(0.022)
Total productivity (log)	-0.341***	-0.827***	-0.329***	-0.833***	-0.201	-0.665***	-0.045	-0.680***
	(0.102)	(0.079)	(0.102)	(0.080)	(0.182)	(0.089)	(0.178)	(0.092)
Normans	-0.009***	-0.029***	-0.010***	-0.029***	-0.011***	-0.035***	-0.013***	-0.035***
	(0.001)	(0.004)	(0.001)	(0.004)	(0.002)	(0.004)	(0.002)	(0.004)
Swabians	0.001**	-0.000	0.001**	-0.000	0.001**	-0.000	0.002***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
Anjou	0.000	-0.001**	0.000	-0.001**	0.000	-0.001***	0.001**	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Spain	-0.000**	0.000	-0.000**	0.000	-0.000	0.000***	-0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bourbons	0.008***	0.048***	0.008***	0.047***	0.009***	0.057***	0.009***	0.056***
	(0.001)	(0.007)	(0.001)	(0.007)	(0.001)	(0.008)	(0.001)	(0.008)
Papal State	0.001***	0.000***	0.001***	0.000***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Venice	-0.000**	-0.000	-0.000**	-0.000	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Austria	-0.000	0.000*	-0.000	0.000*	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Savoy	-0.001***	-0.000	-0.001***	-0.000	-0.001***	0.000**	-0.001***	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Intercept	3.132***	0.397	3.195***	0.371	3.904***	1.125***	4.766***	1.060***
	(0.470)	(0.298)	(0.479)	(0.299)	(0.881)	(0.341)	(0.807)	(0.345)
Regional fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	796	696	796	696	796	696	796	696
First-stage R-squared	0.469	0.447	0.467	0.445	0.405	0.336	0.401	0.334
First-stage instrument 1 (certain Roman roads) coefficient	0.187***	0.291***	0.189***	0.293***	0.207***	0.391***	0.207***	0.393***
First-stage instrument 2 (elevation) coefficient	0.047***	-	-	-	0.062**	-	-	-
First-stage instrument 3 (% mountain) coefficient	-	0.024	-	-	-	0.031*	-	-
First-stage F-statistic (Kleibergen-Paap Wald F-statistic)	63.850	69.265	125.278	133.291	36.397	61.447	66.058	115.630
Hansen's J statistic P-value	0.382	0.130	-	-	0.069	0.486	-	-
Durbin-Wu-Hausman P-value	-	-	-	-	-	-	-	-
Hausman P-value	-	-	-	-	-	0.094	0.000	0.008
Pagan-Hall P-value	0.000	0.000	0.000	0.000	0.006	0.000	0.642	0.000
Instruments	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$	$\mathcal{RR}_i$ elevation	$\mathcal{RR}_i$ % mountain	$\mathcal{RR}_i$	$\mathcal{RR}_i$

Note: $\tau_{i,j}$ refers to world markets and is calculated using the value σ=8; Roman roads are considered only if they were certain and included as a dynamic process, and they are measured in km. All log transformed variables are indicated with (log). Asterisks denote significance levels; * p<0.10, ** p<0.05 and *** p<0.01. Bootstrapped and robust standard errors are reported in parentheses (1000 replications). The first-stage F-statistic (Kleibergen-Paap Wald F-statistic) exceeds all weak identification critical values proposed by Stock and Yogo (2005) for the maximal IV size.

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