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The rise and decline of a Roman market economy in north-western Europe

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Abstract

This study quantifies the importance of the Roman military for the development of a market economy in north-western Europe. Distributions of low denomination coins show how the Roman arrival kick-started a local market economy. Additionally settlement densities of fluvial catchments are used as a proxy for economic development. Our newly constructed dataset of settlement sizes shows a high correlation with Roman military requirements. After the demise of the empire the local market economy faded away. This antique market economy had a different geographical distribution than its medieval successor, which was not mainly driven by military demand.

> *Dum vixi bibi libenter bibite vos qui vivitis*,
>
> engraved on a tombstone of a Roman veteran.

Keywords: market economy, historical development, Roman Empire, north-western Europe, inland waterway transport, coin finds

JEL codes: O18, N33, N63

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Introduction

Two millennia ago Rome had a large economy based on market institutions and a stable government.[1] In Italy, the Middle East and in Egypt the Roman Empire (RE) was highly urbanised with cities of 100,000 inhabitants and more, despite being a pre-industrial society. In a seminal article Keith Hopkins argued that it were the taxes in money that greatly contributed to the development of a market economy in the RE, as people now had to produce a surplus that could be sold on a market to generate the money with which to pay their taxes.[2] This paper aims to study what happened in north-western Europe in this respect. An important and, as yet, unanswered question is how the Romans got a market economy to flourish in the then backward part of the empire that was newly conquered around CE. In considerably less than a century the Romans produced an effective and successful local economic system largely based on market exchange. This is a surprising result: European colonizers in Africa, for example, were to experience that just imposing a tax in money on the native inhabitants does not automatically lead there to the establishment of a market economy even with military presence. How did the Romans succeed? The short answer given by Robert Bruce Hitchner is that it was the Roman military that delivered this feat.[3]

However, for us such an answer is not completely convincing, as the role of the Roman army has up to now only been presented in general terms, while its more specific local influence has not been unravelled and the various regional economic consequences have never been properly quantified. Intriguing questions, such as why did the military *limes* along the Rhine produce the large Roman towns of Cologne and Xanten, while along similar military establishments at a very comparable *limes* in the German Taunus and along Hadrian's Wall in Britain equally sized towns did not develop? And why do we see such a huge difference in economic development between e.g. the Roman settlements along the rivers Scheldt and the Thames, while both are seemingly similar local river systems in north-western Europe and both are located well outside the frontier zones of the RE?

The first aim of this paper is to study the regional development of a Roman market economy, for this we use local coin finds as a proxy. The idea is that the share of small change in these finds is an index of the degree to which processes of commercialisation have occurred; large denomination (gold or silver) coins will mainly have been used in long-distance trade, but the appearance of small (copper or bronze) coins points to the use of them in small, local transactions.[4] The study of the fraction of precious metals in stray coin finds can therefore supply additional evidence about the rise and decline, and the spatial structure, of the monetarisation.

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[1] See e.g. Peter Temin (2006, 133), Bowman and Wilson (2009, 28) argue that the actual extent and the precise nature of the economic growth at the time continue to provoke debate among scholars.

[2] Keith Hopkins, (1980, 101 and later in 2002, 229), this, however, does not preclude that taxes could still be in kind as well, as Richard Duncan-Jones (1990, 30 ff) argued.

[3] Robert Bruce Hitchner (2003, 4, 398). Some decades earlier Lothar Wierschowski (1984) had made a similar point in his study of the Roman army and the economy. And before him A.H.M. Jones (1974, 127) had indicated that the expenditure of the army had stimulated development in backward areas of the RE such as Britain and the Rhineland, and in particular the growth of towns.

[4] The remark that the use of coin of low denominations is an index for the extent of a market economy has already been made by Wolf Liebeschuetz (2001, 24). Jan Lucassen (2007) describes that the end of the Roman rule meant the end of small change, with the consequence that wage labour (a labour market) could no longer exist without a reliable and abundant coinage.

The second aim of this article is to study how the Roman market economy was spatially distributed and which were its main drivers. Therefore we will look at the regional settlement density in various fluvial catchment areas as a proxy for economic development and consider the differing distribution of the Roman military over these areas in north-western Europe as a natural historical experiment that can be used to quantify its influence on the development of the local economy.[5] We will also be looking at the other potential factors that could have driven the local economy in Roman times and try to quantify those. With help of a specific statistical technique (multivariate analysis) we can eventually determine which of these potential drivers were the most important and quantify their influence.

Methodological approach

Study area and period

The study area we concentrate on is the former Roman territory in current day France, Switzerland, Belgium and Luxembourg, England and Wales as well as parts of Holland and Germany. Our study on urbanisation concentrates on the situation around the year 150, at the height of the RE.[6] In 150 CE, our study area and its originally 'barbaric' population has been exposed to nearly one-and-a-half centuries of Roman civilisation, after the original conquests by Julius Caesar and his successors around CE.

Settlement density

In accordance with regular practice in economic history we will use the levels of urbanisation as a proxy for economic success.[7] The term urbanisation needs somewhat more qualification here, as it nowadays usually indicates the fraction of the population living in towns with more than 10,000 inhabitants. For these north-westerly fringe areas and this very early period such a criterion is definitely too stringent, as less than two dozen towns would be large enough to qualify. Therefore we have used the total population that is housed in Roman settlements[8] as an indicator for the urbanisation (or maybe better as an indicator of the not directly agrarian population) around the year 150 in the study area. Also the numbers of this total population living in Roman settlements have in its turn been estimated indirectly, as we lack accurate and detailed population censuses in this time and place. Here archaeological evidence comes to the rescue, and we have used excavation reports of the surface area (in ha) of habited Roman settlements as a direct indicator of the numbers of the Roman population.[9] The names and locations of the more than 2,000 Roman settlements, forts or mines in our study area have been found in the *Barrington Atlas of the Greek and Roman World* edited by Richard J.A.

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[5] Rather similar to the natural experiments of history described by Jared Diamond and James A. Robinson (2010).

[6] The year 150 is some decades before the Antonine plague decimated part of the population in the RE. In accordance with Talbert (2000) we use the time limit from circa 30 BCE to 300 CE as the dates to characterise the Roman period, and use the term Late Antique for the next period from circa 300 to 640.

[7] Elio Lo Cascio (2009) wrote on urbanisation as a proxy of demographic and economic growth in the RE, for more general examples see e.g. Bosker et al, (forthcoming) and Bosker and Buringh (forthcoming).

[8] A settlement is hereby defined as one that is indicated as such on the Barrington Atlas (Talbert, 2000).

[9] Of course, when a surface area in ha is multiplied by the population density as presented by Greg Woolf (2000) or others we arrive at the total population of a settlement. However, in practice we do not have to execute such a multiplication as we only use urbanisation in this article as a relative measure and therefore without any problems can stick to the numbers of ha of surface area of Roman settlements as reported in the archaeological references.

Talbert (2000). A habited surface of a settlement in ha can be directly translated into the numbers of its inhabitants.[10] Such an indicator allows us to visualise the working of the Roman economy and quantify its effects in the various regions.

We scanned the archaeological literature to find the inhabited surface area (in ha) around the year 150 of all Roman settlements from the *Barrington Atlas*. For walled cities we looked further than just to the value of its walled surface area in ha, as sometimes the surface occupied by the extramural population may have been adding substantially to the inhabited surface area of a walled town. While for some other cities the opposite was true, as their walls had been built considerably larger than the surface that was in fact actually inhabited by its population. The methods we used to fill in missing values of surface areas for which we could not find archaeological information and the whole process of data handling has been described extensively in the Data Appendix. Also for more details, and for the various literature references of the sources of information the reader is referred to the Data Appendix.

The geographical unit of analysis

We could have used the current 1990-countries (see *study area* above) as a geographical subdivision to report our findings and do our analyses, but we thought such a subdivision not appropriate, as current national boundaries were completely artificial two thousand years ago. Instead we opted for a subdivision of the study area that incorporates the most important form of transport of bulk goods in Roman times. Buringh et al (forthcoming) have shown that transport on inland waterways was the most widely preferred way to transport bulk goods in antiquity. And therefore we concentrated on fluvial catchment areas as our geographical unit of analysis for this paper. To find the settlements that are interconnected to one another by riverine transport without the necessity of transhipment we grouped all settlements located on one and the same fluvial system. By using fluvial catchment areas as our unit of analysis we follow the more or less natural boundaries that limited waterborne commerce in history. In principle the various settlements along such a fluvial system could be reached by boat or barge and for their mutual trade profited from the relatively lower cost of riverine transport compared to transport over land. We discerned twelve important fluvial systems in the study area, of which the seven largest can be found on Figure 1.

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[10] The actual numbers of inhabitants per hectare have, however, been heavily debated. Greg Woolf (2000, p. 137 n. 103) indicates in *Becoming Roman, the origins of provincial civilization in Gaul* that a figure of 100 inhabitants per hectare seems to be preferred for many towns in our study area and period. We will follow Woolf in this respect. For a more densely inhabited Italian city as Pompeii, covering 65 ha, and sheltering a population of 8,000 to 12,000 Greg Woolf reports that a figure of 123-187 inhabitants/ha has been used. Émile Thevenot (1932, 84) even indicates that for the city of Autun previous scholars had made population estimates based on 500/ha, leading to 100,000 inhabitants in Roman times in Autun, but happily he adds: « nous considerons ce chiffre comme un peu supérieur à la réalité.». We completely agree with Émile Thevenot on this.

Figure 1: The largest fluvial catchment areas in current day Europe

A fluvial system is defined as comprising of all Roman settlements located in the water catchment area of a river flowing from its source(s) to the sea, while also including the various settlements along all of its different tributaries right up to the last Roman settlement before their various sources. The sum of the actual length of all riverine waterways up to the sea (including all of its bends and curves) connecting the Roman settlements in a catchment area has been called the length of the fluvial system.[11] To estimate the relative economic importance of a fluvial system we summed the total habited area in ha of all settlements of that fluvial system and divided that by the total length of the fluvial system to get a relative measure (in ha/km) that can be used readily for comparative purposes.[12]

We can find the main seven catchment areas of our final number of twelve different catchment areas indicated in Figure 1: the Thames, Seine, Loire, Garonne, Meuse Rhone and Rhine. The Rhine catchment area is of course limited to the actual area within the confines of

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[11] Of course we do not know for sure if all the settlements lying on a waterway in the *Barrington Atlas* could in the year 150 actually be reached by boat. However, we use the fluvial length as a relative measure to compare the different fluvial systems, and as long as we treat all fluvial systems uniformly the resulting figures can be very well used for comparative purposes.

[12] In fact this measure in ha/km is quite similar to a local settlement density per surface area (or an indicator of the urbanisation/km^2), as there is a high correlation (R^2=0.8) in north-western Europe between the surface of the water basin in 1000s km^2 of a fluvial system and the direct river length (km). The main outlier here is the river Meuse, if this river is excluded the explained variance rises to a value of 0.9; indicating that generally we are in fact also making some estimate of local settlement density by dividing the habited surfaces in a specific riverine catchment area by its river length (with the Meuse being somewhat less well covered, but we will show that for our later arguments this possible fluvial exception is not relevant).

the Roman *limes*, and we have subdivided it further into three areas: that of the Moselle entering the Rhine at Koblenz (*Confluentes*), that of the Lower Rhine from Remagen (*Rigomagus*) to the sea and that of the Upper Rhine from Remagen inland up to the Alps. In Figure 1 the catchment area of the Garonne also comprises that of the Dordogne, lying in the northern part of the basin. Just above that of the Seine we can find the (rather minor) catchment area of the Somme, a river of local importance. The basin of the Scheldt can be found just north-west between the Meuse and the sea.

Monetarisation

As explained in the introduction, we use data on coin finds to document the rise and decline of local market economies. Thereby we focus on coin finds in the Netherlands, because of the ready availability of this information.[13] Data on coins have been collected from the NUMIS-database that is located at the Netherlands Geldmuseum in Utrecht and which can be assessed from the Internet.[14] It shows all coin finds in the Netherlands (currently some 260,000 coins) on 10x10 km grids or in the respective municipalities where they have been found. NUMIS can be freely searched for different aspects of each individual coin (e.g. was it part of a hoard or a stray find, its minting date and place, find date and place, ruler depicted, metal composition, etc.). Additional Roman coin finds outside the Netherlands have been collected from various specific archaeological reports on excavations. We have mainly used the stray finds of coins and neglected hoards, because we think stray finds probably are a better representation of the coin that was actually in circulation. The choice to use the information from stray finds of course also has a drawback, as obviously the distribution of such coin finds generally will be biased toward the lower values in circulation.[15] One can easily imagine that when a gold coin gets lost the unfortunate owner (if still alive) searches longer and also much more diligently than when it would have been some low value bronze coin.[16] Therefore one should not mistake the proportions found in NUMIS and elsewhere for those that were in actual circulation[17], however, for this paper this is not a real problem, as we just use coin finds as a relative measure and calculate the fraction of precious metals to show relative differences in coin use in various periods and zones.

Geographical results and a few checks on the data

In Figure 2 we show a map of the actual study area and the distribution of the settlements from Roman times found in the *Barrington Atlas*.[18]

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[13] Because the Netherlands was partly in and partly out of the RE, this sample gives us information on the monetary situation in both areas.

[14] http://www.geldmuseum.nl/museum/content/zoeken-numis

[15] Another drawback of lost coins outside a specific archaeological stratification is that the date of loss often will be difficult to determine with any certainty. However, using coin hoards has even larger limitations: the relation between numbers of coins in hoards and those in actual circulation is even more remote, the chance aspect associated with a hoard find also leads to larger statistical uncertainties and finally the composition of coins in hoards is often quite different from those in circulation.

[16] See e.g Figure 21.2 for the rates of loss of coins of different denominations in the nineteenth century (Sargent and Velde, 2002, 347).

[17] To get a better glimpse of the Roman coins that were in actual circulation we should probably look at the stray coins found at battle fields or other sudden disasters. Johan van Heesch (2007, 91) gives an example of finds on the battle field of general Varus (which the Romans lost) at Kalkriese in Germany, where the fraction precious metals was 0.45 ± 0.02 for the (901) stray coins that were found there, while at Oberaden (which was a nearby legionary camp in *Germania* in a similar period) the fraction precious metals was only 0.09 ± 0.02 (364 coins).

[18] The actual results of some 2,300 settlements are available upon request.

Figure 2: Settlements around the year 150 in three Gauls, Britannia, Belgica and the Germanias.
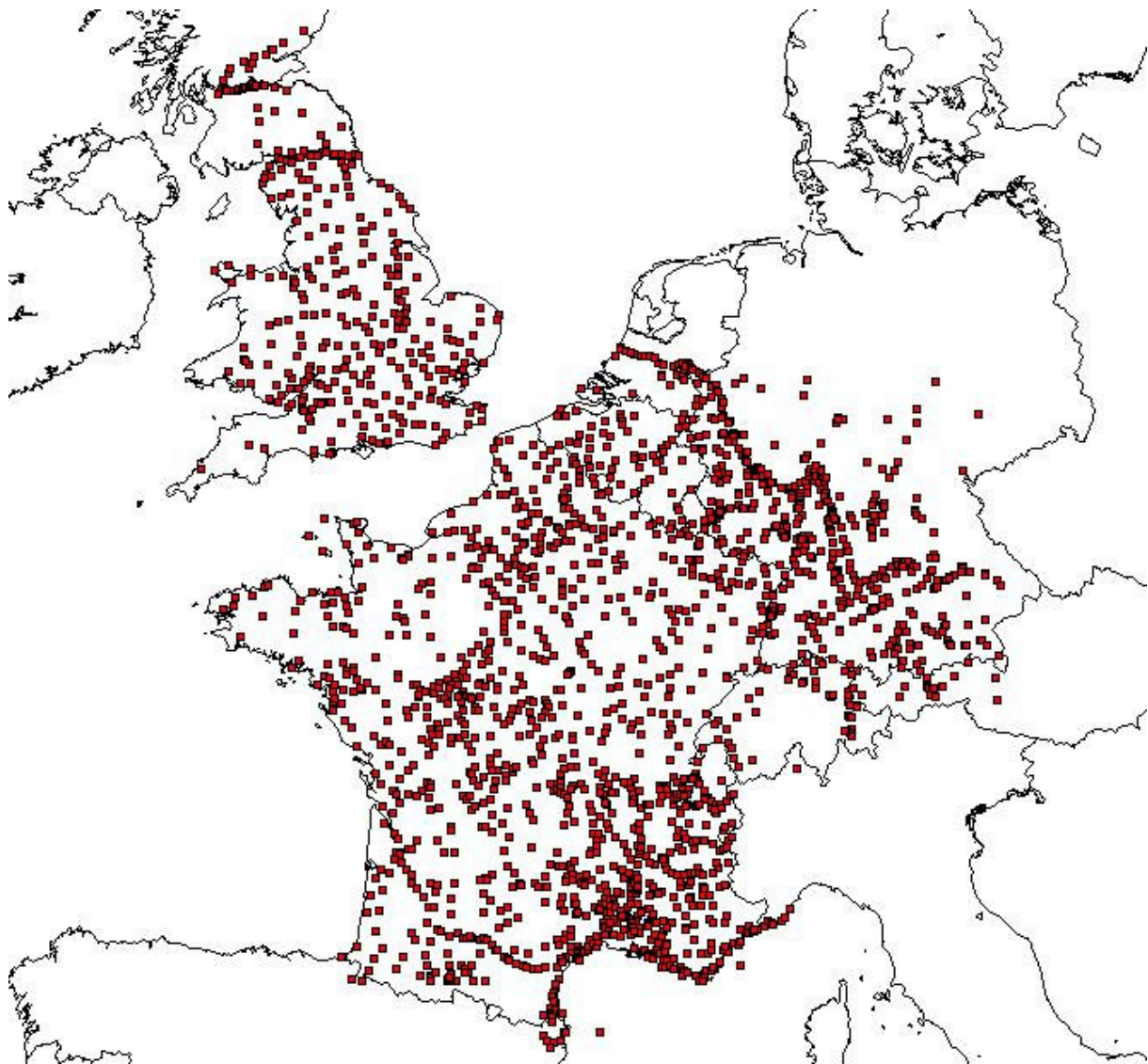
Source: see Data Appendix, section 2

Using an average value of 100 inhabitants/ha we estimated that the various Roman settlements in the study area of nearly one million km^2 probably contained 1.7 million inhabitants in this period, while there were some eleven million inhabitants in total.[19] The two

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[19] This has been estimated from McEvedy and Jones (1979). For Britain (England and Wales) we have changed the 0.7 million inhabitants of Mc Evedy and Jones (1979, 43) to 1.8 million, as we thought that the population density in inhabitants/km^2 in Britain should be rather similar to that in Belgium and France, some 12.0/km^2 (a value of the British population density of 4.6/km^2, at which we arrive by using the non-adapted Mc Evedy and Jones data is unrealistically low we think). For Germany and the Netherlands we have only included in our calculation the area contained within the *limes* that we estimated at 150,000 and 14,000 km^2 respectively. For the German *limes* area we also assumed a similar population density as in Belgium, some 12.0/km^2, which is slightly higher than that derived for the German total of 9.8/km^2, based on Mc Evedy and Jones.

biggest Roman cities Lyon and Cologne each had some 20,000 inhabitants, which certainly was large in this north-westerly area but not very large when compared to Rome or some cities in the east of the empire which could exceed 100,000 or a multiple thereof. In France, in decreasing order, Bordeaux, Amiens, Autun, Vienne, Besancon, Reims, Poitiers, Sens, Saintes, Cahors, Limoges, Metz and Nimes probably contained between 20,000 and 10,000 inhabitants. In Germany: Mainz and Trier, and in Britain: London, Cirencester, St Albans and Wroxeter belong to this size category too. Except for Nimes all of the towns in this largest category were located along a river, indicating that only 5% of this size class was not directly connected to a waterway. In the study area we estimated that some 50 Roman towns had a size between 5,000 and 10,000 inhabitants, while 131 towns may have harboured between 2,000 and 5,000 persons around the year 150. Of the towns of the intermediate class only 18% was not lying on a river, while of those in the smallest size class 23% was not connected to a riverine waterway.

Before coming with an analysis and interpretation of the collected material we think it is appropriate to first perform a few simple checks on the collected settlement sizes. We would expect for instance a relationship between the dimensions of a settlement and the size of its commercial activities. A way to test this is to analyse whether there is a relationship between the size of a *forum* in a Roman town and the dimensions of a town's surface area. We would also expect to find a relationship between the size of a town and the amount of cash that was used locally, when assuming that the sizes of towns are a measure of their economic success. For this aspect we will study the relationship between the total amount of stray Roman coins found in a town and its size around 150 CE.

In Figure 3 we present the relationship between *forum* size (in 1,000s of square meters) and settlement size in ha. Figure 3 shows that there is a considerable relationship in north-western Europe between the excavated surface area of a market in a town and its size in the RE. One of the outliers in Figure 3 is Lyon with a town size of 200 ha where only one *forum* of 17,000 sq meters is reported, which may be due to a lack of systematic archaeological excavations in this town. If Lyon is left out of the regression (as an outlier) the explained variance in Figure 3 rises to 0.73.

Figure 3: *Forum* **size (1,000s sq-m, y-axis) and settlement size (ha, x-axis) around the year 150**

$$y = 0,1663x + 2,7024$$
$$R^2 = 0,6312$$
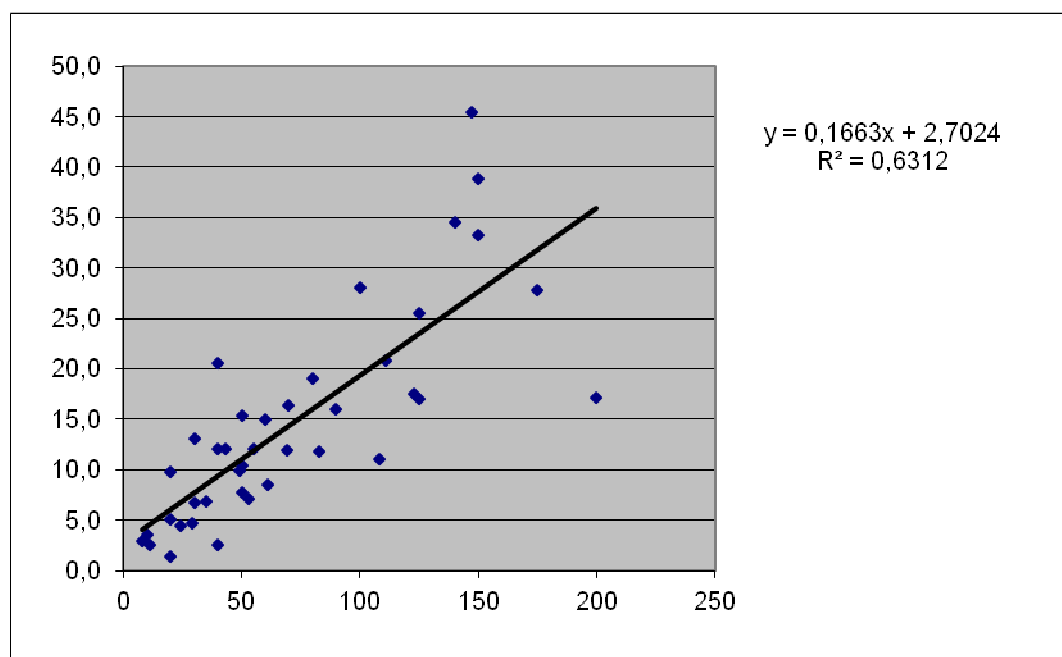
Source: see Data Appendix, sections 2 and 3.2.2

Market transactions need coins and therefore we will explore if we can find a relationship between local coin circulation (with total numbers of stray finds of all Roman coins minted before 402 as a proxy for this) and the size of the various settlements as a different corroboration of the settlement sizes. From John Casey (1974), Richard Reece (1973) and NUMIS we obtained the total numbers of stray Roman coins minted before 402, which were found in Britain and the Netherlands in excavations at various places. We coupled these totals per place with the sizes of the various settlements (ha) see Figure 4.

We have to stress that there is quite some noise in the data in Figure 4 due to the fact that the various find totals have not been corrected for the actual fraction of the Roman town that was excavated. Some settlements have been nearly totally excavated, while this was very partial at other places because e.g. the current habitation prevents such a total excavation. To give an example: the number of stray Roman coins found in Utrecht (only 17 coins) is heavily biased because not more than some 7% of the local military fort has been excavated and nothing of the accompanying *vicus*, so for Utrecht we would have expected a total number of some 970 coins for the whole 8 ha of fort and *vicus* if we would have corrected proportionally for the not-excavated fraction of its habited area. But despite this large noise in the numbers in Figure 4 we still find an R-square of 0.6, which we think is not bad at all for such obviously less than ideal data. This indicates that settlement sizes and circulation of coin have a high correlation too.

Figure 4: Total stray finds of Roman coins (in 1,000s of coins, y-axis) minted before 402 and settlement size in ha (x-axis).

$$y = 0,0665x + 0,1709$$
$$R^2 = 0,6097$$
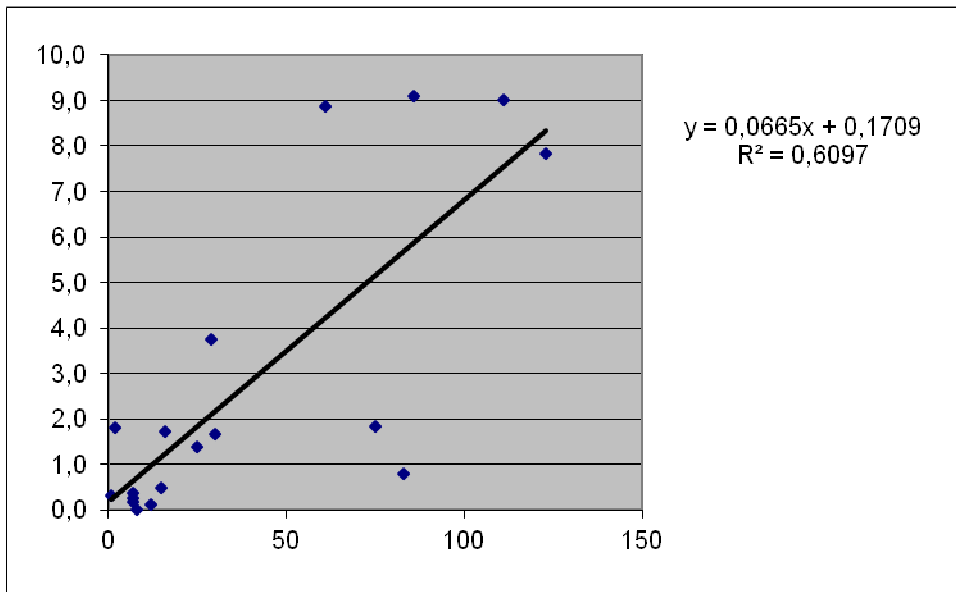
Sources: Casey (1974), Reece (1973), NUMIS and Data Appendix, section 2

We conclude from the two checks performed that there is a considerable relationship between the Roman town size in north-western Europe around 150 CE and the dimensions of its *forum*, as an indicator of local trade, and that we also find a fair relationship between town sizes and the amount of coin in local circulation. These results are a reassuring check for the quality of the data we collected. Now we continue with the question of whether a Roman market economy developed in the study area.

Rise and decline of a Roman market economy

As has been explained in the methodical section we use the fraction of coins composed of precious metal as a proxy for the development of a market economy. For this we will look at three different periods: the pre-Roman, Roman and of course the post-Roman period to find out if the coin finds point to a local market economy with quite some use of small change or on the contrary that they indicate that long-distance trade was the more usual pattern of local commerce.

The pre-Roman period

For the period 330 to 30 BCE directly preceding the Roman period in most of our study area we can observe 195 settlements in the southern part and 93 in the northern part of the study area. For the Roman period (30 BCE- 300 CE) the *Barrington Atlas* indicates 493 settlements below 47 degrees latitude and 1,017 above that line. The number of settlements in the southern part has more than doubled in the Roman period, while that in the northern part– and

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this is the area onto which later on we will concentrate our analysis –has risen more than tenfold. It is relevant to note that according to the *Barrington Atlas* there were no pre-Roman settlements located directly along the Lower Rhine and the Thames.

The more than tenfold rise in the numbers of settlements in the northerly area, above 47 degrees latitude, indicates that this part had been largely devoid of settlements before the Romans arrived. Of course there were Celtic or Germanic settlements pre-dating the Roman conquest, also in the northern areas, but their geographical locations often were quite different from those of the later Roman towns. The larger native settlements in Britain and on the Continent mostly comprised of extensive hill forts not directly connected to navigable water, such as Bibracte in France, where people lived concentrated up to a point when compared with the adjoining countryside, but considerably less concentrated than was customary in Roman towns later on.[20]

The Celts also knew coins. However, such Celtic coins, which were sometimes large and beautifully decorated gold pieces, generally were too valuable to use in daily commercial exchange. The role of Celtic coins was rather limited. It did not comprise regular circulation or monetarisation.[21] Their purpose probably either was to allow a comfortable way of wealth accumulation, or such precious coins may have also been used for social or political reasons, for instance to pay a tribute. In the Netherlands there are no stray coin finds in NUMIS of Celtic coins predating 58 BCE.[22] Because of a lack of coins and small change in our study area we cannot speak of a market economy in this period. This conclusion is corroborated by hoard finds elsewhere, e.g. in the pre-Roman coinage in Britain.[23] John Collis (1974) indicates that 68 pre-Roman hoards had been found of which more than 80% were predominately composed of silver and gold. This figure of 68 hoards is dwarfed by the more than 1,400 Romano-British hoards from the succeeding period (Anne Robertson, 1974).

The Roman period

Over a period of three centuries the Roman silver coinage gradually lost nearly all of its precious metal due to inflation (see Walker, 1976 -78), with the higher inflation occurring in the last part of the third century. In order to get figures that are not too heavily influenced by this phenomenon and to get a picture close to the period around our time window of circa 150 we have concentrated our data collecting on stray coin finds from the period 96 to 192, essentially capturing the Roman coins minted in the second century (from Nerva to Commodus and all emperors in between).[24] For this period we collected the total numbers of

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[20] Corrie Bakels (2009, 155) describes that that there were lowland and hilltop *oppida* in pre-Roman times in the north western European loess areas. The hilltop *oppida* were more common, and were strongly fortified settlements generally occupying strategic higher points in the landscape.

[21] Johan van Heesch (1998, 40).

[22] There is a Celtic hoard found in the south of the country with 116 coins completely composed of precious metal. After he had won the Gallic wars, which started in 58BCE, Caesar had most of the Gallic gold transported to Rome as spoils of war (there leading to a fall in the price of gold) and because of a lack of precious metals then forcing the Celts to use bronze instead to make their coins later on. Therefore 58BCE is a natural cut-off to use to look at the local precious metal fraction in the stray coins of the pre-Roman period.

[23] In Britain the Roman occupation only succeeded halfway the first century and the pre-Roman coinage therefore was a century longer in use than on the Continent.

[24] Of course we do not know for certain that the coins were actually lost during this period, we can only be sure that they were minted then. In the Netherlands Roman coins have been found dating from two centuries before the Romans arrived in the country, suggesting an actual coin use over quite some time in the early empire. Later with the inflation and the strongly reduced silver content in especially the third century the more valuable old coins will have been withdrawn from circulation rather sooner than later and the actual period of coin use will have been considerably reduced.

stray coins and those that were composed of precious metals (either gold or silver: for coins classified in NUMIS as *aureus* or *denarius*). With this we calculated the fraction of precious metals in the stray coin finds. The fortunate coincidence is that part of the Netherlands belonged to the RE while a different part has always remained non-Roman. Therefore the finding spots of coins in the Netherlands are either at various distances from the Roman *limes* within the RE or lying at various distances outside the RE, allowing us to gauge its spatial influence, up to at most circa 200 km from the *limes,* as the Netherlands is a rather small country geographically.

In Table 1 we can see a clear gradient of precious metals in the coins in general use in the second century. Deep within the RE coins of low denominations are by far in the majority as the precious metal content is only 0.08, such a low fraction indicating that mainly small denominations were in circulation may be called indicative for coin use in a local market economy. The precious metal content gradually rises to a fraction of 0.33 as we get closer to the *limes*, suggesting that at least part of the money brought into circulation there was passed out in the form of silver.[25] Outside the *limes* the precious metal content rises further, but not terribly fast, suggesting that Roman coins were used to some extent. Geographically we can see such use more in particular in the Frisian knolls, which were relatively easily accessible by waterways. When we look at coin finds from archaeological excavations at a distance of some 350 km from the *limes* in the Thorsbergermoor in Schleswig-Holstein, we find that the fraction of precious metals of (n=29) Roman coins minted between 96 and 192 has risen to unity.[26] Because these Roman coins were locally used as jewellery or as decoration on clothing they were not in regular use for market purposes any more. The amount of coins lost (and in circulation) has increased considerably in the RE compared to the pre-Roman period. On the *limes* in the RE (which in our opinion should be no surprise) the average coin density is the highest.[27] In the area outside the empire directly bordering the *limes* we find relatively the lowest coin density, suggesting that Romans will not have stimulated barbarian occupation of this frontier zone, and even may have deliberately kept it more or less uninhabited.[28] At a distance of a few hundred kilometres from the *limes* in barbarian land (such as in Germany) the stray Roman coin density drops again to virtually zero.[29]

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[25] The existence of a local market economy in this part of the RE has been corroborated by data collected during a combination of botanical, zoological and settlement archaeology in the Dutch River Area. These data show that it was possible for the local rural communities in the non-villa landscape to produce a surplus of animals as well as cereals for a market, see Maaike de Groot et al, (2009).

[26] *Die Fundmünzen der Römische Zeit in Deutschland. Abt viii. Schleswig-Holstein und Hamburg.* (1994).

[27] Hans-Jörg Kellner et al, (1975, 8) estimate that some 150,000 to 200,000 Roman coins have been found in Germany, which would lead to a coin density there of some 0.3 to 0.4/km^2 per century in Roman Germany when assuming a Roman stay of some four centuries. These numbers are not completely comparable to ours as these German numbers include hoards too.

[28] C. R. Whittaker (1983, 110) mentions the expulsion, reported by Tacitus, in 58 CE by the Romans of two Frisian tribes that had newly arrived and attempted to settle in unoccupied military territory.

[29] As can be deduced from the few Roman coins excavated at the Thorsbergermoor in Schleswig-Holstein.

Table 1: Stray finds of Roman coins in the Netherlands minted between 96 and 192 and the precious metal fraction with its standard deviation

Zone:	gold+silver coins #	Total coins #	fraction precious metals	standard deviation	# coins per square kilometre
Within RE[30]					
> 75 km from *limes*	6	80	**0.08**	$\pm$ 0.03	0.045
0-75 km to *limes*	421	2,291	**0.18**	$\pm$ 0.01	0.209
on the *limes*	508	1,550	**0.33**	$\pm$ 0.01	1.448
Outside the RE:					
0-75 km to *limes*	104	242	**0.43**	$\pm$ 0.03	0.023
75-150 km to *limes*	292	637	**0.46**	$\pm$ 0.02	0.084
>150 km from *limes*	100	196	**0.51**	$\pm$ 0.04	0.092

Source: NUMIS

There are data from outside the Netherlands that can corroborate the picture from Table 1. And they show that we may probably generalise it to north-western Europe, unfortunately these data are not organised in a similar all-covering and easily accessible electronic way as in NUMIS and we have to do quite some tedious counting by hand to find the results. From the data reported by Johan van Heesch (1998, 119) we can determine the second-century fraction of precious metals in the stray finds in north-western Belgian Gaul. There we find on average a precious metal fraction of 0.06 $\pm$ 0.01 for the *vici*, 0.06 $\pm$ 0.03 for the villa's and 0.07 $\pm$ 0.02 for a temple site in Belgium. These fractions are quite similar to what we found at more than 75 km outside the limes in the RE in the Netherlands (see Table 1).

A sample of eight (of the 55) *limes*-stations on the GSR from *Die Fundmünzen der Römische Zeit in Deutschland* leads to a fraction of precious metal of 0.18 $\pm$ 0.02, while the zone in the RE between 0 to 50 km had a fraction of 0.10 $\pm$ 0.01 and the precious metal fraction in the Roman zone at more than 50 km distance had a value of 0.07 $\pm$ 0.01.[31] The pattern of coin use

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[30] All the municipalities along the Rhine and its old course between the line Rijnwaarden to Katwijk have been classified as lying on the limes (in the RE) with a total surface of 1,071 km². The whole of Zeeland has been classified as lying on average more than 75 km from the limes in the RE, with a surface of 1,787 km². All municipalities south of the limes (and not in Zeeland) were classified as a part of the RE lying between 0 and 75 km from the limes with a total surface of 10,960 km². The municipalities south of the line Den Helder to Hardenberg and north of the *limes* were classified as non-Roman and lying between 0 and 75 km from the limes, with a total surface of 10,374 km². All municipalities north of this line and south of the line Ameland to Veendam were classified as lying between 75 and 150 km from the limes with a total surface of 7,570 km². While all municipalities lying north and east of it were classified as further than 150 km from the limes with a total surface of 2,212 km².

[31] For the limes we collected data on stray coins minted between 96 and 192 from Stockstadt, Niedernberg, Obernberg, Miltenberg, Dambach, Rufenhofen, Gnotzheim-Gunzenhausen and Theilenhofen (406 coins). For the zone 0-50km: Regensburg, Nassenfels, Pfünz and Weissenburg (685 coins), while for the zone > 50 km we

that emerges for Germany is more or less comparable to what we found in NUMIS: the fraction of precious metal being the highest at the *limes* and dropping off at increasing distances, to a low value that is quite similar to the one found in Belgium and the Netherlands far from the *limes*. Jean-Marc Doyen (2007) gives information on coin finds in 70 emergency excavations in Reims executed between 1972 and 2005; in this important Roman town (*Durocortorum*) far from the *limes* we find a fraction of 0.07 $\pm$ 0.02, while he also gives comparative information on other towns, such as Cologne (0.07 $\pm$ 0.01) where we find a very similar fraction. The fact that in larger Roman towns as Reims and Cologne as well as in villa's and *vici* in rural Belgium and in parts of the Netherlands far from the *limes* we find rather similar (low) fractions of precious metal in the second-century stray coin finds we think is quite remarkable and we see it as a corroboration of a more or less widely dispersed and developed Roman market economy in north western Europe.

Though the generally low fraction of precious metals in the stray coin finds in north-western Europe, supports the hypothesis of a developing Roman market economy a few spots and areas in the RE show somewhat deviant patterns. Along the *limes* we generally find a higher fraction of precious metals than further away in the RE. This we think points in the direction of the Roman military, who could have spent part of their silver in this *limes* area leading to a higher fraction of precious metals in the local stray coins. The other hotspots we think suggest the influence of the silver resulting from local medium and long-distance commercial and industrial activities. Richard Reece (1973) gives us some data to corroborate such a hypothesis. A town as Rheinzabern (*Tabernae*) (>75 km from the *limes* along the Upper Rhine) did not yet have a large pottery industry in the first century and then had a fraction of 0.08 $\pm$ 0.02 of precious metal in its coin; while in the second century it had flourishing ceramic industry with a yearly production of half a million to one million pieces of samian ware which were sold throughout the north-western area. In Rheinzabern the local fraction precious metal in its stray coins had then risen to 0.16 $\pm$ 0.02. In nearby Speyer (*Spira*) also on the Upper Rhine but without such a flourishing commercial industry these fractions were 0.03 $\pm$ 0.01 and 0.05 $\pm$ 0.02 for the first and second century respectively. These examples corroborate that the occurrence of commercial silver may be a plausible reason why we may locally find a higher fraction of precious metal in stray coins. For an important commercial and legionary centre as Mainz (*Mogontiacum*) the data of Reece come to a fraction of 0.15 $\pm$ 0.02 in the second century and we find a fraction of 0.17 $\pm$ 0.05 for the Rhine valley. Reece's data from Britain show more or less similar fractions: for the averages of the excavations in St Albans (*Verulamium*) 0.12 $\pm$ 0.01 and Cirencester 0.15 $\pm$ 0.02 (*Corinium Dobunnorum*).

Though we have not been able to explicitly cover the whole of our study area with data on local coin finds we may assume that the not covered areas would probably not have been fundamentally different, as only geographical data availability was behind the limited sample we presented. Our conclusion from the Roman coin finds is that they corroborate the idea of a developing market economy after the Roman arrival in these north-westerly fringes of the empire.

The post-Roman period

In the period 240 to 275 CE most of the forts in the Netherlands that were part of the LR-*limes* gradually were abandoned and the Roman military departed. We have only looked at two 10x10 km grids, as the process of correcting for double counts in this late period of time

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sampled Günzburg and Kempten (354 coins). As these data are not available electronically they have to be counted by hand, so we only did a limited sample.

is crucial because of the relatively small numbers involved, and the way NUMIS is accessible makes this correction a rather time consuming exercise.

For the 10x10 km grid in Bunnik (*Fectio*) NUMIS contains 29 coins minted in the fourth century, all of them of non-precious metals (down from 775 coins minted in the first, 281 in the second and 134 in the third century). In Katwijk (*Lugdunum*) there are 9 coins minted in the fourth century, also all from non-precious metals. In Valkenburg (*Praetorium Agrippinae*) we find no fourth-century coins at all in NUMIS.[32] Nevertheless there still was some use of local money in small denominations, though also at a much lower level compared to the first few centuries of the CE. Johan van Heesch (1998, 174) indicates that in *Gallia Belgica* during the fourth century the economy was still largely monetarised with coins of low denominations, which in the fifth century gradually diminished.

In Table 2 we will present data on stray coin finds in the Netherlands that were minted in the sixth and seventh centuries (well after the Roman period). These show that the market economy which was substantiated by the low fraction of precious metals in the coin finds in Roman times seemed to have disappeared by that time, as the fraction of precious metals was close to unity again. A value close to one indicates an inclination to long-distance trade, if we want to speak of commercial activity at all. The low absolute numbers of coins compared to those in Roman times also points in a direction of less trade. The differences in coin use between Roman and non-Roman territories within the Netherlands that was clearly visible in the second century had disappeared as well in the sixth to seventh century.

Table 2: Stray finds in the Netherlands of coins minted between 500 and 700 and the precious metal fraction with its standard deviation

Zone:	gold+silver coins #	Total coins #	fraction precious metals	standard deviation	# coins per square kilometre per century
Previously within the RE[33]	1,267	1,311	**0.97**	$\pm$ 0.01	0.047
Previously outside the RE	412	451	**0.91**	$\pm$ 0.01	0.011

 Source: NUMIS

If for the zone previously outside the RE we limit the analysis of Table 2 to a sub-zone; that of the Frisian knolls which were relatively easily accessible by waterways we find a more or less similar precious metal fraction of 0.90 $\pm$ 0.02. The local coin density for this sub-zone rises to 0.067 (per century), making it quite similar to the zone that previously was Roman and which in this period contained a commercial centre as Dorestad.

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[32] Lothar Wierschowski (1984, 140/1) gives the example of *Vindonissia* were the Roman legion departed in 101 and the local coin finds of coins minted before and after this date changed considerably in volume. When Roman soldiers came back to *Vindonissia* again in 260-268 coin numbers rose too. Other such examples can be found on the pages 142-7.

[33] In NUMIS for this analysis we used the geographical classification of the find place based on the municipalities. All the municipalities along the Rhine and its old course between the line Rijnwaarden to Katwijk have been classified as lying on the limes (in the RE) all municipalities south of this line were later part of the RE, while all that were lying to the north of it never were part of the RE. The Roman area in the Netherlands was roughly 13,800 km², while the non-Roman part was approximately 20,100 km².

Table 2 suggests that the previously existing market economy during Roman times with low fractions of precious metals in the local coins and a somewhat higher coin density had been succeeded by one of long-distance trade, operating at a considerably lower level of intensity.[34] This is the form of commercial activity usually found in the North Sea world in these centuries; see e.g. Barrie Cook and Gareth Williams (2006). Peter Spufford (1988, 15) described that in sixth-century France lacked the necessary coinage to foster its local economy; though the pages of Gregory of Tours drip with blood and gold, it was gold not in circulation and use, but a fortune that was clotted and hoarded. A different indicator of long-term economic output can be found in the numbers of manuscripts that were produced locally. For north-western Europe this production also shows a minimum in the sixth century.[35] In the sixth century the Franks did not pay their soldiers with gold, the loyalty of the vassals now was bought with land.[36] This process later led to the emergence of a feudal system in Europe, which formed a break with the more market based economies of the Roman period.

Our conclusions from this section are that in pre-Roman times there was no market economy in the north-westerly parts of Europe to speak off. The situation changed completely in the Roman period when we can find a large use of small denomination coins virtually everywhere. After the demise of the RE this changes again; we now find a considerably higher fraction of precious metal in the coin finds at a few hot spots, pointing in the direction of long-range commerce.

The distribution of Roman settlement density in north-western Europe

Because of its pivotal role in the transport of commercial goods over inland waterways (see Buringh et al, forthcoming) we have concentrated our analysis on the different fluvial systems, by quantifying the average economic relevance of fluvial systems. As already explained in the methodical section the relative urbanisation of a fluvial system has been calculated as the sum of all habited surfaces of settlements in 150 CE on the catchment area of river in ha divided by the total length in km of the waterway connections in the fluvial system, see Table 3 for the results.

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[34] A similar result was found for South Germany, located just as the Netherlands partly in and partly out of the RE. Jörg Drauschke (2009, 279) describes that after the RE in the eastern Merovingian areas in Germany no money-based economy existed between the late fifth and eighth century.

[35] Buringh and van Zanden (2009, 416); the production for Europe as a whole shows a minimum in the seventh century, but this is caused by the specific local situation in Italy with the Lombard invasions and Byzantine wars reducing the local manuscript production in Europe's largest producer of manuscripts in that period.

[36] Johan van Heesch (1998, 174), which was quite different from how in the Middle East the Muslim armies were compensated after 650 CE, as we will show later on.

Table 3: Settlement density (in ha/km) of the fluvial systems at about 150 CE

Fluvial system	Current basin (in 1000s km^2)	Current length (in km)	Total Roman fluvial connections (in km)	Absolute Roman urbanised area (in ha)	Settlement density (ha/km)
Gironde			*1,960*	*976*	*0.50*
Dordogne	23.8	483	610	131	0.21
Garonne	84.8	602	1,350	845	0.63
Loire	117.0	1,013	2,800	1,219	0.44
Rhone	98.0	813	2,270	1,647	0.73
Rhine	170.0	1,233	*2,765*	*2,688*	*0.97*
Lower Rhine			460	809	1.76
Moselle	28.3	545	610	471	0.77
Upper Rhine			1,695	1,408	0.83
Seine	78.7	776	2,085	1,141	0.55
Somme	6.0	245	215	207	0.96
Scheldt	21.9	350	615	208	0.34
Meuse	36.0	925	955	284	0.30
Thames	12.9	346	470	585	1.24

Source: see Data Appendix, sections 1.2 and 2

The Lower Rhine and the Thames are the two fluvial systems that pop up in Table 3 as the most densely urbanised in north-westerly Europe. First we will try to find out if we can find some corroboration for the pattern of relative urbanisation that seems to emerge from Table 3. Therefore we looked at reports on the archaeological remains of non-perishable Roman goods imported from outside the study area and describing the finding places of such goods, which were commercially transported into the study area. These concern the so-called Dressel 30 amphorae (Peacock, 1978) and oil amphorae and fine pottery from southern Spain (Greene, 1986). Both finds are shown in Table 4 and eventually lead to a combined amphorae index.[37]

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[37] In Table 4 we first show the actual numbers of finds of the various amphorae per fluvial system and then standardise these to an index per 1,000 km fluvial system to make them better comparable mutually. In order to arrive at a combined index of the 32 finds of Dressel 30 amphorae indicated by Peacock and the 54 finds of Spanish wares by Greene we have standardised numbers of Greene to those of Peacock by first dividing his absolute numbers by 54 and then multiplying them by 32. The combined amph index simply is the sum of both individual indexes and is shown in the last column of Table 2.

Table 4: Archaeological remains of non-local amphorae per fluvial system.

Fluvial system	Peacock Dressel 30 amphorae	Amph/1000km	Greene Spanish wares (amph)	Amph/1000km	Combined amph index
Gironde					
Dordogne	0	*0,0*	0	*0,0*	**0,0**
Garonne	0	*0,0*	2,4	*1,8*	**1,8**
Loire	3	*1,1*	3,6	*1,3*	**2,4**
Rhone	6	*2,6*	11,9	*5,2*	**7,9**
Rhine					
Lower Rhine	4	*8,7*	2,4	*5,2*	**13,9**
Moselle	0	*0,0*	0	*0,0*	**0,0**
Upper Rhine	10	*5,9*	8,9	*5,3*	**11,2**
Seine	5	*2,4*	0	*0,0*	**2,4**
Somme	1	*4,7*	0	*0,0*	**4,7**
Scheldt	0	*0,0*	0	*0,0*	**0,0**
Meuse	0	*0,0*	0	*0,0*	**0,0**
Thames	3	*6,4*	3	*6,4*	**12,8**

Sources: Peacock (1978) and Greene (1986)

The combined amphorae index from Table 4, as an indicator of Roman trade intensity, has a quite reasonable correlation ($R^2 = 0.7$) with the settlement density of the various fluvial systems presented in the last column of Table 3.[38] This correlation corroborates that settlement density and commercial transport go hand in glove.[39]

Factors potentially driving the development of a Roman market economy

In this section we will describe various variables that can potentially influence the process of market development we are interested in. We also strive to come to a quantification of those factors because we want to tease out statistically which of them were the most important in this respect, as well as how important they actually are in explaining the found distribution of urbanisation and monetarisation in north-westerly Europe. We have managed to find quantitative information on a number of potential drivers in the various fluvial areas in Roman times: the military demand, the numbers of town councils, the numbers of excavated casks (as a proxy for the wine trade), the density of Roman mines, the density of remains of

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[38] Combining the Moselle and the rest of the Upper Rhine, into one category: Upper Rhine proper, leads to an R-square of 0.86. The current correlation is lower because no amphorae finds were reported in the Moselle area by either Peacock or Greene. However, taking into account how important Trier was economically in the RE it seems hard to believe that the Romans would not have transported such amphorae to Trier or the Moselle area.

[39] A more or less similar general indicator of commerce is the number of casks shown in Table 5 (third column), this indicator also has an R-square of 0.7 with the settlement density. However, a word of caution may also be at its place here. Matthew E. Loughton (2003, 199) warns that it may be easy to fall into the trap of believing that maps showing the distribution of Republican amphorae provide an unbiased picture of trade and exchange, as e.g. ritual and cult activity may seriously complicate this picture. His report on find spots of Republican amphorae is limited to France (and covers only six of our twelve fluvial catchments). The Republican amphorae date from the third century BCE to the Roman period and thereby predate our settlement density data, while they turn out to have no correlation with them at all ($R^2 = 0.1$).

Roman viticulture and the fraction of loess soils as a proxy for the production of grain in Roman times. In Table 5 we will show the various potential drivers of Roman urbanisation per fluvial area. In this table only the indexed values are reported, and not the absolute values as they can be found in the archaeological references (all values have been divided by the total length in km of the waterborne connections per specific fluvial system and multiplied by one thousand in order to get a relative measure). Later on all these data will be used for a multivariate analysis, which then can tell us something about their relative importance.

The Roman military

After the Roman conquests with its temporary campaigns, which started in 58 BCE and continued until the decades around the beginning of the CE, the Roman army was here to stay for centuries. Once a legion was stationed somewhere in the empire it mostly stayed put for at least a number of decades and sometimes even longer, as Roman military transport facilities were a strain on state resources.

The average pay of a soldier was 300 silver *denarii* which is equal to 1,200 bronze sesterces (HS) per year in 100 CE, rising to 1,800 HS in 200 CE.[40] Generally three times a year a soldier received part of his pay as a form of pocket money; deductions were made for his cost of living, his kit as well as for his savings.[41] It has been estimated that he paid some 32% of his salary on food and approximately 40% of his salary on his kit and its upkeep.[42]

The commercial importance of the Roman military can be substantiated by the fact that a legionary fort was generally accompanied by a considerably more extensive civilian *canabae*, where the smiths, tailors, weavers, leather workers and other commercial artisans were making the products and services they sold to the military.[43] Even for a smaller Roman fort there nearly always was a civilian *vicus* lying right next to it, where a bathhouse could be found, for instance. This decentralised Roman way of conducting military business led to a huge demand for such commercial goods and services in the fringes of the empire, which previously had in no way been accustomed to a market economy.[44] The parallel that can be drawn between the military in the RE and those of the early Islamic state (circa 650 to 900) is quite straightforward. Hugh Kennedy (2002, 155) examined the military payment in cash of the early Islamic state, which put a massive amount of coinage into circulation that was spent locally by the soldiers. He concluded that the military payment played an important part in creating the urban, cash based market economy of the early Islamic world, which contrasts so sharply with land and kind based economies of the then contemporary Christian states in the east and in the Latin West.

The first column of Table 5 is an index of the local military demand. The local military demand has been estimated in millions of HS per year. This has been done by multiplying the

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[40] In this article we will give all prices in sesterces (HS) as is costume in works on the Roman economy, despite the fact that the originally Roman abbreviation "d." for denarius still can be found for that of the English penny.
[41] Lothar Wierschowski (1984, 5).
[42] A slightly different estimate comes from Lothar Wierschowski (1984, 203), he estimated that a Roman soldier had some 20% of his salary, or 50 to 60 *denarii* per year to spend freely.
[43] Lothar Wierschowski (1984, 123/5) indicates that the neighbourhood of camps was very attractive for artisans and commerce; and even that traders from further a field were attracted to the camps to fill in gaps in the market, while smaller local farmers also had a regular outlet for the sale of their agricultural products at the nearby forts.
[44] Even nowadays, when the direct local demand of goods by the military is considerably less, as modern transport facilities have become very much more efficient and cheaper than in classical times, the positive economic influence of a military base on the local economy can still be a strong incentive to tolerate such a presence, as can be seen from a report by Alexander Cooley and Kimberly Marten (2006) on a large U.S. base in Okinawa, Japan.

numbers of military per km of fluvial length[45] times 1,800 HS times 0.72 to find what the Roman army generally spent on to keep itself alive and equipped. We have taken this value times 0.8 because we assumed that a certain fraction of the necessary military stuff by its very nature (such as e.g. olive oil, wine, garum, etc.), say 20% in value, had to come from outside the local fluvial area.[46] For the fluvial area of the Thames we have therefore added 20% of the total British military expenditure to the military demand of this fluvial area because London was the main point of entry and distribution for the military in the British Isles.

Roman town councils

Recent economic literature shows that local town councils were an important element in the economic take-off of cities in Europe in the Middle Ages and early-modern period.[47] In order to study whether these institutions, for whose membership a certain amount of personal wealth was a criterion, were influential in the Roman era too we indexed the numbers of town councils per km of fluvial length in the second column of Table 5. We thereby assumed that all towns that were a *civitas* also had a *curia* or town council. Whether or not a town was a *civitas* has been determined from Wikipedia. The Roman term *civitas* originally was used for a provincial capital for a client tribe. Later on it meant that a town had a regional market, with a *forum* and a *basilica*. It generally had a council with an *ordo* or *curia*, who administrated the activity of the *civitas,* which had as a principal purpose to stimulate the local economy, raise taxes and produce raw materials.

A proxy for the wine trade

The third column of Table 5 contains the numbers of casks found in excavations as presented by Élise Marlière (2001, 194-201). As such they signal the end product of the life cycle of a barrel, which was often reused at local wells, and these archaeological artefacts probably are an indicator of previous commerce in alcoholic beverages.[48] The high correlation (R-sq 0.95) in Table 5 between casks and military demand is striking, indicating that booze and soldiers are an ancient combination of which the Romans already were well aware. The third-century emperor Aurelian produced some wishful thinking on the habits of his soldiers by imagining that a Roman soldier would rather have money in his belt than spend it in the pub.[49] The fact and the way that he thought about the habits of his soldiers shows that their daily practice probably was in fact quite different. Already Tacitus had described some heavy binge drinking in the army in *Germania*, which certainly was no exception, as a result of an extra allowance that was finally paid out. And one Roman veteran had engraved on his stone: 'While I lived, I drank freely. You who still live, drink.' (*Dum vixi bibi libenter bibite vos qui vivitis*).[50]

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[45] This has been found from the database by selecting all summed fort areas in ha and multiplying the summed value by 200 soldiers /ha, giving an indicator of the numbers of Roman soldiers.

[46] For the later MLR model the exact realisation of this choice of 20% is not very critical, as different values such as 10% or 30% lead to rather similar results. Also the exact numerical value of the 72% used to estimate what a 'soldier' spent on food and his kit is not critical at all in this respect, as it just leads to a relative measure, which is only used to obtain a relative picture in the different fluvial areas. Using any other fraction that was spent on his upkeep and kit will eventually lead to a similar correlation.

[47] Bosker et al, (forthcoming).

[48] Corrie Bakels (2009, 160) indicates that casks may have been used for transporting other items too in the RE, and gives pomgrenates as an archaeological example, though on p. 179 she indicates that their main purpose was the transport of alcoholic beverages.

[49] See Flavius Vopisius of Syracuse (1967, 207)

[50] Lothar Wierschowski (1984, 125/6).

Roman mines

The fourth column of Table 5 contains the index per 1,000 km of fluvial system of the total number of mines (whether for certain stones or metals) as indicated in the Barrington Atlas.

Regional Roman viticulture
The fifth column of Table 5 is an index of the Roman viticulture. Due to a lack of data this does not comprise the Loire, Upper Rhine and Seine basins, but the other areas probably have been adequately covered. It is based on the numbers of different places where immobile artefacts in connection with viticulture as a vine press, vine yard or wine making establishments have been excavated. For Aquitaine this is based on Catherine Balmelle et al., (2001), for the Moselle area on Jean-Pierre Brun and Karl-Joseph Gilles (2001), for the Tricastin on Cécile Jung et al., (2001), for the Languedoc-Roussillon on Loïc Buffat and Christophe Pellecuer (2001), for the Provence on Jean-Pierre Brun (2001), for the south of Gaul on Philippe Boissinot (2001) and for the British Isles on Brown et al., (2001, 755).

Regional Roman grain production
The sixth column of Table 5 contains an index of the Loess soils per fluvial area. It is preliminary and based on an analysis of a soil map available on the Internet from which the relative surface areas in percent have been deduced that are indicated in Table 5.[51]

Table 5: Potential drivers (indexed per 1,000 km fluvial system) of Roman urbanisation

Fluvial system	Military demand	Town councils	Casks	Mines	Viticulture (preliminary)	Loess (preliminary)
Gironde						
Dordogne	*0.8*	*1.6*	*0.0*	*0.7*	*19.7*	*0*
Garonne	*0.7*	*3.0*	*0.7*	*1.2*	*12.6*	*0*
Loire	*0.3*	*3.9*	*2.9*	*0.9*	*no data*	*0*
Rhone	*0.4*	*9.3*	*4.4*	*2.6*	*14.5*	*5*
Rhine						
Lower Rhine	*77.0*	*8.7*	*82.6*	*1.1*	*0.0*	*0*
Moselle	*0.0*	*3.3*	*0.0*	*0.3*	*27.9*	*5*
Upper Rhine	*29.5*	*4.7*	*18.9*	*0.2*	*0.6*	*10*
Seine	*0.7*	*4.3*	*1.9*	*0.0*	*no data*	*10*
Somme	*7.0*	*4.7*	*0.0*	*0.0*	*0.0*	*70*
Scheldt	*1.6*	*1.6*	*8.1*	*0.2*	*0.0*	*10*
Meuse	*3.1*	*2.1*	*4.2*	*0.0*	*no data*	*5*
Thames	*29.5*	*8.5*	*23.4*	*1.1*	*2.1*	*0*

  Sources: see Data Appendix, section 1.2 and text

In a simple multivariate analysis (leading to expression 1) the first two columns of Table 5 already explain 86% of the variance in the settlement density (the last column of Table 3):

$$\text{Settlement density} = 0.0117 * \text{Mil.demand} + 0.0668 * \text{town c.} + 0.27 \qquad (1)$$
$$[\pm 0.003] \qquad\qquad [\pm 0.0246] \text{ standard deviations of the slopes}$$

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[51] Source: http://www.ufz.de/data/European_Loess_Map_hires7613.jpg

On itself the military demand in monetary terms explains some 75% of the variation in the urbanisation around the year 150 in north-western Europe, and adding into the regression the effect of town councils explains another 11 percent points.[52] The fact that none of the other variables concerning mining or agriculture has any significant additional contribution to the explained variance of the relative urbanisation in the various fluvial areas indicates that these variables have probably not driven the urbanisation in this part of the RE to a similar extent as the military demand (75%) and the presence of local town councils (11%). By itself the associations determined with a multivariate analysis of course do not imply causation. However, the historical narrative that points at the important role of the military presence for the local economy, makes causation plausible. There are many examples that when the Roman army departed somewhere the local economy declined or examples of the contrary: that their arrival gave a boost to it. Lothar Wierschowski (1984, 140/1) gives the example of *Vindonissia* were its legion departed in 101 CE and the local finds of coins minted before and after this date changed considerably in volume. When Roman soldiers returned to *Vindonissia* in 260-268 coin numbers rose too. A different example he gives is for Strasbourg (*Argentorate*) where after the departure of the Legio II Aug. to Britain the local coin numbers declined. These rose again after the new arrival in 71 CE of Legio VIII Aug. into the legionary camp at Strasbourg. In Cannstadt there was a military camp between 90 CE and 150/160 CE; and economically this town managed to prosper for another two decades after the Roman troops had left. However, after that, local prosperity declined markedly. Oberstimm is an example of a town where 'with the departure of the troops the market economy stopped de facto'(Wierschowski, 1984, 143). He continues with more examples in his book on 'the Roman army and the economy'. In the multivariate analysis above we found a high correlation between the military requirements and the settlement density in the various fluvial areas. Though a formal econometric proof has not been given for causation we nevertheless think that the historical narrative on individual towns and settlements developed by Lothar Wierschowski and others supports our interpretation of the Roman military as the most important driver of the local economy in the study area.

If we take a different geographical unit of analysis (grids of 1x1 degrees squared, in north-westerly Europe an area of approximately 110x75 km) we arrive at 135 observations in our study area instead of the only twelve fluvial catchments used above.[53] However, with a similar multi-variate analysis as previously this larger number of observations does not lead to a higher explained variance, quite the contrary. The explained variance reduces to a value of 41% (was 86%); the effect of town councils now becoming the more important one and explaining 32 percent points of the variance and the military demand now only explains a mere 9 percent points. We think that differences in the geographical scale of operation of the various driving factors are responsible for this very different outcome compared to that of the previous analysis based on the considerably larger fluvial areas. Bosker and Buringh (forthcoming) have shown that urban interaction and development is hampered at close range (by an 'urban shadow') and at far ranges (by transaction costs becoming too high) while at intermediate distances of some 20 to 100 km a different nearby town (for which the town council effect may be seen as a proxy here) stimulates urban growth. This stimulating effect

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[52] A.R. Birley (1986) indicated in a book review that Lothar Wierschowski had not taken the infrastructural works of the Roman military into account when attempting to assess their economic influence. Though in this analysis we have also not done that directly the fact that military demand and the Roman infrastructure in ha have such a high correlation suggests this aspect has been treated to some extent somewhat more implicitly here.
[53] An implicit assumption with such a smaller unit of analysis is that the effect of the different potential drivers of the economy is geographically restricted to such a smaller unit.

falls exactly in the range of our 1x1 degree squared unit of analysis. On the other hand Lothar Wierschowski (1984, 140) indicates that provisioning the army was not only a regional affair but even supra regional, as general purchasing agents were sent out by the army (*seplasiarii*) far a field, and he indicates that the direct economic effect of the military demand would have been visible much further away than at a distance of one degree (e.g. grain and wine coming from Gallia, olive oil from the Mediterranean, etc.,).[54] We can see a similar distance effect in the fraction of precious metals in Table 1 that is visible in the coin distribution outside the *limes* over a range of two or three degrees. The reduction of our unit of analysis to a smaller geographical scale than that of the economic influence of the military seems to reduce its significance considerably. This very different analysis thus strengthens us in our conception of the use of a fluvial catchment area as the preferred analytical unit for the analysis of the economic effects of the military demand.

Local Roman economic growth along inland waterways

The three different Roman *limes* systems can be considered a kind of natural historical experiment, allowing us to delve somewhat deeper into factors influencing economic growth in Roman times and unravelling the influence of the military and other variables thereby. A Roman system of manned forts and watchtowers was in operation along the north-westerly borders to collect taxes on passing commerce in and out of the RE and to prevent marauding gangs of barbarians from plundering the more wealthy and therefore to them attractive countryside of the Empire. These forts were interconnected by walls or were located along a river, where the water formed a natural border. In the year 200 Hadrian's Wall (HW) with a length of 100 km and 16 forts was operational at the border between the Scottish territories and Roman Britain, and lying between South Shields (*Arbeia*) and Burgh by Sands (*Aballava*). In the lower-Rhine area from Bonn (*Bonna*) up to the now disappeared fort of Brittenburg at the North Sea we have discerned the Lower-Rhine *limes*, or LR-*limes*. This LR-*limes* without any walls had the Rhine as the natural border and had a length of 325 km with 35 forts. The third *limes* was the Germania Superior-Raetia-*limes* (GSR-*limes*, in the German literature it is also known by the acronym of ORL, the *Obergermanischen Raetischen Limes*) it ran from Heddesdorf on the Rhine to Eining (*Abusina*) near Regensburg on the Donau. This specific *limes* was formed partly by a wall through the Taunus mountains and for a larger part by a wall through southern Germany and for a small part it also was fluvial with the river Main as a natural border. Overall it had a total length of some 500 km and contained 55 forts.[55]

On the basis of the surface areas we collected from the archaeological record we can easily calculate the military strength in "ha of fort" per "km of *limes*", by summing all by the military habited surfaces (in ha) and dividing this value by the length (in km) of the *limes* in question:

Hadrian's Wall:	0.30 ha/km
Lower Rhine *limes*	0.36 ha/km
GSR-*limes*	0.25 ha/km.

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[54] Paul Middleton (1983, 82) also makes the point that army garrisons of necessity drew their bulked supplies from regions far beyond their *territoria*.

[55] One has to realise that the habitation density of military settlements (legionary, cohort or auxiliary forts and road stations) was approximately a factor of two higher than the 100 inhabitants/ha of a typical urban civilian settlement in the Gauls and Germanias. Thus military settlements as a rule comprised some 200 men/ha.

Despite the geographical differences in location and terrain these values seem remarkably similar in their sizes; one could say that we find on average some 0.30 $\pm$ 0.06 ha/km for the strength of the Roman *limes* in north-western Europe. For one of the values found we even have an independent check. Dietwolf Baatz (1982, 140) indicates that he estimates the strength of the GSR-*limes* to have been approximately 50 men/km.[56] When we multiply our value of 0.25 ha/km with the average value of the military density of 200 men/ha, we also arrive at exactly the same figure as Baatz does of 50 men/km for the GSR-*limes*.

Around the year 200 there were three legions in Brittania[57] and four legions along the Rhine, not only at the *limes* itself but also more strategically located somewhat behind the actual *limes,* such as in York, Nijmegen, Mainz or Strasbourg. All the legionary forts in north-westerly Europe were located on rivers and could be reached easily by inland water transport. In Table 6 we will model the expected settlement density in ha/km (with expression (1)) based on the military demand in millions of HS per year for the three different *limes* systems in north-western Europe. Table 6 also contains the residuals, a statistical concept used to quantify the differences between realised and modelled values.

Table 6: Modelled (with expression 1) and actual urbanisation around 200 CE and their residuals for the three *limes* systems

limes system	Modelled value	Realised density (ha/km)	Residuals	Transport mode
Hadrian's Wall	1.00	0.88	**– 0.12**	land
GSR *limes*	0.88	0.78	**– 0.10**	land
Lower Rhine *limes*	1.14	1.31	**0.17**	river
LR-*limes* + Cologne, Xanten	1.55	1.99	**0.44**	river

Sources: see Data Appendix, section 2, text and expression (1)

Though the differences between the realised settlement density and the modelled values in the three *limes* systems are within a reasonable band width of $\pm$ 30%, the residuals nevertheless show a distinct pattern. Both *limes* systems without a waterway had negative residuals, indicating that they actually had a smaller settlement density than expression (1) would expect them to have had, while along the lower Rhine the *limes* had realised a somewhat higher urbanisation than would have been expected. This actually points at the important role of the rivers themselves in realising economic growth, which does not follow from our analyses because we have analysed the influence of various factors (such as military demand or town councils) on a fluvial system. The actual settlement density along the whole of 460 km of fluvial connections on the lower Rhine is considerably higher (1.76 ha/km) than what actually was realised along the military camps and their *vici* (1.31 ha/km) along the 325 km of the LR-*limes*.

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[56] Dietwulf Baatz reports the length of the limes to be 375 km and at the same time postulates that 17,000 to 19,000 soldiers have been involved with it.
[57] These legions in Britannia were located at the borders of fertile agrarian areas to allow an easy provisioning of the military (Lothar Wierschowski, 1984, 66).

Along the limes there are also two civilian settlements Cologne (*Col. Claudia Ara Agrippinensium*) and Xanten (*Col. Ulpa Triana*) of which the habited areas had not yet been included into that of the *limes*, because strictly speaking they were no part of it. Both towns were civitates. When we include these two towns, which originally were colonies of veterans we model a value of 1.55 ha/km in Table 6, while the actual realisation is 1.99 ha/km, indicating a residual of 0.44, or an influence of some 28% extra urbanisation because of a navigable waterway. Assuming a Roman presence of some 140 years then leads to an average extra economic growth rate of 0.18% per year because of the local connection to an inland waterway.[58]

Joel Mokyr (1990, 4) distinguishes four distinct processes that, roughly speaking, can lead to economic growth: investment, commercial expansion, scale effects and increase in human capital. These four processes seem to have been more or less similar in their impact and consequences for the three different *limes* systems. However, the main difference between HW and GSR (the two landlocked *limes* systems), and the Lower Rhine *limes* located strategically along a river are the lower transaction costs at the latter because of the reduced cost of transport due to the riverine character of the traffic. Table 6 suggests that this lower transport cost has lead to some 25% to 30% extra economic growth for locations along a river under otherwise more or less similar circumstances.

Despite the fact that it was a boon to be situated on a river in Roman times, our conclusion is that the various fluvial systems in Roman times differed considerably in their economic significance. Especially the Lower Rhine stands out as a major artery of transport of goods to the local military and probably further a field to and from Britain.[59] In Britannia London is the major hub in the distribution of goods for the local legions and therefore economically the role of the Thames is considerably larger than that of the nearby Scheldt. The fluvial system of the Thames, Seine and Somme seem to be relatively important economically. That the Rhone and Upper Rhine come out as not unimportant too, is logical when their intermediate function in the transport routes to the Mediterranean is taken into account.

Spatial differences in Roman and medieval market economies

In the Latin West market economies started to function again somewhere around or after the twelfth century. (See for instance Bas van Bavel and Jan Luiten van Zanden (2004) for the Netherlands, were this process started later still.) In Table 7 we will explore whether the patterns of relative urbanisation in 1200 and in 1400 can be called similar to that of the RE (as presented in Table 3). The relative urbanisation in 1200 and 1400 is calculated as the total number of medieval town dwellers in thousands in a specific fluvial catchment area divided by the same fluvial length we used for the RE (see Bosker and Buringh, forthcoming).

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[58] Simply calculated as: (1 + growth rate) ^ 140 = 1.28 → growth rate is 0.18% per year. As a matter of comparison, based on Buringh and van Zanden (2009), we come to a yearly average growth rate of 0.23% for the urbanisation in the Latin West in the period from the sixth to fifteenth centuries, which is a very reasonable growth rate for pre-industrial societies.

[59] See e.g. Richard Duncan-Jones (1990, 35).

Table 7: Settlement density in the RE and the medieval relative urbanisation in 1200 and 1400 per fluvial area

Fluvial system	Settlement density in the RE x 100	1200		1400	
		inhab. 1,000s	Relative urb	inhab.1,000s	Relative urb
Dordogne	**21**	0	**0**	6	**10**
Garonne	**63**	35	**26**	71	**52**
Loire	**44**	101	**36**	139	**50**
Rhone	**73**	74	**33**	140	**62**
Lower Rhine	**176**	64	**139**	101	**220**
Moselle	**77**	52	**85**	36	**59**
Upper Rhine	**83**	103	**61**	157	**93**
Seine	**55**	225	**108**	312	**150**
Somme	**96**	12	**56**	10	**47**
Scheldt	**34**	84	**137**	278	**452**
Meuse	**30**	41	**42**	102	**107**
Thames	**124**	40	**85**	50	**106**

Sources: Bosker and Buringh (forthcoming) and Data Appendix, section 2

Table 7 shows that at the restart of a market economy in the study area after the twelfth century the pattern of relative urbanisation has become quite different from that in the RE. The R-square between Roman times and the year 1200 is 0.2; and when comparing with the later date of 1400 the explained variance even drops to zero. In 1400 especially the Scheldt area stands out as the undisputed centre of urbanisation. Note that this area does not contain the inhabitants of the important medieval town of Bruges because geographically this town does not belong to the Scheldt's fluvial catchment area. Including Bruges would even have made the difference larger. A comparison of the relative urbanisation in 1200 and 1400 in the study area leads to a R-square of 0.63, which is pointing to a fair continuity in the medieval commercial development. The differences between the RE and the medieval pattern are obviously related to the disappearance of military demand and the *limes* as factors driving the urban system, and to the rise of the Flanders cities as the typical 'producer cities' of the Middle Ages. But some similarities can be found as well: the south-west of France is not very urban (the Dordogne, the Garonne and the Loire are only weakly urbanised), and the Lower Rhine continues to be strongly urbanised. The high level of urbanisation of the Netherlands has, seen in this light, very old – even Roman – roots.

Conclusions

We have studied the kick-start of the process of urbanisation and the development of a market economy in Roman times in two different ways: via coin finds and in particular the share of coins composed of precious metals, and via the size and place of Roman settlements in the region. Both approaches tell a similar story of urbanisation and monetarisation, directly linked to the Roman military presence in the region. Roman military presence and its huge demand of goods and services can explain to a large extent (75%) the differences in the economic development of the various fluvial systems in north-western Europe around the year 150. The local finds of large numbers of coins and the low fraction of coins consisting of precious metals suggest a functioning market economy in the region. The high correlation between the Roman military demand in monetary terms and the local distribution of archaeologically recovered casks (probably once containing alcoholic beverages) is striking – it suggests a strong impact of the combination of soldiers and booze.

After the Roman military had left the study area its market economy faded away (as coin finds show) and only a few centres of long distance trade remained active in the following centuries. The much later medieval market economy that started somewhere during the eleventh and twelfth century in north-western Europe had a geographical pattern that differed considerably from the one that was found during the RE, which is quite logical because the medieval market economy was the result of local or regional bottom-up commercial processes and not of a market economy that was mainly driven by the military demand of some large army.

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Appendix A. Data Appendix of Roman settlements in north-western Europe

In this Data Appendix we will first present the geographical information of the Roman settlements in north-western Europe, the local river systems used for inland water transport and the Roman limes systems, which were guarding the borders of the Roman Empire (RE). Next we will describe the sources of the surface areas of the various Roman settlements, as this is our main economical proxy. Additionally we will carefully describe our data treatment and the applied statistical methods of supplementing the then still missing data of the smaller settlements. Finally we will briefly describe the various additional data, mainly of an administrative nature that were also collected.

1. Geographical information

1.1 Distribution of Roman settlements in north-western Europe

We collected geographical and historical information on all Roman settlements located between circa –5° and +13° longitude and circa 42° and 57° latitude, covering the various Roman provinces of the Britannias, Gallias, Germanias and part of Reatia in the Roman period (30 BCE to 300 CE) and the following Late antique phase (300 to 640).[60] For this we analysed the maps 7 to 12 and 14 to 18 and map 25 (partly) from the *Barrington Atlas of the Greek and Roman World* edited by Richard J.A. Talbert (2000).

We transferred to a database all the Roman and/or modern names of the settlements and mines or quarries from the map-by-map directory and a digital version of the atlas gazetteer. The mines and quarries were classified according to the more than a dozen different materials or combinations thereof that were mined or extracted. We also included the five different size classes with which the settlements were classified in the *Barrington Atlas*. Their classification with the numbers "1" to "5" is an indication of the relative importance of the various settlements, with the lower numbers being the more important towns; and "1" the most important category. We discerned five different types of settlements (a settlement proper, temple complex, road station, fort or spa) and indicated the time periods in which they were each inhabited or active (Archaic, Classical, Hellenistic, Roman and Late antique).[61] For each of the more than 2,000 local settlements we found on the maps in the study area we included its latitude and longitude in decimal degrees with two relevant digits after the decimal point and all of its (first-nature) geographical information concerning its location at a river or seacoast as well as the numbers of known and approximate minor or mayor Roman roads leading to it as indicated in the *Barrington Atlas*. If there was a Roman bridge or a pass near a settlement this fact was included in the database of Roman settlements. We excluded the category estates, villas and the category churches and monasteries from our database, as we did not consider these three categories to be settlements in a strict sense.[62]

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[60] With the sign minus we mean West of Greenwich, while East of Greenwich and North of the equator are positive signs. The database now contains information on 2,058 settlements in the Roman territories in the study area; a swath between 7° to 13° longitude and 43° to 47° latitude is not included in the study area (this concerns mainly Italy and the eastern Alps).

[61] We have included in the database the following symbols used in the Barrington Atlas: that for a settlement (a full stop), road station (a diamond), fort (a square), mine (two crossed hammers), spa (undulating lines) and a bridge.

[62] This concerns the following symbols in the Barrington Atlas: estate or villa (a triangle), church or monastery (circle with a cross), catacomb or cemetery (a square with a half circle on top) or tumulus (three full stops in a

As a proxy for a city's accessibility (as well as agricultural potential) we used its elevation above sea level, and the ruggedness of the terrain within 10 km of each location. This variable is obtained from the Global Land One-km Base Elevation project (GLOBE) of the US National Geophysical Data Center. We assigned each city an elevation by matching its coordinates to the GLOBE database. Furthermore we calculated ruggedness as the standard deviation of the terrain within 10 km from each settlement.

1.2 River systems

Transport by water was the main method to move bulk goods from one place to another in Roman times (and for long thereafter). To catch transport's first-nature geography the database has discerned whether a settlement is located on a river, the sea or a road. However, to see which settlements are interconnected to one another by riverine transport we have to discern which settlements are located on the same fluvial system.

We defined a specific fluvial system as comprising of all Roman settlements located along a river flowing from its source(s) to the sea while also including the settlements along all of its different tributaries up to their sources.[63] We discerned the following main fluvial systems in the study area[64]:

Gironde (Garonne and Dordogne): 1,475 km length with 55 settlements;
Rhone: 1,360 km length with 98 settlements;
Loire: 2,375 km length with 97 settlements;
Seine: 1,260 km length with 77 settlements;
Somme: 170 km length with 7 settlements;
Scheldt: 500 km length with 21 settlements;
Meuse: 640 km length with 25 settlements;
Rhine: 2,200 km length with 209 settlements;
Thames: 395 km length with 11 settlements.

The total length in km of all different waterways in one specific catchment area of such a fluvial system (from sea right up to the last settlement deep inland) has been estimated with a map measurer (*curvimètre*) from the maps in the Barrington Atlas by summing the length of all waterways just up to the last settlement that we have found to be located on that river or one of its tributaries.[65]

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triangle. A second reason for omitting this additional information was that we suspected that the use and distribution of these symbols and especially that of the villas had not been geographically uniform in the various maps of the Barrington Atlas. A map in Kevin Greene (1986, 118-9) e.g. shows a multiple of the only 4 villa complexes that are indicated in the Barrington Atlas in the Amiens – St Quentin area.

[63] To determine the length of a river we did not actually go up to its source but stopped at the last Roman settlement along the river in question or its tributaries. However, also the sea itself can be a source of some ambiguity too, as it is somewhat arbitrary for instance at the Gironde, Thames or the Scheldt as to where we stop with counting it as a river and start calling its waters a sea. In practice a different definition of a border could lead to a difference of some 70 km in the length of the Gironde and approximately 40 to 50 km in the lengths of the Scheldt and Thames.

[64] We could of course have discerned many more different fluvial systems by including smaller rivers such as the Vilaine or the Canche in France, but have deliberately not done that, as the larger systems really matter for the analysis. Note that the fluvial system of the "Gironde" comprises a.o. the rivers Garonne, Dordogne, Lot, Aveyron, Tarn, and Arriège to name its main rivers.

[65] If a river becomes a delta when arriving at the sea, as happens with e.g. Rhine or Rhone, we only included one (main) river arm in our classification of its length. The lengths determined with the map measurer may not be

For the Rhine we have furthermore discerned the lower-Rhine from Remagen (the Roman town of *Rigomagus*) to the sea (350 km), forming the Roman province Germania Inferior, and the upper part of the Rhine (Germania Superior, including the Moselle (400 km) and the rivers Neckar and Main) in order to allow for a separate analysis of the influence of the Roman *limes* along the lower-Rhine.

1.3 Limes systems

A Roman system of forts and watchtowers was in operation along the borders to collect taxes and to prevent marauding gangs of barbarians from plundering the more wealthy and therefore to them attractive countryside of the Empire. These forts were interconnected by walls or were located along a river, where the water formed a kind of natural border. We have included all forts (or road stations) lying within a distance of 5 km (or roughly one hours journey) from the wall or from the river as belonging to a specific limes system.[66] We discerned three *limes* systems in the study area:

> Hadrian's Wall (HW): 100 km length with 16 forts;
> Lower Rhine limes (LR): 325 km length with 35 forts;
> Germania Superior-Raetia limes (GSR): 500 km length with 55 forts.

In the year 200, at the border between the Scottish territories and Roman Britain, Hadrian's Wall (HW) was operational and lying between Arbeia (South Shields) and Aballava (Burgh by Sands). In the lower-Rhine area from Bonn up to the now disappeared fort of Brittenburg at the North Sea we have discerned the Lower-Rhine *limes*, or LR-limes. This LR-limes without any walls had the Rhine as the natural border. The third *limes* was the Germania Superior-Raetia-limes (GSR-limes, in the German literature it is also known by the acronym of ORL, the *Obergermanischen Raetischen Limes*) it ran from Heddesdorf on the Rhine to Eining near Regensburg on the Donau.[67] This specific *limes* was formed partly by a wall

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completely accurate, though relatively they are reliable (they have been measured twice with the same curvimeter and averaged) and can therefore be used reliably for purposes of comparison.

[66] We introduced this distance band of 5 km in order to connect a fort as Vindolanda that was not directly located on HW with the other forts on the wall proper. All forts that were lying at a larger distance have not been connected to the limes in question.

[67] Dietwulf Baatz (1982, 140) reports a length of 375 km for the ORL or the Germania Superior-Raetia to the relative lengths determined with the map measurer, knowing that it is a relative measure in which any faults are shared with all the lengths that have been determined.

[67] A few forts had been deserted, as they had been part of a previous limes system that was no longer of use in our time window.

[67] We choose for circa 150 CE, some decades before the Antonine plague decimated parts of the RE.

[67] Measured surfaces have of course been rounded off to the nearest digit and often to multiples of 5 or 10, as total inhabited areas some two millennia ago are not always very accurate and mostly some kind of a guesstimate.

[67] Examples of towns that had a walled area that was larger than the inhabited area are e.g. Vienne, Trier and Windisch.

[67] This relationship between walled and extra mural areas in Roman Britain will be reported later on under the heading of data treatment.-limes, our value of 500 km has been determined with a map measurer, which has some uncertainty associated with it as its measuring wheel may slip occasionally. A more exact measurement with a flexible tape measurer came to 530 km on the Barrington Atlas (it was possible to measure the GSR-limes with a flexible tape measurer because this wall did not meander as much as rivers normally do). We will use our measurements for relative purposes and as it is impossible to measure the lengths of the rivers accurately with a flexible tape measurer, for our calculation we therefore stick to the relative lengths determined with the map

through the Taunus mountains and for a larger part by a wall through southern Germany and for a small part it also was fluvial with the river Main as a natural border. Also for these two limes systems we have included all forts or road stations lying within a distance of 5 km from the wall or rivers as belonging to the specific limes system, similarly as we did for HW. The GSR-limes contained 58 forts of which 55 were still operational in the year 200.[68]

In the database all forts along Hadrian's Wall have been classified with a "1", those along Antonine's Wall and elsewhere in Scotland, which were in use during the Flavian period, and no longer operational in the year 200 have been classified with a "2", those of the Lower-Rhine-limes have been classified with a "3" and those along the Germania Superior-Raetia Limes with a "4".

2. Economical data

2.1 Inhabited surface areas

We have striven to find the dimensions (in ha) of the inhabited area in settlements around the year 150, at the height of the Roman Empire.[69] These have been generally found from literature references or measured from archaeological maps.[70] For France, Germany and Switzerland this implies that sometimes the reported surface of the walled town will be too large, as not all of the enclosed area was actually occupied; though the reverse might also be true and a walled town might have had an inhabited extramural area too.[71] For France we had information on the extramural suburbs from Penelope Goodman (2007) who wrote on the city and its periphery in Roman Gaul. For Roman Britain systematic information on extra mural suburbs was missing and the local relationship between walled surface and extra mural areas had to be quantified from those observations where both values were reported.[72]

In the database we therefore discerned the walled area and the extramural area of a town in 150 as two separate categories. A third category that we also discerned in a settlement was the area (in ha) actually occupied by the enclosed area of the urban Roman fort or road station in the year 150. In a fourth column we present the total surface area (in ha) as the sum of the previous three categories. If, by chance, we happened to find information on settlement sizes outside our main time window, which is concentrated around the year 150: such as around the year 100, 200, 300 or 400, we also reported these values in separate columns in the database.

During the process of data collection we had become interested to analyse how an originally military settlement had later on developed into a mixed civil/military settlement by the arrival of civilians forming a *vicus* or a *canabae* at a legionary fortress. One has to realise that the occupation density of military settlements (legionary, cohort or auxiliary forts and road

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measurer, knowing that it is a relative measure in which any faults are shared with all the lengths that have been determined.

[68] A few forts had been deserted, as they had been part of a previous limes system that was no longer of use in our time window.

[69] We choose for circa 150 CE, some decades before the Antonine plague decimated parts of the RE.

[70] Measured surfaces have of course been rounded off to the nearest digit and often to multiples of 5 or 10, as total inhabited areas some two millennia ago are not always very accurate and mostly some kind of a guesstimate.

[71] Examples of towns that had a walled area that was larger than the inhabited area are e.g. Vienne, Trier and Windisch.

[72] This relationship between walled and extra mural areas in Roman Britain will be reported later on under the heading of data treatment.

stations) was approximately a factor of two higher than the 100 inhabitants/ha of a typical urban civilian settlement in the Gauls and Germanias. Thus military settlements as a rule comprised some 200 men/ha. Because the *vicus* neighbouring a fort will probably have resembled a rural hamlet more than a real urban environment the civilian occupation may generally have been a factor of two lower than that of a urban settlement proper; and the use of an overall habitation density for such mixed settlements of some 100 inhabitants per ha seems to be plausible.[73]

2.1.1 The three Gauls and two Germanias

For each of the settlements for which there was archaeological information we determined the surface of its inhabited area in hectares (ha) at the zenith of the Roman Empire in the second century (data for circa 150). We also collected walled surface area (ha) around the year 300 or the surface of the late Roman occupation of a settlement as it had developed after the troubles in Gallia in the 270s.[74] Sources for these figures were the maps in the various volumes of the series *Topographie Chrétienne des Cités de la Gaule, des origines au milieu du VIIIe siècle* (*TCCG*) and the maps and data in the *Atlas des villes, bourgs, villages de France au passé romain* by Robert Bedon (2001). As far as the texts gave no quantified surface areas these have been measured from the various maps.[75] Supplementary information on inhabited surface areas in Roman times was derived from the *Histoire de France Urbaine, la ville antique* by Paul-Albert Février *et al.*, (1980) and from *The Roman city and its periphery, from Rome to Gaul*, by Penelope J. Goodman (2007). For the secondary settlements in Roman Belgium and the Germanias we used Jean-Paul Petit *et al.,* (1994) and for Bruges, Oudenburg, Aardenburg, Gand and Courtrai we used Adriaan Verhulst (1977).

2.1.1.1 The Lower-Rhine limes (LR-limes)
Though the previously used general references for the three Gauls and two Germanias should in principle also have been covering the *limes* in those areas, in practice *Limes*-studies has developed into a somewhat separate field of Roman Archaeology. We wanted to be as precise as possible on the surface areas of the forts and road stations along the limes to allow for later analyses. And to fill in the gaps of our knowledge concerning frontier towns and forts we have consulted this specific branch of literature.
General information could be found in *Roman Frontier Studies 1979* edited by W.S. Hanson and L.J.F. Keppie and in *Studien zur Militärgenzen Roms III, 13. Internationaler Limeskongress Aalen 1983*. Specific information for Vechten was found in Wilfried Hessing *et al.,* (1997, p. 23) *Romeinen langs de snelweg, bouwstenen van Vechtens verleden*, Valkenburg was covered by Anne E. De Hingh *et al.,* (2005, p.40), *De Romeinen in Valkenburg (ZH),* Chrystal R. Brandenburgh *et al.,* (2005, p. 40) covered Matilo in *Matilo-Rodenburg-Roomburg, de Roomburger polder van Romeins castellum tot moderne woonwijk*, W.J.H. Willems described Nijmegen in *Romeins Nijmegen, vier eeuwen stad en centrum aan*

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[73] Because these three different categories have been discerned, later on a separate analysis with other habitation densities is possible if such would be desired. We will come back on the average habitation density of mixed civilian and military settlements later when we derive a numerical relationship between the fort size and the size of its accompanying *vicus*.

[74] The inhabited area must not be confused with the walled area, as originally the occupied surface area of a number of Roman cities sometimes was considerably smaller than the walled surface area (e.g Vienne and Avenches). While after the troubles in the 270s in Gallia the opposite effect often occurred and the newly walled areas to protect towns were considerably smaller than the previously inhabited surfaces. A further source of confusion of the inhabited surface area of a settlement (especially when exhaustive excavations have not been performed at a location) can be the indicated total surface area over which Roman finds have been reported.

[75] For the surface areas in Cahors, Evreux, Auch, Saint-Bertrand-de-Commignes, Tarbes and Agen we used the middle ground between the values of Bedon and *TCCG*.

de Waal (1990). Helmut Gilliam (1983, p. 47) describes Neuss in *Römer in Neuss, 2000 Jahre Römer am Rhein*, while J. Mertens (1980, p. 446) describes Arlon in 'Recherches recentes sur le Limes en Gaule Belgique', p. 423-470 in *Roman Frontier Studies 1979* edited by W.S. Hanson and L.J.F. Keppie. The surface classification of Roman Xanten and Bonn was based on maps found on the German language version of Wikipedia.

2.1.1.2 The Germania Superior-Raetia Limes (GSR-limes)
For the size of forts and *vici* along the *limes* in southern Germany we found quantitative information in Dietwulf Baatz (1974) *Der Römische Limes, Archäologische Ausflüge zwichsen Rhein und Donau;* and in: Dietwulf Baatz and Fritz-Rudolf Herrmann's (eds) (1982) *Die Römer in Hessen.* Willi Beck and Dieter Planck (1980) covered parts of the GSR-limes: *Der Limes in Südwestdeutschland.* While the additional parts of the *limes* in South West Germany and Bavaria were treated by Philipp Filtzinger, Dieter Planck and Bernhard Cämmerer (1976) *Die Römer in Baden-Württemberg,* Hans-Jörg Kellner (1971) *Die Römer in Bayern*, Margot Klee (1989) *Der Limes zwischen Rhein und Main*, and by Günter Ulbert and Thomas Fischer (1983) in: *Der Limes in Bayern.*

2.1.2 Roman Britain
As our main sources we used *An Atlas of Roman Britain* by Barri Jones and David Mattingly (1990), *A companion to Roman Britain*, edited by Malcolm Todd (2004), *An Imperial Possession, Britain in the Roman Empire* by David Mattingly (2006, with town sizes on p. 328-9), *The 'small towns' of Roman Britain* by Barry C. Burnham and John Wacher (1990), *The 'small towns' of Roman Britain, papers presented to a conference, Oxford, 1975* edited by Warwick Rodwell and Trevor Rowley (1975)[76] and *The towns of Roman Britain* by John Wacher (1975). Additional information on sizes of fortified cities and their habited extramural area was found in Michael J. Jones (2004, p. 162-92) 'Cities and Urban life', in *A companion to Roman Britain*, and in Peter Marsden's (2004, p.11) *Ships of the port of London.*

2.1.2.1 Hadrian's Wall (HW)
Additional information on fort sizes was found in a contribution to the 13th Limes congress by Julian Bennet (1986, p.707-17); 'Fort sizes as a guide to garrison type: a preliminary study of selected forts in the European provinces', an article by Stephen Johnson (1980, p. 325-43) 'Excavations by Charles Green at Burgh Castle, 1958-61', for *Roman Frontier Studies 1979* edited by W.S. Hanson and L.J.F. Keppie; in the same bundle we found information on fort sizes in an article by C. Daniels (1980, p.173-93) 'Excavations at Wallsend and the fourth-century barracks at Hadrian's Wall', for Binchester information was found in an article by M. Ferris and R.F.J. Jones (1991) 'Binchester- a northern fort and a vicus', in R.F.J. Jones ed. *Roman Britain, Recent Trends*. Information on Housesteads was found in Robin Birley (1973, p. 3) *Housesteads, (Vercovicium) Roman fort and civilian settlement.* Additional information on the still missing forts sizes at Hadrian's Wall has been collected from Wikipedia and checked in Frank Graham's (2003) *Hadrian's wall in the days of the Romans.*

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[76] For four settlements found in Rodwell and Rowley (1975): Wickford (11ha), Wixoe (11ha), Heybridge (19 ha) and Hacheston (24 ha), we could find no accompanying information in the Barrington Atlas (neither in the gazetteer or on the maps).

2.2 Additional data treatment to reconstruct Roman settlements around 150

A number of values of surface areas of settlements had to be mathematically manipulated to arrive at the relevant numbers describing a reconstruction of the Roman settlements around the year 150 that we could use as a basis for our analyses. Numerical reports of some of the surfaces of settlements were obviously too large because they covered the total area of (often much more widely dispersed) current Roman finds instead of the area that was actually inhabited at the time. Sometimes for a specific settlement we only found a value of the (then much smaller) walled area in Gaul around 300, while we wanted to have the actually inhabited area in 150. On other occasions in Roman Britain we only found a walled area while we also wanted to know the extra mural surface that was inhabited and take this additional occupied area into account too in order to find a more accurate indicator of a settlement's total population. For military forts we also liked to find out the surface area of the accompanying civilian *vici*, to have a better approximation of the total population that was living then and there. And sometimes we missed any numerical indication of settlement sizes, especially of the smaller size class "4" and "5" settlements. Nevertheless we have a general idea about the nature of their overall size distribution and have used that theoretical (log normal) distribution to statistically estimate the still missing values in the database, in order not to omit a non-negligible part of the Roman population. All different steps in the data treatment will now be presented and elaborated.

2.2.1 Adaptation of data

2.2.1.1 Corrections
The purpose of the collection of the inhabited surface area in the various settlements is to use its values later on to estimate the numbers of its inhabitants. Therefore we corrected those surface areas downwards that were presented as maximal values of dispersion of Roman finds. We used a factor of five in accordance with the ratio found for the surface area of 10 ha for Vannes in *TCCG*, which Robert Bedon (2001, 319) reports as being dispersed over 50 ha. This correction has been applied to the maximal possible surface areas of Les fins d'Annecy, Carhaix, Entrains-sur-Nohan and Chassenon. For Cologne we added 47 ha to its 100 ha of walled surface as an extra mural area, to let the totality of its area (together with Köln-Marieburg) come at 200 ha, and thereby let its surface area become an indicator of some 20,000 inhabitants (if we assume a general habitation density to be 100 inhabitants/ha, the value we have chosen to quantify this habitation density).[77] Some 20,000 inhabitants are believed to have lived in Roman Cologne around the year 150.

2.2.1.2 From walled area in the year 300 to the non-walled area in 150 in Gaul
In the Gallias there were serious troubles in the 270s, which afterwards led to defensive walls being built for protection around settlements where such structures had previously not been necessary because of the local peace and quiet. Building walls is a rather costly investment for a community, therefore the walled areas of settlements in Gaul in 300 were considerably smaller than their non-walled areas in 150. From the 86 settlements in Gaul of which we have data in 150 and 300 the total area shrunk from 4,920 ha to 2,038 ha. The average ratio is even

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[77] Such an extra mural area for a town of 100 ha of 47% may be called not too different to become implausible from the size of the extra mural surface area we will derive later on for walled towns of 100 ha in Roman Britain (39%).

somewhat lower because a number of larger towns had shrunk less than proportional. The average ratio in settlement size in 300 versus 150 is 0.412, indicating that settlement sizes in 300 had to be multiplied by 2.43 to find their size in the year 150. For the 25 settlements for which we only found a walled surface area in 300 we applied this approach to obtain their unknown sizes in the year 150.[78]

2.2.1.3 Extra mural areas for walled towns in Roman Britain
Map 5.12 in Jones and Mattingly (1990) shows the location (and therewith the names) of the sixty Roman British towns that were fortified, all the others were therefore considered to be not-fortified and therefore by definition not having an extramural surface area.[79] For a number of fortified towns (Lincoln, Alcester, London, Bath, Ilchester, Caistor, Brampton and Towcester) we found information on the surface area of their walled and their extra-mural areas.[80] The relationship between walled area and extra mural area in Roman Britain can be found in Figure A1.

Figure A1. Relationship between walled area (in ha) of fortified towns and their extramural area (in ha) around the year 150 in Roman Britain.
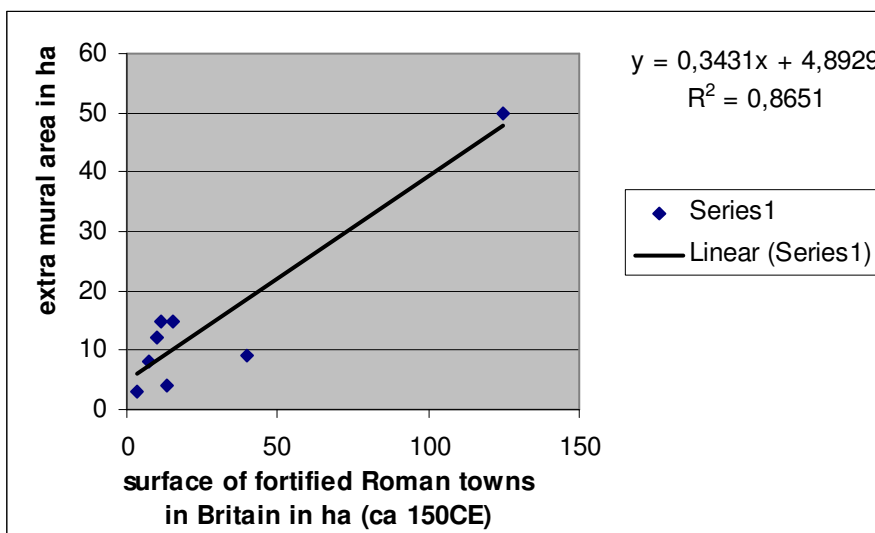
The numerical relationship (extramural = 0.34*walled + 4.9) has been used to estimate the extramural area of the fortified towns in Roman Britain around the year 150.[81] This value has been included in a separate column and indicated with a specific colour (brownish) in the database in order to let anyone make other corrections later on if preferred.

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[78] This concerns Brest, Exmes, Noyon, Famars, Chalons-sur-Marne, Cambrai, Toul, Angoulême, Auxerre, Macon, Dijon, Basel, Mende, Viviers, Gap, Embrun, Briancon, Agde, Toulon, Vence, Albi, Carcasonne, Béziers and Elne. Their sizes in 300 have been multiplied by 2.43 and the obtained numbers have been indicated in red in the database for the year 150.

[79] This concerns: Exeter, Ilchester, Dorchester, Bitterne, Chichester, Carmarthen, Caerleon, Caerwent, Bath, Gloucester, Alchester, Cirencester, Dorchester, Mildenhall, Winchester, St Albans, London, Braughing, Colchester, Chelmsford, Rochester, Canterbury, Whitechurch, Wroxter, Leintwardine, Blenchester, Penbridge, Red Hill, Worcester, Leicester, Mancetter, Cave's Inn, Wilthon Lodge, Chesterton-on-fosse, Dorn, Alcester, East Bridgeford, Ancester, Great Chesterton, Chesterton, Godmanchester, Irchester, Towcester, Cambridge, Great Chesterford, Caister-on-sea, Caister-by-Norwich, Chester, Middlewich, York, Brough-on-Humber, Caistor, Lincoln, Horncastle, Brough, Thorpe-by-Newark, Piercebridge, Corbridge, Carlisle, Catterich.

[80] Contrary to the study of Penelope Goodman (2007) on the Roman suburbs in France I found no such study on extramural structures and their sizes in Britain.

[81] Please note that this relationship should not be used outside Roman Britain.

2.2.1.4 From fort to vicus
In the older archaeological excavations of the nineteenth and the beginning of the twentieth centuries the *vici* or the civilian settlements accompanying a Roman fort were mostly overlooked or deemed not that interesting; and for quite a number of forts we only have its fort size in ha, with absolutely no information on the dimensions of the civilian settlement once going with it. Map 5.13 in Jones and Mattingly (1990) shows that only six of the 99 Roman British forts in our database certainly did not have a *vicus* (or *canabae* for the legionary fortresses). Of those six forts, three were naval bases. For those six forts we have concluded that we should not try to estimate the size of their *vici*.[82] For the others we will present an estimate of the *vicus* sizes possibly accompanying the fort.[83] As a rule for forts outside Britain we have also assumed the existence of a civilian *vicus* unless of course we have concrete evidence to the contrary.

For two forts in Roman Britain along HW and for 22 forts along GSR-limes we found both *vicus* and fort sizes. For GSR we find a total of 58.9 ha of fort and 131.1 ha of *vicus*, indicating that on average a *vicus* was 2.2 times the size of the accompanying fort. For Roman Britain (Vindolanda and Housesteads) we have respectively 3.5 ha and 5.5 ha for the summed fort sizes and their *vici*, leading to a factor of the *vicus* of 1.6 times the fort size. For two Roman legionary forts (Nijmegen and Bonn) we have their summed fort sizes and those of their *canabae*: 45 ha versus 83 ha, leading to a factor of 1.8. When making a grand total of all these forts sizes we find 107 ha of fort and just under 220 ha of *vicus* leading to a factor of 2 for the average size of a *vicus* with which the size of the fort has to be multiplied.

The very simple linear relationship (*vicus* = 2*fort) has been used in this study to estimate the size of a *vicus* of the forts in the Roman Empire around the year 150 and therewith compensate for the bias in reported sizes of Roman settlements in Britain and elsewhere in Europe (as a similar situation happened along the German *limes*) due to selective excavations in the past. This value has been included in a separate column and indicated with a specific colour (brownish) in the database in order to let anyone make other corrections later on if preferred. A *vicus* size being twice that of the fort and the *vicus* habitation density being ¼ of that of the fort: 50 men/ha versus 200 men/ha; makes that as a rule we can simply multiply the summed area of fort and *vicus* by 100 men/ha to find an estimate of its average total population.

2.2.1.5 Standardisation of:
fort sizes in Roman Britain
For a number of Roman military settlements (forts) in Britain of which we have no size information we can nevertheless make some educated guesses, as we already know a lot about such Roman forts in general and because such military objects were standardised to a large extent. Therefore we can plausibly make some inferences about the forts of which we do not yet have precise information and assume them to be rather similar to others that we know and that were built for similar military purposes. The larger forts are all quantified, for instance we had reports on the dimensions of all the three legionary forts in Britain. A fort of size class "3" at Usk has been given the same total surface area (13 ha) as that of Carmarthen (also class

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[82] The forts are: Portchester, Peveny, Abergavenny, Lympne, Hard Knoll and Burrow Walls/Piercebridge.
[83] C.Sebastian Sommer (1984, 12) has a final conclusion: "Practically <u>all</u> forts … should have a military vicus, for an auxiliary cohort even a detachment of it was attractive enough for camp-followers to establish themselves; moreover the military vicus would be in existence at the latest from the moment the permanent garrison moved into the fort."

"3"). The forts of size class "4" have been classified to 13 ha in total, similar to Eintwardine a size class "4" fort. The actual fort sizes (without their *vici*) have of course been sized downwards, as C. Sebastian Sommer (1984,1) indicates that he uses a size range between 0.5 ha as the lower size of a fort and its upper limit of 5 ha. The average value of 2.4 ha found later on for continental forts is very near the average of this size range, and has therefore also been used as a proxy for the actual fort size in these two size classes in Roman Britain. However, the sizes of 44 of the 72 smaller British forts (class "5"), which were occupied around the turn of the second to third century, are not known. We have found size information on 28 of them (of which three were reported to have been 1 ha).[84] We can estimate that the unknown forts will probably be small, most probably smaller than 2-3 ha, which applies to 75% of the known forts; and have opted for a size somewhere around a value of 1 to 2 ha. To err on the safe side the default value that we have given forts for which nothing is known is 1.5 ha, similar as the class "5" forts of Castle Steads and Carraw Burgh. (Of course we will still establish an estimated size of the *vicus* for these forts with the formula derived above from our observations, leading to a total occupied area of 1.5+3 = 4.5 ha for an unknown Roman fort of size class "5" in Britain).

fort sizes in the Continent
We approximated the missing forts on the Continent for size class "4" and "5" slightly differently by just averaging them arithmetically from the known sizes of forts of the same size class, as such Roman forts were deliberately planned and built to size and not some result of random economic forces leading to their growth.[85] We came to an average size of 2.4 ha for the forts on the Continent, which in combination with the times two *vicus*-rule, leads to a surface of on average 7 ha for such missing forts.

2.2.2 Statistically supplementing missing values of settlements

For all Roman British settlements with a size class of "2" and "3" in the Barrington Atlas (the larger towns) we have found numerical information on their dimensions in one or more references. Nevertheless we still have a number of missing observations, settlements for which we have no information concerning their sizes. For size class "4" we have eight values of settlement sizes that have been quantified, ranging form 30 ha to 10 ha; and for size class "5" we have 30 values, ranging from 33 ha to 1 ha.[86] For three out of the eleven British settlements with size class "4" we have not found a quantification of their sizes (meaning that 8 out of 11 are known, n'= 8 and N=11)[87], while the sizes of 66 of the 96 British settlements

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[84] And knowing how many forts have already been excavated, we can seriously doubt if all the currently not yet excavated and reported forts ever will be fully described because the priorities in archaeological research may be shifting in other directions than pure military history.

[85] Because Roman forts were planned according to the sizes of army units they are supposed to be housing we do not directly expect them to be distributed log normally; and therefore we cannot use the method we will describe later on to find missing settlement sizes.

[86] That the range of the 'smaller' settlements is larger than that of the 'larger' settlements does not have to disturb us. First of all we have many more 'smaller' observations leading to a larger range and secondly the original classification in a size class "4" or "5" was not based on hard criteria and will not have been perfect, as it was up to the personal judgement of the map maker, making some sort of an overlap inevitable for such by their nature very difficult to classify settlements.

[87] Let n' denote the number of settlements in a size class of which we have information on its area and N denote the total number of settlements in that size class, while n is the number of settlement sizes we will finally use for the estimation of the log normal distribution of the sizes of the N settlements in this specific size class. Because we will probably not use all our observations for the estimation of the parameters of the log normal distribution, as our observations are biased to some extent you can assume that n < n'.

with size class "5" are unknown (n' = 30 and N=96). However, such unknown values can still be estimated under two conditions: first that we presume that settlement sizes are log normally distributed, and second that we know the total numbers of settlements per size class. This last condition is fulfilled because we have the maps in the Barrington Atlas, and the first condition has been often reported to be true with more recent city sizes.[88] Therefore the obtained observations can in principle be used to estimate the unknown underlying log normal distributions of Roman settlements in the various size classes.

We have to be careful, however. We cannot use all the values of settlement sizes that we have observed because the observed size distribution will probably be biased to the larger values. It is quite plausible that bigger settlements may have had a somewhat larger chance of getting researched and reported. This implies that the size distribution of the larger observations may be complete while we have unknown lacunae in the distribution of the smaller size areas in our sample. Therefore we will selectively use the larger sizes in our sample of observations to minimise the chances of having lacunae in our distribution. Therefore we first establish the maximal number (n) of the n' observed values per size class that we will use for the estimation of the underlying log normal distribution (n < n'). To establish this number n we classify all the observations within a size class according to their rank from the top downwards, and afterwards take the logarithms of both its rank and its size in ha. Mathematically the higher tail of a log normal distribution can be approximated by a straight line by putting log rank and log size together in one graph. With a simple linear regression analysis we then find a certain expression of log(rank) versus log(size) with an accompanying R-square. The higher the R-square the better the fit, and the relative maximum of it probably is an optimal basis (while at the same time being unambiguous) to estimate the underlying log normal distribution, as some of the outliers and lacunae in rank and size then have been taken care off.[89] To find this relative maximum we stepwise exclude the smallest observation (the settlement with the lowest size and highest rank) from the analysis, and observe the resulting R-square, as soon as this R-square has reached its relative maximum we stop with our stepwise exclusion and the logs of the values of the remaining n sizes of observations (and their ranks) are then used for the estimation of the underlying log normal distribution. In practice we will mostly pass this relative maximum at first, but by noticing a diminishing R-square we will have become aware of the fact that we have to retrace our steps.[90]

Because we know the total number N (of settlements) in a size class from the Barrington Atlas we also can determine the chances of finding a value that is higher than the highest observation in our sample: this is simply $1/(N+1)$, and such a chance is called the p-value of that specific observation. Similarly we can determine the p-value of the second observation in the sequence of ranks. This simply is twice the previous value: $2/(N+1)$. We can repeat this process of determining p-values right up to the n observations we will eventually use for the estimation of the unknown distribution.
For a (log)normal distribution we can construct a confidence interval of finding a value larger than the log of the specific observation by decomposing it into a mean m of the log normal

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[88] see e.g. Jan Eeckhout (2004); the underlying economic processes some two thousand years ago will have been more or less similar to those currently influencing city sizes and therefore such an assumption for Roman settlements seems warranted.

[89] We will use the maximal amount of available information in our observations. This relative maximum means that the fit will always be below the value of 1, which it automatically gets when only two values are left for the linear regression.

[90] There are two preconditions for this number of n: it must not get lower than (the arbitrary value of) 7 to have at least some numerical basis for our statistical analysis and the R-square should be minimally (the equally arbitrary value of) 0.9 in order to use data that resemble some sort of a log normal distribution.

distribution and a z-value multiplied by the standard deviation of that distribution.[91] The z-value is only determined by the chance of its occurrence (the p-value), and as a symbol we use z_p.[92] By choosing an arbitrary value of m we can calculate the value of s for the first observation, and when we repeat this process for all n observations of course all with the same arbitrary value of m, we find n (most probably different) values for s, for which we then determine the overall arithmetic average š of the standard deviation of the log normal distribution.[93] And with the so calculated š and our first arbitrary value for m we can calculate a zero-order approximation of the whole log normal distribution of N settlement sizes. The square of the difference between this zero-order approximation and the observed n values is then calculated and used for an optimisation of the input parameter of m. In Microsoft excel we can easily tweak the value of m by increasing or decreasing its value in discrete steps till the square of the difference is minimal.

Then we have found the optimal log normal distribution; one that best fits the observed data of town sizes with the now obtained values for m and š. With these two optimised parameters m and š we can calculate the best-fitting log normal distribution for all N p-values of our sample. To finalise the procedure we then distribute all the observed values with a minimal difference over those of the estimated log normal distribution based on the optimised m and š. We have estimated N values of the best-fitting log normal distribution and only have n' observations, so we will be missing a number of (N-n') values. The arithmetic average of those (N-n') missing values of the estimated log normal size distribution finally is the average size of the settlements (the observations) that we originally missed in our sample.

Though the description above may seem complicated the procedure is not. For Roman Britain in size class "4" we cannot use our statistical procedure above, as we do not meet both of our criteria at the same time (n >= 7 and R-square >= 0.9).[94] For size class "5" we find an average size of 7 ha for the 66 Roman British settlements of which currently a size classification is missing in our observations (n = 28 and R-square = 0.93). The range of the 66 missed values goes from 12 ha to 3 ha. According to the estimated total distribution we missed three towns with a size of probably 12 ha, three of 11 ha, etc., right up to four with a probable size of 3 ha. Because we do not know which of our 66 missed settlements actually belongs where in the distribution we all give them the appropriate average value of 7 ha, thereby accepting an amount of extra random noise in our data.

Check
This value of 7 ha in size class "5" can be compared with that of the previously found relationship between walled towns and the extra mural area in Roman Britain. When the walled size = 0 ha we find an extramural area of 5 ha. This size is quite near the average minimal value of 7 ha for the size class "5" settlements for which we did not have any additional information, and may be seen as an extra check on the procedures above.

As log normal distributions of settlement sizes (and the processes underlying this distribution) are independent of the scale that we use, we could in theory also proceed to smaller areas than the total study area, just as we have already done implicitly above by filling in the missing

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[91] This can be written as: $y = m + z_p * s$
[92] In Microsoft excel z_p is found with NORMSINV(p).
[93] In a formula this becomes: $\Sigma s / n$
[94] This is not a real problem as we can combine the size class "4" settlements of roman Britain and the Continent into one batch and use all the data together to estimate the average size of the missed class "4" settlements in the Latin West. In size class "4" we have a total of 143 settlements of which 38 are unknown, and for this now larger distribution we can easily meet both criteria.

values of size class "4" and "5" in the Roman province of Britain, providing of course that the two preconditions concerning n and the R-square are met.

The values that we have found by statistically supplementing the still missing data from the Continent produced the following results: it lead to an average size of 49 ha for the two class "3" towns currently missing in the three Gauls and two Germanias (Ventigmilia and Albenga)[95], an average size of 10 ha for the 38 missing settlements out of 143 of size class "4" (by exception this is a combination of Roman Britain and the Continent); and an average size of 2.7 ha for the 559 missing size class "5" settlements from the Continent.[96] For the 143 road stations on the Continent of which 132 were missing a size classification we found on average a value of 1.3 ha. This value can be compared with the value found above for the size class "5" settlements, as the military part of a road station would have a minor surface area (otherwise it would have been a fort), and such road stations with their *vici* probably resembled small size class "5" settlements somewhat. For the missing temple complexes in Roman Britain and on the Continent we found on average a size of 1.4 ha.[97] All these additional values have been indicated in brownish hue in the database so they can later on be corrected easily if so desired.[98]

3. Additional quantitative and administrative information

3.1 Administrative information

Administrative information on Roman cities in the Gallias and Germanias has been collected from different sources. The 86 settlements that were a provincial capital around the beginning of the Christian era under Augustus have been found from the tables in Paul-Albert Février *et al.*, (1980) pp. 96 and 98; and similarly for the situation at the end of the fourth century (based on the Roman *Notitia Dignitatis*) from the tables on pp. 119 and 118 (if so desired, for intermediate periods more detailed information of the Roman provincial structure can be found in Robert Bedon, 2001). We also included into the database information representing the situation in the fifth century contained in the *Tabula Peutingeriana* by Ekkehard Weber (1976). We noted whether a settlement had its name actually written on the *Tabula Peutingeriana*, if it was characterized with houses, as a port or as a complex (mostly a spa), and we also included the numbers of roads leaving the various Roman settlements indicated on the *Tabula Peutingeriana*. The provincial capitals in Britain were found from map 5.12 in Jones and Mattingly (1990). The certain provincial capitals in southern Germany have been found from the map on page 155 presented by Klaus Kortüm (2005).

3.2 Additional quantitative information as checks on settlement sizes

We collected additional quantitative information on a number of important material structures in Roman settlements in order to have some additional and quite independent checks on the estimated numbers of inhabitants as suggested from their surface areas. First of all we looked

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[95] The towns Rottweil (20 ha), Windisch (12 ha) and Chateau Rousillion (8 ha) currently classified in size class "3", seem to fall out off the best-fitting log normal distribution of class "3" towns on the Continent.

[96] My gut feeling is this result of on average 2.7 ha may be somewhat low for these settlements (suggesting some 270 inhabitants for class "5" settlements on the Continent in Roman times), but it has been estimated according to the rules developed above, and therefore should be accepted if we do not have strong arguments to reject it.

[97] A temple complex at Grannum (Grand in France) with a surface area of 64 ha seems to be quite an exception.

[98] We have added an extra 0.01 ha to all statistically determined values in order to be able to pick them up easily from the database, as the search function in excel does not work on colours.

at the capacity in numbers of spectators of Roman entertainment structures: amphitheatres, theatres, mixed Gallic theatres and Roman circuses. Next we looked at forum sizes, assuming there is some relationship between forum size and town size. The third material structure was the discharge of the Roman aqueducts to a town, also here implicitly assuming some relationship between total discharge of water and its uses based on the town size.

3.2.1 Entertainment structures

3.2.1.1 Amphitheatres
The first item was the capacity in numbers of spectators (in 1000s) of local Roman amphitheatres, which generally are ellipsoid in form and also have an ellipsoid arena. For 40 amphitheatres in the study area this number of spectators was derived directly from the lists presented by Jean-Claude Golvin (1988).[99]

Figure A2. Relationship between numbers of spectators (1000s) (y) and the length (in m) of the long axis of a Roman amphitheatre (x) (source: Golvin, 1988, all Roman amphitheatres).
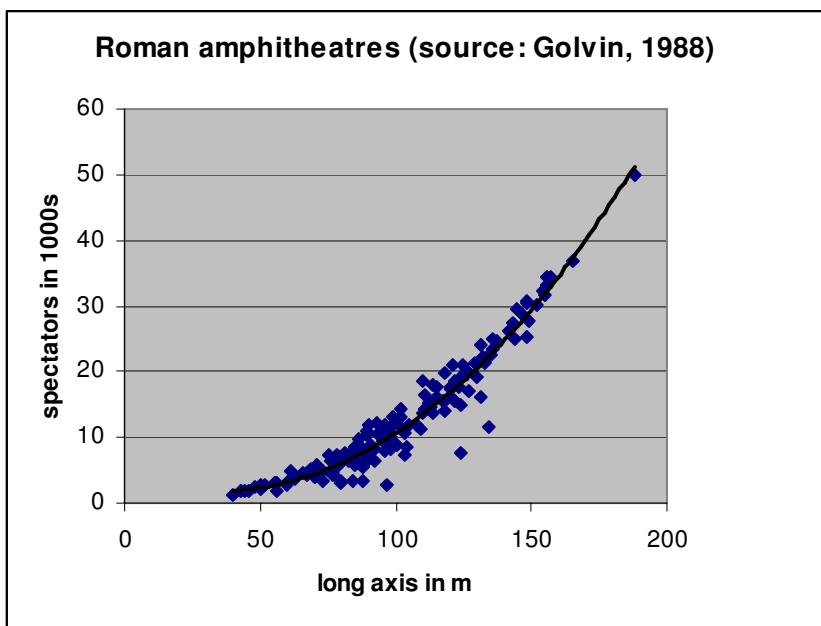
For 13 other amphitheatres we had only partial information such as data on the sizes of one or more of their axes (for instance for some now completely disappeared Roman amphitheatre from an early-modern source, see e.g. Robert Bedon, 2001). For such partial data we used the total sample from Golvin to establish the relationship between numbers of spectators and the lengths of the axes of Roman amphitheatres, an example of such a relationship can be found in Figure A2. Similar relationships as in Figure A2 have also been made by performing regressions for the short axis of the amphitheatre and spectator numbers, and for the long and

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[99] The seating area (between [   ]) and numbers of spectators can be easily calculated as follows:
spectators = [(long axis amphi * short axis amphi) − (long axis arena * short axis arena)) * π / 4] * 2.5

short axes of the arena.[100] In the database these estimated numbers on the basis of regressions have been indicated in red. Jean-Claude Golvin (1988) generally uses a number of 2.5 spectators per square meter of seating area, while David Lee Bomgardner (2000) uses 3.1 spectators per square meter; we have followed Golvin in our estimates because we also used his lists.[101]

3.2.1.2 Roman theatres

The next entertainment structures for which we collected quantitative information were the Roman theatres, which generally have the form of a half a circle. Roman theatres not only differed in their exterior form from amphitheatres, they had a different function too and probably attracted a different group of spectators. Also their location in towns differs from that of amphitheatres. Theatres can be found on temple complexes as well as in cities, while most amphitheatres are located just outside Roman cities. As far as the capacity of theatres (in 1000s of spectators) was presented in the literature we included those numbers. Sometimes, if there were no direct numbers, the various maps of towns presented a Roman theatre with its façade and seating area. The diameter of the theatre in the form of a half circle or the length of its façade was then measured from the maps and used to calculate the number of spectators (the numbers derived from the equation between [   ] will lead to the total surface area of seating in square meters) in the following way:

$$\text{Spectators} = [((\text{façade}\ /\ 2)^2 - (\text{façade}\ /2 * 0.45)^2\ ) * \pi\ /\ 2\ ] * 2.5 \qquad [102]$$

For a few large Roman cities there was also an Odeon, apart from a theatre.

3.2.1.3 Mixed Gallic theatres

The next entertainment structure on which we assembled quantitative information was the mixed theatre: a specific local Gallic mix between a Roman amphitheatre and a Roman theatre. For this type of theatre we also established the relationship between the length of the main axis and the seating capacity (in 1000s) of spectators.[103] The so estimated spectator sizes have been indicated in red, and are categorized under the heading theatres in the database.

3.2.1.4 Roman circuses

The last entertainment structure we looked at was the Roman circus, of which there were only a few in the Gallias and Germanias. Anthony C. King (1990, p. 81) locates them in Lyon, Trier, Vienne, Arles and Saintes. The sizes of the circuses in the various locations differ less than 10% and this apparent similarity is largely dictated by its use. Its seating capacity is in the order of 20,000 spectators, and therefore for our purpose of size classification of towns the circuses are probably less discriminatory, as a more or less uniform circus was only present in the really large Roman agglomerations.

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[100] The explained variance in the numbers of spectators for the long and short axis of the amphitheatre was respectively 0.94 and 0.97; for the long and short axes of the arena this was much lower: 0.25 and 0.15 respectively. So we had a strong preference to base the estimates on the axes of the amphitheatre proper.

[101] Though a difference of 19% may seem considerable, it does not bother us very much here, as the differences in the total discharges of aqueducts can be considerably higher (some 50%, as the example of Rome shows later on), and because we mainly use such numbers as relative indicators to compare different towns with each other.

[102] We have subtracted an amount of surface area to compensate for the orchestra, where no spectators would be seating, estimating its size as an rule of thumb as 0.45 times the length of the façade of the theatre.

[103] Seating capacity (in 1000s) = 0.0152 * (long axis mixed theatre)^1.3807 R^2 = 0.68

3.2.2 Forum sizes

The next item that probably has a relationship with city sizes is the surface area of the Roman forum (this size has been assessed in 1000s of square meters). To quantify this item we included in the size of the forum that of the porticos, basilica and temple as is customary when forum sizes are reported. We used the reported local forum sizes whenever available.[104] When no forum size was reported while a forum was indicated on one of the archaeological Roman city maps, we calculated the local forum size by measuring its dimensions from the map. As a first attempt to study this relationship in another domain than our study area we turned to Roman Britain. Jones (1991, 58 in Figure 7.2) suggests a relationship of :

$$\text{Walled surface area (in ha)} = \text{forum size (in 1000s of sq m)} * 4.9 + 0.6 \qquad (\text{R-square} = 0.93)$$

John Wacher (1975) gives local maps indicating city surface areas and forum sizes in Roman Britain. The square of the correlation coefficient is 0.49 (N=7) and the following relationship between forum size and city surface for Roman cities in Britain is found:

$$\text{Walled surface area (in ha)} = \text{forum size (in 1000s of sq m)} * 3.9 - 2.6$$

Because of these high correlations we also included forum sizes in our data collection exercise for the study area.

3.2.3 Discharge of aqueducts

A last item we will quantify is the total discharge of water by Roman aqueducts into a specific town or settlement. Intuitively one can assume some relationship between Roman city sizes and the capacity of aqueducts or the flow of water in 1000s of cubic meters per day, as Romans were skilful engineers and one cannot easily imagine them squandering money on megalomaniac aqueducts that would not be used. Though Romans also used wells to get water, the larger towns as a rule had at least an aqueduct supplying water; whether or not a town was located on a river was of little relevance in this respect.

Calculation of discharges of aqueducts is not as unambiguous as the mathematical formulas to estimate them may suggest. In the formulas one has to insert a number of parameters such as the actual water level and the surface roughness of the channel that change unpredictably over time and whose values often have to be assumed, as they have not been presented in any of the references. This may lead to quite some uncertainty or in other words quite some noise in the estimates of total water discharge. A. Trevor Hodge (1992, p 347) in his book on *Roman aqueducts & water supply* gives a striking example of this. He estimates the total discharge of the eleven aqueducts of Rome to be 1.1 million cubic meters per day, while he also presents a different reference, which comes to 0.5 to 0.6 million cubic meters per day for Rome, leading to a difference of some 50% between both estimates. To get a uniform approach of the estimation of discharges we have as far as possible calculated the discharges of aqueducts from the various sources ourselves, and not used a value from literature references directly. Based on the procedure described below we have halved the theoretical maximal discharge for Vienne (Robert Bedon, 2001, 329) to 50,000 m^3/day, as a typical value of the actual water level is only half the maximal level. For the various settlements we have also indicated whether the local use of wells has been attested archeologically in the *Atlas des villes, bourgs, villages de France au passé romain*.

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[104] As reported by Robert Bedon (2001), and for Narbonne and Limoges by Blanchet (1931) or mentioned in *TCCG*.

3.2.3.1 Calculation of discharge
The formula we will be using to calculate the discharges of aqueducts is that of Manning
(presented by A. Trevor Hodge, 1992, p. 355). We can estimate the average water speed in a
channel as a result of a flow on the basis of gravity as follows:[105]

average water speed = K * (hydraulic radius)^0.67 * (average slope)^0.5

Thereby we used a value of 50 for the K coefficient, as the surface of roman aqueducts was
very rough, and even somewhat rougher than rough concrete (K=55), while smooth concrete
has a value of K=100. The average slope is the numbers of meters the aqueduct falls off per
kilometre of length. In a number of references this slope of the local aqueduct is presented. If
it is not, then we assume a typical value of an average slope of 1 m per kilometre: leading to a
value of 0.001 for this parameter.
The hydraulic radius of a channel with width W meters depends on the actual water level
(h).[106] If we assume this water level to be typically half the height of the channel of H meters
we can find the following relationship:

hydraulic radius = (W * ½ H) / (W + H)

Assuming the average water level to be half the height of the channel H, implying half the
maximal capacity (meaning half the height of H of the channel is in use) as a typical value
seems me to be necessary, as the Roman aqueducts were clogged up after some time by
carbonate deposits limiting the theoretically possible maximal values and engineers generally
do not assume maximal load as a typical value. The total discharge of an aqueduct in a day
than lets itself be calculated by:

discharge in cubic meters per day = average water speed * (W * ½ H) * 3,600 * 24

When the discharge of an aqueduct was not given by some reference we calculated it, if at
least we could find information on the sizes of the Roman aqueducts (the width W and height
H in m) as minimal values and preferably also a value of the average slope (in m/km) for the
aqueduct. When the references indicated that there were several aqueducts in a certain town
and only for one of those we could find the minimal values to allow calculations we
multiplied the estimated daily discharge for this specific aqueduct with the numerical value of
several.

As the reader can deduce from this quite substantial explanation and the various values that
have to be assumed sometimes, the found numerical values of the total discharge of Roman
aqueducts have to be seen as rough estimates, which are quite uncertain. Adding to that
uncertainty is of course, as has been explained at the beginning of this paragraph, the fact that
in some towns Romans also used wells to an unknown extent to supply their water needs.[107]
Apart from the information found in Robert Bedon (2001) and A. Trevor Hodge (1992)
additional numerical information as an input for the calculation of the discharge of local

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[105] In theory one could even use the flow though the channel of an aqueduct to assess the numerical value of the
local gravitational acceleration, though in practice such a measurement would make no sense at all because of
the uncertainty introduced by the various unknown or inadequately measured parameters in the equation.
Therefore the local gravitational acceleration has been treated as a constant in this analysis.
[106] The more general formula for the hydraulic radius is:
hydraulic radius = (W * h) / (W + 2h)
[107] For some specific towns, as for instance Laon, an aqueduct was a technical impossibility, due to its location.

aqueducts in Glanum, Beziers, Narbonne, Nimes, Arles, Limoges, Cahors, Reims, Besançon, Metz, Lisieux, Jublains and Carhaix was collected from Robert Bedon, ed. (1997) *Les aqueducs de la Gaule romaine et des régions voisines*. For the aqueduct in Bavay numerical information as an input for the calculations was found in a contribution by René Jolin (1955). Additionally, information on the appearance of an aqueduct in the study area has been taken from the Internet: http://www.romanaqueducts.info/aqualib/aqualit.htm. Discharges for aqueducts in Die, Aix, Arles, Limoges and Alba have been calculated from information in the various volumes edited by Blanchet (1931).

3.2.4 Other data as indicators of the numbers of inhabitants

We have pondered about including the surface area of Roman baths as yet a different indicator of Roman city sizes. Eventually we decided not to include this parameter in the database, because as a rule the Roman baths were decentralised institutions in the Gallias and Germanias. The sometimes very different numbers (and sizes) of the thermae that are reported for otherwise more or less similar Roman cities therefore signify more how meticulous its excavations have been, than how populous a city was.[108]
Other data that we have included was the capacity of the Roman grain mills at Barbegal (Antony C. King, 1990, p. 101), as they allow us to calculate how many mouths could be fed in Arles with its products, unfortunately we did not find more of such data.

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[108] This is in contrast to an amphitheatre that was one single institution per city, of which we either have information or not, but not a numerical value that is some unknown fraction of its true value.

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