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Cultural Imprinting: Ancient Origins of Entrepreneurship and Innovation in Germany

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Abstract

A region's present-day economic performance can be deeply anchored in historical factors. We provide the first systematic evidence of a deep imprinting effect in the context of Roman rule in the south-western part of Germany nearly 2,000 years ago. Our analysis reveals that regions in the former Roman part of Germany show a stronger entrepreneurship and innovation culture today, evident by higher levels of quantity and quality entrepreneurship and innovation. The data indicate that this lasting 'Roman effect' was constituted by the early establishment of interregional social and economic exchange and related infrastructure. Our findings thus help in unpacking the hidden cultural roots of present-day economic performance, with important implications for research and economic policy.

Keywords: Entrepreneurship, innovation, historical roots, Romans, Limes

JEL classifications: N9, O1, I31

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1. Introduction: Far-reaching historical roots[1]

A growing body of evidence indicates that historical events that may reach far back in time—possibly centuries or millennia ago—can affect economic outcomes today.[2] Going back to ancient high cultures to understand the nature and roots of entrepreneurship and innovation has guided seminal theorizing on these topics (e.g., Baumol, 1990), but our knowledge and understanding of such a long-lasting imprint of history is still rather limited. Recent studies of regional entrepreneurship and innovation activity have found strong indications for historical roots that reach back more than a century.[3] For example, Fritsch and Wyrwich (2018) and Fritsch, Obschonka and Wyrwich (2019) showed for the case of Germany that many regions with high levels of self-employment and innovation activity today also had high levels of self-employment and innovation in the early 20th century. Since it is plausible to assume that entrepreneurship and innovation in the early 20th century did not come out of thin air, these historical roots may reach much deeper. The respective long-term relationships are, however, rather difficult to identify because appropriate data do not exist.

Throughout the course of history, regions are exposed to all kinds of cultural imprints, but these events may leave different effects, with some overshadowing others. Scholars have developed a special interest in identifying those historical factors that left a particularly deep imprint in that they anchored comparative economic advantage (Acemoglu and Robinson, 2012; Huggins et al., 2021). In this study, we focus on the long-lasting effects of the occupation of certain parts of Germany by the Roman Empire about 1,700 years ago on entrepreneurship and innovation activity in these regions today. One may expect

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[1] We are indebted to Sibylle Lehmann-Hasemeyer, Giacomo di Luca, Andy Pickering, Korneliusz Pylak and Michael Stuetzer for helpful comments and suggestions on an earlier draft. Discussions with Helmuth Albrecht were of great help in understanding the economic impact of the Romans. Holger Schaaff provided detailed information about the role of the Romans in the development of trade with basaltic millstones in the *Eifel* region.

[2] E.g., Alesina and Giuliano (2015), Bazzi et al. (2017), Buggle and Durante (2017), Giuliano and Nunn (2013), Guiso, Sapienza and Zingales (2006), Lowes et al. (2017), and Schulz et al. (2019).

[3] For long-term persistence of entrepreneurship in the United Kingdom see Bennet et al. (2020), Fotopoulos and Storey (2017), and Stuetzer et al. (2016). For the case of the United States see Glaeser, Kerr and Kerr (2015).

such a deep imprinting effect since the Roman civilization was not only much more developed than that of the 'Barbarians' at that time but particularly offered abundant opportunities for entrepreneurship and innovation.

Our analysis does indeed indicate a positive impact of Roman occupation on the quantity and quality of today's level of entrepreneurship and innovation in the respective territories. According to our results, such a Roman imprinting effect can also be found when looking at the level of commercial activity and education in the late Middle Ages that can be regarded as conducive to entrepreneurship and innovation. The results remain robust when accounting for a number of some important developments, such as membership in the Hanseatic League, massive cultural and socioeconomic shocks, such as medieval plagues, the effect of Napoleonic occupation, the massive inflow of German expellees from Eastern Europe after World War II, as well as German separation and re-unification.

To better understand the 'Roman effect' on present-day economic performance, we tested two potential transmission channels. The first is the intensity of the direct cultural imprint as indicated by the number of Roman markets and mines in a region. The second transmission channel could be the massive increase in geographic mobility, social interaction, and economic exchange due to the network of roads that were built by the Romans and that have been shown to have shaped the geographic patterns of interregional relationships until today. We find a significantly positive effect for the regional density of the Roman road network while the results for the number of Roman markets and mines are much weaker. Given the many disruptive shocks and the vast migration movements following the demise of the Roman Empire, this weaker effect of the direct cultural imprint of Roman presence is hardly surprising.

By analyzing the nature and scope of the effect of Roman rule in Germany, we contribute to the literature on historical imprinting mechanisms (e.g., Diamond and Robinson, 2010; Nunn, 2009), and particularly the present-day geography of entrepreneurship (Obschonka, Fritsch and Stuetzer, 2021; Sorenson, 2017) and innovation (Fritsch, Obschonka and Wyrwich, 2019; Crescenzi et al., 2020). Given that innovation and entrepreneurship can be regarded as the key drivers of growth and represent economic vitality in modern economies, investigating their historical roots is of key importance. A better understanding of historical sources of innovation and entrepreneurship may be particularly helpful for respective policy promotion programs since the failure of such programs may have to do with deep cultural imprints (see, e.g., Huggins et al., 2021).

The remainder of the paper is organized as follows. Section 2 describes the Roman occupation and its direct impact in some more detail. Section 3 introduces data and definitions. Section 4 presents the results of the empirical investigation, and Section 5 concludes the paper.

2. Roman occupation in Germany

2.1 The Roman Limes: a cultural border through Germany

About 2,000 years ago, the Romans attempted to expand their empire north to what is Germany today. After a period of fights with the incumbent 'Barbarian' tribes, they built the Limes around the year 150 AD as a border of their Empire. The Limes consisted of three major rivers, namely the Rhine, the Danube, and the Main ('Main Limes'), as well as a physical wall. This wall had two parts, the Upper Germanic and the Rhaetian Limes, which were connected by the river Main.[4] The walled parts of the border left physical traces like the remains of walls and towers, surviving ditches and forest aisles, as well as hills with stone rubble at

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[4] The location of the Limes originated from the fact that, after the defeat in the Battle of the Teutoburg Forest (in 9 CE), the Romans retreated to the Rhine and the Danube. As a result, it was difficult for them to move troops between both separated areas. The area to the east of the Rhine, especially the Black Forest, constituted a significant obstacle for troop movements and acted like a block between the two Roman areas to the east of the Danube and the west of the Rhine. Therefore, the Romans aimed to connect their territory to the west of the Rhine with that on the east of the Danube. To do so, in 74/75 CE the Romans—coming from Mainz—conquered the area between the Wetterau (the south of the northernmost parts of the Limes) and the High Black Forest, and built new forts there and in the area between the rivers Rhine and Main. At the same time, they began to build new forts in the Neckar area and the south of Bavaria by sending legions from Strasbourg eastwards and from Switzerland northwards.

After the victory against the Germanic tribe of the Chatti in Hesse in 85 CE, the Roman Emperor Domitian was able to further expand the area controlled by the Romans to the north and east. He also ordered the building of new forts and developed the Limes borderline by moving troops into newly constructed camps along the Limes. In the following, Trajan extended the line of Limes forts first on the Main and then later along and south of the Danube. He also built the so called 'Odenwald-Limes' (a more or less straight line connecting the Main area with the Neckar). However, in around 150 CE the Limes moved to the east, to its final location, to further shorten the travel time between the Upper German and the Rhaetian province capitals Mainz and Augsburg.

the location of watchtowers. Moreover, a whole number of Roman forts were built along this border (Henrich, 2012, 2014).

The Romans abandoned the Limes at the latest in 275/276 AD due to the invasion of German tribes and retreated to positions west of the Rhine, south of the Danube, and east of the river Iller.[5] The Limes represents the border of the largest territory in Germany that the Romans were able to retain for a longer period of time. During these more than 100 years, the Limes constituted not only a physical but also an economic and cultural border between the Roman and the Germanic culture during the Roman period (Von Schnurbein, 1995).[6] There was, however, a rather significant amount of controlled trade between the Roman and non-Roman areas. The Limes also marks the boundary of the Roman road network (according to McCormick et al., 2013); there existed no significant roads in terms of constructed routes for travel on land north-east of the Limes in those times.

From the viewpoint of identifying a causal effect, it is important to note that the general course of the Limes was determined by the need to establish a safe connection between the two Roman provinces of Upper Germany and Rhaetia. Hence, the Limes tried to connect these two provinces by conquering the smallest territory necessary in order to avoid additional wars with the local tribes. Its course reflects primarily military and strategic, not economic, considerations. This reasoning is further supported by the fact that, for around 80 km, the Limes followed a straight line and was built without regard to the varied topographies. One reason for this was to make the surveillance of the border as well as communication between watchtowers via smoke and light signals easier. Another reason could have been to demonstrate the superior scientific knowledge and abilities of the Romans to the local population (Wahl, 2017; Schallmayer, 2011; Planck and Beck, 1987).

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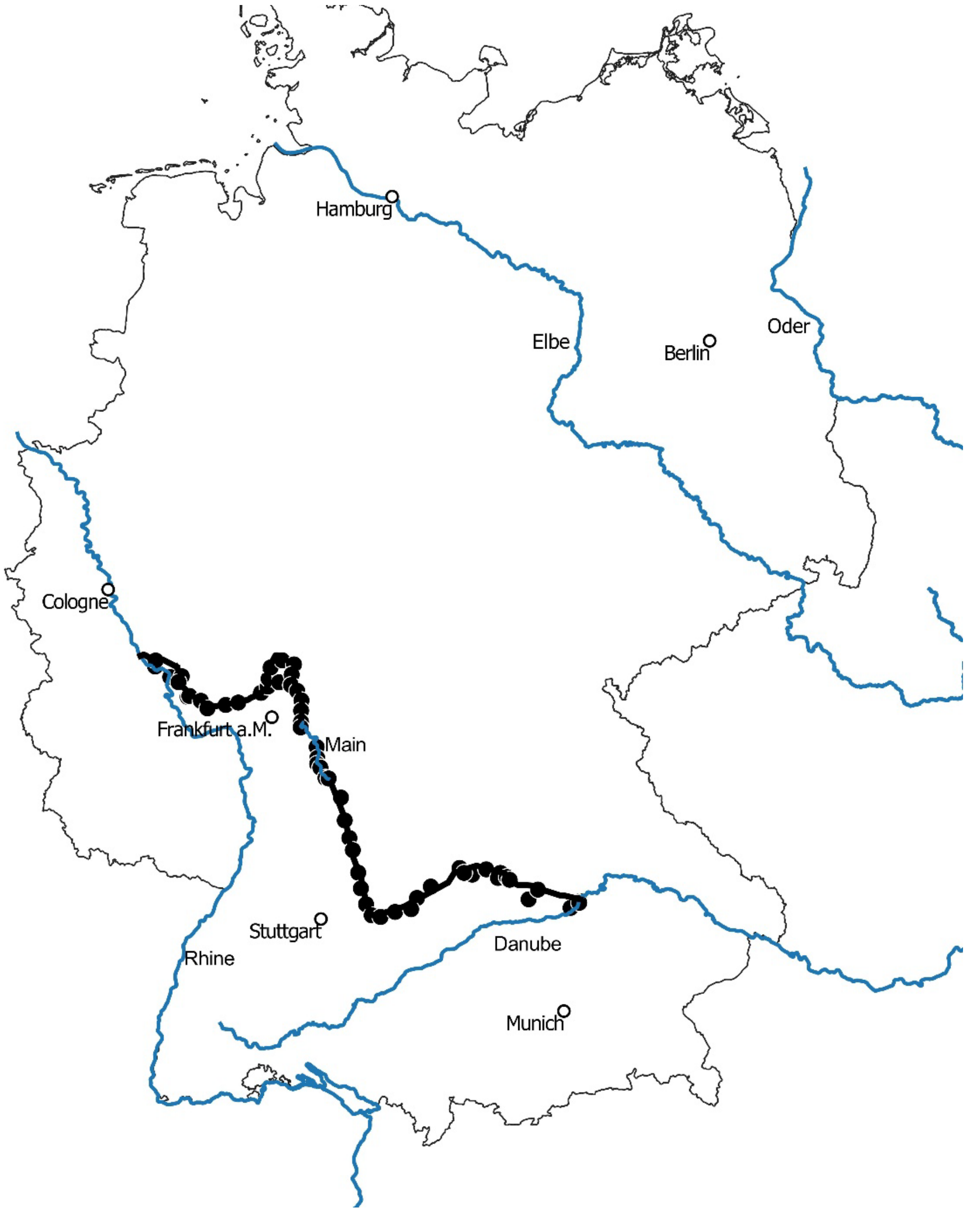
[5] In consequence, the area that roughly corresponds to the part of Germany south of the Danube and west of the Rhine experienced Roman rule for a longer period than the area that was given up after the Limes wall was invaded.

[6] It should be noted that the Roman territory at that time was dominated by Celtic tribes, while most of the population north-east of the Limes is commonly classified as German. See Rieckhoff (2008) for details.



Note: The Limes Germanicus (Upper-Germanic and Rhaetian Limes) is the solid black line. Roman forts are shown as black dots. The borders are those of current German Federal States.

Figure 1: The Limes Germanicus in 200 AD, major rivers and cities, Federal States, and Roman forts

Figure 1 shows the course of the Limes wall through Germany around the year 200 AD.[7] It also depicts the rivers Rhine and Danube, as well as the parts of

[7] Based on a shapefile of European borders from the Digital Atlas of Roman and Medieval Civilizations (DARMC) by McCormick et al. (2013), which is the digital version of Talbert's (2000) atlas. The DARMC can be accessed at http://darmc.harvard.edu/icb/icb.do?keyword=k40248&pageid=icb.page188865. Regarding Roman roads, we limit ourselves to roads that are classified by Talbert to be certain and major. We do not show the location of earlier border walls like the 'Odenwald Limes'.

the river Main that constituted a part of the border. It also shows the location of Roman forts, which can be used to check the validity of the location of walled parts of the border (the Upper Germanic and Rhaetian Limes), as well as some contemporary large cities.

2.2 Deep imprinting effects of Roman rule

When the Romans occupied certain parts of Germany, they brought with them superior scientific knowledge and a civilization that—compared to the local tribes—was in many respects much more developed and offered abundant opportunities for entrepreneurship and innovation. Roman society was much wealthier and considerably more structured and organized with a quite effective public administration and a relatively well-elaborated legal system (Drexhage, Konen and Ruffing, 2002; Franke 1980). That many state tasks were performed by private entrepreneurs—most importantly tax collection (Badian, 1980, 1997; Löffl, 2014)—suggests that a belief in the ability of the private economic sector to be efficient might have already existed during the Roman era. The Romans possessed large parts of the technological and natural scientific knowledge that existed at that time. They developed water mills, mining technologies, water supply systems (e.g., their well-known aqueducts), and many of their cities had sewerage systems (De Martino, 1985; Lucas, 2005; Schneider, 2005).[8] There existed a quite well-educated upper class and a considerable literacy rate among the population. Actually, the Roman schooling system provided the basis for the later western education systems in the Middle Ages and still today (Bloomer, 2011; Bonner, 1977).

The Roman economy was characterized by a relatively pronounced division of labor. The presence of well-accepted money and a banking system facilitated economic exchange and financial relationships (Drexhage et al., 2002; Finley, 1973). Non-agricultural production was mainly at a small scale, but there also existed some larger manufacturers. Commercial activity such as

[8] It is remarkable that the Romans hardly conducted any basic research but applied existing knowledge mainly in a problem-oriented learning-by-doing mode. Large parts of the technological knowledge were present in the powerful Roman army that was frequently involved in setting up infrastructure facilities.

entrepreneurship was, however, of low prestige in Roman society and rather unpopular among the 'upper class' (Baumol, 1990; Finley, 1973). Hence, most of the entrepreneurs came from the lower classes, such as former slaves. In the occupied German territories, a considerable number of the entrepreneurs during the Roman period were natives of the local tribes (Badian, 1997).

The Romans built a road infrastructure that connected the occupied territories to the rest of their empire. The road system that the Romans built had a strong influence on the geographic pattern of trade, mobility, and social interactions. It has been shown for a number of countries that Roman roads had long-lasting effects by shaping the traffic infrastructure and urbanization patterns that exist today (Wahl, 2017; Dalgaard et al., 2020).[9] Flückiger et al. (2021) demonstrate that the Roman trade network across Europe is still important for understanding today's trade patterns and cross-regional investment behavior. The authors explain the long-run persistence of this connectivity by a relatively high level of cultural integration in terms of converging values and preferences of the population that may be due to dense and repeated social and economic interactions between the well-connected parts of the network.

Wahl (2017) suggests that these long-lasting consequences of the Roman road network could be regarded as responsible for a 'Roman development effect' that can still be identified today. He showed that regions in the former Roman part that are within 100 km from the border to the German Barbarians—the Limes—have significantly (at least 10%) higher night-light luminosity today than those within the same distance on the other side of the Limes. Closely related to this study, Dalgaard et al. (2020) investigated night-light intensity around the location of historical Roman roads, finding that not only night-light intensity but also the density of nearby historical settlements are notably and robustly larger. All of these studies make use of the fact that, according to historical accounts and empirical tests, Roman roads follow an economically sub-optimal path.[10] Hence,

[9] For example, around 87% of the contemporary highways in the Roman parts of Germany are located within 10 km of a Roman road (Wahl, 2017).

[10] The reason may be that these roads were primarily built for military purposes (e.g., shifting troops from one location to another) without accounting for terrain characteristics such as

the course and the location of Roman roads can be considered exogenous to Roman or pre-Roman economic patterns.[11]

2.3 Did the Romans leave a particularly deep imprint on entrepreneurship and innovation?

The brief description of the general economic conditions in the German regions south and west of the Limes during Roman times suggests that the integration of these areas into the Roman Empire made a rather deep, lasting cultural imprint. Previous research indicates that some effects of this deep imprint of Roman rule remain today, leading to higher levels of wealth and economic activity in the former Roman areas (Wahl, 2017). In our detailed analysis of a Roman imprint on entrepreneurship and innovation, we distinguish two types of effects: first, the direct imprinting effects of the Roman cultural civilization that has given the Roman regions an initial development advantage over the less advanced 'barbaric' regions on the other side of the Limes that may still exist today; and, second, the indirect effects that are related to the long-lasting infrastructure built by the Romans, particularly the road system.

The *direct civilization-based imprinting effect* due to the integration of the occupied area into the Roman Empire has many facets. It implies relatively early contact with and learning from a considerably more developed society with an advanced knowledge base, a higher level of economic organization and labor division, as well as a wider geographic scale of economic interactions such as larger markets (De Martino, 1985). Hence, there was room for knowledge spillover from the Romans to the local population that is crucial for the emergence

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elevation or slope—which would be important for the efficient transportation of goods with oxen or by foot.

[11] Michaels and Rauch (2017) came to a more nuanced conclusion about the effect of the Romans on subsequent developments. Investigating urbanization in Britain and France from the Roman Era until today, they found that the breakdown of the Western Roman Empire ended urbanization in Britain but not in France. When urbanization started again in the medieval period, towns in France were often rebuilt or founded on old Roman town locations. In England, where Roman rule ended considerably earlier than in France, the urban network of Roman roads did not persist. Much later, new towns emerged close to the coast or at navigable waterways. This gave these newly emerging cities a decisive advantage over their counterparts from the Roman period, as access to waterways became a decisive growth factor for cities only after the time of Roman occupation. Michaels and Rauch (2017) conclude that it was actually advantageous to be part of the Roman Empire, but it was better if it was not for too long.

of innovation and entrepreneurial ideas (e.g., Acs et al., 2009). It is quite likely that contact with Roman entrepreneurs led to demonstration and peer effects that were conducive to entrepreneurial spawning among the local population. Such a pattern would be in line with the abundant empirical evidence on the pivotal impact of role-modeling effects for the decision to become an entrepreneur (e.g., Bosma et al., 2012; Andersson and Larsson, 2016; Wyrwich, Stuetzer and Sternberg, 2019). Locals working in Roman ventures may have acquired entrepreneurial skills by observing the behavior of the owner-manager. Role-model effects are also a source of self-perpetuation and persistence of entrepreneurship over time (Minniti, 2005; Andersson and Koster, 2011; Fritsch and Wyrwich, 2018) and may imply that regions that were part of the Roman Empire have an above-average level of (high-quality) entrepreneurship today. Knowledge transfer from the Romans to the local population had many channels, such as diverse types of cooperation and economic exchange or apprenticeship of locals in Roman-led firms. People from the local tribes also served in the Roman army (Coulston, 2016), which was an important repository of the technological knowledge at that time with institutionalized training of the antique 'engineers' (Goldsworthy, 2011).

Although the demise of the Roman Empire was followed by vast migration movements and many fundamental changes, some elements of the 'direct imprinting effect' of the Romans in the occupied German area may have remained until today. An illustrative example of such a long-lasting effect of the adoption of advanced technology, managing methods, and the integration into larger markets in Roman times is the mining, preparation, and export of basaltic millstones from the village of Mayen in the *Eifel* region. Due to geological specificities, the basaltic rock in that region has special properties that make it well-suited for use as a millstone. In pre-Roman times, the local Celtic tribes produced and traded such millstones across a distance of up to 100 km. Demand by the Roman army,[12]

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[12] In the Roman army of that time, smaller groups of soldiers used to share a small handmill for grinding grain. Handmills with millstones from the *Eifel* region were widely used in the Roman army because of their higher productivity and because their use led to lower levels of mechanical wear. It is estimated that production of handmills with these millstones over the entire Roman period may have amounted to about 17 million units (Mangartz, 2008).

application of more advanced technology, and export to other parts of the Roman Empire (e.g., France and Britain) led to a strong increase of the produced amounts of millstones involving up to 600 workers.[13] The region considerably benefited from the production and trade of basaltic millstones until the late 19th century (for details see Mangartz, 2008). Such centers of economic activity might have been characterized by pronounced incentives for creativity and innovativeness and may, therefore, have attracted people with entrepreneurial talent. In our empirical analysis, we use the number of Roman markets and mines in a region to test for such a lasting direct imprinting effect on innovation and entrepreneurship (Section 4.2).

An *indirect long-term imprinting effect* on entrepreneurship and innovation that is rooted in the former integration into the Roman Empire more than 1,700 years ago could be higher levels of geographic mobility and interregional trade, particularly the knowledge transfer that was related to these activities. We know from previous research that the geographic structure of the road network built by the Romans strongly shaped the traffic infrastructure today and also has a significant effect on today's structure of interregional trade relationships (Flückinger et al., 2021). Higher interregional mobility and interaction were not only important for the transfer of knowledge and economic development but could very likely have also affected attitudes of the population that are important for innovation and entrepreneurial activity, such as tolerance toward strangers, openness for change, and new ideas as well as a certain willingness and ability to bear risk (Tavassoli, Obschonka and Audretsch, 2021). Hence, even if a direct civilization-based imprinting effect did not persist, the Roman road network, as a cultural artifact, might have fueled the described indirect imprinting effect even long after the Romans had to give up their German provinces. In the empirical analysis, we use the density of Roman roads in a region to test for a persistent effect of the Romans on innovation and entrepreneurship.

[13] Mining of the basalt stones was organized in several open pits that were operated by private entrepreneurs.

3. Data and empirical approach

3.1 Data

3.1.1 Outcomes related to entrepreneurship and innovation

The spatial framework of our analysis comprises the current 401 German NUTS3 (Nomenclature of Territorial Units for Statistics) regions (counties).[14] We overlaid shapefiles of the walled Limes parts and courses of the Danube, Rhine, and Main, with one of the current borders of the counties. In doing so, we were able to assign the counties to the historical Roman area. We assigned countries to the historical Roman area if their centroid (mid-point) is located within the Roman Empire.

We are interested in the effect of Roman rule on entrepreneurship and innovation today. We therefore examined regional differences in present-day quantity and quality entrepreneurship and innovation. Quantity innovation activity is measured as the number of patents per region, taken from the RegPat database provided by the Organization for Economic Co-operation and Development (OECD) (see Maraut et al., 2008). Patents as an innovation indicator have a number of advantages and disadvantages (for an overview see Griliches, 1990; Nagaoka, Motohashi and Goto, 2010). Patents are assigned to the region where the inventor has her or his residence to avoid a bias from counting any patent invented at any establishment in a given firm to count toward the region of the firm's headquarter. If a patent has more than one inventor, the count is divided by the number of inventors, and each inventor is assigned his/her share of that patent. We considered the average number of patent applications filed in the years 2008 to 2016, with at least one inventor residing in the region per 10,000 workforce. Information on the size of the regional workforce comes from the German Federal Statistical Office's labor market statistics.

Focusing on quality innovation, we used common indicators for the originality and radicalness of a patent, provided by the OECD RegPat database

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[14] Shapefiles for the borders of the counties and federal states are from the Federal Agency of Cartography and Geodesy (Bundesamt für Kartographie and Geodäsie). They are freely available at https://gdz.bkg.bund.de/index.php/default/digitale-geodaten/verwaltungsgebiete/verwaltungsgebiete-1-250-000-ebenen-stand-01-01-vg250-ebenen-01-01.html.

(see Squicciarini, Dernis and Criscuolo, 2013 for details). Both measures are based on backward citations and are supposed to indicate inventions of a relatively high quality in terms of technological and economic impact. While radicalness is measured by the number of International Patent Classification (IPC) classes of the patents that are cited by the focal patent, originality is measured by the breadth of the distribution across these IPC classes. We used the top 10% of German patents with respect to the OECD radicalness indicator and the originality indicator per priority year.

Quantity entrepreneurship is measured by the average number of start-up companies per 10,000 economically active population in the years 2008 to 2016. The information on the number of new businesses comes from the Enterprise Panel of the Center for European Economic Research (ZEW-Mannheim). These data are based on information from the largest German credit rating agency (*Creditreform*).[15] We used the average regional start-up rates for a longer period of time in order to avoid possible bias related to short-term and stochastic effects.

Quality entrepreneurship is measured by means of the start-up rate in high-tech manufacturing industries, representing knowledge-intensity that requires specific qualifications. Since high-tech start-ups are relatively likely to introduce risky innovations, setting up and running such a firm requires certain entrepreneurial attitudes and abilities. Moreover, start-ups in high-tech industries can be assumed to generate a particularly pronounced positive impact on regional development by being often economically or technologically more successful than other firms and by creating larger numbers of promising entrepreneurial opportunities for other firms.[16]

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[15] As with many other data sources on start-ups, these data may not completely cover the case of solo entrepreneurs. However, once a firm is registered, hires employees, requests a bank loan, or conducts reasonable economic activities, even solo entrepreneurs are included, and information about their activities is gathered beginning with the 'true' date the firm was established. Hence, many solo entrepreneurs are captured along with the correct business founding date. This information is limited to the set-up of a firm's headquarters and does not include the establishment of branches. For details see Bersch et al. (2014).

[16] The definition of high-tech start-ups is based on the common classification of industries according to their innovativeness as measured by their share of research and development (R&D) inputs (OECD, 2005; Gehrke et al., 2010). A problem of this classification is that industry affiliation is a fuzzy criterion because there may be innovative and not so innovative firms in all industries. However, given the limited availability of data on the innovativeness of individual

3.1.2 Historical and geographical data

For each region, we also created a variable for the number of Roman-era markets or mines. These variables were extracted shapefiles from the DARMC. Data on the course and coordinates of Roman roads were taken from the shapefile of McCormick et al. (2013), who digitized the information in the "Barrington Atlas of the Greek and Roman World."[17] Based on these data, we calculated Roman road density (kilometers of major Roman roads per km² of area) as an indicator for the integration into the Roman Empire and a resulting indirect long-term imprinting effect (Section 2.3).

We calculated a host of historical variables at the county level. To account for pre-Roman settlement patterns in the non-Roman areas, we report the number of Celtic settlements (Oppida; i.e., hillforts or princely residences) within a region.[18] A dummy variable indicates if a region includes at least one leading member of the medieval German Hanseatic League (=1) based on Dollinger (1966).[19] This variable controlled for historical openness and social interactions with strangers due to intensive interregional trade relationships and the resulting economic prosperity. Since historical plague outbreaks may have left traces in the regional population, we controlled for this potential influence in our empirical

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businesses, this is often the only feasible way to identify new businesses as being innovative (for details see Fritsch, 2011). New businesses in innovative manufacturing industries make up only a rather small fraction of all start-ups. In the 2008‒2016 period the average share is below 0.8%.

[17] The data can be downloaded from https://harvard-cga.maps.arcgis.com/apps/View/index.html?appid=b38db47e08ca40f3a409c455ebb688db (latest access June 27, 2021). The course, building, and characteristics of Roman roads have been extensively studied by historians and archaeologists (e.g., Laurence, 1999). From such works, the Roman road network can be reconstructed with some certainty. Nevertheless, for some of the roads, there is a scholarly disagreement about their exact course. These roads are classified in the Barrington Atlas as being uncertain and are excluded from the subsequent analysis.

[18] Information on Celtic settlements comes from the Digital Atlas of the Roman Empire (DARE) and the Pleiades Database of Ancient Places that is hosted by the Ancient World Mapping Center (AWMC) of the University of North Carolina. This digital atlas is edited by Johan Ahlfeldt from Lund University. It can be accessed at: http://dare.ht.lu.se/. The Pleiades database is from the AWMC website: http://awmc.unc.edu/awmc/map_data/shapefiles/cultural_data/Pleiades_data/. We validated and supplemented the DARE data based on information in several other historical and archeological publications (Kristiansen, 2000; Kuckenburg, 2000; Menghin, 1995; Rieckhoff, 2008). Compared to the Celtiv Opedia, the settlements of German tribes at that time were rather small and there is no evidence of larger fortified villages.

[19] Leading members are either the capitals of Hanseatic quarters or cities considered to be important by Dollinger (1966).

models.[20] Data on the number of historical plague outbreaks in a region are taken from Biraben (1975), who collected information on the spread of the plague in Europe and the Mediterranean from 1347 to 1900. Overall, he recorded 11,180 major outbreaks. Imprecise geographical descriptions and other remaining uncertainties reduce the number of localizable outbreaks to 6,929. We used the geo-located data for these outbreaks provided by Büntgen et al. (2012).

The intersection of a region with the rivers Danube, Elbe, Oder, or Rhine indicates relatively easy means of transportation and interregional trade. We accounted for such an influence with a dummy variable equal to 1 if a region intersects with one of those rivers.[21] For the same reason, we considered a location at the coast with a respective dummy variable (yes=1, no=0).[22] As further geographic variables, we considered the suitability of a region's soils for growing crops (according to Zabel, Putzenlechner and Mauser, 2014). This measure reflects a combination of climatic and geographic factors (topography etc.) as well as soil characteristics (pH value etc.) ranging from 0 (no suitability) to 100 (perfectly suitable). Furthermore, we included measures for the mean elevation in meters and terrain ruggedness (according to a digital elevation model of the European Environment Agency) as well as mean sunshine duration and temperatures in July. These variables control for natural conditions in a region.

Finally, we considered the effect of access to coalfields because of their important role in the process of industrialization and the consequences for entrepreneurship in the regional economy (Fernihough and O'Rourke, 2014;

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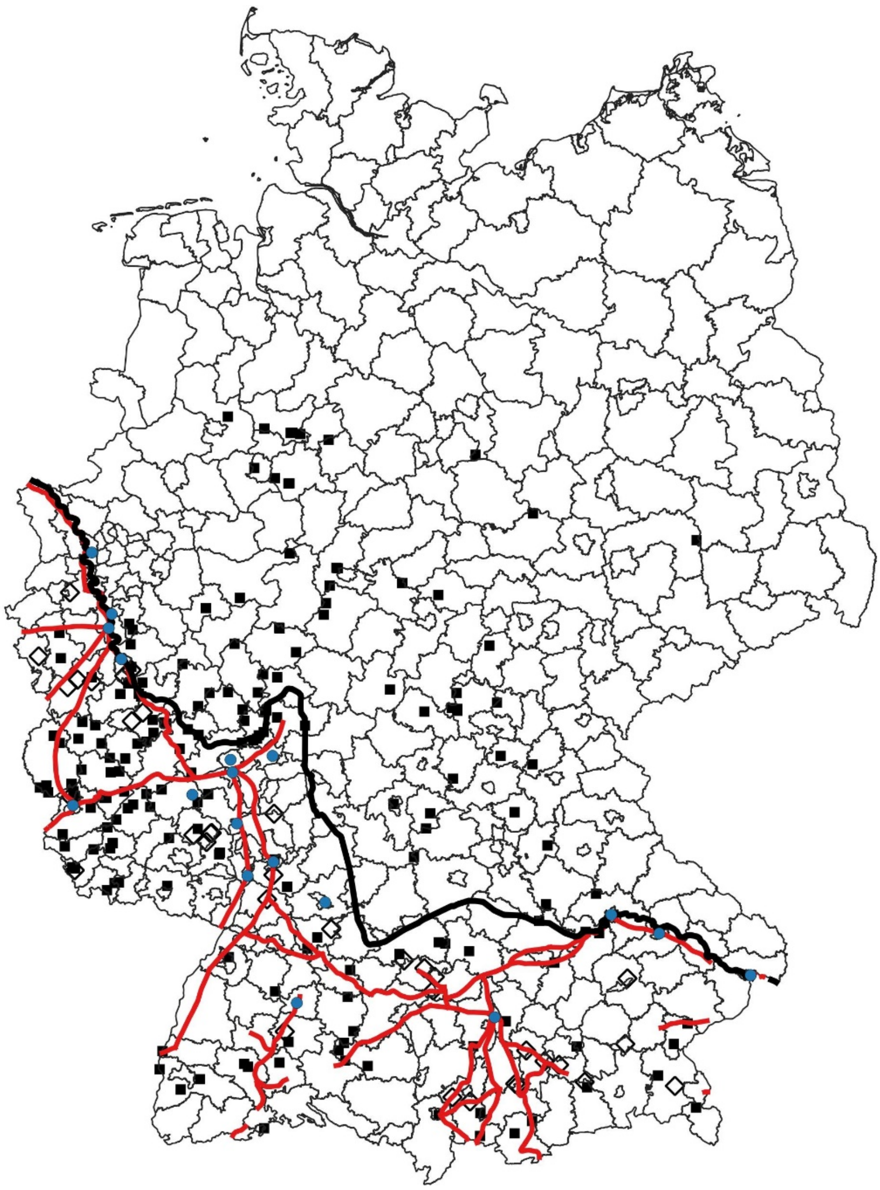
[20] The data can be downloaded at https://www.wsl.ch/fileadmin/user_upload/WSL/Landschaft/Landschaftsentwicklung_Monitoring/Landschaftsgeschichte/Historical_plague_outbreaks.txt.

[21] Information about the location of these rivers is taken from a shapefile provided by the European Environment Agency and is downloadable at https://www.eea.europa.eu/data-and-maps/data/wise-large-rivers-and-large-lakes/zipped-shapefile-with-wise-large-rivers-vector-line/zipped-shapefile-with-wise-large-rivers-vector-line/at_download/file

[22] A respective shapefile is downloadable at: https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1/gis-data/europe-coastline-shapefile



Note: The Limes Germanicus (Upper-Germanic and Rhaetian Limes) is the solid black line. Red solid lines are certain, major Roman roads. Black rectangles are Celtic Oppida, and diamonds indicate the location of a Roman market or mine. The borders indicate NUTS3 regions (counties).

Figure 2: The Limes Germanicus, Roman roads, markets, mines, and Celtic Oppida

Huggins et al., 2021; Stuetzer et al., 2016).[23] As actual coal access and regional coal employment could be endogenous, we proxy coal access with the presence of

[23] A number of recent studies found that regions with a tradition of coal mining are characterized by relatively low levels of self-employment (e.g. Glaeser, Kerr and Kerr, 2015; Stuetzer et al., 2016). The obvious reason for this relationship is that large-scale industries like coal mining and related industries (e.g. steel production) provide an economic environment that is unconducive to entrepreneurship.

late Carboniferous rock strata. Rock strata from the Carboniferous Age are where coal is often found. Hence, coalfield locations should be close to or on such rock strata (Fernihough and O'Rourke, 2014). We used a geological shapefile of Europe showing the location of those rock strata[24] and created a dummy variable equal to 1 if there are late Carboniferous rock strata in a county. Figure 2 shows the historical data alongside county borders.

3.1.3 Descriptives

Table A1 in the Appendix provides an overview of the definition of variables and data sources. Table A2 shows some descriptive statistics and Table A3 depicts correlations between the three indicators for Roman presence and the measures of regional entrepreneurial and innovative activities. This gives a first, very suggestive, indication that there is a relationship between Roman presence and contemporary innovation and entrepreneurship levels.

While many of these correlations are statistically significant, we find that the relationship between the number of Roman markets and mines and the outcome variables is relatively weak. The correlation of all three Roman variables and the number of radical patents over workforce is insignificant. The statistical relationship between the dummy variable for Roman presence and Roman road density is considerably larger than between the Roman dummy and the number of Roman markets and mines. The correlation between Roman road density and the number of Roman markets and mines is comparatively low (2.00) but statistically significant.

3.2 Empirical approach

Our main analysis of the effect of the Romans on entrepreneurship and innovation in Germany is based on cross-sectional ordinary least squares (OLS) regressions. We estimate the equation

$$Y_{is} = \alpha + \beta R_{is} + \gamma' \boldsymbol{X}_{\text{is}} + \varepsilon_{is} \quad (1)$$

[24] The shapefile is downloaded from the website of the Federal Institute of Geoscience and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoff). The file can be downloaded here: https://download.bgr.de/bgr/Geologie/IGME5000/shp/IGME5000.zip.

where Y_{is} is one of our measures of regional innovative or entrepreneurial activity. The indices i and s represent counties (i) and federal states (s), respectively. R_{is} is the variable for a Roman effect that can have three alternative forms. A dummy variable for Roman presence that is equal to 1 if the centroid of region i in federal state s is located in the historic Roman area. The number of Roman markets and mines is supposed to measure the direct civilization-based imprinting, and Roman road density is supposed to indicate the indirect long-term imprinting effect (Section 2.3). $\boldsymbol{X}_{is}$ is a vector of geographical and historical control variables. ε_{is} is the error term. We estimate heteroskedasticity robust standard errors throughout the analysis.

4. Results

4.1 Results for Roman occupation

We start the empirical analysis by investigating the relationship between innovation and historical Roman occupation. We find highly significant positive relationships between Roman occupation and the share of R&D employees as a measure of innovation input (Table 1, models 1–3) and the overall number of patents over workforce as an indicator for innovation output (models 4–6). These relationships are rather robust when dummies for the federal states and further control variables are included. The positive relationship with Roman rule remains if only patents that are classified as being radical or original are taken into account (models 8 and 9).

Besides the positive effects on quantity and quality innovation, formerly Roman regions also show significantly higher rates of quantity and quality entrepreneurship. Specifically, the data reveal a positive effect on new business formation in general (models 1–3 in Table 2). It is quite remarkable that the estimated coefficient for the Roman dummy increases quite considerably when federal state dummies and further control variables are included. These findings also hold for start-ups in innovative manufacturing industries (models 4–6 in Table 2). Higher start-up rates in high-tech manufacturing industries in the formerly Roman regions correspond to the higher levels of innovation activities there (Table 1).

Table 1: Innovation and Roman occupation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable	*Share of R&D employees*			*ln(patents over workforce)*			*Patents over workforce*	*ln(original patents over workforce)*	*ln(radical patents over workforce)*
Roman (1=yes)	0.350***	0.434***	0.470***	0.876***	0.277***	0.247**	0.0004**	0.319***	0.101***
	(0.101)	(0.145)	(0.137)	(0.0812)	(0.0871)	(0.101)	-0,0002	(0.0717)	(0.0294)
Terrain ruggedness			-0.0487*			0.0200	-1.01e-05	0.0143	0.00035
			(0.0293)			(0.0195)	(3.82e-05)	(0.0136)	(0.00516)
Mean elevation			-0.0007			-0.0008**	-1.42e-06**	-0.0008**	-9.96e-05
			(0.0005)			(0.0003)	(6.48e-07)	(0.0003)	(9.92e-05)
Coast region (1=yes)			-0.389**			-0.824***	-0.0005***	-0.0873	-0.0311
			(0.157)			(0.159)	(0.0001)	(0.115)	(0.0552)
Carboniferous rock strata (1=yes)			0.223			-0.0432	1.26e-05	-0.0268	-0.0095
			(0.163)			(0.121)	(0.0002)	(0.0854)	(0.0327)
Hanseatic League (1=yes)			-0.124			-0.0175	-7.72e-05	-0.0142	0.0182
			(0.134)			(0.114)	(0.0001)	(0.0894)	(0.0318)
Number of Celtic Oppida			-0.0560*			-0.0587	-5.42e-05	-0.0573**	-0.0230**
			(0.0336)			(0.0382)	(6.14e-05)	(0.0278)	(0.0094)
Soil suitability			-0.0025			0.00782**	3.67e-06	0.00143	1.29e-05
			(0.0055)			(0.00332)	(6.96e-06)	(0.0025)	(0.0009)
Intersects major river (1=yes)			-0.184*			0.00314	-1.35e-05	0.0520	-0.0123
			(0.108)			(0.0927)	(0.000158)	(0.0589)	(0.0233)
Number of plague outbreaks			0.0504***			0.0268***	1.61e-05	0.0097***	0.0014
			(0.0116)			(0.0077)	(1.09e-05)	(0.0036)	(0.0015)
Federal state dummies	No	Yes***	Yes***	No	Yes***	Yes***	Yes***	Yes***	Yes***
R^2	0.034	0.117	0.228	0.206	0.496	0.553	0.312	0.126	0.221

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. Stars after the "Yes" indicate the level of joint statistical significance of the federal state dummies. The number of observations (counties) is 401 in all models.

Table 2: Entrepreneurship and Roman legacy

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	*Start-ups over workforce*			*High-tech start-ups over workforce*		
Roman (1=yes)	2.907***	4.155***	5.715***	0.690***	0.710***	0.758***
	(0.876)	(1.295)	(1.324)	(0.101)	(0.149)	(0.151)
Terrain ruggedness			-0.0253			-0.0293
			(0.238)			(0.0290)
Mean elevation			-0.005			-7.13e-05
			(0.0044)			(0.0005)
Coastal region (1=yes)			-3.569**			-0.576***
			(1.545)			(0.128)
Carboniferous rock strata (1=yes)			0.345			-0.0736
			(1.760)			(0.141)
Hanseatic League (1=yes)			-0.804			-0.0909
			(1.022)			(0.109)
Number of Celtic Oppida			-1.009**			-0.0959*
			(0.492)			(0.0523)
Soil suitability			-0.140***			-0.0077**
			(0.0322)			(0.0038)
Intersects major river (1=yes)			-1.390			-0.245**
			(0.993)			(0.114)
Number of plague outbreaks			0.345***			0.0680***
			(0.0918)			(0.0120)
Federal state dummies	No	Yes***	Yes***	No	Yes***	Yes***
R^2	0.030	0.196	0.293	0.120	0.241	0.360

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. Stars after the "Yes" indicate the level of joint statistical significance of the federal state dummies. The number of observations (counties) is 401 in all models.

The size of these 'Roman effects' on entrepreneurship and innovation is also remarkable. For example, Roman legacy is associated with, on average, around 25% more patents per 10,000 economically active people in historically Roman counties (according to Table 1, column (6)), and at least three more start-ups per 10,000 economically active persons.

4.2 Where does the effect of the Romans come from?

We focus on two mechanisms that may be responsible for the long-lasting effect of the Romans on current entrepreneurship and innovation: first, the number of Roman markets and mines; and, second, Roman road density. While the number of Roman markets and mines can be regarded as a measure for the intensity of the cultural imprinting in Roman times that may have given these regions a head start, Roman road density measures the long-term effect of traffic infrastructure that

Table 3: Entrepreneurship, innovation and Roman legacy: accounting for potential mechanisms

Dependent Variable	(1) Start-ups over workforce	(2) High-tech start-ups over workforce	(3) Share of R&D employees	(4) ln(patents over workforce)	(5) ln(original patents over workforce)	(6) ln(radical patents over workforce)
Number of Roman markets and mines	0.143	0.519	0.175	0.165*	0.0496	0.00882
	(0.142)	(1.076)	(0.111)	(0.0850)	(0.0477)	(0.0205)
Roman road density	4.112**	40.50***	4.328**	1.907	2.286***	0.542*
	(1.807)	(14.81)	(1.822)	(1.287)	(0.817)	(0.293)
Terrain ruggedness	-0.0425	-0.116	-0.0525*	0.0185	0.00956	-0.00159
	(0.0300)	(0.247)	(0.0291)	(0.0192)	(0.0136)	(0.00528)
Mean elevation	0.0006	0.0003	-0.0003	-0.0007**	-0.0005*	-6.23e-06
	(0.0005)	(0.0044)	(0.0005)	(0.0003)	(0.0003)	(0.0001)
Coastal region (1=yes)	-0.524***	-3.209**	-0.370**	-0.815***	-0.0682	-0.0237
	(0.128)	(1.551)	(0.157)	(0.159)	(0.113)	(0.0547)
Carboniferous rock strata (1=yes)	-0.0823	0.255	0.222	-0.0404	-0.0309	-0.0111
	(0.152)	(1.774)	(0.165)	(0.120)	(0.0864)	(0.0329)
Hanseatic League (1=yes)	-0.155	-1.230	-0.134	-0.0198	-0.0356	0.00860
	(0.108)	(1.026)	(0.132)	(0.113)	(0.0876)	(0.0313)
Number of Celtic Oppida (1=yes)	-0.106**	-1.036**	-0.0591*	-0.0637*	-0.0593**	-0.0240**
	(0.0491)	(0.471)	(0.0329)	(0.0364)	(0.0270)	(0.0094)
Soil suitability	-0.0048	-0.122***	-0.0019	0.0081**	0.0024	0.0004
	(0.0039)	(0.0330)	(0.0056)	(0.0033)	(0.0027)	(0.0009)
Intersects major river (1=yes)	-0.185*	-1.120	-0.179	0.0132	0.0668	-0.00425
	(0.111)	(0.959)	(0.109)	(0.0917)	(0.0609)	(0.0241)
Number of plague outbreaks	0.0667***	0.318***	0.0464***	0.0254***	0.00813**	0.00124
	(0.0130)	(0.100)	(0.0121)	(0.008)	(0.0039)	(0.0015)
Federal state dummies	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
R^2	0.	0.326	0.231	0.556	0.197	0.103

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. Stars after the "Yes" indicate the level of joint statistical significance of the Federal State dummies. The number of observations (counties) is 401 in all models.

considerably shaped the geographic pattern of the road infrastructure and the structure of interregional trade relationships through to today (see Section 2.2). We substituted the dummy variable for Roman presence with these two variables (Table 3). There is a certain overlap between both measures (see Table A3 in the Appendix), and many cities located on Roman roads that were not original centers of the Roman economy in Germania developed into trade centers in later periods. In this sense, one may suppose that the effect of markets and mines is likely to pick up an 'early start advantage' of the original Roman economic centers.

According to the results, density of road infrastructure built by the Romans shows a statistically significant and positive effect on all the outcome variables, with the exception of the overall number of patents over workforce, which is significantly related to the number of markets and mines. Our measure for Roman markets and mines is always insignificant for the other outcomes. These results suggest that access to Roman roads—the indirect long-term imprinting effect (Section 2.3)—is the dominant channel through which the effect of the Romans transmits to entrepreneurship and the ability of groundbreaking innovations today.

4.3 Results for other historical outcomes

Until now, we have only investigated the relationship between Roman rule and entrepreneurship and innovation today. However, if there is really a persistent effect of the Romans on such socioeconomic outcomes, it should also be visible when looking at earlier outcomes. To this end, we explored data from the 15th and 16th centuries that indicate the level of education and local development, which are both crucial conditions for entrepreneurship and innovation.

One of these datasets is the study of Dittmar and Meisenzahl (2020), containing information on 239 German-speaking cities for which Bairoch, Batou and Chevre (1988) offer city population figures in 1800. This data set is a cross-section where most of the variables are measured in the 15th or 16th century. Based on the information about the course of the Roman border, we assigned each city to the Roman and the Germanic part. We also created a dummy variable if a city is located closer than 5 km from a Roman road.[25] Among the variables in this data set, the average number of students in a city between 1458 and 1508 and the number of books printed before 1517 are of most interest to us as they could proxy for innovativeness and human capital back then. Apart from these two variables, we included a host of control variables coming from Bairoch, Batou and Chevre's (1988) data set, like dummy variables for cities that were members of the Hanseatic League, had a university, or are located on a river, among others. As both outcome variables are count data, we estimated Poisson models here. We

[25] This is the equivalent to the Roman road density variable used before. In this analysis, cities are considered to be sizeless points in space.

also included territory fixed effects, and we report heteroskedasticity robust standard errors.

Columns (1) to (4) in Table 4 show the results of the Poisson regressions. These estimates suggest that cities in the historically Roman part of Germany had significantly more students (even when controlling for university location) and more printed books in the 15th and 16th centuries. This implies that their human capital stock and probably also their level of innovativeness were already higher during the late Middle Ages. Location close to a Roman road does, however, only matter for explaining the number of students, not the number of books. This suggests that Roman roads are only one of several mechanisms explaining the effect of the Romans on these outcomes.

Table 4: Roman legacy and medieval economic outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Number of students 1458-1508		Number of books pre-1517		Number of markets in 1470		Share of economic buildings 1400-1600	
Data set	Dittmar and Meisenzahl (2020)				Cantoni et al. (2018)			
Method	Poisson				OLS			
Roman (1=yes)	0.628*** (0.193)		2.937*** (0.812)		0.111 (0.069)		0.0198** (0.0088)	
Roman road (1=yes)		0.228 (0.179)		0.916* (0.497)		0.137* (0.0751)		0.0194* (0.0106)
Number of observations	229	229	229	229	2218	2218	2218	2218
(Pseudo) R^2	0.471	0.464	0.504	0.488	0.086	0.087	0.037	0.036

Notes. All models include the complete set of control variables used in Table 3. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. In columns (1)–(4), the following control variables are always included: a river, Hanseatic League, university by 1517 and Reformation law before 1600 dummy, the number of monasteries of non-mendicant orders and the Augustinians within 10km of the city in 1517, the natural logarithm of a city's distance to Wittenberg and historical states dummies are included. For the sources, see Dittmar and Meisenzahl (2020). In columns (5)–(8), the controls are a university by 1517 (from Dittmar and Meisenzahl), a city near the border of a different religious denomination dummy, a Protestant dummy and a variable indicating which noble family ruled the territory in 1500. For the sources see Cantoni, Dittmar and Yuchtman (2018)

Next, we used Cantoni, Dittmar and Yuchtman’s (2018) data set, which provides information on historical construction activities in all 2,257 cities in the German Empire (as of 1937) that ever had city rights. This data set provides yearly information for the period from 1400 to 1600. Information on construction activities in those cities comes from the “*Deutsche Städtebuch*” (Handbook of German Cities) edited by Keyser and Stoob (1939–1974). From the information in the *Städtebuch*, Cantoni, Dittmar and Yuchtman (2018) also take information on the number of markets in each of the cities in 1470. Their data set also includes other variables, such as a dummy for Protestant religion and the number of monasteries in the region around a city (and whether they were closed in the course of the Reformation or not).

We were interested in testing whether cities in the Roman area had more markets and constructed more economic buildings. We calculated the average number of buildings constructed each year between 1400 and 1600 and then calculated the share of economic buildings. As before, we assigned each city in their data set to the historically Roman part of Germany or to the non-Roman part based on our map of the Limes. We then assessed whether a city was located within 5 km from a Roman road. We included several controls from the data sets of Cantoni, Dittmar and Yuchtman (2018) and that of Dittmar and Meisenzahl (2020), among them a dummy for the presence of a university by 1517 and a dummy for cities that became Protestant.

Columns (5) to (8) of Table 4 report the results of OLS estimations, explaining the number of markets and the share of economic buildings with a Roman dummy or a Roman road dummy and controls. It turns out that both cities in the Roman area, as well as those located close to Roman roads, had significantly more markets and significantly higher shares of economic buildings. This suggests that those cities were centers of trade and commerce—and therefore a breeding ground for entrepreneurial activity and behavior—already during the late Middle Ages and the early modern period.

All in all, the results are not only in line with previous results on the persistent development effect of Roman legacies in Germany (Wahl, 2017) but also show that the Roman part of Germany had a higher educational level and more trading and commercial activity and, thus, probably also a more developed entrepreneurial and innovative culture already in the Middle Ages.

4.4 Results for imprinting effects of further historical events

Given the rather long period of time between the Roman occupation and today, other major historical events that occurred during this period may also have had a long-term imprinting effect, shaping regional outcomes. Two such events are of special interest in our case. The first of such events is the French occupation of several areas of Germany during the Napoleonic period, which, among other things, induced the early adoption[26] of the Code Napoleon (Buggle, 2016). The Code Napoleon introduced equality before the law and led to the abolition of guilds and trade licenses, thereby significantly enhancing economic freedom and creating entrepreneurial opportunities for large parts of the population. As shown by Donges et al. (2021), the Code Napoleon had positive effects on innovative activities and especially on high-tech innovations as measured by patents.

The second event is the labor demand shock caused by the influx of refugees from the previously German areas of Eastern Europe after World War II. At that time, Germany was divided into four Allied occupation zones, and the zone in the South-West of Germany that was governed by France was the only one that did not allow immigration of these refugees. As a consequence, the area of the French occupation zone experienced lower population growth at least until the 1970s (Schumann, 2014; Wyrwich, 2020). Since both events were limited to areas on the Roman side of the Limes, they may confound our results with regard to the effects of Roman occupation. To account for these two events, we made use of two dummies equal to 1 if a county is located in the area occupied by Napoleon in 1804 or within the French occupation zone after 1945, respectively. We created these variables using information about the border of the French-occupied territories that introduced the Code Napoleon in 1804 (from Buggle, 2016) and of the French occupation zone (from Schumann, 2014).[27]

To test the influence of those variables and whether and how they affect the coefficient of the Roman dummy, we included both into the regression models with a full set of controls as reported in Tables 1 and 2. Table 5 reports the results of these extended specifications. Most importantly, the coefficient of the Roman dummy remains virtually unchanged and significant for all outcome variables.

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[26] The Code Napoleon was introduced in all French territories in the year 1804. Later on it was also adopted in some other regions and particularly led to rather similiar regulations in many parts of Germany over the course of the 19th century.

[27] Descriptive statistics of both dummy variables are reported in Table A2 in the Appendix.

Table 5: The Roman effect when controlling for Napoleon and the French occupation after World War II

Dependent variable	(1) High-tech start-ups over workforce	(2) Start-ups over workforce	(3) Share of R&D employees	(4) ln(patents over workforce)	(5) ln(original patents over workforce)	(6) ln(radical patents over workforce)
Roman(1=yes)	0.748***	5.562***	0.447***	0.239**	0.279***	0.122***
	(0.158)	(1.441)	(0.144)	(0.108)	(0.0781)	(0.0408)
French Occupation Zone (1=yes)	-0.126	0.285	-0.738**	0.0708	0.192	-0.0406
	(0.220)	(2.340)	(0.313)	(0.176)	(0.140)	(0.0724)
Code Napoleon (1=yes)	0.0314	0.609	0.045	0.0338	0.166*	0.0779**
	(0.162)	(1.508)	(0.174)	(0.133)	(0.0932)	(0.0394)
Terrain ruggedness	-0.0317	-0.046	-0.0579*	0.0194	0.0098	-0.0048
	(0.0314)	(0.260)	(0.0299)	(0.0208)	(0.0142)	(0.007)
Mean elevation	2.08e-05	-0.0048	-0.0003	-0.0009**	-0.0007**	-3.75e-05
	(0.0006)	(0.0054)	(0.0005)	(0.0004)	(0.0003)	(0.0001)
Coastal region (1=yes)	-0.573***	-3.560**	-0.374**	-0.825***	-0.0869	-0.11
	(0.129)	(1.557)	(0.158)	(0.159)	(0.113)	(0.123)
Caroboniferous rock strata (1=yes)	-0.0635	0.354	0.276*	-0.0465	-0.0322	-0.0104
	(0.143)	(1.719)	(0.159)	(0.122)	(0.0874)	(0.0590)
Hanseatic League (1=yes)	-0.0853	-0.709	-0.113	-0.0125	0.0111	0.0553
	(0.117)	(1.114)	(0.131)	(0.118)	(0.0913)	(0.0445)
Number of Celtic Oppida	-0.096*	-1.018**	-0.0547	-0.0593	-0.0601**	-0.007
	(0.0523)	(0.492)	(0.0335)	(0.0385)	(0.0276)	(0.0125)
Soil suitability	-0.0078**	-0.138***	-0.0036	0.008**	0.0022	-0.002
	(0.0039)	(0.0324)	(0.0055)	(0.0034)	(0.0026)	(0.0015)
Intersects major river (1=yes)	-0.234**	-1.438	-0.110	-0.0051	0.0274	-0.008
	(0.114)	(1.049)	(0.103)	(0.0942)	(0.0595)	(0.0303)
Number of plague outbreaks	0.0678***	0.347***	0.049***	0.0270***	0.0104***	0.0043**
	(0.012)	(0.092)	(0.0111)	(0.0077)	(0.0038)	(0.0021)
Federal state dummies included	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Number of observations	401	401	401	401	401	401
R^2	0.361	0.294	0.242	0.553	0.225	0.105

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. Stars after the "Yes" indicate the level of joint statistical significance of the federal state dummies.

This result clearly demonstrates that these two other historical events are not behind the Roman effect. The dummy variable for the French occupation zone is insignificant in almost all models and only shows a significantly negative effect on the share of R&D employees. The Code Napoleon dummy seems to positively and significantly affect the number of original and radical patents per workforce but not the overall number of patents per workforce. This is in line with the findings of Donges et al. (2021), showing that the effect they found for historical patenting activity is still visible today, although not for patenting in general anymore.

4.5 Further robustness checks

To further test the robustness of our results, we conducted two additional empirical exercises. First, we re-ran the regressions from Tables 1 and 2 with all the controls but excluded the 13 cities in Germany that have more than 500,000 inhabitants.[28] These cities are also clusters of entrepreneurial activity due to reasons that could be unrelated to Romans' presence. Therefore, we wanted to show that our results are robust to the exclusion of those large cities and also hold when just considering small and medium-sized cities and rural counties. Table A4 in the Appendix shows the results of these regressions. The coefficients of the Roman dummy are virtually identical to the ones obtained, including the large cities.

Second, we included an additional control variable for the dominant mode of inheritance in the baseline regressions. This variable is a dummy with a value of 1 for counties where equal partition was the dominant way to inherit agricultural property in the mid-1950s—meaning that farmland is split equally among all surviving children. In the opposite case of primogeniture, where only the eldest son inherits the farmland, the dummy variables have the value of 0.[29] Huning and Wahl (2021a) show for the case of the German Federal State of Baden Wuerttemberg that a tradition of inheritance by equal partition is significantly related to early industrialization, high levels of self-employment, as well as relatively high shares of small and medium-sized companies. Because small firms are commonly regarded as seedbeds for entrepreneurship (Parker, 2009), and due to a regional tradition of relatively high self-employment, the

[28] These cities are Berlin, Bremen, Cologne, Dortmund, Dresden, Düsseldorf, Essen, Frankfurt am Main, Hamburg, Leipzig, Munich, Nuremberg, and Stuttgart.

[29] Data were taken from Hager and Hilbig (2019) and aggregated to county level. The data represent the most recent detailed assessment of the dominant inheritance mode at a small regional scale that is available in Germany. Although East German regions are not included in these data, we know from other sources that the dominant mode of inheritance in this part of the country was primogeniture. A potential influence of 40 years of socialist regime in East Germany on the effect of the ineritance mode should be accounted for by the federal state dummies.

inheritance mode of equal partition could be a significant predictor of entrepreneurial activity. Since equal partition was mostly prevalent in the historically Roman parts of Germany, we investigated to what extent the relationship between inheritance mode and entrepreneurship might confound the results of our analysis. Table A5 in the Appendix shows the results of the regressions, including the equal partition dummy. We find that the dummy for equal partition has a significant and positive effect on start-up rates, but there is no robust relationship with patenting activity. The size of the Roman dummy decreases because of the inclusion of an equal partition dummy, but it remains high statistically for all the outcomes. These results should, however, be interpreted with caution, as the findings of Huning and Wahl (2021b) suggest that equal partition in Germany has significant Roman roots, which makes it a bad control. In sum, our results and conclusion remain fully intact even after these additional robustness checks.

5. Conclusions

We have presented empirical evidence for a statistically significant relationship between being part of the Roman Empire about 1,700 years ago and present-day quantity and quality of entrepreneurship and innovation, indicative of a stronger entrepreneurial and innovative culture. These statistical relationships remain rather robust when controlling for a number of alternative explanations, such as locational characteristics (climate, quality of the soil, terrain ruggedness), or historical events, like the number of plague outbreaks in the Middle Ages, membership in the Hanseatic League, and introduction of the Code Napoleon.

Although we have no single explanation for the persistence of the ‘Roman effect’ over such a long period of time, there is a solid indication that the density of the Roman road network played a particularly important role in the transmission of this deep cultural imprinting. The establishment of a road network in the formerly Roman parts of Germany facilitated interregional mobility and interaction within these regions and particularly linked them to other parts of the Roman Empire. Since the Roman part of Germany was inhabited by Roman Government officials, soldiers and their relatives from all over the Empire, the population in these regions was comparatively diverse. The high level of geographically widespread social and economic interactions as well as the heterogeneity of the population might have shaped an attitude of openness, lower levels of risk aversion, and greater tolerance toward change, which ultimately fostered a positive entrepreneurial and innovative culture. Generally, being part of the Roman Empire and participating in its culture could have led to an early development advantage in these German regions over the less developed ‘barbaric’ regions on the other side of the Limes. The Roman culture did not vanish once the Romans had to give up these German territories. Cultural artifacts such as the advanced Roman road network, which still shapes the geographic structure of the road network in the previously Roman area today (Section 2.2), continued to facilitate economic development in these regions.

Another Roman legacy and cultural artifact that may explain a relationship between Roman occupation and current innovation and entrepreneurship is the presence of Roman markets and mines, which indicate high levels of social activity and economic exchange. Such high activity levels may have created pronounced incentives for creativity, innovativeness, and commercialization that could have attracted like-minded people to these places. In our statistical analysis, the number of Roman markets and mines turned out to be statistically significant for patents per workforce, but the relationship was much weaker than for the density of Roman roads.

Whether, among others, selective migration into the Roman area or the persistence of specific characteristics of the population of this area contribute to our results is, however, speculative. The vast migration movements following the demise of the Roman Empire make it extremely difficult to assess such conjecture. Nevertheless, Gomtsyan (2017) provides evidence in this direction by showing that cities in the former Roman part of Germany experienced higher in-migration rates until today and that these migration movements have shaped the attitudes of the city’s residents toward migration.

What is particularly interesting and impressive is that the ‘Roman effect’ seems to have endured the many disruptive changes that the German regions have experienced over the last 1,700 years. Over this period there were, for example, enormous levels of in- and out-migration of population, numerous devastating wars and diseases, changing administrative borders and political regimes, new religions as well as—last but not least—enormous developments in technology, social practices, and a pronounced increase in economic welfare. Clearly, our understanding of more recent disruptive changes and developments needs to be updated by an understanding of underlying deep and often not directly ‘visible’ cultural imprinting that could shape the past, present, and future, including complex migration patterns (Abdellaoui et al., 2019). Access to a unique global macro-psychological dataset that provides regional data for Germany (see Obschonka et al., 2017; Fritsch et al., 2018) enables us to test whether this ‘Roman effect’ might also be detectable when looking at the less tangible facets of culture. Quite strikingly, we indeed find that our variables for Roman presence predict the regional variation in an entrepreneurial personality profile (see Fritsch et al. (2018) and Stuetzer et al. (2016) for the measurement of this psychological profile). We interpret this result as being in line with our assumption that the Romans indeed left a deep cultural imprint in those regions that formerly belonged to the Roman Empire. This ‘Roman effect’ is likely to transcend to the more hidden facets of culture, such as a region’s macro-psychological profile.

The astonishing empirical evidence that we have presented here calls for more research on such deep cultural imprinting effects of historical events. What characterizes events that have long-lasting effects on the respective regions? What are the mechanisms behind the long-term persistence of such effects despite several rather disruptive shocks, including massive in- and out-migration? Even more importantly, what are the concrete implications for economic policies addressing entrepreneurial and innovative cultures in regions (Huggins et al., 2021)? Is there something like the ‘spirit’ of a place—or what Alfred Marshall (1920) suspected to be ‘in the air’—that immigrants tend to adapt to? Does a region-specific, place-based ‘cultural memory’ (Gieryn, 2000; Olick et al., 2011; Zukin, 2011) play a role here that might get lost for some longer time period but can return when triggered by certain events? What are the relevant cultural artifacts by which ancient cultures have shaped today’s region? Altogether, there is considerable evidence that Roman rule left a long-term imprint on regional development in general. Our study specifies how it might have shaped entrepreneurship and innovation activities via massive, lasting, cultural anchoring.

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Appendix

Table A1: Definition of variables

Variable	*Definition*	*Data source*
Roman	Dummy variable for a county being completely Roman territory in the 2nd century AD (=1) or not (=0)	McCormick et al. (2013)
Roman road density	Kilometers of major Roman roads per km² of area	McCormick et al. (2013)
Numbers of Roman markets and mines	Number of Roman markets and mines in a region	McCormick et al. (2013)
Roman road	Dummy variable for a county being within 5 km from a major Roman road (=1) or not (=0)	McCormick et al. (2013)
Patents over workforce	Average Number of patent applications in 2008 to 2014 by 10,000 employees	RegPat database of the OECD (version February 2019)
Start-ups over workforce	Average number of new businesses in a county in the years 2008 to 2016 over 10,000 persons in the workforce	Enterprise Panel of the Center for European Economic Research (ZEW-Mannheim)
High-tech start-ups over workforce	Average number of new high-tech businesses in a county in the years 2008 to 2016 over 10,000 persons in the workforce	Enterprise Panel of the Center for European Economic Research (ZEW-Mannheim)
Share of R&D Employees	Average share of employees working in the R&D sector in 2008 to 2014	German Establishment History Panel
Intersection of major river	Dummy variable for a county intersecting with a major river (Danube, Elbe, Oder, or Rhine) (=1) or not (=0)	WISE Large Rivers and Lakes dataset provided by the European Environment Agency (EEA)
Coastal region	Dummy variable for a county being located on the coastline (=1) or not (=0)	Europe coastline shapefile from the EEA
Mean elevation	Mean elevation of a planning region in meters	Digital Elevation Model over Europe (Euro-DEM) of the EEA. The resolution of the raster data is 1 arc second.
Terrain ruggedness	Standard deviation of a county's elevation	Own calculation using QGIS
Soil suitability	Average suitability of a county's soils to grow the 16 globally most important food and energy crops (from 1961 to 1990)	Zabel et al. (2014)
Number of Celtic Oppida	Number of Celtic Oppida in a county	Atlas of the Roman Empire (DARE); Pleiades Database of Ancient Places; Kristiansen (2000); Kuckenburg (2000); Menghin (1995); Rieckhoff (2008)
Hanseatic League	Dummy variable for a county being an important member of the Hanseatic League (either a capital of a quarter or otherwise considered to be a leading city)	Dollinger (1966)
Number of plague outbreaks	Number of major historical plague outbreaks in a county	Biraben (1975); Büntgen et al. (2012)
Carboniferous rock strata	Dummy variable for a county having late Carboniferous rock strata (=1) or not (0)	Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)
Federal state dummies	Dummy variable assigning each county to a federal state	Bundesamt für Kartographie und Geodäsie (shapefile of federal state borders)
Code Napoleon	Dummy variable indicating whether in a county the Code Napoleon was introduced in 1804.	Buggle (2016)
French Occupation Zone	Dummy variable for counties located within the French occupation zone after World War II	Schumann (2014)
Equal partition	Dummy indicating whether equal partition is the dominant agricultural inheritance tradition in a county (=1) or not (=1).	Hager and Hilbig (2019)

Table A2: Descriptive statistics

Variable	*Mean*	*Minimum*	*Maximum*	*Standard deviation*
Carboniferous rock strata (1=yes)	0.067	0	1	0.251
Coast region (1=yes)	0.057	0	1	0.233
Code Napoleon (1=yes)	0.19	0	1	0.392
Equal partition (1=yes)	0.197	0	1	0.398
French Occupation Zone (1=yes)	0.057	0	1	0.233
Hanseatic League (1=yes)	0.167	0	1	0.374
High-tech start-ups over workforce	2.558	0.944	8.712	0.964
Intersects major river (1=yes)	0.214	0	1	0.411
ln(original patents over workforce)	-2.585	-5.501	-1.405	0.482
ln(patents over workforce)	-7.023	-9.661	-4.630	0.935
ln(radical patents over workforce)	-1.625	-2.214	-1.132	0.178
Mean elevation	274.7	0.925	1,110	210.5
Number of Celtic Oppida	0.444	0	7	1.004
Number of plague outbreaks	1.416	0	37	4.513
Patents over workforce	0,001	6.37e-05	0,01	0,001
Roman (1=yes)	0.374	0	1	0.484
Share of R&D employees	1.463	0.329	7.830	0.923
Soil suitability	41.53	3.833	74.44	13.77
Start-ups over workforce	38.72	24.13	81.88	8.175
Terrain ruggedness	4.068	0,024	20.36	3.123
Roman (1=yes)	0.374	0	1	0.484
Number of Roman markets and mines	0.087	0	4	0.381
Roman road density	0.018	0	0.223	0.363

Table A3: Correlations among outcome variables and the variables of Roman presence

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Roman (1=yes)	1.000								
(2) Number of Roman markets and mines	0.270 (0.000)	1.000							
(3) Roman road density	0.598 (0.000)	0.200 (0.000)	1.000						
(4) Start-ups over workforce	0.172 (0.001)	0.033 (0.516)	0.217 (0.000)	1.000					
(5) High-tech start-ups over workforce	0.347 (0.000)	0.104 (0.037)	0.311 (0.000)	0.757 (0.000)	1.000				
(6) Share of R&D Employees	0.184 (0.000)	0.079 (0.116)	0.259 (0.000)	0.229 (0.000)	0.546 (0.000)	1.000			
(7) ln(patents over workforce)	0.454 (0.000)	0.167 (0.001)	0.374 (0.000)	0.319 (0.000)	0.601 (0.000)	0.499 (0.000)	1.000		
(8) ln(original patents over workforce)	0.114 (0.023)	0.032 (0.528)	0.175 (0.000)	0.202 (0.000)	0.188 (0.000)	0.175 (0.000)	0.188 (0.000)	1.000	
(9) ln(radical patents over workforce)	0.028 (0.570)	0.003 (0.952)	0.054 (0.276)	0.139 (0.005)	0.114 (0.022)	0.092 (0.065)	0.035 (0.486)	0.681 (0.000)	1.000

Table A4: The Roman effect when leaving out cities with more than 500,000 inhabitants

Dependent Variable	(1) High-tech start-ups over workforce	(2) Start-ups over workforce	(3) Share of R&D employees	(4) ln(patents over workforce)	(5) ln(original patents over workforce)	(6) ln(radical patents over workforce)
Roman (1=yes)	0.723***	5.322***	0.473***	0.260**	0.317***	0.104***
	(0.150)	(1.271)	(0.140)	(0.103)	(0.0736)	(0.0300)
Terrain ruggedness	-0.0253	0.00820	-0.0467	0.0197	0.0156	0.000737
	(0.0289)	(0.239)	(0.0298)	(0.0198)	(0.0138)	(0.00519)
Mean elevation	-4.46e-05	-0.00441	-0.000703	-0.000848**	-0.000754**	-9.88e-05
	(0.000525)	(0.00447)	(0.000514)	(0.000347)	(0.000296)	(0.000100)
Coastal region (1=yes)	-0.574***	--3.515**	-0.384**	-0.826***	-0.0860	-0.0309
	(0.128)	(1.529)	(0.156)	(0.160)	(0.115)	(0.0551)
Carboniferous rock strata (1=yes)	-0.119	0.113	0.200	-0.0236	-0.0556	-0.0272
	(0.137)	(1.832)	(0.177)	(0.132)	(0.0908)	(0.0344)
Hanseatic League (1=yes)	-0.104	-1.108	-0.103	-0.00541	-0.0229	0.0168
	(0.101)	(0.943)	(0.133)	(0.115)	(0.0913)	(0.0325)
Number of Celtic Oppida	-0.0922*	-0.946*	-0.0546	-0.0588	-0.0577**	-0.0234**
	(0.0525)	(0.499)	(0.0337)	(0.0383)	(0.0278)	(0.00940)
Soil suitability	-0.00719*	-0.136***	-0.00172	0.00803**	0.00152	-9.66e-06
	(0.00378)	(0.0324)	(0.00562)	(0.00341)	(0.00259)	(0.000922)
Intersects major river (1=yes)	-0.264**	-1.506*	-0.174	-0.00667	0.0510	-0.0133
	(0.108)	(0.893)	(0.108)	(0.0944)	(0.0600)	(0.0240)
Number of plague outbreaks	0.0585***	0.286***	0.0401***	0.0214**	0.00917**	0.00219
	(0.0122)	(0.109)	(0.0119)	(0.00849)	(0.00455)	(0.00197)
Federal state dummies included	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Number of observations	388	388	388	388	388	388
R^2	0.318	0.254	0.189	0.552	0.199	0.121

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. Stars after the “Yes” indicate the level of joint statistical significance of the federal state dummies.

Table A5: The Roman effect when controlling for equal partition

Dependent Variable	(1) High-tech start-ups over workforce	(2) Start-ups over workforce	(3) Share of R&D employees	(4) ln(patents over workforce)	(5) ln(original patents over workforce)	(6) ln(radical patents over workforce)
Roman (1=yes)	0.701***	5.114***	0.449***	0.233**	0.299***	0.0960***
	(0.154)	(1.298)	(0.138)	(0.102)	(0.0730)	(0.0300)
Terrain ruggedness	-0.0405	-0.144	-0.0529*	0.0173	0.0103	-0.000672
	(0.0293)	(0.240)	(0.0292)	(0.0198)	(0.0135)	(0.00523)
Mean elevation	0.000338	-0.000643	-0.000540	-0.000745**	-0.000605**	-6.25e-05
	(0.000548)	(0.00448)	(0.000533)	(0.000368)	(0.000304)	(0.000105)
Coastal region (1=yes)	-0.564***	-3.433**	-0.384**	-0.821***	-0.0827	-0.0300
	(0.129)	(1.553)	(0.157)	(0.159)	(0.115)	(0.0552)
Caroboniferous rock strata (1=yes)	-0.0567	0.525	0.230	-0.0391	-0.0207	-0.00792
	(0.144)	(1.735)	(0.161)	(0.120)	(0.0850)	(0.0327)
Hanseatic League (1=yes)	-0.0598	-0.475	-0.113	-0.00996	-0.00307	0.0211
	(0.110)	(1.036)	(0.135)	(0.116)	(0.0902)	(0.0321)
Number of Celtic Oppida	-0.119**	-1.248***	-0.0642**	-0.0642*	-0.0654**	-0.0251***
	(0.0498)	(0.482)	(0.0320)	(0.0379)	(0.0289)	(0.00961)
Soil suitability	-0.00772**	-0.140***	-0.00252	0.00780**	0.00142	8.52e-06
	(0.00384)	(0.0315)	(0.00548)	(0.00333)	(0.00252)	(0.000909)
Intersects major river (1=yes)	-0.218*	-1.095	-0.173	0.00985	0.0620	-0.00979
	(0.113)	(0.986)	(0.106)	(0.0927)	(0.0584)	(0.0233)
Number of plague outbreaks	0.0658***	0.322***	0.0496***	0.0262***	0.00892**	0.00121
	(0.0120)	(0.0906)	(0.0115)	(0.00767)	(0.00354)	(0.00151)
Equal partition (1=yes)	0.418***	4.421***	0.153	0.101	0.150*	0.0379
	(0.153)	(1.541)	(0.158)	(0.108)	(0.0767)	(0.0306)
Federal state dummies included	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	401	401	401	401	401	401
R^2	0.374	0.314	0.229	0.554	0.221	0.126

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. Stars after the “Yes” indicate the level of joint statistical significance of the federal state dummies.

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