LANDSCAPE CHANGE AND TRADE IN ANCIENT GREECE: EVIDENCE FROM POLLEN DATA

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Abstract

In this paper we use pollen data from six sites in southern Greece to study long-term vegetation change in this region from 1000 BCE to 600 CE. Based on insights from environmental history, we interpret our estimated trends in the regional presence of cereal, olive, and vine pollen as proxies for structural changes in agricultural production. We present evidence that there was a market economy in ancient Greece and a major trade expansion several centuries before the Roman conquest. Our results are consistent with auxiliary data on settlement dynamics, shipwrecks, and ancient oil and wine presses.

JEL Classification: C81, F14, N53, N73, Q17

Keywords: agricultural production, ancient Greece, environmental history, market integration, pollen data, trade

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The concepts of market and market economy play a central role in economics. Many prominent social scientists, including Marx and Weber, asserted that the market economy is predominantly a modern phenomenon. For example, Weber (1978 [1922]) argued that although markets had existed in antiquity, they had not constituted a significant part of the structure of ancient economies and had never become fully integrated as mature market systems, which according to Weber had developed in the 19th century.

Similar views on markets dominated the field of ancient history for most of the 20th century. While such earlier scholarship argued that markets had played a minor role in the agricultural economies of Greek and Roman communities (see, *e.g.*, Polanyi, 1968; Finley, 1973; Polanyi, 1977), recent research has changed this picture by highlighting the high volumes of trade and increasing market integration, particularly for the Roman Mediterranean (see, *e.g.*, Kessler and Temin, 2008; Temin, 2013). Although archaeological evidence from these periods documents the movement of goods, quantifiable data on market integration and structural changes in agricultural production have been very limited. This is unfortunate, given that the crucial role of structural change in economic development has been acknowledged since at least Kuznets (1966), who documented the relationship between economic growth and major changes in the structure of the economy.

In this paper we demonstrate how palynology—the study of pollen remains extracted from cored sediments—can be used to examine changes in the structure of agricultural production and to link these changes to periods of increasing market integration in the context of ancient pre-industrial economies. In doing so, we extend the methodology of Izdebski *et al.* (2016), which allows us to combine evidence from a number of sites in southern Greece to estimate regional trends in the presence of pollen attributable to different plant taxa, including cereals, olive, and vine. These cultivars are particularly important in our empirical context, as wheat, olive oil, and wine formed the basis of ancient diets (see, *e.g.*, Sallares, 1991; Isager and Skydsgaard, 1992). Consequently, our analysis of these data—which have not been previously used to study the economic history of Greco-Roman antiquity—provides novel evidence on structural changes in ancient Greek agriculture across sixteen centuries, from 1000 BCE to 600 CE.

Our results strongly support the view that there was a market economy in ancient Greece and a major trade expansion in the Archaic and Classical periods. Throughout the paper, we focus mostly on these periods and pre-Roman Greece in general, given the paucity of prior quantitative evidence for this era. We demonstrate that in a period of apparent population growth southern Greece decreased its relative production of cereals. We also observe a simultaneous increase in the relative importance of olive and vine. Since southern Greece had a comparative advantage in the production of olive oil and wine, we interpret this result as evidence of a trade expansion. The growing demand for wheat could only have been satisfied by massive grain imports, perhaps from the Black Sea region, which were offset by exports of olive oil and wine. These commodities were in high demand in Greek colonies and other neighbouring areas—which needed them for cultural reasons but were not always able to produce them locally.

This finding constitutes one of our main contributions to the recent literature in ancient economic history. Our empirical results point towards agricultural production strategies structured at least partly in accordance with market integration, as previous research has also suggested (see, *e.g.*, Kessler and Temin, 2008; Temin, 2013). Most previous contributions, however, have concluded that ancient market integration was also related to the expansion of the Roman Empire (see, *e.g.*, Temin, 2001; Geraghty, 2007; Erdkamp, 2016). In this paper we provide evidence that regional specialization started centuries earlier than many of the previous studies have assumed.

Admittedly, ours is not the only possible explanation of the patterns we observe in the data. However, we provide additional supporting evidence for our initial interpretation. First, we argue that our empirical results are consistent with the timing of the foundation of the Greek colonies in the Black Sea region. Moreover, we review some of the recent historical scholarship which has emphasized high levels of bulk exchange in pre-Roman Greece (see, *e.g.*, Moreno, 2007; Bresson, 2016). Second, we use data from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) project to corroborate our earlier assertion that southern Greece had a comparative advantage in olive cultivation as opposed to cereals. Finally, we perform a difference-in-differences exercise to demonstrate that there was a differential trend in agricultural production in the late Archaic and Classical periods, which was associated with trade costs and the distance to the Black Sea colonies. In other words, in places where trade costs were higher, local populations seem to have been growing more cereals and less olive and vine, which would otherwise have been exported to the Black Sea region.

We contribute to the growing literature in economic history which has recognized the importance of new sources of quantitative data on ancient economies. In a recent paper, Temin (2006a) argued that '[t]here is a lot of information [about ancient economies], but hardly any of what economists call data'. Thus, out of necessity, some studies have been based on unusually small samples. For example, Kessler and Temin (2008) studied the effects of the distance from Rome on local wheat prices. While the authors found evidence of an integrated grain market, their analysis involved only six observations. Other papers have provided estimates of Roman GDP and income inequality (see, *e.g.*, Goldsmith, 1984; Temin, 2006b; Allen, 2009; Milanovic *et al.*, 2011), which again are derived from a very small number of data points. As Temin (2013) stated it: 'All of the GDP estimates ... rest on an exceedingly narrow evidentiary base. They are at best conjectural estimates based on a few observations, some about the early Roman Empire and some about modern economies.'

Given the extremely limited quantitative data from the essential regions of the Greco-Roman world, many scholars have instead analysed much richer data from Babylon and Egypt. Others have studied the data on Mediterranean shipwrecks, originally collected by Parker (1992) and more recently expanded by Wilson (2011), McCormick (2012), and

Strauss (2013). These data have often been used as a proxy for seaborne trade or even for the overall level of economic activity (see, *e.g.*, Hopkins, 1980; Geraghty, 2007; Kessler and Temin, 2007; Terpstra, 2019). Following this interpretation, the shipwreck data are suggestive of an economic boom and a trade expansion in the early Roman Empire. Still, shipwreck-based studies have certain inherent limitations, as discussed by Wilson (2011) and McCormick (2012), among others.

Thus, in recent years, further sources of quantitative data on ancient economies have been introduced to economic history. A number of studies, such as de Callataÿ (2005), Jongman (2007), McConnell *et al.* (2018), and Terpstra (2019), discussed the implications of lead pollution recorded in Greenland ice for our understanding of ancient economic history over the very long term. Barjamovic *et al.* (2019) analysed commercial records from the Old Assyrian trade network in the 19th century BCE. They estimated a gravity model of trade and used this model to predict locations of lost ancient cities. While the authors did not explicitly study the question of market integration, their data documented the importance of long-distance trade in the Bronze Age. Finally, Bakker *et al.* (2018) contributed to our knowledge about the link between trade (or, in fact, trade potential) and development by establishing a positive relationship between the connectedness of points on the Mediterranean coast and the presence of archaeological sites.

In this paper we introduce pollen records as a new source of quantitative data in ancient economic history. We argue that pollen data have a number of important advantages. First, unlike most previous studies, we have access to a relatively large number of data points from southern Greece, an essential region of the ancient world. Second, unlike many sources of data which offer a single snapshot from ancient economic history, pollen data allow us to study long-term change in a principal economic activity of ancient communities and to go further back in time than many previous studies. Indeed, in this paper we provide evidence on structural changes in ancient Greek agriculture across sixteen centuries, from 1000 BCE to 600 CE, although most of our interpretations focus on pre-Roman economic developments. Third, the methodology of data collection in palynology is standardized; the procedures followed by palynologists are virtually identical from site to site, which is not generally true for archaeological data or textual sources. Finally, in the case of pollen data, it is possible, in principle, to obtain more and more information about regions and time periods that we wish to study. Palynological research is very labour intensive and many potential pollen sites await exploration. When more data become available, it will be possible to replicate existing studies—such as ours—and obtain more efficient estimates. On the other hand, of course, each source of data also has its limitations. In the case of pollen data, we cannot make inferences about the *levels* of economic activity; instead, we focus on the *structure* of agricultural production, as we only observe percentages of pollen attributable to different plant taxa.[1]

The remainder of the paper is organized as follows. Section 1 provides a brief overview of ancient Greek history. Section 2 describes our data and estimation method. Section 3 presents our main results. Section 4 validates our methodology by comparing our estimates with auxiliary data on settlement dynamics, shipwrecks, and oil and wine presses. Section 5 provides additional evidence for our main claim. Section 6 concludes.

1 Historical Background

The pollen data used in this paper are derived from cored sediments in the southern Greek mainland, incorporating the Peloponnese and central Greece. After the destruction of Bronze Age palace systems in the Greek mainland in the late 13th century BCE, major transformation occurred in terms of settlement structures and economic systems. From the 11th century onward Greece seems to have been organized through small-scale

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[1] Interestingly, however, it also turns out that our estimates, despite only having a relative interpretation, are often informative about general economic and population trends. After we present our main findings, we validate our methodology by comparing our estimates with three sources of auxiliary data: on settlement dynamics (Weiberg *et al.*, 2016), ancient shipwrecks (Strauss, 2013), and large-scale oil and wine presses (Marzano, 2013). Our estimates are consistent with each of these sources of data.

village systems engaged primarily in subsistence farming. By the 8th century BCE we see evidence of expanding settlements and more expansive land-use systems within large parts of southern mainland. In the eastern part of central Greece and the north-eastern Peloponnese, rapid urbanization and development of autonomous and semi-autonomous city-states (*poleis*) occurs from the late 8th century BCE and onward with particular landscape developments occurring between the end of the Persian Wars in 480 BCE and the death of Alexander the Great in 323 BCE. By the late 4th century BCE, the southern mainland was a densely populated region of the Mediterranean dominated by urban communities comprised to a large extent of citizen farmers. It is also in the second half of the 4th century BCE that we can observe the growing importance of the Macedonian kingdom in the northern mainland. By the death of Alexander, Macedonia would control territories in all of the Greek mainland as well as regions formerly incorporated in the Achaemenid Persian Empire. In the 3rd and early 2nd century BCE, the Macedonian kingdom under the Antigonid dynasty would continue to dominate parts of the Greek mainland, though large areas of southern Greece were also controlled by Leagues of cities in Achaea and Aetolia, which incorporated agriculturally-based urban communities into broader federal political units.

By the early 2nd century BCE, Rome became increasingly involved in political and military affairs in the Greek mainland. In 168 BCE the Antigonid king Perseus was defeated at the battle of Pydna, with the subsequent establishment of the Roman province of Macedonia in the northern mainland. In 146 BCE the Achaean League was dismantled in the Peloponnese and the city of Corinth was destroyed by the Roman general Lucius Mummius. Further Roman military incursions in southern Greece occurred in 88 BCE following the war with Mithridates leading to the sacking of prominent Greek cities, such as Athens, by the Roman general Sulla. A formal imperial province of Achaea was established in southern Greece in 27 BCE but by then this part of Greece had already been under strong Roman political and military influence for over a century. In the following

Table 1: *Major Events and Conventional Periodization of Ancient Greek History*

1000 BCE	the beginning of the early Iron Age
700 BCE	the end of the early Iron Age – the beginning of the Archaic period
480 BCE	the second Persian invasion of Greece – the end of the Archaic period
323 BCE	the death of Alexander the Great – the end of the Classical period
146 BCE	the Roman conquest of Greece – the end of the early Hellenistic period and the beginning of the late Hellenistic/early Roman period
31 BCE	the Battle of Actium – the end of the Hellenistic period
330 CE	the foundation of Constantinople – the end of the imperial Roman period
600 CE	the end of antiquity

period, Greece was consolidated as part of imperial political and economic structures, without a strong military presence. By late antiquity the area of Greece started to become a more economically significant region, especially after seemingly destructive incursions of barbarian tribes in the 3rd century CE. In this context, rural developments in the Greek mainland seem to have taken place after the re-foundation of Constantinople (former Byzantion) as the new capital of the Eastern Roman Empire in 330 CE. The foundation of the city brought the landscapes and agricultural production systems of mainland Greece closer to the urban markets of the new imperial capital, prompting transformation of rural settlement structures and landownership.

A recapitulation of some of these major events in ancient Greek history as well as its conventional periodization are provided in Table 1. A number of figures presented in this paper will highlight two of these events: the death of Alexander the Great in 323 BCE, *i.e.* the end of the Classical period, and the Roman conquest of Greece in 146 BCE.

2 Data and Method

The study of pollen in lake and peat sediments, known as palynology, is one of the most detailed and reliable ways of studying landscape change in the past. Palynologists study pollen found in sediment cores taken from lakes, lagoons, peat bogs, and other anaerobic environments, where the organic material can be preserved for thousands of years. In each core, researchers take samples at regular intervals, ranging from a few millimetres to a dozen centimetres, depending on the core length and the desired temporal resolution of the final reconstruction.[2] These samples are then processed in a laboratory in a way that allows the counting of pollen grains within each sample. In this way, a researcher gets snapshots of the vegetation structure surrounding a given site at a certain moment in time.[3] The sequence of such snapshots, or, more precisely, pollen assemblages, builds a pollen profile, which provides a detailed image of the landscape change in a given locality over time. For a more detailed discussion of palynology and its use for historians and economic historians, see Izdebski *et al.* (2016).

This relative pollen-based reconstruction of landscape change needs to be tied to historical time, and this is typically achieved by the means of radiocarbon (14C) dating. Usually, despite the fact that a pollen profile consists of at least one sample per a hundred years, only a few of these samples are actually radiocarbon dated. The number of radiocarbon dates is limited by their cost—much higher in the past than today—and the availability of organic matter—necessary for dating—in the cored sediments themselves. Moreover, as is the case with any laboratory measurement, the radiocarbon dating involves an error, expressed in confidence intervals. This error is further modified by the

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[2] This is not the only way of reconstructing vegetation history using pollen data. Pollen is also sometimes preserved on archaeological sites and on other sites where debris accumulates, such as abandoned animal shelters (termed middens). For example, Fall *et al.* (1990) used pollen data from hyrax middens to study deforestation and land degradation near the ancient city of Petra in a similar time frame to this paper. See also Diamond (1992) for a summary of this study.

[3] The exact spatial representativeness of pollen data from a single site depends on the type of the site and the type of pollen. For example, pine and olive pollen can travel up to fifty kilometres, while cereal and vine pollen travels only a few kilometres.

process of calibration. In this process, researchers recalculate raw radiocarbon dates into calendar years that take account of the annual and secular differences in solar activity.[4] In the end, using the radiocarbon dates obtained for a few samples, researchers estimate the age of all the remaining samples with the use of formal models that approximate the process of sediment formation over time.

Pollen data are never interpreted as raw counts. Rather, one follows the change in percentage values for individual plant taxa from one sample to another, or studies the change in the overall composition of the sample. A plant taxon can be a species, a family, or a genus, depending on how precise a palynologist's attribution for a given pollen grain can be; some plants are identifiable to the level of a species (*e.g.*, olive), while others are grouped in more general categories (*e.g.*, grasses). For each sample, different amounts of pollen grains are counted, and this depends in particular on the preservation of the pollen itself. These percentage values are therefore calculated against a basis sum of all pollen grains identified in a given sample, excluding pollen of plants with local over-representation (Berglund and Ralska-Jasiewiczowa, 1986).[5] In this paper the pollen sum includes trees, shrubs, and herbs, unless the original investigator of a given site recommended exclusion of some taxa from the total sum (*e.g.*, local marsh vegetation, pine pollen in marine deposits); this sum also excludes unidentifiable pollen grains and non-pollen material. Although the pollen sum includes all the standard taxa, our analyses are focused on the anthropogenic indicators, as well as on the most important arboreal taxa.

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[4] The energy from the sun is the physical force behind the process of the 14C creation in the upper layers of the atmosphere. Thus, it determines the changing amounts of the 14C in the atmosphere and in the living organisms which take the 14C with breathing and whose remains provide the material for the dating.

[5] Because some of the excluded plants might also eventually be of interest, palynologists sometimes end up calculating percentage values for plant taxa which do not contribute to the pollen sum. In this case the sum of all percentage values will be greater than 100.

2.1 Data

Most of the palynological data for Europe are available online in the European Pollen Database (EPD). For the purpose of this paper, we selected sites from southern Greece whose pollen profiles covered our period of study. Moreover, for a pollen site to be included in our data set, it also needed to be of satisfactory chronological reliability. Consequently, our data set includes only those pollen sites which are provided with at least one radiocarbon date for the last three and a half millennia. Apart from using the data available in the EPD, we have also made efforts to contact all investigators whose data are not published in the EPD, and as a result our analysis is based on all the relevant data available for southern Greece as of January 2018. Since some of our sites were originally analysed several decades ago, we use new age-depth models that were recently developed in a study of the medieval economic history of southern Greece and neighbouring regions (Izdebski *et al.*, 2015).

As is visible in Figure 1, our sites are clustered in mainland southern Greece, primarily composed of regions bordering the Gulf of Corinth. It is worth emphasizing that our sites

Table 2: *Pollen Sites in Southern Greece*

ID	Site name	No. of samples	Available dates
1	Vravron	19	1069, 971, 872, 774, 676, 578, 479, 381, 283, 185, 86, 37 BCE, 61, 110, 209, 307, 405, 503, 730 CE
2	Elefsina	23	1078, 1040, 984, 946, 889, 852, 795, 672, 597, 484, 380, 276, 201, 87, 12 BCE, 101, 167, 262, 347, 460, 535, 564, 630 CE
3	Lerna	14	1045, 863, 688, 346, 265, 117 BCE, 15, 118, 209, 269, 374, 472, 555, 613 CE
4	Kotychi	11	1072, 525, 451, 378, 231, 157, 10 BCE, 63, 137, 210, 504 CE
5	Voulkaria	41	554, 535, 517, 498, 489, 472, 454, 437, 420, 402, 385, 368, 351, 334, 317, 299, 281, 263, 245, 226, 186, 166, 145, 124, 101, 78, 55, 30, 5 BCE, 21, 48, 76, 104, 165, 229, 262, 332, 406, 484, 565, 649 CE
6	Halos	7	1219, 833, 239 BCE, 155, 400, 542, 630 CE

Notes: Site identifiers correspond to those in Figure 1. The total number of samples is 115. Further information about these pollen sites is provided in Table A2 in online Appendix A.

Figure 1: *Pollen Sites in Southern Greece*

Notes: The map has been created using the ASTER GDEM, a product of METI and NASA. Elevation is measured in metres above sea level.

are relatively homogeneous in terms of elevation above sea level and distance from sea. In Table 2, we report the number of samples as well as all years for which a sample is available at each site. The total number of samples in our data set is 115, with a range from 7 (Halos) to 41 (Voulkaria) per site. Each sample documents the whole structure of vegetation around a given site at a particular point in time.

Further details about our data are provided in online Appendix A. We begin by discussing the plant taxa that are available in our data set. Then, Table A1 reports the conventional names of all these taxa in palynological publications as well as their English counterparts. Table A2 reports the coordinates and the bibliographical information about each pollen site. Table A3 illustrates the structure of our data set by presenting a snippet of our data for the site of Vravron. Finally, Table A4 reports the summary statistics for all available plant taxa.

2.2 Method

Since palynological research typically focuses on local phenomena, our interest in regional vegetation requires the use of methods from outside the usual palynological toolkit. Izdebski *et al.* (2016) developed new methods of aggregating pollen data into regional trends. In this paper, however, we use a simpler method which is based on standard panel regression models.

Our method consists of two steps. In the first step, we use linear spline functions to interpolate missing yearly observations for each site and each plant taxon. This step is necessary because there is limited overlap across sites in calendar years for which some measurements are available. In cases where the first observation at a given site is dated after 1000 BCE or the last observation is dated before 600 CE, we do not impute the missing data outside of the original support.[6] In the second step, we estimate panel data models which have a simple form:

$$\log(y_{it} + 1) = \sum_{k=1}^{K} \tau_k t^k + c_i + u_{it}, \tag{1}$$

where y_{it} is the (possibly interpolated) raw percentage of pollen grains for a given plant taxon at site i in year t, t^k is the kth power of year, c_i is the individual effect of a given site, and u_{it} is the idiosyncratic error term. In this way, we approximate our regional trends of interest using flexible polynomials in time. We estimate our models using the

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[6] In practice, therefore, we treat all observations for Voulkaria before 554 BCE and Kotychi after 504 CE as missing data.

fixed effects estimator and we choose K, the degree of our polynomial, using the Akaike information criterion (AIC), with the maximum degree of 10. Our estimation sample is restricted to observations from 1000 BCE to 600 CE. All our main results are robust to using the methods of Izdebski *et al.* (2016) instead.

3 Empirical Results

In this section we discuss our main empirical results on pre-Roman trade. While, for the sake of brevity, we do not provide a detailed discussion of our results for the Roman period, we note that our trend estimates confirm that the Roman conquest in the middle of the 2nd century BCE constituted a watershed in the economic history of southern Greece, as previous research has also indicated. See Section 4 for further discussion.

3.1 Pre-Roman Trade: Cereals, Olive, and Vine

We present our main results on the long-term change in the presence of cereals, olive, and vine in Figure 2. Because we focus on pre-Roman Greece, all graphs are cropped at the end of the Hellenistic period. For comparison, we also plot a proxy for demographic change in southern Greece, namely the total number of sites from all archaeological survey projects that have been conducted in the Peloponnese since the 1960s (based on Weiberg *et al.*, 2016).[7] This variable approximates the overall trend in site density over the major part of southern Greece.

The results in Figure 2 indicate that southern Greece experienced demographic growth in the early Iron Age as well as in the Archaic and Classical periods. After the beginning of the Hellenistic period in 323 BCE, the number of sites started to decrease. The relative presence of olive and vine pollen was increasing—and then continued to be comparatively large—throughout the early Iron Age, the Archaic period, and the (early) Classical

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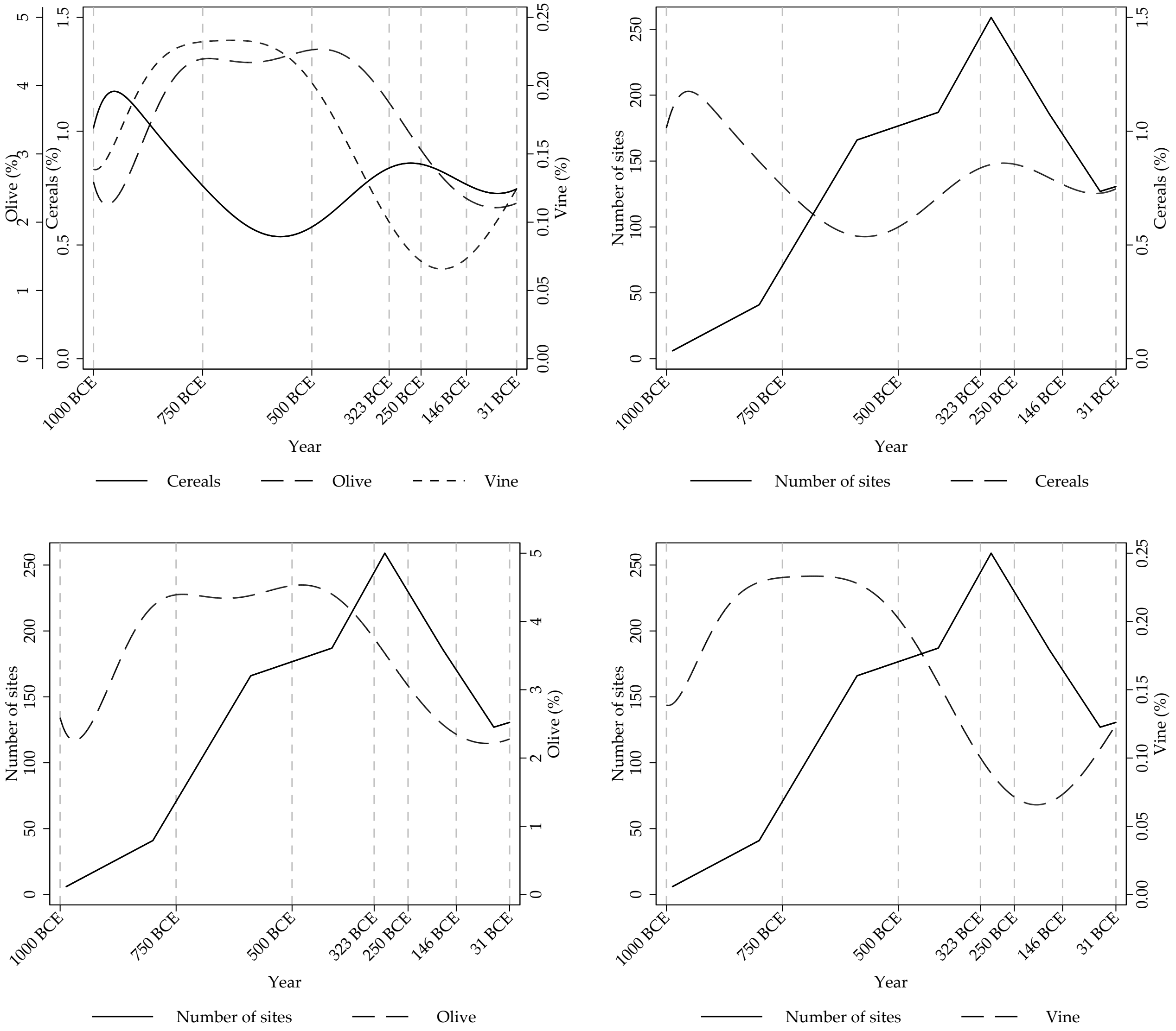
[7] Survey projects do not involve excavations but instead focus on examining the land surface for visible remains of ancient rural sites and settlements from different periods.

Figure 2: *Cereals, Olive, and Vine in Southern Greece*



Notes: The upper left panel displays pollen-based trends in the presence of cereals, olive, and vine in southern Greece. The remaining panels compare each of these trends with the total number of sites from archaeological survey projects in the Peloponnese (based on Weiberg *et al.*, 2016).

period. On the contrary, the proportion of pollen attributable to cereals was trending downwards in the early Iron Age and in the Archaic period, which ended in 480 BCE. In the Classical period and especially in the Hellenistic period, the importance of cereal cultivation appears to have increased.

The crucial observation is that, despite the apparent demographic growth in the Archaic period, cereals played an increasingly smaller role in the southern Greek agriculture and were becoming less and less visible in the landscape. At the same time, the importance of olive and vine cultivation was steadily increasing, leading to the question of why local producers chose to plant olives and vines instead of sowing grains, when the demand for this basic foodstuff must have been mounting.

Our answer is simple: southern Greece was developing an export economy based on cash cropping already in the Archaic period, primarily through olive (perhaps also vine) cultivation, which would be consistent with the exploitation of the comparative advantage of this region.[8] Following the Athenian model, cereals were likely obtained from the Black Sea area (see, *e.g.*, Moreno, 2007; Bresson, 2016), while olive products were traded on both a local and interregional scale. These changes from a basic subsistence economy primarily based on grain cultivation into a system based around more expansive investment in cash crops for export can potentially be linked with early urban developments taking place from the late 8th and early 7th century BCE onward.

While previous research on the Archaic and Classical periods often emphasized subsistence farming (see, *e.g.*, Finley, 1973; Sallares, 1991; Isager and Skydsgaard, 1992), regional studies have also discussed olive cultivation in the context of broader market production and its effects on landscape developments in the Classical and early Hellenistic periods (see, *e.g.*, van Andel *et al.*, 1986). Previous arguments for increasing market production have usually been based on evidence from survey data and written sources. Thus, the palynological evidence used in the current study adds important new data to our understanding of cash cropping, while highlighting the apparent pre-Roman trade expansion in the southern Greek mainland.[9]

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[8] See Foxhall (2007) for a discussion of ancient olive cultivation and agricultural investment. Our analysis below also confirms that southern Greece indeed has a comparative advantage in olive cultivation.

[9] Further results on the presence of various plant taxa in southern Greece are provided in online Appendix B. In particular, Figure B1 presents our main results for cereals, olive, and vine across sixteen centuries, from 1000 BCE to 600 CE. Figure B2 presents trend estimates for the remaining primary anthropogenic indicators (chestnut and walnut) as well as for all secondary anthropogenic indicators available in our data. In online Appendix A, we briefly discuss the concept of secondary anthropogenic indicators.

3.2 Alternative Explanations

Naturally, ours is not the only possible explanation of pollen-based trends in Figure 2. While the increase in the production of goods such as olives and wine might be driven, as we argue, by trade and an increased division of labour, it could also be driven by changes in taxation, changes in demand due to immigration, or nonhomothetic preferences and an increase in income. While immigration was generally small and taxation on a scale needed to influence agricultural production also did not occur before the Roman period, nonhomothetic preferences are more difficult to rule out. Indeed, under the assumption that incomes were rising in the Archaic and Classical periods, if olive and wine have a higher income elasticity than cereals, we should expect an increase in the consumption of olive and wine relative to cereals. It might be particularly plausible that the elites of the Greek city-states were increasing their consumption of olives and olive oil for both dietary and cultural reasons, including sports in the gymnasia. On the other hand, olives and wine should not be regarded as luxury goods in ancient Greece; on the contrary, together with cereals, they were responsible for much of the calorific intake and should be seen as staples (see, *e.g.*, Sallares, 1991; Isager and Skydsgaard, 1992). We admit, however, that it is impossible to disprove any such differences in income elasticities of cereals, olives, and wine in ancient Greece.

To help rule out these alternative mechanisms, we instead provide further evidence that supports our original interpretation. First, we summarize a body of historical research on the Archaic and Classical periods which has provided evidence of grain imports from the Black Sea area. Also, it turns out that the timing of the foundation of the Greek colonies in this region is consistent with our main argument. Second, we use data on contemporary crop suitability of different regions to demonstrate that southern Greece has a comparative advantage in olive cultivation as compared with cereals. As long as the suitability for cultivating olive and cereals have not been differentially trending across regions, these contemporary data are also suggestive of historical comparative advantage. Third, we perform a difference-in-differences exercise to demonstrate that the distance to the Black Sea colonies influenced the site-specific presence of cereals, olive, and vine in the late Archaic and Classical periods. Our results are consistent with importing cereals from the Black Sea region and exporting olives and wine; they are also robust to using two distinct measures of distance. Before we present these results in Section 5, we also demonstrate that our pollen-based reconstruction of vegetation change in southern Greece is consistent with three sources of auxiliary data. This validation of our methodology is discussed in the next section.

4 Validation of the Methodology

In this section we compare our pollen-based trends with three additional sources of data: on Mediterranean shipwrecks, on large-scale oil and wine presses, and—again—on the number of sites from archaeological survey projects in the Peloponnese. We discuss each of these sources below.

We argue that our trend estimates for grasses as well as deciduous and coniferous forest trees are consistent with the survey data throughout the (extended) time frame of our study, from 1000 BCE to 600 CE. As discussed above, the survey data are derived from independent archaeological investigations which allow us to approximate demographic change and anthropogenic pressure in the Peloponnese. We also demonstrate that our trend estimates for the main cash crops—cereals, olive, and vine—are consistent with the data on shipwrecks and oil and wine presses throughout the Roman period. The lack of consistency in earlier periods is not surprising, however. While pre-Roman data on oil and wine presses are simply not available, such earlier data on shipwrecks are often considered unreliable, which we also discuss below.

4.1 Archaeological Field Surveys

Figure 3 presents a comparison of two different sources of data—environmental and archaeological—that make it possible to approximate the scale of human impact on the landscape of southern Greece. The environmental data are represented by our pollen-based trends. For the purpose of this comparison, we select the summary indicators for grasses and the two types of forest dominant in southern Greece—coniferous, consisting of pine and fir, and deciduous, consisting of alder, hazel, hornbeam, and deciduous oak.[10] Together, these variables reflect the proportion of land that remained uncultivated and did not receive direct inputs of human labour. As before, the archaeological data are represented by the total number of sites from Weiberg *et al.* (2016). Both indicators—our pollen-based estimates and the total site count—should be negatively correlated, as an increase in the number and the density of settlements should lead to an increase in human exploitation of the land, and hence reduce the amount of land that is not cultivated.

In the case of our study, the expected correlation is evident for all historical periods: whenever we observe an increase in settlement numbers, there is a parallel decrease in uncultivated landscape, and vice versa. The only component of pollen-based trends that is inconsistent with archaeological data is the trend in the relative presence of coniferous forest trees in the period of *c.* 200–400 CE. At that time, the entire Roman Empire was experiencing a profound political crisis, and Greece was among the provinces that suffered from the barbarian raiding and political instability.[11] The increase in the presence of conifers, which quickly encroach on abandoned fields and pastures in the process of secondary ecological succession, would point to some decrease in the anthropogenic pressure, which, however, did not lead to a major episode of landscape change.[12] Altogether,

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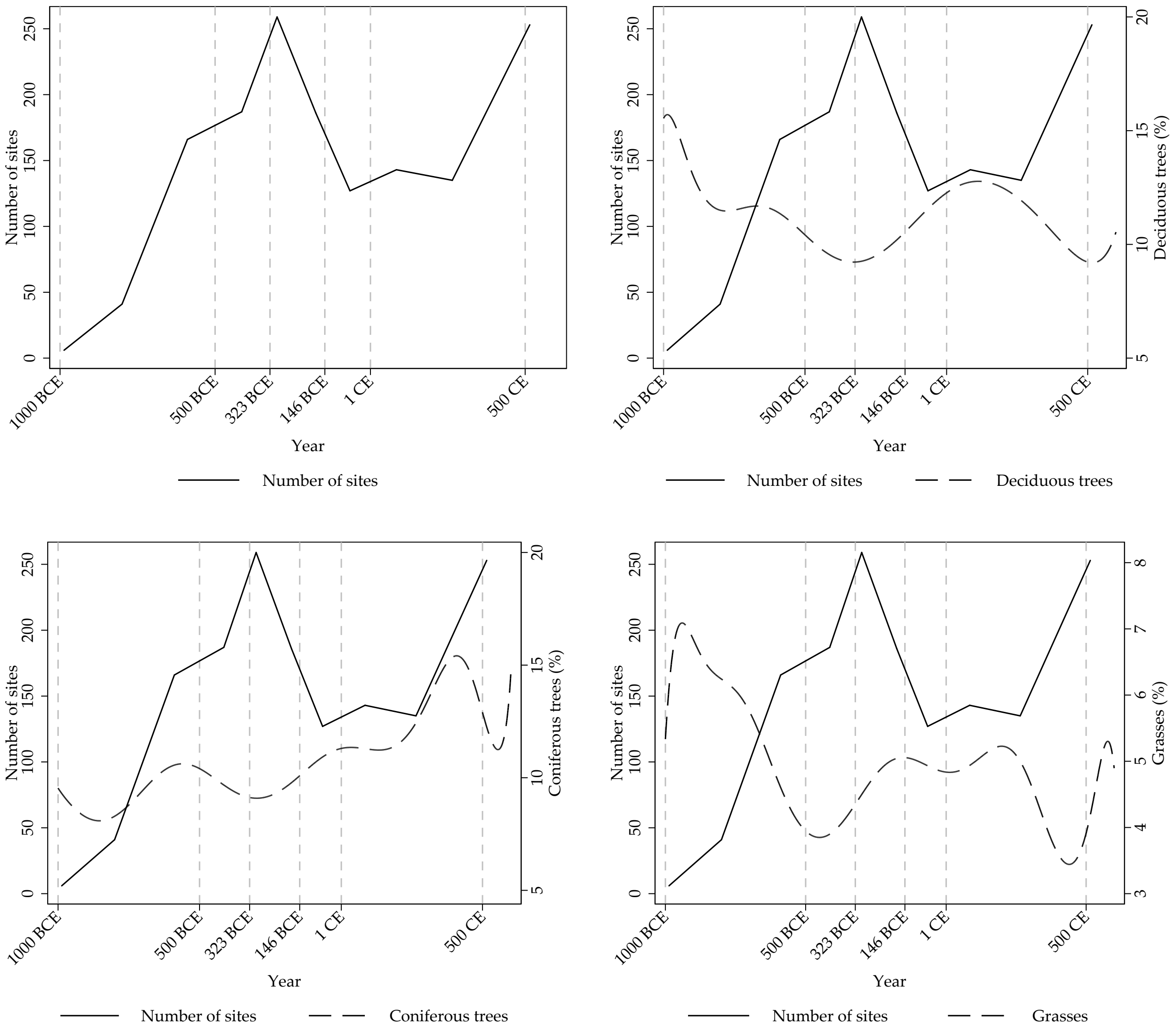
[10] If, at a given pollen site, the data for some forest trees are missing, we still sum the available values for the remaining taxa.

[11] The political crisis was preceded by the Antonine plague in the 2nd century CE. In a recent book, Harper (2017) connected this crisis with climate change and the Cyprianic plague in the 3rd century CE. See also Haldon *et al.* (2018) for a critical response to Harper (2017).

[12] As an additional exercise, we match each observation from Weiberg *et al.* (2016) with the corresponding values of our trend estimates. The data in Weiberg *et al.* (2016) are reported for different historical periods.

Figure 3: *Pollen Data vs Demography in Southern Greece*



Notes: The upper left panel displays the total number of sites from archaeological survey projects in the Peloponnese (based on Weiberg *et al.*, 2016). The remaining panels compare these data with pollen-based trends in the presence of deciduous forest trees, coniferous forest trees, and grasses in southern Greece.

this comparison of two independent sources of data paints a very optimistic picture of our methodology.

We match the midpoint of each period with our pollen-based trends for the same year, which gives us ten matched observations. For these data, the correlation between the number of sites and the relative presence of deciduous forest trees (grasses) is -0.8554 (-0.8764); for coniferous forest trees, surprisingly, the correlation with the number of sites is positive and equal to 0.3414.

4.2 Mediterranean Shipwrecks

The data on Mediterranean shipwrecks, introduced by Parker (1992) and recently updated by Wilson (2011), McCormick (2012), and Strauss (2013), have routinely been used in ancient history as a proxy for maritime trade and the overall level of economic activity (see, *e.g.*, Hopkins, 1980; Geraghty, 2007; Kessler and Temin, 2007; Terpstra, 2019). In general, these data are suggestive of an economic boom and a trade expansion in the early Roman Empire. As Hopkins (1980) stated it: 'The dated shipwrecks show that in the period of Roman imperial expansion and in the High Empire … there was more seaborne trade in the Mediterranean than ever before, and more than there was for the next thousand years.'

Since the number of shipwrecks is used as a proxy for maritime trade, we need to compare these data with our trend estimates for the main cash crops. Figure 4 combines our estimates for cereals, olive, and vine with a histogram for the shipwreck data (based on Strauss, 2013). For most shipwrecks, of course, it is not possible to determine the exact date of sinking, and we follow the conventional approach of using the midpoint of the interval from the earliest to the latest possible date. We restrict our attention to those shipwrecks whose location is sufficiently close to our region of interest. More precisely, Strauss (2013) coded the location of shipwrecks in three different ways—based on sea area, country, and exact latitude and longitude—but there are many missing values for each variable. We consider all shipwrecks whose location is coded as *(i)* Aegean, Northern Aegean, or Southern Aegean, *(ii)* Greece, or *(iii)* in the latitude range 34° to 42°N and longitude range 20° to 30°E.

It is clear that our estimated trends for cereals, olive, and vine are consistent with the shipwreck data in the Roman period and onward; both sources of data are suggestive of an economic boom in the 1st and 2nd century, a decline in the 4th and 5th century, and a smaller boom in the 6th century CE.[13] On the other hand, these sources of data

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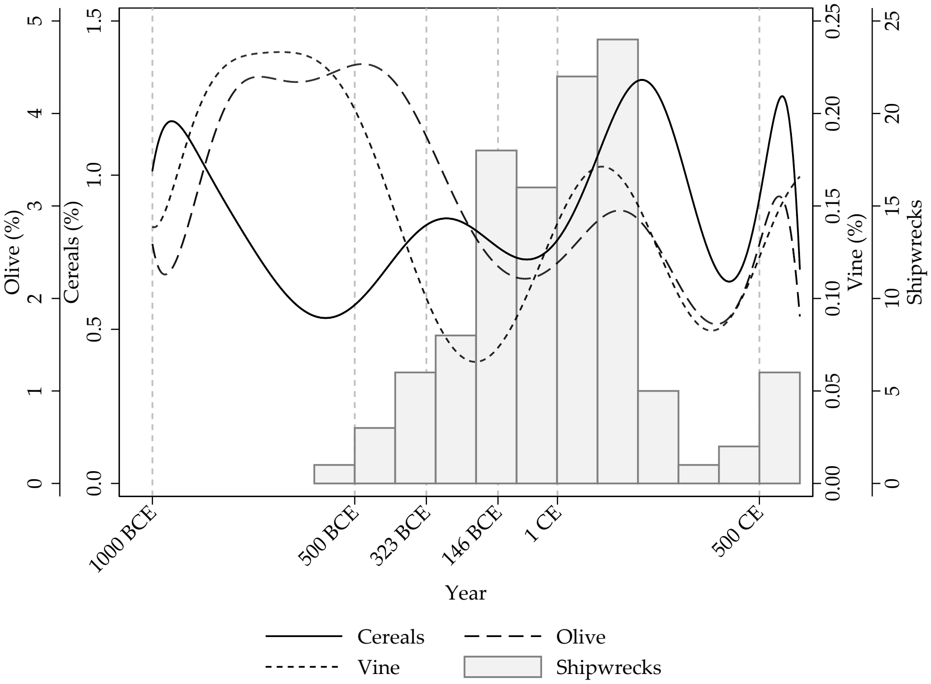
[13] In a manner similar to footnote 12, we also match the number of shipwrecks in each century with our

Figure 4: *Pollen Data in Southern Greece vs Shipwrecks in Greece*



present conflicting pictures of pre-Roman Greece. While there is only one shipwreck in our region which is dated prior to 500 BCE, our pollen-based trends are suggestive of major economic developments in this period (see Section 3). Such a lack of consistency between both sources of data, however, is less surprising than it might seem. According to Parker (1990), 'the oared ships of the earliest traders and explorers were lightly built, and so have not been preserved at all'. There may also be a number of other taphonomic and preservation issues that could have influenced the recovery pattern. What follows, we conjecture that our pollen-based trends are likely to present a more reliable picture of pre-Roman developments than the shipwreck data—while both sources are clearly in agreement in later periods. We further corroborate our interpretation in Section 5.

As a robustness check, we also consider the recent criticism of shipwreck-based studies by Wilson (2011) and McCormick (2012), who recommended focusing on a particular

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trend estimates for the midpoint of this century. This gives us seven matched observations from the 1st century BCE onward. The correlations between the number of shipwrecks and the estimates for cereals, olive, and vine are equal to 0.0434, 0.3630, and 0.6775, respectively.

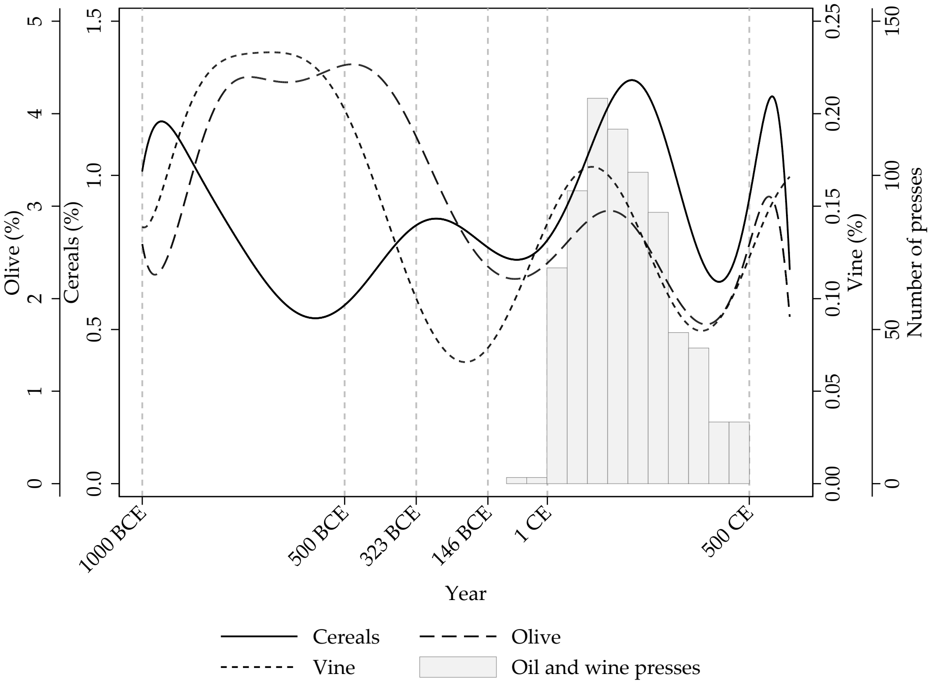
subsample of shipwrecks and prorating shipwrecks dated to multiple centuries. We discuss these recommendations in online Appendix C and report our results in Figure C1.

4.3 Oil and Wine Presses

Finally, in Figure 5, we compare our estimated trends for cereals, olive, and vine with data on large-scale oil and wine presses in Gaul, the Iberian Peninsula, and the Black Sea region from Marzano (2013). As explained by Marzano (2013), large-scale oil and wine presses can be used as a proxy for capital investment in agricultural crop processing. Because these data do not, in fact, come from Greece, their role in our study is to indicate a pattern of broad Mediterranean trends stimulated by the imperial economic structures and incentives for the production of olive oil and wine. As before, our pollen-based estimates are consistent with these auxiliary data throughout the Roman period.

There are of course limitations of using specific classes of archaeological data in this

Figure 5: *Pollen Data in Southern Greece vs Mediterranean Oil and Wine Presses*



capacity since the record is bound to be fragmentary depending to a large scale on where archaeological excavations have been carried out. The comparisons presented here nevertheless highlight trends that can be sufficiently matched with cash crop production in Greece during the Roman period. Since Marzano (2013) did not consider pre-Roman oil and wine presses, the lack of consistency between both sources of data before the Roman conquest is unsurprising. The geographical context of the presses would further make such pre-Roman comparisons difficult since these different production systems would largely have operated within different political and cultural contexts. The trends highlighted for the Roman period may nevertheless be used to identify a stimulus towards production systems offered by the integration with new imperial structures.[14]

5 Further Evidence

In this section we discuss further evidence that supports our original interpretation, as presented in Section 3. In particular, we review the historical literature on the Archaic and Classical periods as well as on the Black Sea colonies; we corroborate our earlier assertion that southern Greece had a comparative advantage in olive cultivation; and we use a difference-in-differences exercise to demonstrate the importance of the distance to the Black Sea colonies for the cultivation of cereals, olive, and vine.

5.1 Historical Literature

We first turn to our review of the historical literature on Greek colonization and grain shipments to mainland Greece. We argue that our results are broadly consistent with this

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[14] Again, in a manner similar to footnotes 12 and 13, we match the number of oil and wine presses from Marzano (2013) with the corresponding values of our trend estimates. The data in Marzano (2013) are reported for half centuries. We match the midpoint of each half century with our pollen-based trends for the same year, which gives us twelve matched observations. The correlations between the number of presses and the estimates for cereals, olive, and vine are equal to 0.8767, 0.7676, and 0.7289, respectively. Interestingly, and perhaps coincidentally, when we present separate histograms for oil and wine presses in online Appendix D, it turns out that both sources of data—palynological and archaeological—are suggestive of an earlier peak in the production of wine (Figure D1) as compared with olive oil (Figure D2).

literature. At the same time, while recent scholarship has used textual sources to emphasize high levels of bulk exchange in pre-Roman Greece, we are able to revise this picture and offer new insights into an era for which there is no prior quantitative evidence.

Greek colonization of the Black Sea region was primarily directed by Greek cities on the west coast of Asia Minor. It seems to have started in the 7th century BCE and intensified in the 6th century BCE (Avram *et al.*, 2004). There is no conclusive evidence that colonization might have been driven by an interest in grain imports. Many of the colonies were not situated in the primary grain-producing areas by northern shores and textual evidence for large-scale transfers of grain from the Black Sea region primarily belongs to later periods (see, *e.g.*, Tsetskhladze, 1998; Moreno, 2007).

On the other hand, many of the Greek colonies established in the early Iron Age and in the Archaic period were settled in areas with higher average rainfall compared to the southern Greek mainland and the Aegean, which made them more suitable for wheat production (Osborne, 2007). Greek colonies in southern Italy and Sicily, the Black Sea region, and North Africa would therefore have had the ability to produce large quantities of grain that could be exported.

Both literary sources and inscriptions from the Classical period provide us with examples of grain transfers occurring over significant distances to major urban centres, such as Athens (see, *e.g.*, Moreno, 2007; Bresson, 2011, 2016). Bresson (2016) also argued for the increasing integration of markets facilitated by city-state economies in the 5th, 4th, and 3rd centuries BCE, affecting the fluctuations of grain prices and occasional specialization of crop production. Archaeological evidence also points to trade in food commodities (not just olive oil and wine) at quite long distances in the Classical period (Munn, 2003), presenting a possible case for market integration in a wide geographical context already in the 5th century BCE. Earlier evidence was also presented by Bakker *et al.* (2018), who documented a positive relationship between the connectedness of points on the Mediterranean coast and the settlement density from *c.* 750 BCE.

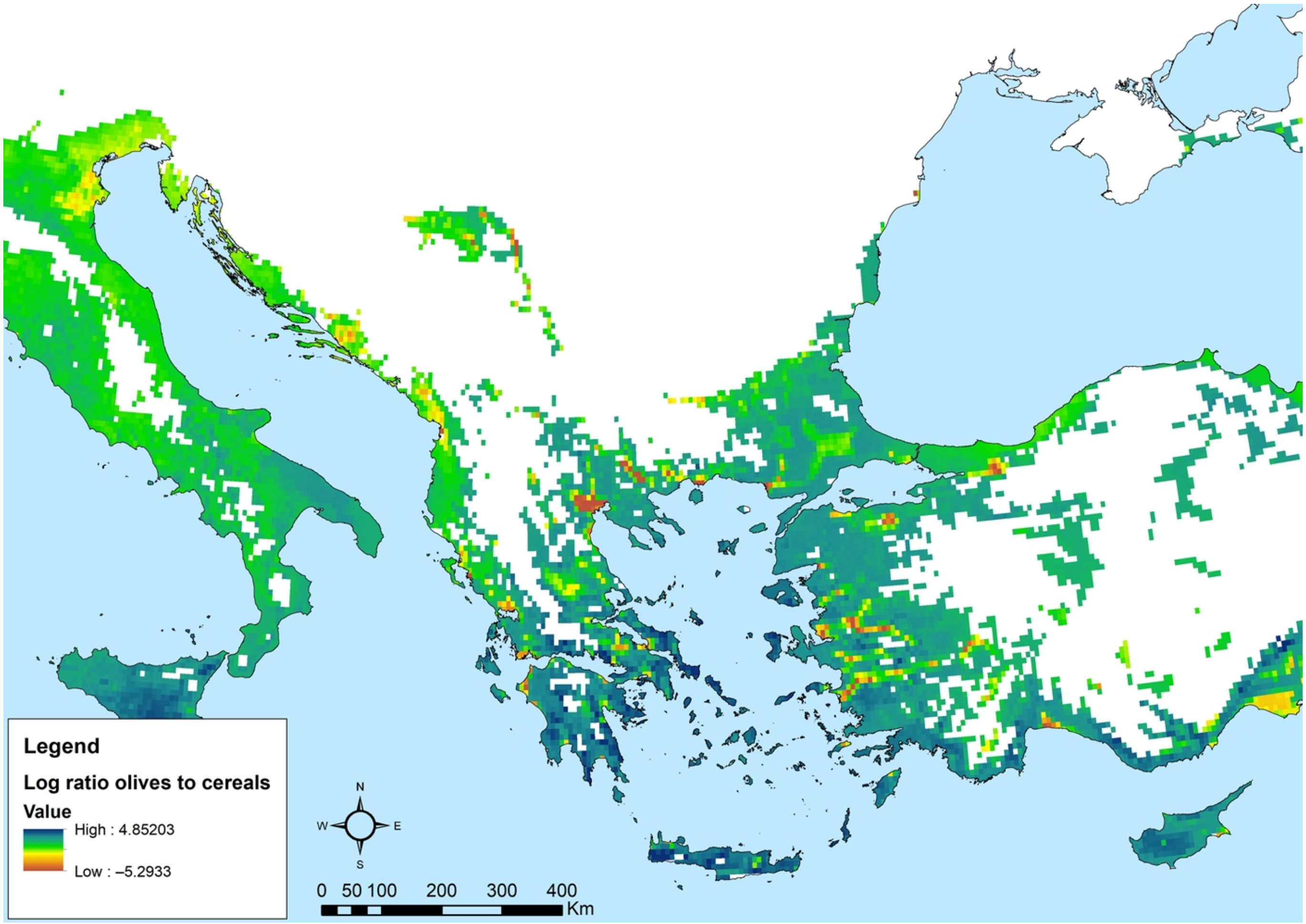
Earlier grain shipments between the Black Sea region and southern Greece are indeed manifested in the written sources. For example, Herodotus provided an account of grain shipments from the Black Sea area to the Peloponnese in the period of the Persian Wars in the first half of the 5th century BCE (Hdt. 7.147). Beyond the evidence of grain imports from the Black Sea region, we can also find further indications of grain being moved to mainland Greece from other areas of the Mediterranean (Bresson, 2011; Bonnier, 2016).

While there are numerous references to grain shipments to Athens, there has also been much discussion on the scale of such transfers and the dependence of the city-states on grain imports. Jardé (1925) argued that Athens became dependent on grain imports already in the 6th century BCE. Garnsey (1988) suggested that grain shipments to Athens would have occurred regularly but in normal years Attica could have supplied enough grain to feed its population. Moreno (2007) argued that grain imports were essential for Athens to feed its population as well as for the Athenian political elites to secure their status and political prestige; he also argued that trade links with the Bosporan kingdoms in the northern Black Sea region intensified after the Peloponnesian War in the 5th century BCE. Since our main results suggest an early focus on olives and wine in southern Greece, we argue that their production would have been directed at exports and grain would have been imported already in the 6th century BCE and certainly in the 5th century BCE.

5.2 Evidence on Comparative Advantage

Our next argument involves contemporary evidence on crop suitability of different regions. Following previous studies, such as Nunn and Qian (2011) and Costinot and Donaldson (2016), we use detailed micro-level data from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) project. These data measure the suitability for cultivating various crops at a local level. Because the GAEZ database does not include information on vine suitability, we restrict our attention to olive and cereals; more precisely, we use the GAEZ measures of total production capacity (t/ha) for low

Figure 6: *Crop Suitability in the North-Eastern Mediterranean*



Notes: The map shows micro-level information on the natural log of the ratio of the total production capacity (t/ha) for low input level rain-fed olive and low input level rain-fed cereals in the north-eastern Mediterranean. The data come from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) project (FAO/IIASA, 2011). We use data for the baseline period 1961–1990 without CO2 fertilization.

input level rain-fed olive and cereals, as this selection should resemble most closely the ancient agricultural technology. Given our interest in comparative advantage, we focus on the ratio of these measures. This approach follows Costinot and Donaldson (2016).

The results in Figure 6 are striking. Within the north-eastern Mediterranean, the southern Greek mainland—together with the Aegean and Crete—has the strongest comparative advantage in olive cultivation. Figures E1 and E2 in online Appendix E separate the measures of suitability for cultivating olive and cereals, respectively. It turns out that the missing values in Figure 6 typically correspond to unsuitable conditions for olive cultivation. In particular, most of the Crimea and the northern Black Sea region have no production capacity for olives (Figure E1) and considerable production capacity for cereals (Figure E2). Under the assumption that the GAEZ database is informative about historical comparative advantage, we should expect that southern Greece specialized in olive cultivation and the Black Sea colonies specialized in cereals.

In an additional exercise, we draw circles with a radius of 0.356 degrees (*c.* 30–40 kilometres) around each of our pollen sites and calculate summary statistics for both suitability measures within each circle. We repeat the same procedure for nine further locations around the Mediterranean, which we chose to represent main colonization targets and trading areas in the Archaic period. This list consists of the following cities: Marseille, Carthage, Cumae, Syracuse, Metapontion, Cyrene, Byzantion, Chersonesus, and Tyre. Table E1 in online Appendix E reports the coordinates and present-day countries where each of these cities was located, together with the summary statistics for both the pollen sites and these additional locations. Importantly, two of these cities—Byzantion (Byzantium) and Chersonesus, a prominent Greek colony in the Crimea—were located in the Black Sea region.

Of special interest in Table E1 is the ratio of mean values of both suitability measures, which we calculate for each of the six pollen sites and nine additional locations. It turns out that Vravron, Cyrene, Tyre, and Elefsina have the strongest comparative advantage in olive cultivation, with the ratio of both suitability measures in the range from 2.118 for Elefsina to 2.733 for Vravron. On the other hand, Chersonesus, Cumae, Marseille, and Byzantion—neither of which is located in southern Greece—have the strongest comparative advantage in cereal cultivation, with the measure of relative olive suitability in the range from 0 for Chersonesus to 1.148 for Byzantion. What follows, southern Greece appears to be particularly suitable—and the Black Sea region particularly unsuitable—for olive cultivation as compared with cereals.

In Table E1, we also report the mean values of location-specific olive and cereal suitability measures across all pollen sites and all additional locations. For the six pollen sites, the mean value of the olive (cereal) suitability measure is 132.32 (74.52) t/ha; for the nine remaining locations, the mean values are 166.16 and 144.82 t/ha, respectively. It turns out that the measure of relative olive suitability is much greater among the pollen sites located in southern Greece ($132.32/74.52 = 1.776$) than among the nine cities located elsewhere ($166.16/144.82 = 1.147$).

The evidence on olive and cereal suitability of different regions supports our earlier assertion that southern Greece has a comparative advantage in olive cultivation. While it is unclear whether the GAEZ database is informative about historical crop suitability, our conclusions remain unchanged as long as the suitability measures for cultivating olive and cereals have not been differentially trending across regions.

5.3 Distance to the Black Sea

Our main analysis focuses on time-series variation. In what follows, we exploit both time-series and cross-sectional variation in our data to assess whether there is evidence of a differential post-600 BCE trend in agricultural production associated with trade costs and the distance to the Black Sea colonies. If trade with these colonies had been unimportant in the late Archaic and Classical periods, there would have been no association between trade costs and agricultural production. See also Kessler and Temin (2008) for a related point on the distance to Rome and wheat prices.

We use two distinct measures of trade costs. Our first measure is based on the Stanford Geospatial Network Model of the Roman World (ORBIS), which provides a representation of the transport network of the Roman Empire *c.* 200 CE. The ORBIS model uses the relevant ancient sources to approximate the time and cost which was necessary to move goods and people around the Mediterranean. From among several ORBIS destination points in the Black Sea region, we choose Sigeion, an ancient Greek city-state situated at the Aegean entrance to the Dardanelles. As the Dardanelles lead to the Sea of Marmara and then, through the Bosporus, to the Black Sea, Sigeion will represent all the trade points in the Black Sea region in our analysis.[15]

One disadvantage of using the ORBIS model to measure trade costs is that our pollen sites do not constitute its destination points. What follows, each of our pollen sites is instead represented by the nearest coastal destination point in ORBIS. We report these destination points, their coordinates, and great circle distances between each pollen site and the corresponding ORBIS destination point in Table F1 in online Appendix F. While using this approximation is unavoidable, it introduces a small amount of measurement error to our measure of trade costs. It might seem that another disadvantage of using the ORBIS model in our context is that it approximates travel costs *c.* 200 CE. It is important to note, however, that navigation technologies and sea routes around the Aegean did not change much between the Archaic/Classical and Roman periods. Thus, the ORBIS model should provide a good approximation to the relative differences in trade costs in the late Archaic and Classical periods. We report these trade costs for each of our pollen sites in Table F1. They are expressed in denarii, the Roman currency *c.* 200 CE, and correspond to the transport of one kilogram of wheat in July.

Our second measure of trade costs is the great circle distance between each pollen site and Sigeion. We use this measure primarily as a robustness check. Again, we report the distances for each of our pollen sites in Table F1.

We use the information on trade costs as well as our original data to estimate two-way fixed effects specifications which modify equation (1) to take the following form:

$$\log(y_{ih} + 1) = \alpha_h + c_i + \delta post_h \cdot \log(d_i) + u_{ih}, \tag{2}$$

where y_{ih} is the raw percentage of pollen grains for a given plant taxon at site i in half

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[15] We provide more information on Sigeion in online Appendix F. A map with its exact location is also provided (Figure F1).

century h, α_h is a half century 'fixed effect', c_i is the individual effect of a given site, $post_h$ is an indicator for half centuries in the late Archaic and Classical periods, d_i is a measure of trade costs between site i and Sigeion, and u_{ih} is the idiosyncratic error term. Our estimation sample is restricted to observations from the early Iron Age as well as the Archaic and Classical periods.[16] We ignore later time periods because it is difficult to ascertain when the costs of trade with the Black Sea colonies ceased to matter. Even when this happened, the distance to Sigeion could still proxy for new trade routes, especially to Byzantium/Constantinople. Thus, our exercise implicitly focuses on the effect of the activation of the new trade connections in the late Archaic period.

It is also difficult to perform accurate statistical inference in our setting. While we use the traditional cluster-robust variance estimator, standard asymptotic theory only provides a good approximation to the distribution of the corresponding test statistic when the number of clusters, G, is large. In practice, researchers typically use critical values based on the t distribution with $G - 1$ degrees of freedom to partially address this challenge. Even in this case, however, it is expected that the test might overreject, especially in a case like ours, where we have a small number of unbalanced clusters (see, *e.g.*, Cameron and Miller, 2015). What follows, as suggested by Cameron and Miller (2015), we use critical values based on the t distribution with $\hat{G}^*$ degrees of freedom, where $\hat{G}^*$ is an estimate of the 'effective number' of clusters, as defined by Carter *et al.* (2017).

Table 3 presents our difference-in-differences estimates of δ in equation (2). It turns out that the costs of trade with the Black Sea colonies influenced the site-specific presence of cereals, olive, and vine in the late Archaic and Classical periods. This result holds regardless of whether we use trade costs from the ORBIS model (top panel) or the great circle distance between each pollen site and Sigeion (bottom panel).

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[16] To approximate the end of the Classical period in 323 BCE, we define our half centuries as time periods from 1025 BCE to 975 BCE, from 975 BCE to 925 BCE, ..., and from 375 BCE to 325 BCE. We approximate the beginning of the late Archaic period with the turn of the 6th century BCE, and so $post_h$ takes the value of one from 625 BCE to 575 BCE, from 575 BCE to 525 BCE, ..., and from 375 BCE to 325 BCE. All our results are robust to assuming that the late Archaic period began one half century earlier or later. To avoid artificially reducing the standard errors, we use raw data and ignore the interpolated observations.

Table 3: *Difference-In-Differences Estimates*

	log(Cereals+1)	log(Olive+1)	log(Vine+1)
		ORBIS model	
log(Trade costs)	2.483**	–2.956**	–0.505**
	(0.725)	(0.669)	(0.082)
Observations	37	37	37
G	6	6	6
$\hat{G}^*$	2.698	2.698	2.698
R^2	0.539	0.617	0.347
		Great circle distance	
log(Trade costs)	2.166**	–2.578**	–0.440**
	(0.633)	(0.581)	(0.071)
Observations	37	37	37
G	6	6	6
$\hat{G}^*$	2.700	2.700	2.700
R^2	0.539	0.617	0.347

Notes: The table presents difference-in-differences estimates of the effects of the costs of trade (top panel) and the distance to Sigeion (bottom panel) in the late Archaic and Classical periods. Trade costs are measured using the ORBIS model. More information on both measures is provided in Table F1 in online Appendix F. The dependent variable is the log of one plus the percentage of pollen grains attributable to cereals, olive, or vine at site i in half century h. The estimation sample is restricted to observations in the period from 1025 BCE to 325 BCE. The beginning of the late Archaic period is approximated with the turn of the 6th century BCE. See also footnote 16 for more information. Cluster-robust standard errors are in parentheses. G is the number of clusters. $\hat{G}^*$ is an estimate of the 'effective number' of clusters, as defined by Carter *et al.* (2017). Critical values are based on the t distribution with $\hat{G}^*$ degrees of freedom.

*Statistically significant at the 10% level; **at the 5% level; ***at the 1% level.

The estimates in Table 3 are consistent with our earlier assertions that *(i)* southern Greece engaged in large-scale interregional trade in the late Archaic and Classical periods; and *(ii)* the Greek city-states were importing cereals from the Black Sea region and exporting olives and wine. Indeed, the greater the distance to Sigeion—and greater the costs of trade with the Black Sea colonies—the greater is the site-specific production of cereals and the lower is the presence of olive and vine pollen. Where trade costs were higher, local populations needed to grow more cereals on their own and were less likely to produce olives and wine for exports.

6 Conclusion

We find strong empirical support for an assertion that there was a market economy in ancient Greece and a major trade expansion in the late Archaic and Classical periods. Using data from over one hundred samples collected at six pollen sites in southern Greece, we study vegetation change in this region from 1000 BCE to 600 CE. Given the modern knowledge of ancient diets, we focus primarily on the relative presence of cereals, olive, and vine. We document that in a period of apparent population growth southern Greece decreased its production of cereals and increased its production of olives and wine.

We interpret this result through the lens of comparative advantage. Since southern Greece appears to have had comparative advantage in olive cultivation, such regional specialization would be expected in a period of trade expansion. Did ancient Greeks, however, really engage in large-scale interregional trade before the Roman conquest? In this paper we also provide further supporting evidence for this interpretation. First, we review the historical literature on grain shipments to mainland Greece and Greek colonization of the Black Sea area. It turns out that the foundation of the Greek colonies in this region is consistent with our main argument. Also, some of the recent historical scholarship has emphasized high levels of bulk exchange in pre-Roman Greece. Second, we use contemporary data from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) project to corroborate our claim that southern Greece had a comparative advantage in olive cultivation. While it is unclear whether these data are informative about historical crop suitability, our interpretation will be unaffected unless the regional capacities for producing olive and cereals have been differentially trending across regions. Finally, we perform a difference-in-differences exercise to demonstrate that the costs of trade between southern Greece and the Black Sea colonies affected the site-specific production of cereals, olive, and vine in the late Archaic and Classical periods. The greater the trade costs, the lower the propensity to import cereals from the Black Sea region or export olive and wine. In line with this prediction, we document that—in the late Archaic and Classical periods—higher trade costs were associated with a larger local presence of cereal pollen and a smaller local presence of olive and vine pollen.

Importantly, our benchmark estimates are also consistent with other archaeological and historical sources, particularly on settlement dynamics in the Peloponnese, shipwrecks, and large-scale oil and wine presses across the Mediterranean. By means of presenting estimated trends in the regional presence of cereal, olive, and vine pollen across sixteen centuries, we contribute to the emerging literature on ancient economic history over the very long term (see, *e.g.*, de Callataÿ, 2005; Jongman, 2007; McConnell *et al.*, 2018; Terpstra, 2019). Several of these previous studies have incorporated the data on lead pollution in Arctic ice to improve our understanding of the Roman economy. In this paper we use an alternative source of environmental data—pollen data—which allows us to shift attention to ancient Greece and provide a more detailed and more localized study of an ancient economy over the very long term.

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