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Household sorting in an ancient setting☆

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ABSTRACT

We use archaeological data from ancient settlements of three different historical eras on a Greek island to construct novel measures of consumption. Using these, we show that the shares of high-quality consumption goods were relatively more concentrated closer to the center of nucleated settlements as compared to low-quality consumption goods. There is no such pattern in a placebo settlement. In this unique setting, these quality gradients may reflect differences in household consumption baskets across these settlements. We argue that some alternative, trade or production based hypotheses for such gradients can be weakly ruled out based on our data and archaeological sources.

"Socrates to Critobulus: I had been struck with amazement, I remember, to observe on some occasions that where a set of people are engaged in identical operations, half of them are in absolute indigence and the other half roll in wealth. I bethought me, the history of the matter was worth investigation…. What if I begin by showing you two sorts of people, the one expending large sums on money in building useless houses, the other at far less cost erecting dwellings replete with all they need; will you admit that I have laid my finger here on one of the essentials of economy?…. And suppose in connection with the same, I next point out to you two other sets of persons: The first possessors of furniture of various kinds, which they cannot, however, lay their hands on when the need arises…. The others are perhaps less amply, or at any rate not more amply supplied, but they have everything ready at the instant for immediate use."
Xenophon

1. Introduction

In this paper, we study the problem of spatial household sorting in a unique setting. We use archaeological data from within four ancient settlements across three different historical eras on the Greek Mediterranean island of Antikythera to hypothesize how households may have sorted in early settlements. The data include precise spatial locations for finds of several different qualities of pottery, an important ancient consumption good.

Exploiting the fine spatial resolution at which the data are collected, we estimate density gradients for various pottery qualities. We find that higher quality goods are relatively more concentrated near the centers for settlements with a known historical center with likely commercial activity, so called "nucleated" settlements. These settlements are agglomerated in some respect, with a centralized area used for commerce and social life.

In contrast, we find little-to-no such relative concentration for a non-nucleated settlement that was a collection of farms and pasture land. Given the unique setting for this data, we argue that the density gradients are informative of the spatial distribution of shares of high quality goods in household consumption baskets. We acknowledge the inherent uncertainty in drawing conclusions with archaeological data and examine competing hypotheses for our findings, such as production centers, markets and trade routes.

Obtaining testable hypotheses on sorting from millennia-old archaeological data is non-trivial. Our main challenge is that we do not have data on housing or land consumption; we only have data on various forms of "non-durable" consumption, ironic nomenclature given that the data for these goods were collected several millennia after being consumed. The data we use, collected by the Antikythera Survey

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Project (ASP)[1], feature several advantages. For one, Antikythera has been sparsely inhabited in modern times, which means relatively little data contamination over the centuries and also that the archaeologists were able to survey the entire island at a very fine level without worrying about disturbing (or being disturbed by) modern structures. For another, the island was characterized by a phenomenon of "roller-coaster demographics" (Bevan et al., 2006): a rather unique pattern of settlement followed by long periods of near abandonment, implying a degree of temporal independence across eras. Moreover, we see a variety of types of settlements in the data, including a plausible placebo.

In pre-modern settings, the effects of location-based amenities typically dissipate rapidly with distance (e.g. Heblich et al., 2020). In other words, in ancient times, when transport was mainly by foot, changes with respect to distance in the willingness to pay to live close to an amenity could be acutely large (see Nevett, 2000, discussed below, for an ancient example, or Arzaghi and Henderson, 2008 for a modern one). Larger ancient cites, like ancient Rome, may have had complicated sorting patterns both across and within neighborhoods within the city.[2] This can bias estimates of sorting unless the researcher has access to highly granular data, and particularly so if there was also vertical sorting within buildings (see Frier, 1977). Our data are indeed highly granular and the Antikytheran settlements, in contrast to larger cities, are relatively simple to orient ex-ante relative to the one or two attractions (such as the port) that households may have wanted to live near to. This allows us to more easily establish whether any sorting was positive (highest incomes nearer the amenity) or negative.

Our nonparametric estimates offer fairly clear pictures that the concentrations of consumption were highest closest to the nucleated settlements' centers with significant differences in spatial gradients by quality. In two out of the three historical eras that we study, namely the Hellenistic (ca. 325 BC-0 AD) and Late Roman (ca. 350 AD-650 AD) eras, we find evidence of luxury (higher grade pottery) consumption declining more steeply with distance from the center of settlements than lower grade pottery.[3] The most ancient era that we study, which we term the Minoan era (ca. 2700 BC-1200 BC), acts a type of placebo or contrapositive test. Bevan and Conolly (2013), p. 124, notes that Antikythera during this period was scattered with single family homesteads which did not coalesce into anything approximating a quasi-urban settlement.[4] Correspondingly, the gradients for this era look markedly different.

1.1. Related literature

Our work complements several strands of literature. It adds to the growing use of archaeological data or insights to test economic theory, dating back at least to Hodder (1974a,b), Smith (1975). The works by Hodder compare the spatial distribution of fine versus coarse pottery wares (among other goods) near their respective production sites in Roman Britain to estimate how gravity-like models of "marketing" vary with product value. Intriguingly, Hodder (1974b) notes that fine wares have far greater relative concentrations within towns and along main roads as compared to their outskirts. Due to the production sites in Hodder's data, one cannot necessarily infer consumption or income profiles from his results. Rihll and Wilson (1987) looks at similar models for ancient Greek settlements. Hodder and Millett (1980) estimates how the densities of Roman British villas vary with distance from a town center and attempts to correlate the hazard rates with various characteristics of the town, though sample sizes are very small. Fulford (1987) examines the percentage of imported pottery in total finds across Roman Britain to infer trade patterns. Veal (2012) studies the distribution of different types of charcoal to try to infer demand for fuel in Pompei circa A.D. 79 and explores whether the distribution of charcoal correlates with known settlement patterns. Palmisano et al. (2017) contains a useful discussion of the use of raw counts of archaeological data (including pottery) to compute demographic statistics and finds that these estimates compare well with other techniques.[5]

At least since the latter half of the 20th century, lower income households have tended to live closer to city centers than their richer counterparts in most cities in the United States (see e.g. Glaeser et al., 2008; Rossi-Hansberg et al., 2009). More globally, this pattern does not always hold (Brueckner et al., 1999) and recent trends in the United States may be reversing the pattern there as well (Couture et al., 2019; Couture and Handbury, 2020). Inferring the ways various amenities and technologies shape household location decisions, even within variations of the static monocentric city model, poses its own series of challenges (see Duranton and Puga, 2015; Fretz et al., 2021 for further discussion of these issues). Moreover, if inferences are based on modern cities, the preexisting, "sticky" built and settled environment can further complicate matters (see e.g. Brueckner et al., 1999; Brueckner and Rosenthal, 2009; Lee and Lin, 2017). Our data, which feature multiple, simple yet different settlements over time with no known legacy complications, offers an alternative to estimating more complex models of sorting.[6]

Section 2 provides the appropriate historical and geographical context for the island and a summary of the archaeological project that our data is sourced from. In Section 3 we explain how we infer consumption from the data, while Section 4 uses these measures to estimate spatial gradients relative to the centers of economic activity. Section 5 examines alternative hypotheses for our findings and Section 6 concludes. In the online appendix, we discuss how we center settlements, some robustness checks, and how a plausibly calibrated, simple extension of the Alonso-Muth-Mills model with multiple goods can predict the same sorting pattern we find in our nucleated settlements.

2. The island and data

2.1. Historical and geographical context

The data were collected from the Greek island of Antikythera (see Fig. 1 and Fig. 2), in a project described in detail in Bevan and Conolly (2014). An overview of the history and geography of the island can be found in Bevan and Conolly (2012), an excerpt from which reads: *"Antikythera is a small island (ca. 20.8 sq.km) in the Mediterranean Sea. Despite being comparatively remote from larger land masses in Mediterranean terms, it lies along important routes of maritime interaction between the Peloponnese and Crete, and between the eastern and central Mediterranean. This*

[1] https://www.ucl.ac.uk/asp, co-directed by Andrew Bevan (University College London), James Conolly (Trent University) and Aris Tsaravopoulos (Greek Archaeological Service).

[2] As Stambaugh (1988) notes, rich households tended to live on top of Rome's hills and poorer households somewhere in the valleys between.

[3] The word "luxury" is used in a strictly technical economic sense: a good is more luxurious the higher its elasticity of expenditure share of total goods spending by a household. As we describe below, though there are goods of differing quality in our data, they probably contain few goods that would be considered especially luxurious (in a conventional sense) even by the standards of the time.

[4] In fact, they state (p. 126) that "*there does not appear to be any strong preference for coastal connection to the outside world, or indeed any sign of an obvious port community, and there is also little sign of any settlement nucleation. What we are left with is an impression of individual small household farms whose closest major town centres are likely to have been off-island at Kastri on Kythera and in western Crete.*" Note that our definition of 'Minoan' has some overlap with what historians consider the Bronze Age and Mycenaean eras. We acknowledge this abuse of terminology, but maintain the usage for ease of presentation as the Minoan influence dominated most of this time period.

[5] More recently but less directly related, Bakker et al. (2021) examines data on the location of ports from a similar period to ours to document trade and development patterns across settlements while Barjamovic et al. (2019) uses commercial records from Assyrian traders to estimate trade patterns and the location of lost cities. Izdebski et al. (2020) analyzes pollen data to infer production and trade patterns in ancient Greece.

[6] Brown and Cuberes (2021) also examines urban growth in a setting of no prior urban settlement in the context of central Oklahoma.

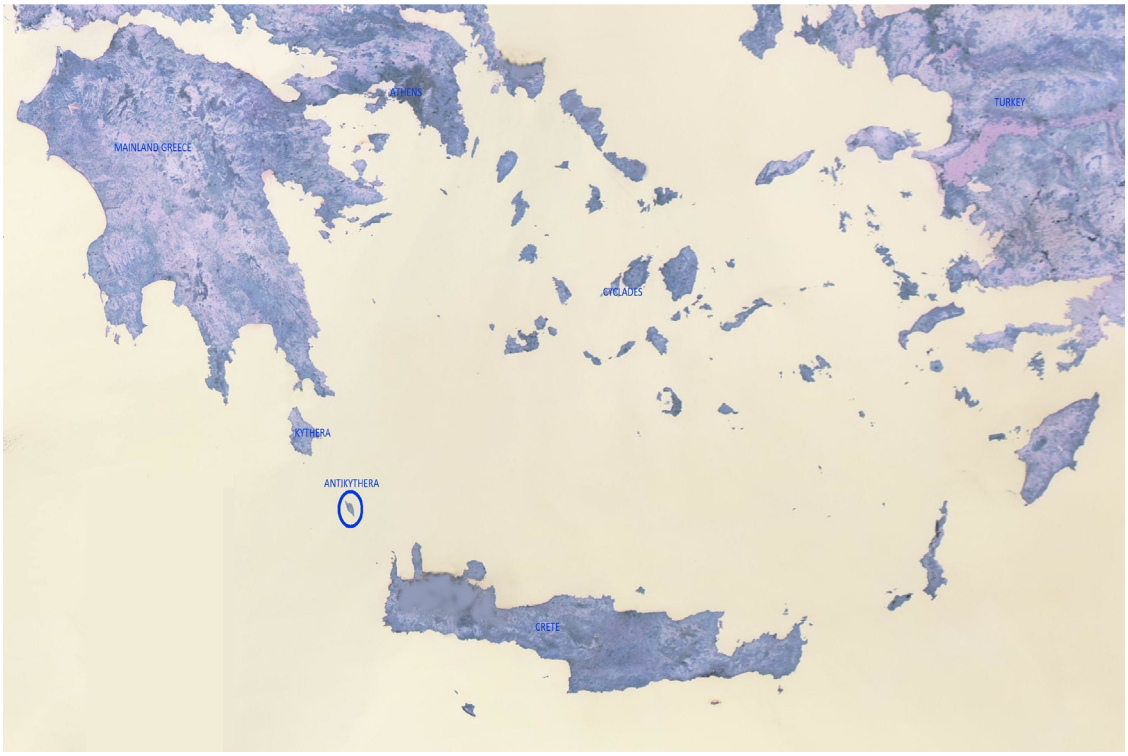

Fig. 1. The Mediterranean (original image courtesy of NASA Terra-MODIS).

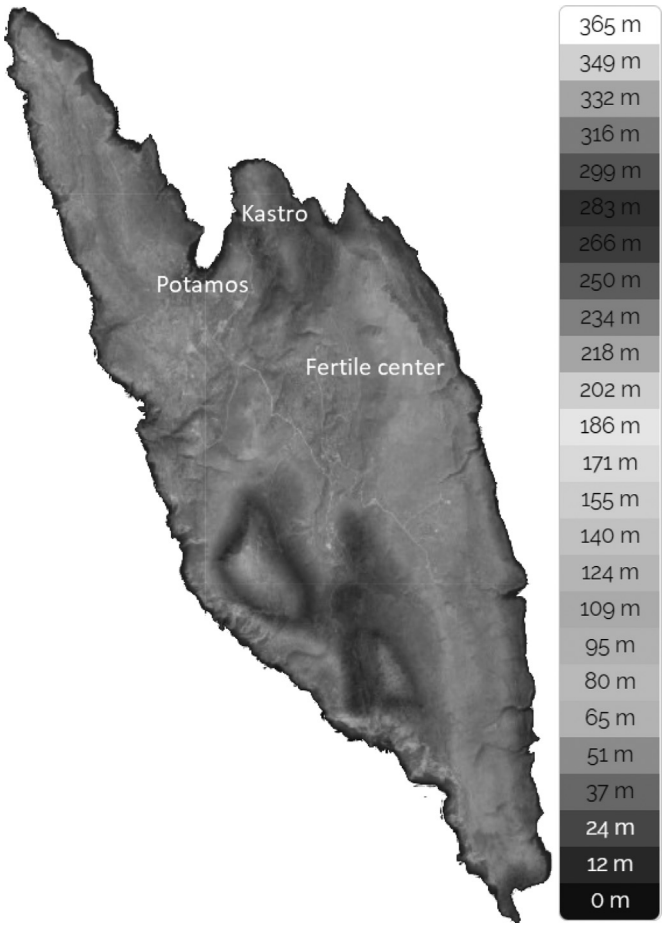

Fig. 2. Antikythera: key areas and elevation.

geographical position has contributed to its very episodic history of human exploitation stretching back some 7000 years, but with periods of substantial settlement followed by others of near complete abandonment. Highlights of this long-term history include evidence visits by Neolithic hunters from the Cyclades, Bronze Age farms with cultural links to Crete during the period of the Minoan palaces, a fortified settlement of Hellenistic pirates, a clutch of Late Roman communities, some glimpses of Middle Byzantine settlement and a recolonisation by west Cretan families in the late 18th century AD."

Our study focuses on three major historical periods in the history of Antikythera: the Minoan period, the Hellenistic period and the Late Roman period. The Minoan period covers the time period between 2700-1200 BC when Antikythera was influenced by the Cretan civilization. The Hellenistic period covers 325 BC-0 AD, while the Late Roman period covers 350 AD-650 AD. We choose these three distinct time periods for our study because of the vastly different characteristics of settlement observed on Antikythera during them, because the archaeological finds from subsequent periods are less abundant and less well epochly differentiated and because the island seemed to be relatively abandoned for large spells between these periods. Antikythera is well-known in the archaeological literature for exhibiting a high degree of historical variance in its settlement. Bevan et al. (2006) describes this phenomenon as one of "rollercoaster demographics".

For the purposes of our study we highlight several elements of the island's history. The Minoan period was dominated by "cultivators" living in the fertile central part of the island who may have colonized the island from its larger neighbor, Crete. In this period many large settlements in ancient Greco-Near East were politically, economically and socially centered around "palaces". Palace-based elites in some places oversaw redistribution of goods and organized production. Crete is a prominent example. However, there is no evidence of a palace or similar structure on Antikythera during this period. After the Minoan period, archaeologists have yet to find "good evidence... for much activity" (Bevan et al., 2006) in other words, it may have been abandoned (a situation comparable to its current lightly inhabited state) for an extended period of time. This abandonment would be consistent with general demographic

and economic decline throughout the region following the destruction of most palaces from fires or other disasters.

During the Hellenistic period Antikythera was resettled but in a different part of the island. The island was, as Bevan et al. (2006) notes,"dominated by a fortified town at a strategic position on its northern coast, overlooking a natural protected harbor. Documentary evidence suggests its role in piracy." This indicates that, contrary to the Minoan era, the Hellenistic era featured a distinct center of economic activity.

Subsequent to the sack of this fortified town by the Romans in 69-67 BC the island once again suffered a near abandonment before settlements appeared in and around the port town of Potamos and in the fertile central area of the island, culminating in a peak of activity during the Late Roman era. Thus, Antikythera appears to have been primarily an agricultural economy with atomized dwellings in Minoan times, a maritime economy in Hellenistic times and a combination of maritime and agrarian in Late Roman times. Bevan et al. (2006) notes that the agrarian settlements in the Late Roman era were rather less amorphous than in the Minoan era, nucleating into hamlets.

Thus our choice of the three time periods is motivated precisely by archaeological and historical observations: these three periods correspond to distinct and prosperous phases in Antikythera's history. The discontinuity in settlement also makes the task of distinguishing between historical phases much simpler; in the words of Bevan et al. (2006) the discontinuity makes the landscape *"a less complicated palimpsest than in most other Mediterranean locations."*

2.2. The data

Between 2005-07, ASP conducted a painstaking pedestrian survey of the island. The uniqueness of this exercise lay in the coverage of an entire island in a uniform manner with intensive survey methods.[7] As a result, the data offer a remarkable level of detail in both the individual finds and their precise spatial locations.

In the data, each piece of pottery is given a classification by Bevan and Conolly (2014) according to its fabrication or thickness: "Fine", "Medium" or "Coarse" in the former case and "Thick", "Medium" and "Thin" in the latter case. In our analysis we combine the "Medium" and "Thin" categories into a single "Non-Thick" category. In addition, for each piece of pottery Bevan and Conolly (2014) assign a probability to it belonging to a particular chronological phase, using methods in Bevan et al. (2013).[8]

Table 1
Pottery summary statistics.

	Pottery piece counts for pottery quality					
	Minoan		Hellenistic		Late Roman	
	Raw	Weighted	Raw	Weighted	Raw	Weighted
Coarse	5497	5342.85	32	16.10	49	19.50
Medium	906	833	818	433.66	1173	882
Fine	226	192.60	856	506.55	1369	1029.30
Total	6629	6368.45	1706	956.31	2591	1930.80

	Number of cells with at least one pottery piece by grade			
	Minoan	Hellenistic Grid Cell Size		Late Roman
		$633m^2$	$70m^2$	
Coarse	541	29	22	42
Medium	364	172	377	704
Fine	108	243	399	835
Total	684	309	566	1310

	Pottery piece counts for pottery thickness					
	Minoan		Hellenistic		Late Roman	
	Raw	Weighted	Raw	Weighted	Raw	Weighted
Thick	516	491.40	101	60.10	102	69.90
Non-Thick	6113	5877.05	1605	896.21	2489	1860.90
Total	6629	6368.45	1706	956.31	2591	1930.80

	Number of cells with at least one pottery piece by grade			
	Minoan	Hellenistic Grid Cell Size		Late Roman
		$633m^2$	$70m^2$	
Thick	225	83	75	91
Non-Thick	800	330	598	1442
Total	684	309	566	1310

The use of quantity and variety of pottery by archaeologists for making economic inferences is widespread. See Greene (2005) for examples, including inferences related to trade and the spread of technology and processes. In this study, we use the data on pottery to estimate the share of high quality goods in a particular location's consumption basket and use the estimates to infer the locations of relatively wealthy and non-wealthy households. We are not able to identify population densities from our data.

3. Measuring consumption

In this section we detail how we measure consumption gradients using the ASP data set. Our method covers the island of Antikythera with a fine grid of cells, and then measures pottery counts and hence an estimate of consumption for each of these cells. The cells are approximately 633 sq. meters each, and Table 1 provides details about how many of these cells contain finds. The exercise is conducted separately for all three eras of settlement, although based on our initial analyses we refine our gridding strategy for the Hellenistic era, as we detail below.

We focus on pottery as our measure of consumption for several reasons: it is by far the largest type of artifact found in the ASP data; with a few notable exceptions, remnants of building structures are not abundant in the data. A variety of quality of pottery was used by households in these eras for cooking, storage and display, among other uses (Sparkes, 2013), which allows us to potentially measure spatial differ-

[7] Quoting from the description in Bevan and Conolly (2012)*"... the entire island was fieldwalked in parallel lines 15-m apart. For certain interesting or problematic surface artefact scatters (particularly those of prehistoric date) this stage-one survey was followed by more detailed stage-two collections on a 10×10-m grid. In terms of digital recording, this project was unusual for the detail of its treatment of the location, dating and other attributes of its artefacts. First, all artefacts and standing structures were entered individually in a database (with information on shape, size, decoration, fabric, date, location, etc.), rather than in aggregate, and these records were all the result of sustained laboratory study rather than decisions in the field. Second, the project sought to standardise the recording of the spatial location of all material culture, regardless of the survey method by which it was observed, such that all finds and observations had an effective spatial precision of ± 10 m. Third and finally, it was the first substantial fieldwork project, to our knowledge, to adopt a probabilistic approach to assigning dates to individual collected artefacts."*

[8] The phases are: Middle to Late Neolithic (pre-4500 BC), Final Neolithic to Early Bronze 1 (ca. 4500-2700 BC), Early Bronze 2 (ca. 2700-2200 BC), Cretan late Prepalatial (ca. 2200-1950 BC), First Palace or Cretan Protopalatial (ca. 1950-1750 BC), Second Palace or Cretan Neopalatial (ca. 1750-1450 BC), Third Palace or Mycenaean (ca. 1450-1200 BC), Post Palatial to Protogeometric phases (1200-900 BC), Geometric phase (900-600 BC), Archaic phase (600-500 BC), Classical phase (500-325 BC), Hellenistic phase (325-0 AD), Early Roman phase (0–200 AD), Middle Roman phase (200–350 AD), Late Roman phase (350–650 AD), Early Byzantine phase (650–900 AD), Middle Byzantine phase (900–1200 AD), Early Venetian phase (1200–1400 AD), Middle Venetian phase (1400–1600 AD), Late Venetian phase (1600–1800 AD), Recent phase (1800-present), any other chronological phase.

ences in the consumption of quality. While some types of pottery were more valuable than others, in general pottery was not particularly expensive (Gill, 1988; 1991).[9] Almost all households in these eras likely possessed some pottery, so pottery remains are potentially an indication of all settlement activity.

There are a number of potential challenges in "counting" pottery. The survival rates of sherds can vary by composition, location and era of use (Morris, 2007). This can make it difficult to draw inferences about, say, how raw population numbers might have varied across time based solely on pottery. For these reasons, we will mainly draw inferences from the share of a particular (period, quality)-type of sherd relative to the total from that period in a particular location. As long as the survival rates of sherds do not differentially vary by type across locations, then the inferences we make below are valid for our purposes.[10]

3.1. Measuring quality

Pottery was used during these time periods in a wide variety of ways for everyday life. It was used for household storage, cooking, dining and for display items (i.e. "art"), among other uses. In addition to their size and shape, pottery sherds can reveal a lot about the ware they were a part of through their glazing and clay composition, for example. We use two widely accepted dimensions to measure quality: coarseness of the fabrication material of the pottery and the thickness of pottery pieces, with finer and thinner being more luxurious. This is consistent with evidence of the significance of pottery in ancient Greece and that finer fabrication and thinner walls, which generally required relatively capital intensive productive methods (i.e. kilns) and higher skilled labor, correlated with higher quality pottery wares (Chankowski, 2013).[11] As we document in Section 4.1.2, the two measures of luxury are not perfectly correlated in our data.

Quality distinctions along these dimensions are often made in the literature (Hodder, 1974a; 1974b; Greene, 2005; Kron, 2012). This is consistent with our view that "luxury" goods in our model are not luxurious in the typical sense of being extremely expensive but not indispensable (such as a gold vase, affordable only for the very cream of the Athenian elite in Hellenistic times), but rather those whose consumption share elasticity is increasing in total goods spending. In this way we exploit the variegated bundle of pottery that was consumed in this era.[12]

Evidence on prices of pottery from these periods points to non-trivial price dispersion between types of pottery. While a simple cup sold (perhaps wholesale) by a mass producer near Athens might fetch around 1/100th of a low-skilled Athenian laborer's daily wage, prices for finer vases and amphorae (storage vessels) could easily eclipse their daily wage (Boardman, 1988). Trade costs were likely considerable, meaning the costs to Antikytherians relative to their daily production were likely considerably higher (Boardman, 1988; Bresson and de Callataÿ, 2013; Chankowski, 2013).[13] Some basic pottery may have been home-produced by people on the island using household fires or bonfires to fire the clay. Such items would have been low in quality. In any case, given that around 70 percent of daily wages typically went towards food alone, the income elasticity of demand (and therefore variation thereof) for pottery goods was likely much higher than would be for similar goods nowadays (von Reden, 2007).

Furthermore, the types of fine pottery found in particular periods and places in the ancient world varied greatly in a way that was not merely reflective of changes in technology. Local tastes played a great role in determining demand for, say Athenian fine pottery versus Corinthian fine pottery and merchants evidently responded to regional variation in tastes by supplying the goods that were in greater demand (Osborne, 2007). The literature's identification of the greater role of "style" in the fine pottery is consistent with our treatment of fine (or thin-walled) pottery as a relative luxury. The ASP data sometimes contain identifying information beyond merely "fine", such as potential origin. Formally differentiating along these additional dimensions would be difficult and estimates on such a basis would likely lack power. However we do exploit some of this extra information in other ways at the end of this section.

Given our data on both quantity of pottery as well as quality (fine, medium, coarse or thick, non-thick), we already have a natural separation of consumption quality. With a number of caveats, total pottery counts can proxy for total consumption, subject to variation in survival by location. Meanwhile, relative gradients of pottery counts by quality can measure the relative consumption of higher quality goods by location. These relative gradients are our chief objects of interest.

In Fig. 3, we illustrate the distribution of pottery over the island, separately for each era. In each figure, the panels correspond to the Minoan, Hellenistic and Late Roman eras respectively from left to right. Table 1 presents some summary statistics about the data, and these are visualized in the presented maps. Examining Fig. 3, the pottery pieces in the Minoan era are mostly concentrated around the fertile center of the island but in clumps that belie the presence of a true quasi-urban settlement, while the pieces that correspond to the Hellenistic era are almost entirely concentrated around the port of the Kastro and a temple of Apollo just southwest of it, see e.g. Figure 6.8, p. 138 of Bevan and Conolly (2013). For the Late Roman era the greatest concentrations are in the Potamos area, but with scatters that suggest the presence of some farmsteads in the "hinterland" of the island even while the bulk of economic activity takes place in the vicinity of the port. Thus, we already see some evidence of the vastly changed economic structure of the island across eras.

We also exploit additional information in the data, for some sherds, on the type of vessel a sherd originates from. This data allows us to zoom in at a very fine resolution into pottery scatters to confirm that a vari-

[9] In fact, according to Gill (1988, 1991), pottery's presence on merchant ships owes as much to its role as a space-filler or ballast than to its trade value, with Vickers and Gill (1994) also describing pottery as "saleable ballast". Nevertheless the authors themselves regard the latter terminology as troublesome, and this description has also has been criticized by Boardman (1996).

[10] For instance, if the relative survival rates of fine versus coarse pottery from the Hellenistic period varied by distance from the center of the settlement, then that could bias our results. We know of no reason why this should be true.

[11] Boardman (1988) discusses the importance of the pottery trade in ancient Greece by studying its value relative to other commodities. In his seminal encyclopedic account of ancient Roman life, Pliny the Elder relates an anecdote about a competition between a master and an apprentice to make the thinner earthenware, the delicate results of which are displayed in a temple. He further describes the Greek island of Cos to be particularly famous for their thin pottery, see p. 337, article 161, in Pliny the Elder (1991). Clark et al. (2002), p. 77, discuss the especially fine Attic and Corinthian clays, and indeed such Greek pottery wares were important import goods in neighboring regions such as Palestine and Phoenicia, often inspiring cheaper local imitations (Rosenthal-Heginbottom, 1995; Berlin, 2015). Local imitations are not likely in our setting because, as we note, there seem to have been no kilns on the island during these periods.

[12] There has been a vigorous, even rancorous, debate in archaeology about the importance of fine pottery wares in ancient Greece. Vickers and Gill (1994) strongly argue against the value imputed to pottery by modern constructs, instead claiming that truly luxurious items were made of gold and silver. This view has been vehemently contested by Boardman (1996), among many others, and challenged more recently in Williams (2013) and Tsingarida (2013). A central argument is that gold and silver were necessarily much more expensive than any form of pottery, but this does not make certain types of pottery inexpensive for the majority of the populace. Cook (1987) also provides some arguments against the view of Vickers and Gill (1994) that some ancient Greek pottery techniques explicitly attempted to replicate metalwork. We do not claim a true luxury value for the pottery in our work. Luxury has a specific meaning for us that is somewhat distinct from these debates.

[13] Indeed there is evidence that the ceramics in ships' holds, far from being mere ballast (Vickers and Gill, 1994), were valuable enough to be used as collateral for loans by merchants (Chankowski, 2013).

Fig. 3. Pottery locations: Minoan, Hellenistic, Late Roman eras (left to right).

ety of pottery was being used, especially in the densest scatters. Doing so gives us some degree of evidence that the densest scatters represent consumption, rather than production facilities where only one type of pottery may be found. Indeed, we present some zoomed-in scatters in Fig. 4a–d, where (sherds from) small open fineware shapes are represented by triangles, pithoi (large storage jars) by squares, large open basin shapes by circles, cooking pots by diamonds and jars, amphorae and jugs by stars. For the Minoan era we zoom into into one of the farmsteads in the fertile part of the island, while for the Hellenistic era we zoom into the Kastro. For the Late Roman era we present zoomed-in pictures of pottery clusters in the vicinity of Potamos and the fertile inland areas of the island. We see in each figure that a variety of pottery types can be found in the scatters.

4. Consumption profiles

4.1. Consumption relative to center of economic activity

Our analysis in the previous section indicates the presence of quality gradients. In this section we estimate how pottery finds change with distance and discuss our findings in relation to the figures we have already presented. Throughout we refer to the profiles we estimate as "consumption" profiles, as we believe that the pottery found on Antikythera was part of the consumption basket of household there. In Section 5 we discuss alternative hypotheses.

We fit regression models of the type $y = m(x) + \epsilon$, where $m(\cdot)$ is a nonparametric function of distance x from the economic center, y is the specific pottery series we use for a particular analysis and ϵ the unobserved regression error. We use the series or sieve estimation method which approximates the regression function $m(x)$ by a linear combination of, say, ℓ basis functions, which we choose to be splines. Thus the regressions estimated are of the form $y = \sum_{j=1}^{\ell} s_j(x)\beta_j + e$, where $e = \epsilon + m(x) - \sum_{j=1}^{\ell} s_j(x)\beta_j \equiv \epsilon + r(x)$, say. The remainder $r(x)$ is the approximation error which is negligible under various technical conditions involving the smoothness of $m(\cdot)$, see e.g. Chen (2007). The estimation is implemented using the GAM package in R.

As we will see below, nonparametric fits allow us to capture nonlinearities in the profiles that reflect economic features of the island's consumption distribution as well as the island's geography and topography. Solid, dashed or dot-dashed lines correspond to the fitted profile while asymptotic 95% confidence intervals (i.e. based on a standard normal critical value of 1.96) are traced out with dotted lines in each figure. Distance from the economic centers, defined as the fertile center, Kastro and Potamos in the Minoan, Hellenistic and Late Roman eras respectively, is in meters on the horizontal axes. For the Late Roman era we will also examine the situation where two separate economic centers, Potamos (maritime) and the fertile center (agrarian) are considered.

4.1.1. Absolute consumption profiles

To make our consumption measures mathematically precise, suppose that in a given cell C in era $\mathscr{E}$ we observe $p^{\mathscr{E}}_{C,f}$, $p^{\mathscr{E}}_{C,m}$, $p^{\mathscr{E}}_{C,c}$, $p^{\mathscr{E}}_{C,t}$ and $p^{\mathscr{E}}_{C,nt}$ pieces of fine, medium coarse, thick and non-thick pottery, respectively, with each individual piece denoted with i subscript. Denoting by $\pi^{\mathscr{E}}_{i,f}$ the probability of the ith piece of fine pottery belonging to era $\mathscr{E}$ as computed by Bevan et al. (2013), with similar probability notations for other pottery qualities, the probability-weighted consumption measure in cell C is

$$\tilde{P}^{\mathscr{E}}_{C} = \underbrace{\sum_{i=1}^{p^{\mathscr{E}}_f} \pi^{\mathscr{E}}_{i,f} p^{\mathscr{E}}_{C,i,f}}_{\tilde{P}^{\mathscr{E}}_{C,f}} + \underbrace{\sum_{i=1}^{p^{\mathscr{E}}_m} \pi^{\mathscr{E}}_{i,m} p^{\mathscr{E}}_{C,i,m}}_{\tilde{P}^{\mathscr{E}}_{C,m}} + \underbrace{\sum_{i=1}^{p^{\mathscr{E}}_c} \pi^{\mathscr{E}}_{i,c} p^{\mathscr{E}}_{C,i,c}}_{\tilde{P}^{\mathscr{E}}_{C,c}} = \underbrace{\sum_{i=1}^{p^{\mathscr{E}}_t} \pi^{\mathscr{E}}_{i,t} p^{\mathscr{E}}_{C,i,t}}_{\tilde{P}^{\mathscr{E}}_{C,t}} + \underbrace{\sum_{i=1}^{p^{\mathscr{E}}_{nt}} \pi^{\mathscr{E}}_{i,nt} p^{\mathscr{E}}_{C,i,nt}}_{\tilde{P}^{\mathscr{E}}_{C,nt}}, \tag{1}$$

$\mathscr{E} \in$ {Minoan, Hellenistic, Late Roman}, while raw consumption measures can be constructed without the use of probability weighting and are denoted $P^{\mathscr{E}}_{C}$ and $P^{\mathscr{E}}_{C,q}$, q =Fine, Medium, Coarse, Thick, Non Thick, i.e. without tilde adornment. Estimated profiles of total consumption, obtained from the probability-weighted formula of equation (1) and its unweighted version are displayed in Figs. 5 and 6. Plotted in each figure are spline-based nonparametric fits; dashed lines correspond to the probability-weighted measure as in Eq. (1) while the solid lines correspond to the unweighted versions. The origin is a center of economic activity for each era: the fertile heart of the island for the Minoan era, Kastro for the Hellenistic era and the fertile heart again for the Late Roman era.

Nonlinearity in the profiles is captured by the nonparametric fits, which show secondary humps in the consumption profiles in the Minoan and Late Roman eras. The Minoan hump is a smaller peak than the peak at the origin and corresponds to other fertile areas of the island. The hump is more pronounced (corresponding to Potamos), and the profiles generally less steep, in the Late Roman era. Assuming a constant survival probability of pottery across eras as discussed in the third paragraph of Section 3, this can be interpreted as reflecting the more equitable distribution of economic activity on the island during this phase, as both maritime and agrarian activity co-existed. Thus in our analysis

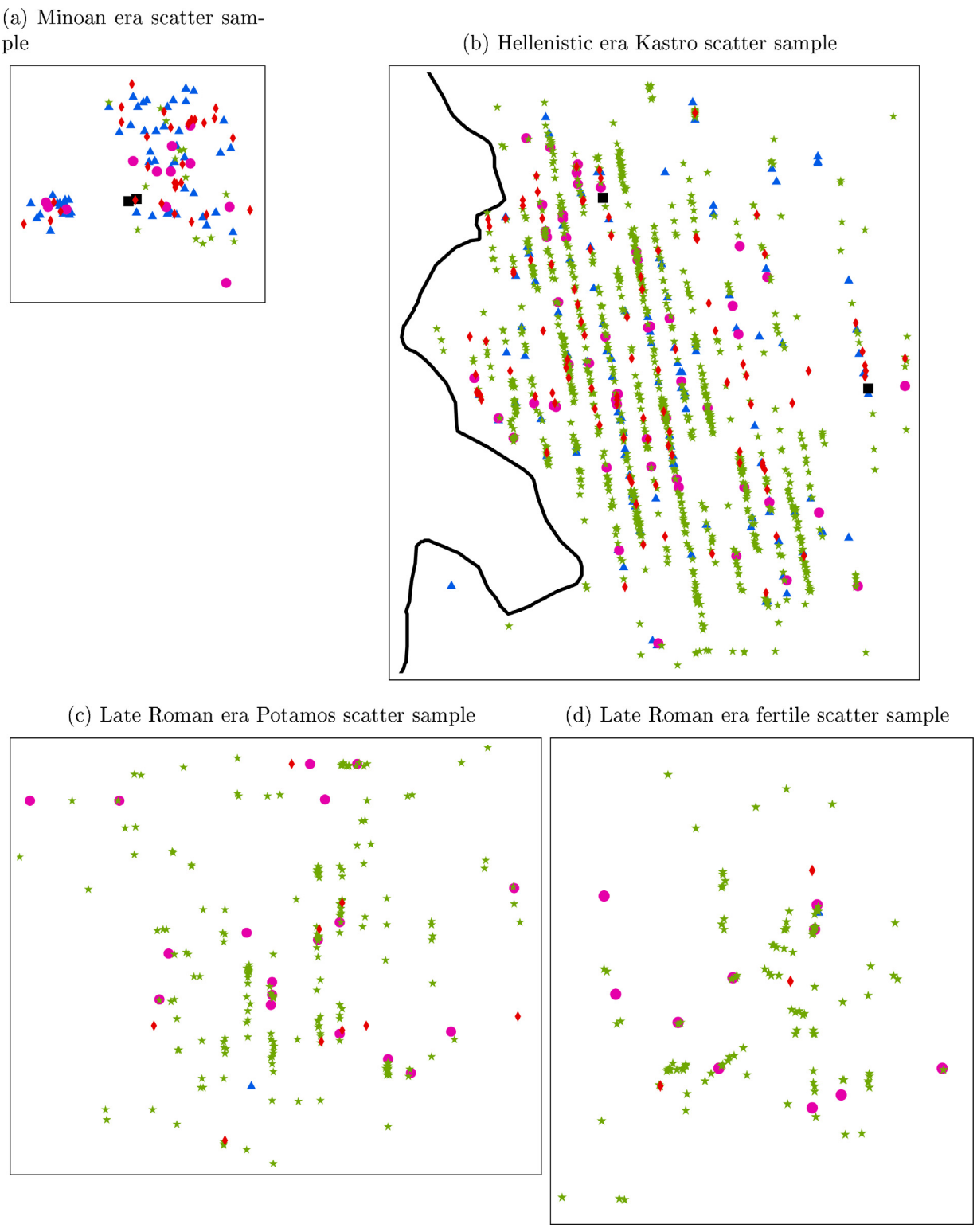

Fig. 4. Zoomed-in pottery scatters. Small open fineware shapes: ▲ Pithoi: ■ Large open basin shapes: ●; Jars, amphorae, jugs: ⋆; Cooking pot: ♦.

of relative consumption gradients below, we analyze the two centers as separate economic hubs. On the other hand, the nonparametric fits for the Hellenistic era essentially plummet to zero at just about one kilometer from Kastro, reflecting the concentrated nature of economic activity in this era.

The slight upward bend observed in both fits for the Hellenistic era at large distances could be ascribed to the presence of isolated communities in the coastal areas of the island, as seen in the presence of small quantities of pottery in some coastal areas in the center panel of Fig. 3. Note though that confidence bands (plotted always as dotted lines) become wide at the extremities of distance (as in the other two eras considered), so this upwards bend could reflect the imprecision of these estimates due to sparse data.

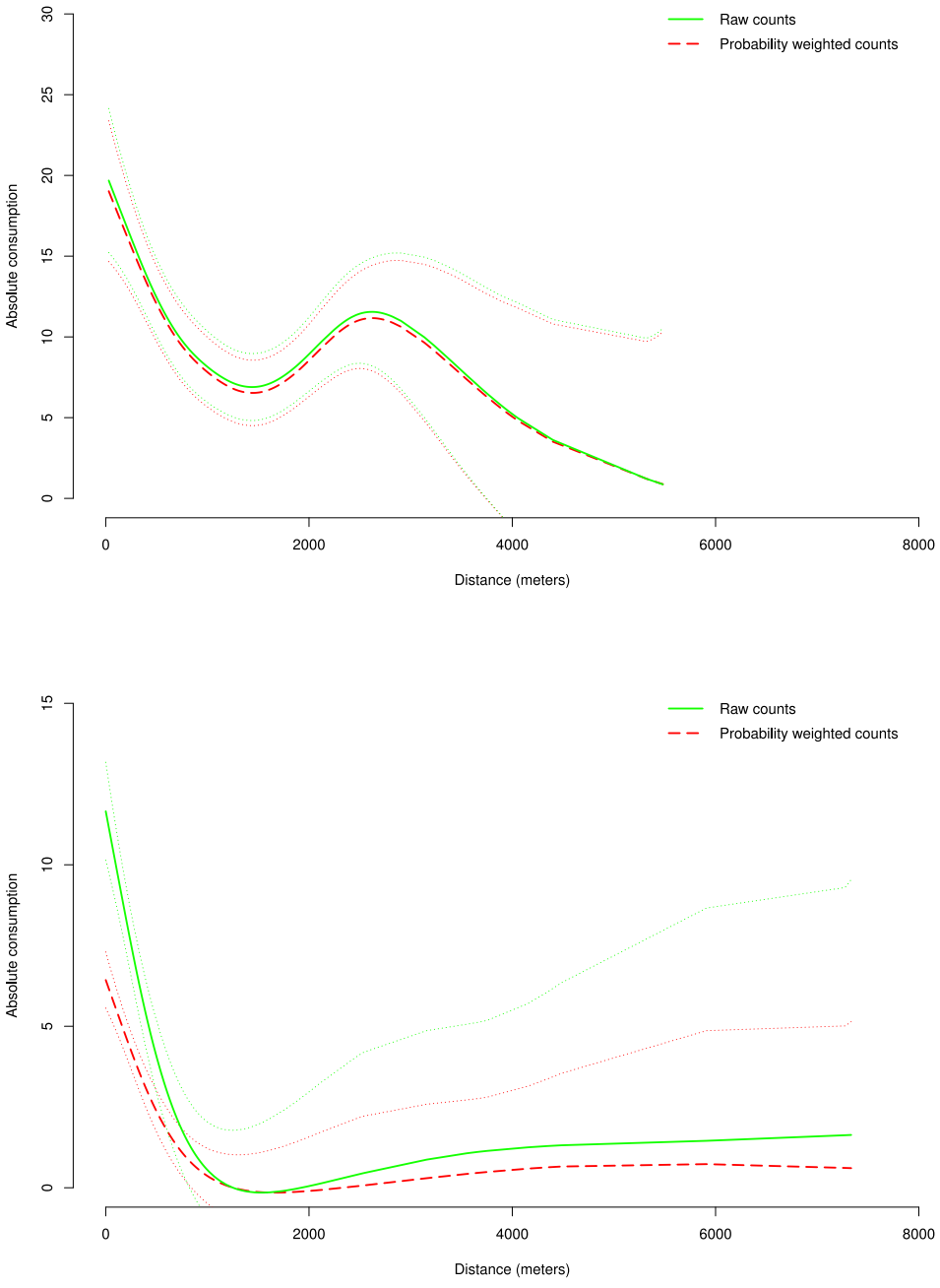

Fig. 5. Nonparametric absolute consumption profiles by era: Minoan (top), Hellenistic (bottom).

4.1.2. Relative consumption profiles

From our examination of absolute consumption profiles above we see no qualitative difference between considering probability weighted and unweighted pottery quality counts, so we focus on the latter. Plots with the former lead to no difference in interpretations. Furthermore, the Hellenistic gradients show the highly local nature of pottery concentration in that era. Thus, in order to better utilize the data and obtain clearer insights we adopt a finer spatial resolution for this period. We do this by gridding the data with cells of approximately $70m^2$, as compared to the $633m^2$ used earlier. Such 'zoomed-in' smaller cells are not very useful in the other two eras with pottery scatters ranging over a much wider area, but are feasible and indeed useful in the Hellenistic era. Table 1 includes summary statistics for the Hellenistic era with this finer resolution.

Using these grids, we fit a nonparametric spline to the logarithm of pottery counts in each cell by quality, on distance from the economic center. Detailed discussions on the choice of center and robustness to alternative centering can be found in Sections 1 and 2 of the online supplement. As our goal is to measure the relative consumption of each type of pottery across space, we wish to avoid unsettled regions contaminating any inference, so we exclude cells which contain no pottery of any type. As there remain some cells which contain some, but not all, types of pottery we take the logarithm of $1 + P^{\mathscr{E}}_{C,q}$, q = Fine, Medium, Coarse, Thick or Non-Thick. Thus in this section our nonparametric regression estimates take $y = \log\left(1 + P^{\mathscr{E}}_{C,q}\right)$.

Figures 7 –10 plot the fitted nonparametric regression curves, which are normalized to be unity at the origin. In each figure the upper panel corresponds to consumption of coarse, medium and fine pottery (dot-dashed, dashed and solid lines, respectively) while the lower panel shows thick and non-thick pottery (solid and dashed lines, respectively). As discussed above we present separate plots relative to the two distinct centers observed in the Late Roman era. While Potamos and the

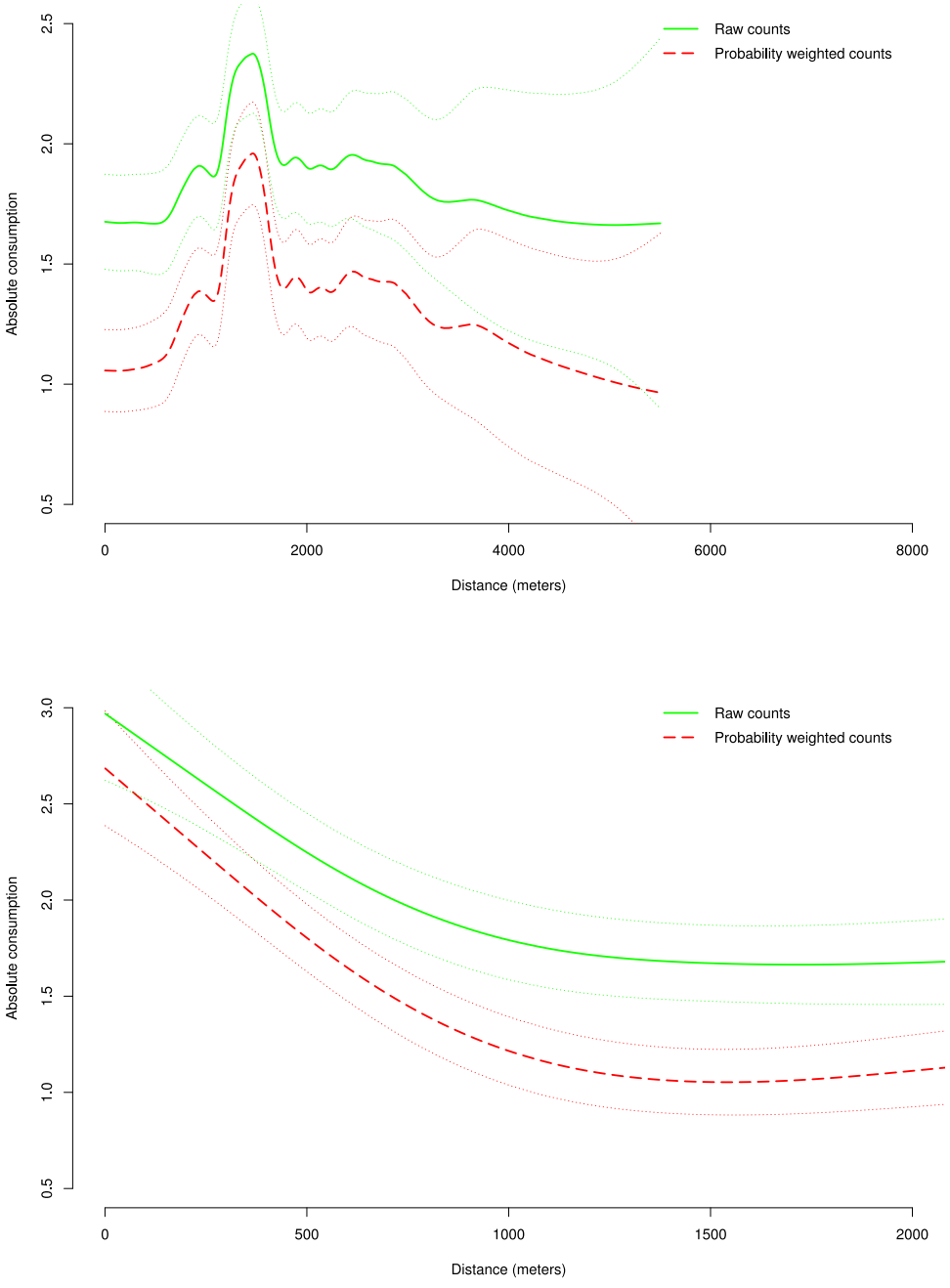

Fig. 6. Nonparametric absolute consumption profiles by era: Late Roman relative to fertile center (top), Late Roman relative to Potamos (bottom).

Kastro are distinct economic centers, the fertile center of the island is not as sharply defined as a condensed ancient fortified town. Thus, we present figures where the origins for Potamos and the Kastro corresponds roughly to the respective centers of their towns, while for the fertile center (both in the Late Roman and Minoan era) this point is taken to lie more generally within farmland. This implies that the region of highest consumption need not lie at zero (or very small) distance in the plotted figures, as is the case for Potamos and the Kastro.

For settlements such as Potamos and the fertile center in the Late Roman era and the Kastro in the Hellenistic, consumption of fine and medium pottery decreases noticeably from the settled center (approximately the cell with the highest total pottery count). Meanwhile coarse pottery consumption remains relatively flat with distance. For the Hellenistic era, this manifests itself relative to the point of highest consumption at the origin (Fig. 7). On the other hand, the upper panel of Fig. 9 shows a hump for both fine and medium pottery corresponding to the fertile center, with profiles increasing (decreasing) as one gets closer to (farther from) the hump, while coarse pottery shows no such pattern. This is consistent with greater "luxury" consumption in the economic center, as we emphasized in the previous paragraph. This pattern is similar to ones found in various Roman-Britain towns in Hodder (1974a,b). The upward bend in fine pottery for the Hellenistic era at the farthest distance is due to the presence of the aforementioned coastal temple of Apollo, which does not correspond to an economic settlement. In addition, Johnston et al. (2012) points out the existence of a graveyard at a similar distance from the Kastro walls that would typically have some fine pottery buried with the deceased; see Fig. 2 therein and the discussion on p. 248.

Similar patterns are observed in the thick and non-thick pottery gradients: in the Hellenistic era (lower panel of Fig. 7) non-thick "luxury" pottery consumption exhibits a sharp negative gradient while thick pottery consumption remains relatively flat. For the fertile center settle-

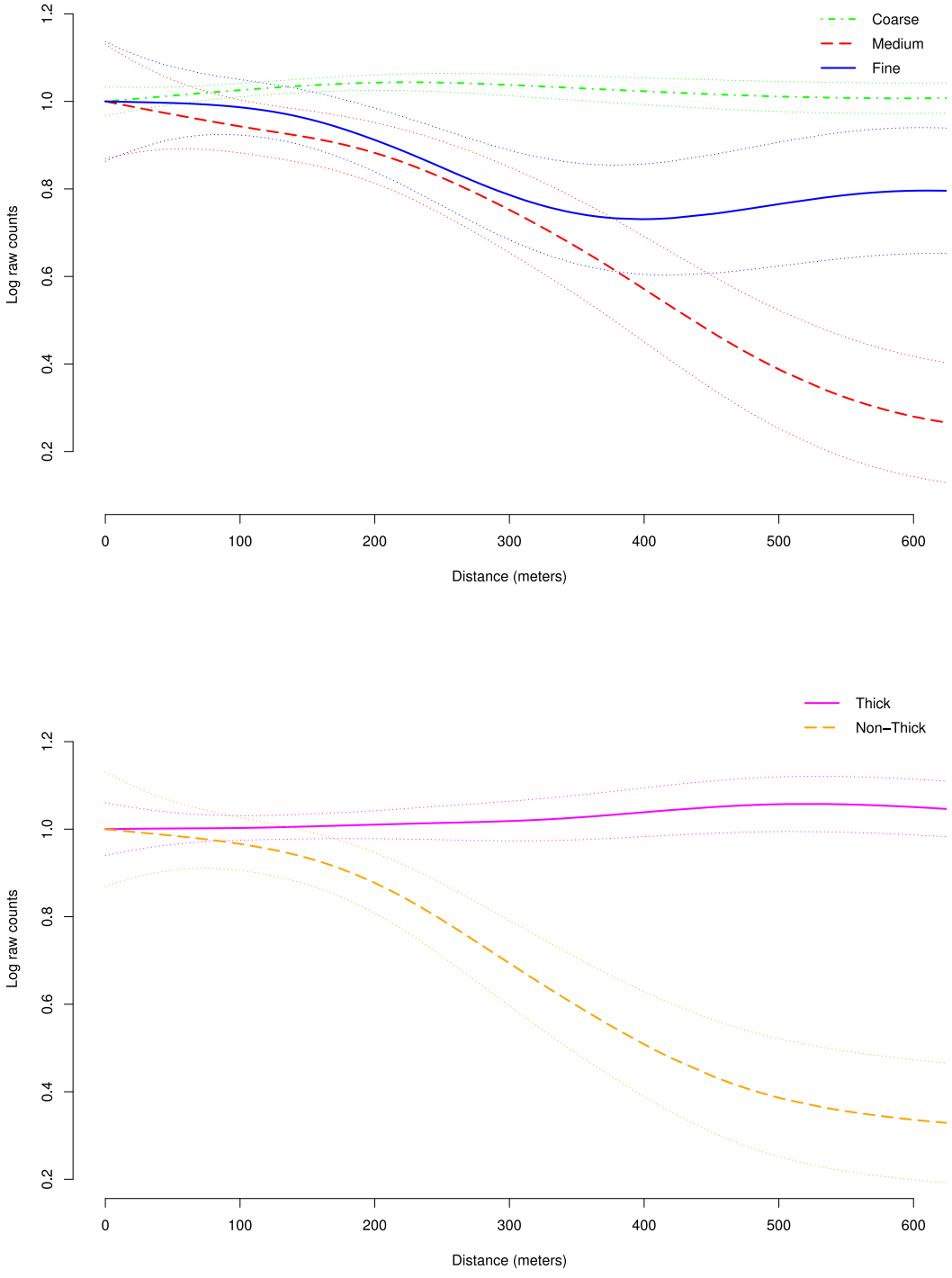

Fig. 7. Relative consumption profiles: Hellenistic era.

ment in the Late Roman era (lower panel of Fig. 9) consumption of non-thick "luxury" pottery increases more rapidly than that for thick pottery as the center of the settlement is approached. This is again consistent with greater "luxury" consumption in the economic center. Similarly, for Potamos in the Late Roman era (lower panel of Fig. 8) we see a marked difference in the gradients of pottery quality consistent with the discussion in the previous paragraph.

Contrary to the time periods discussed above, the Minoan era featured single family farmsteads with no discernible center of economic activity, as discussed by Bevan and Conolly (2013), p. 124–126. It thus constitutes a more primitive economy and acts as a kind of informal placebo. We have no formal alternative hypothesis about the distribution of income (and thus pottery) in this era. As a mostly subsistence agrarian settlement, it is likely that income variations across most farmsteads were small, in which case the undulations of the consumption profiles for all qualities of pottery may roughly parallel each other.

As the preceding discussion stressed, in the other eras that we consider these gradients are markedly different across pottery types with consumption of higher quality pottery declining more steeply with distance from the economic center. On the other hand, in the upper panel of Fig. 10, fine and coarse pottery move in tandem while medium pot-

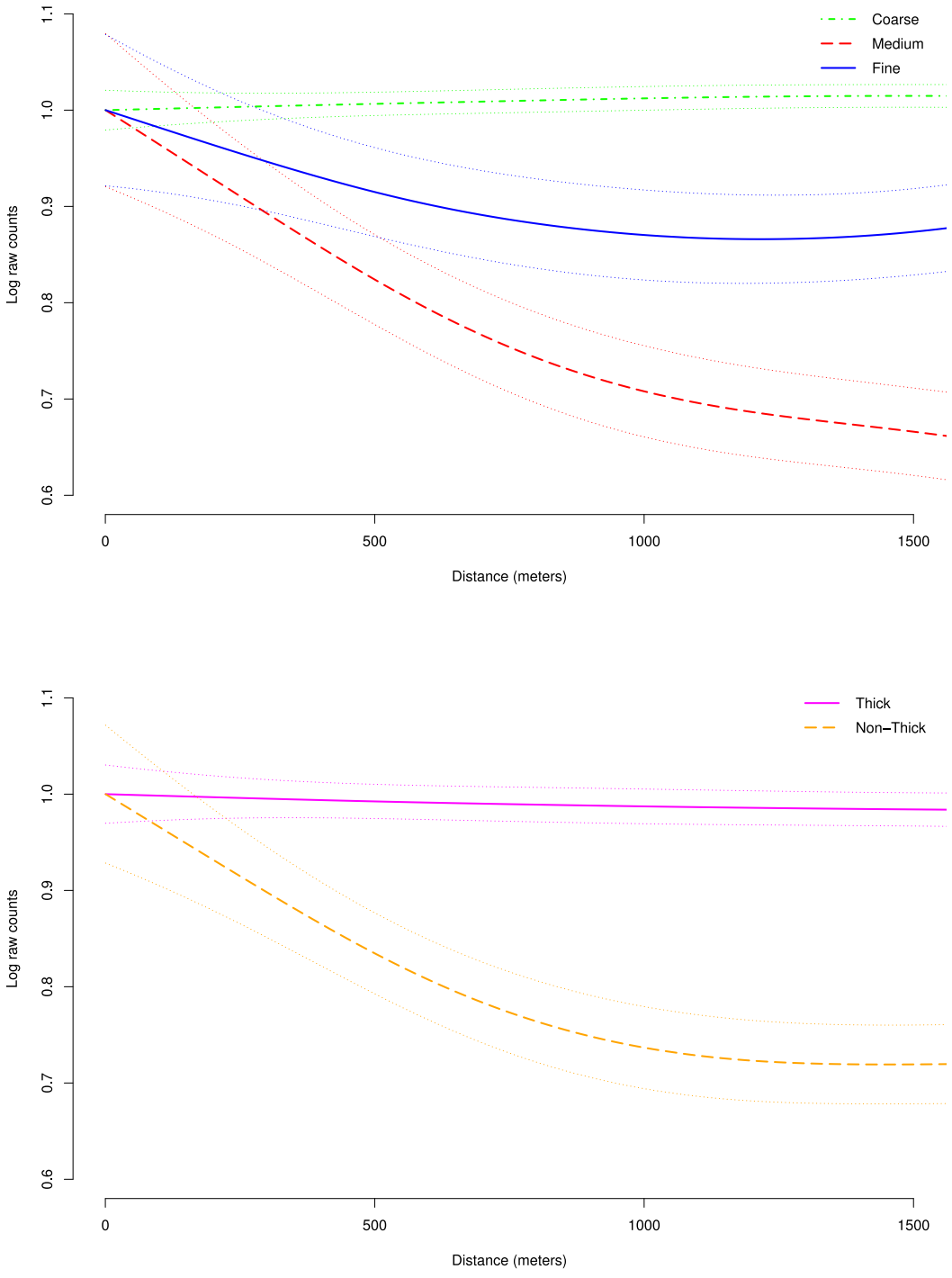

Fig. 8. Relative (to Potamos) consumption profiles: Late Roman era.

tery's gradient is less steep than coarse's. In the lower panel we observe an initial flat gradient for thick pottery as opposed to a steep slope for the non-thick pottery near the "peak" settlement (the area with the most pottery during this era), but at a distance of 1000m both profiles behave in almost identical fashion indicating no detectable difference in the patterns of "luxury" versus non-"luxury" consumption across most of the island at this time.

We also compute some correlations that augment our visual analysis. Our two measures of quality - fineness and thinness - are far from perfectly correlated. For instance, depending on the era, the correlations between the log counts of coarse and thick pottery are between 0.14 and 0.72. Table 2 shows the correlation between $\log\left(1+P_{C,q}^{\mathscr{E}}\right)$ and $\log\left(P_{C}^{\mathscr{E}}\right)$, i.e. between pottery quality (coarseness or thickness) and total consumption within cells in different eras. We observe that there is little difference in the pattern of these correlations for the Minoan era that suggest a decline in luxury consumption with a decline in total consumption: all correlations are strong. On the other hand, for the Hellenistic and Late Roman eras the correlations are clearly stronger for the higher grades of pottery (whether in quality or thickness), implying that a higher share of luxury consumption is associated with higher (not per capita) consumption. This is consistent with the sorting predicted by our model below. The equality of the correlations (to two decimal places)

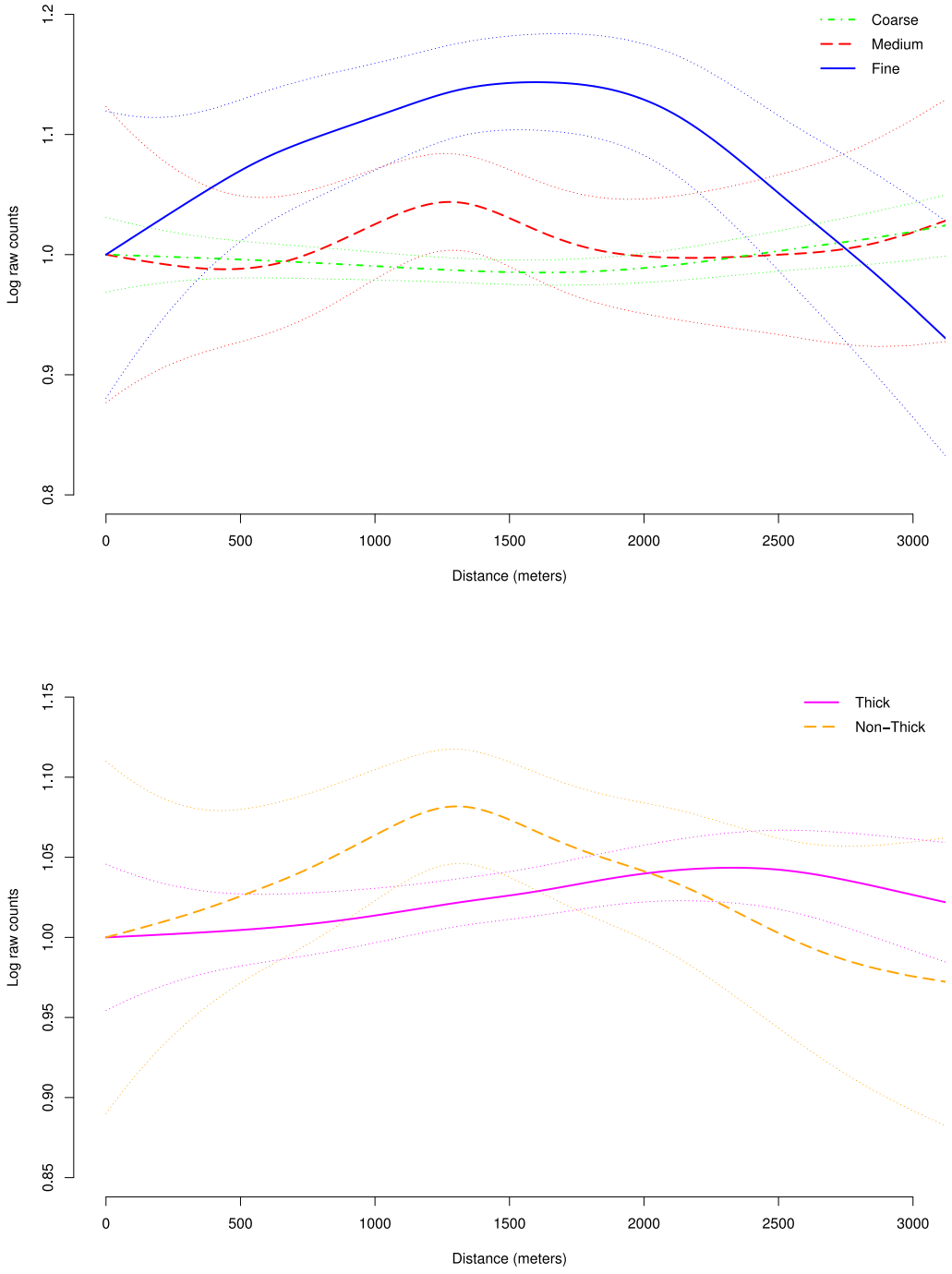

Fig. 9. Relative (to fertile center) consumption profiles: Late Roman era.

for fine and medium pottery in the Late Roman era is simply the result of chance.

4.2. Links with the historiography of the region

As the results discussed above show, our empirical evidence for sorting varies with settlement patterns. An interesting question is whether these differences have counterparts in the historiography of the region. Indeed, archaeologists have linked settlement patterns with specific agricultural practices, and these links match what we observe in the Minoan and Late Roman eras in particular (recall that the Hellenistic era settlement was mainly not devoted to agriculture).

As discussed by Davis (1991), p. 138–139, Halstead (1987) classifies Mediterranean agriculture into *traditional* and *alternative* practices. The traditional system featured nucleated settlements involving long travel time to fields and a form of production with scattered land holdings as well as large livestock herds often grazing in uplands, thereby depositing manure far from cultivated fields. This is similar to the patterns we observe in the Late Roman era, when at least part of the island was devoted to agriculture. On the other hand, the older, alternative practice involved smaller herds that grazed on fields adjoining a homestead only. There was little surplus yield to support non-farming households and therefore little need for a market. As a result, settlements were more dispersed. These dispersed consumption patterns are the patterns we ob-

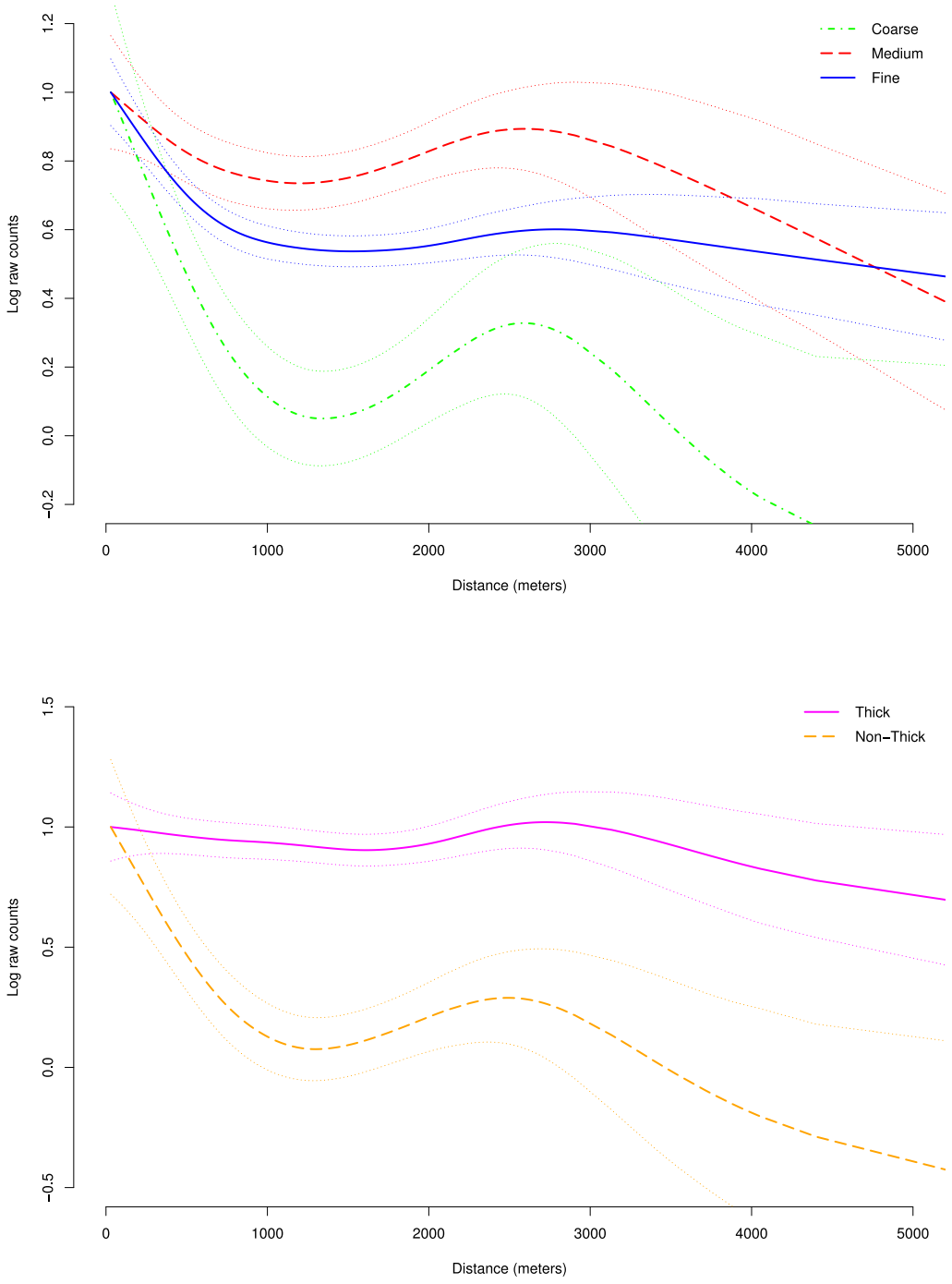

Fig. 10. Relative consumption profiles: Minoan era.

serve in the Minoan era. Thus our empirical evidence is consistent with this archaeological historiography.

4.3. Summary of empirical findings

Our empirical findings indicate the presence of quality-differentiated pottery consumption gradients relative to economic centers of activity in two of the three eras that we have considered. In particular higher quality goods exhibit steeper profiles. Both of these eras featured some form of nucleated or proto-urban settlement pattern on the island. On the other hand, for an entirely agrarian settlement pattern we do not find such gradient patterns. The visual patterns are congruous with simple correlation measures of consumption quality with total consumption. Our findings are also consistent with observations made in the historiography of the region for these time periods. A reasonably consistent finding across many figures is that the gradients are ordered medium > fine > coarse. The online appendix presents a monocentric model that shows how such a pattern in the data can be generated by dispersion in households' consumption baskets caused by sorting. In the next section, we discuss the possibility that some other economic process instead generated the data.

5. Alternative hypotheses for our findings

Our setting is free from the complications of a sticky built environment and attendant confounding factors, but naturally carries the caveat

Table 2
Correlation between type of consumption and total consumption.

	Minoan	Hellenistic	Late Roman
$corr(\log(1+P^{g}_{C,c}),\log(P^{g}_{C}))$	0.97	0.14	0.06
$corr(\log(1+P^{g}_{C,m}),\log(P^{g}_{C}))$	0.70	0.75	0.63
$corr(\log(1+P^{g}_{C,f}),\log(P^{g}_{C}))$	0.57	0.69	0.63
	Minoan	Hellenistic	Late Roman
$corr(\log(1+P^{g}_{C,t}),\log(P^{g}_{C}))$	0.64	0.13	0.24
$corr(\log(1+P^{g}_{C,nl}),\log(P^{g}_{C}))$	0.98	0.96	0.96

of some uncertainty in the conclusions that we can draw. For example, we cannot rule out with complete certainty that the gradients we find are not an artifact of a central market. Nor can we entirely rule out that they possibly originated as result of trade routes. Nevertheless, in this sections we examine some of these alternative hypotheses and offer our arguments, based on the information in the data, to tentatively reject them.

Thus far we have interpreted the location of a pottery sherd as being informative of where that pottery was going to be consumed. To test hypotheses relating to the sign of the consumption gradients, it is not necessary that these sherds were "consumed" exactly where they were found. As long as sherds found further away from the center were more likely to be consumed further away from the center than sherds found close to the center, we can use the data to infer relative consumption locations.

There are several competing hypotheses, not uncommon in other archaeological studies of different data, that could cast doubt on the above assumption. They are all related. The first is that location finds may be evidence of localized trade (i.e. a marketplace) rather than consumption. The second is that the pattern of sherds may be evidence of trade routes. The third is that localized finds are evidence of production sites. We discuss each below. In each, we hypothetically suppose that, instead of there being consumption gradients based on income sorting, the city could have a flat income and consumption gradient. We then consider whether any of the above alternative hypotheses could generate on their own higher shares of luxury pottery in finds near the center and lower shares of luxury pottery in finds at distances removed from the center.

5.1. Market hypothesis

Archaeologists have studied many areas where pottery was known to be made for sale or trade.[14] Local trade in a market would typically leave behind pottery, much as broken objects and refuse can be found near all sorts of modern markets. In the case of Antikythera, however, archaeologists have noted that there is no evidence whatsoever of even a seasonal fair in Antikythera for any period of its existence, leave alone a market. Rather they have concluded that its inhabitants were likely intermittent visitors to markets on neighboring islands such as Crete and Kythera, see Bevan and Conolly (2013, p. 81).

No matter where the pottery was acquired, to the extent that there was any trade in the settlement center, the direction of bias in our estimate of the gradient of the share of luxury consumption would likely be in the opposite direction to the results we find. If, as seems sensible, any hypothetical market was located near the settlement center, one might imagine that some pottery would be left there as a by-product. This could be due to breakage of pottery meant for sale or discards of amphorae and other pottery used to store perishable goods.

Consistent with marketing models of pottery finds (described in Section 5.2 below), it is therefore likely that the share of pottery left near markets that is low-quality would be quite high. If the share of luxury pottery (relative to lower grade sherds) due to market discard was lower than nearby households' luxury share of pottery consumption, then our measure of the gradient of the share of luxury consumption in the area of the market would be biased towards zero - away from our hypothesis. Thus it seems unlikely that in a "flat" settlement, a central marketplace would generate higher shares of luxury goods near the center.

5.2. Are pottery finds reflective of trade routes?

Pottery finds have often been used to understand trade routes in a large archaeological literature. This is often the case when studying long distance trade. Hodder (1974a,b) indeed assume that their pottery data reflects trade patterns as opposed to consumption patterns. Their pottery finds laid along (or near) known roads in Roman-era Britain. In the case of Antikythera, while some thick/coarse pottery may have been produced "at home" on the island, it remains likely that much of it was also imported one way or another from ships, or picked up from "tramping trade boats that occasionally pulled up at the quayside" (Bevan and Conolly, 2013; Casson, 1938; 1951).[15] What matters for our hypothesis is whether and how movement caused by *within*-island trade could distort our consumption inferences. We believe that it does not, for several reasons.

For one, our pottery finds are more dispersed than one would typically expect if they were to accumulate alongside a road as result of disposal or breakage in transit.[16] Secondly, there is no other evidence of there being any major trade route on the island itself. During the historical periods we look at, there was likely at most one port and therefore no reason to transport goods across the island for reasons other than consumption on the island (i.e. no within island, port-to-port movement). In fact, there is a lack of archaeological evidence for any roads at all on the island, this being a "famously late [near-modern] phenomenon" on Antikythera (Bevan and Conolly, 2013, p. 177). It thus seems reasonable to assume that pottery that moved about the island was likely for consumption somewhere within the settlement. Any pottery dropped in-transit while on route to a homestead would be a censored estimate of its ultimate within-settlement intended consumption destination. This may complicate using pottery densities to infer granular population densities; another reason we do not attempt to do this. Such censoring would not necessarily invalidate using changes in the relative concentration of types of pottery to make inferences about sorting.[17]

Thirdly, similar to the discussion of marketplace effects above, if different types of pottery had different hazard rates of being discarded or lost during overland transport, then that too could complicate any inference we make about consumption propensities. For instance, if fine pottery was more likely to get broken and then discarded while en-route from a settlement center to the periphery, then the concentration of fine pottery would be higher closer to the center even if households did not sort by income or wealth. Hodder (1974b,a) however finds that transportation issues tended to disperse fine pottery more, not less, than coarse pottery; evidently finer pottery's higher value led to a higher willingness to transport it further. So, in a "flat" settlement, trade routes would probably create positive quality gradients with respect to distance from the center; higher shares of luxury pottery further away from the origin of the trade caravan. Finally, we can use the data we have to

[14] *loc cit* Section 1.

[15] Indeed in a number of cases, based on composition of the clays, possibly via petrography, and other factors, archaeologists were able to determine where off-shore the pottery was made. For example, the data can contain information such as "Micaceous Siphnian cooking pot fabric", "African amphora fabric" etc, although such information is available for a limited number of sherds.

[16] For example, simply eyeballing Fig. 4, the finds delineate no clear roads. The striped pattern of the finds is due to how the fieldwalked sample was geolocated by the archaeologists.

[17] For instance, suppose we observe that the share of fine pottery in total pottery found at distance d_1 from the center is higher than the share found at $d_2 > d_1$. We could infer then that the average share of fine pottery being consumed at distances $d \geq d_1$ was greater than the average share being consumed at $d \geq d_2$.

partially check the trade hypothesis. While we cannot completely rule out differential breakage as a factor driving our data, one way to test for it, at least weakly, is to exploit the identification of some sherds in the data as being from amphorae. Amphorae were a specific type of pottery used as containers for storage. As such, they may be a type of "necessary" good even if their fabrication may differ by coarseness or thickness. We wish to check if our empirical results are robust to the exclusion of amphorae. The quantity of amphora fragments is negligible in the Minoan era (40 out of 6629) so we do not present results for this. Figures presented and discussed in Section 4 of the online appendix confirm robustness.

5.3. Consumption or production?

Not surprisingly, sites where pottery was being produced are festooned with the type of pottery being made there.[18] There are no such locations known in our data. Bevan and Conolly (2013) report finding no evidence of any kilns on the island for any of these periods or, indeed, after. While coarse pottery could have been home-produced using a bonfire instead of a kiln (Greene, 1992; Sparkes, 2013), it is likely that most if not all (especially fineware) pottery found on the island from these periods was acquired from "passing ships" or off-shore marketplaces (Bevan and Conolly, 2013). Local production of coarse pottery meant for local consumption is also consistent with our assumption that the location of the find is informative of the consumption in that area.

Moreover, as noted above, even at a granular level, the data always feature pottery that can traced back to a number of different off-shore origins using variations in the clay composition, among other hallmarks. Given this, it is very unlikely that a dense area of pottery sherds with variegated clays in our data was the product of an on-island kiln. These facts give us grounds to tentatively reject the production hypothesis.

6. Conclusion

The extent to which differences in earnings, skills or wealth maps into spatial sorting within cities and thus into, perhaps, differential access to public goods is a fundamental question for urban and public economics (e.g. Glaeser et al., 2008; Glaeser et al., 2009; Chetty and Hendren, 2018). Modern cities are shaped by an amalgam of forces, some present and some historical. Modern transportation networks often are partially molded by historic networks (in part to reduce frictions to rights of way). Modern public goods often have explicit links to the location preferences of past generations (the Louvre and Frick Museums were formally residences of their patrons). The legacies of past policies, such as red lining, cast long shadows.

Ancient settlements, especially those that were built without meaningful antecedents, offer a different laboratory to test urban economics theories. We show how to infer the spatial distribution of consumption from the data and then, in the online appendix, how a simple model with modern preferences but ancient transportation costs, can match the data. We sound a note of caution, as our conclusions cannot rule out with complete certainty other plausible hypotheses for such gradients but we use the information in the data to tentatively reject these as best we can.

CRediT authorship contribution statement

Abhimanyu Gupta: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jonathan Halket:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

[18] Examining production sites is very common in the archaeological literature, see e.g. Brown and Sheldon (1974), Gibson and Lucas (2002).

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.jue.2023.103548.

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