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A small change revolution. Weight systems and the emergence of the first Pan-European money

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ABSTRACT

In the Bronze Age (c. 2300–800 BC), European communities gave up their economic independence and became entangled in a continental trade network. In this paper, we will test the hypothesis that the adoption of a 'Pan-European' currency has favoured the development of such a network. We define a methodology to test the money-hypothesis in pre-literate economies, based on analogies with the material characters of metallic money in the Ancient Near East. The statistical properties of metals from European hoards are compared with those of balance weights, in order to test the following expectation: if they were used as money, complete objects and fragments are expected to comply with standard weight systems. The results meet the expectation, and indicate that bronze fragments possess the same statistical properties as hack-silver money in the Ancient Near East. The sample includes approximately 3000 metal objects, collected from two test-areas: Italy and Central Europe. The sample of balance weights includes all the items known to date for pre-literate Bronze Age Europe, collected within the framework of the ERC Project 'Weight and Value.'

1. Introduction

The widespread diffusion of weighing technology in Bronze Age (BA) Europe (c. 2300–800 BC) hints at the gradual increase in relevance of a commercial economy. Since weight systems[1] have barely any other application than accounting for incomes and expenditures, assessing economic value, and negotiating prices (e.g. Powell, 1977; Renfrew, 2012), their diffusion must be correlated to an increasing involvement of merchants. In the second half of the second millennium BC, the emergence of a Pan-European weight unit created the preconditions for the widespread adoption of weight-regulated metallic money (Ialongo and Rahmstorf, 2019).

In the next section, two we introduce the argument based on the archaeological evidence for weighing technology, metal fragmentation, and metal trade. In the third section, we define the money-hypothesis, describe our statistical methodology and test the hypothesis on a large sample of metal objects from Italy, Germany and Poland. The analysis is grounded on a comparative methodology recently proposed and tested on hack-silver money of BA Mesopotamia (Ialongo et al., 2019). Based on a comparison with the metrological properties of balance weights, we conclude that the results of the analyses support the interpretation of bronze fragments as 'Pan-European money'. In section four we discuss the results of the statistical analysis in connection with the questions of weight-regulation, value, and the origin of money.

In the conclusions, we outline the potential impact of future research on pre-coinage money on the understanding of the economy of prehistoric societies. We propose that the growing economic specialisation and the increasing volume of trade in the Late BA (c. 1350–800 BC) can be partly explained by the widespread adoption of a 'Pan-European money'.

2. The argument

2.1. The rationale for a commercial economy in BA Europe

The BA of Western Eurasia is always accompanied by three

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[1] In this article we make an equivalent use of the terms 'weight' and 'mass.' 'Mass' is the formally correct term to identify the quantity measured by balance scales, whose unit in the SI is the gram (g). 'Weight' is a force, and its unit is the newton (N). In both common language and scientific terminology, however, the term 'weight' is widely used in popular locutions, such as 'weight system,' 'weight regulation,' and 'balance weight'. We decided to maintain these locutions for the sake of clarity.

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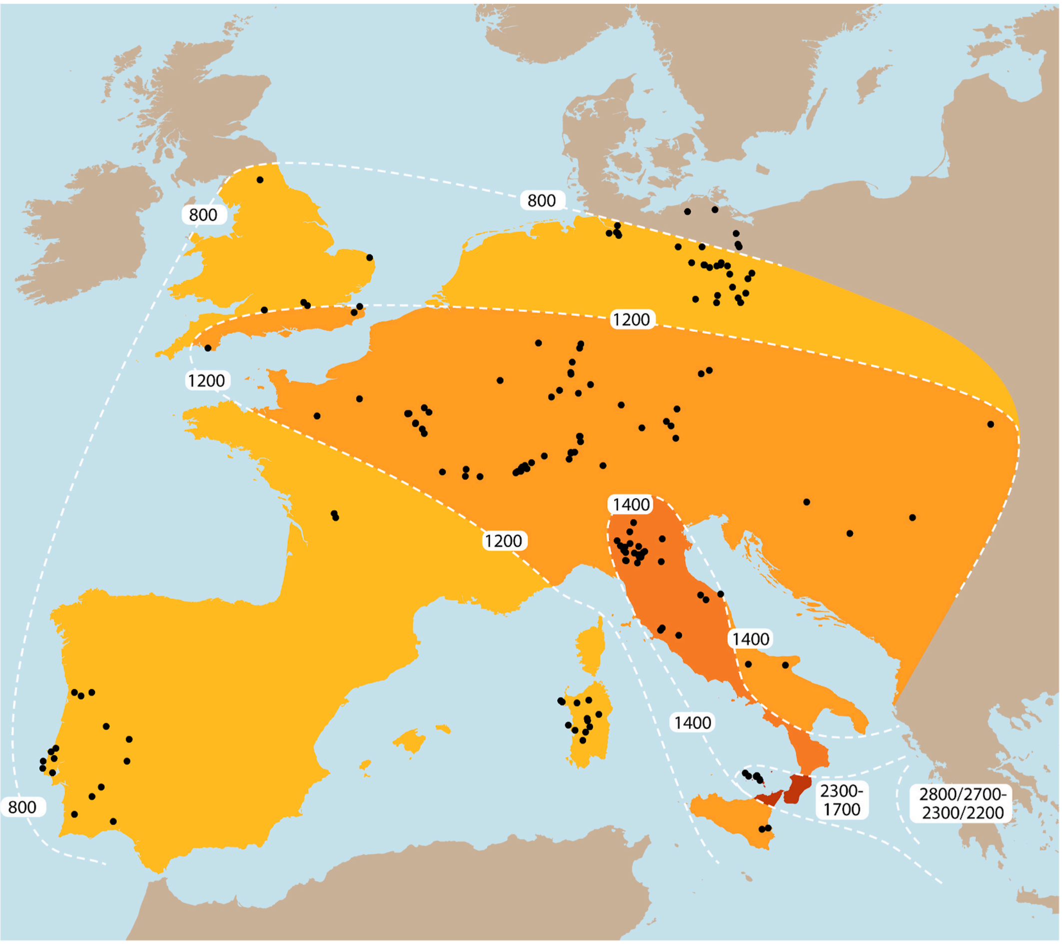

Fig. 1. Diachronic diffusion of balance weights in BA Europe (based on Ialongo and Rahmstorf, 2019). Dates are in years BC.

Fig. 2. 'Scrap hoard' from the Late BA battlefield of Tollense Valley (Northern Germany, c. 1350–1200 BC). The assemblage was probably contained in a box of organic material and includes fragmented objects, semi-finished items and blunt tools (from Uhlig et al., 2019; photo by Volker Minkus; courtesy of Thomas Terberger).

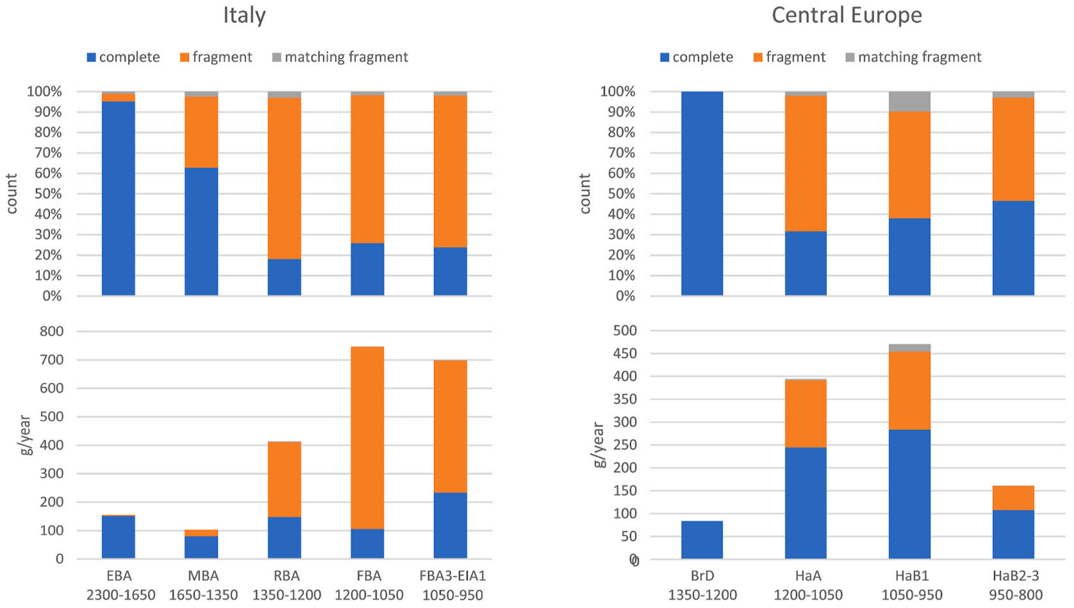

Fig. 3. Diachronic quantification of metal fragments in BA hoards in Italy (data from Lago, 2020) and Central Europe (data from Sommerfeld, 1994).

interrelated, overarching phenomena: The ubiquitous presence of tin bronze (e.g. Vandkilde, 2016), frequent human mobility (e.g. Vandkilde et al., 2015), and the widespread diffusion of weight systems (e.g. Rahmstorf, 2010). The simultaneous development of these phenomena hints at the formation of a continental network based on long-distance trade (Kristiansen, 2018).

For BA Europe, there is evidence that the extraction of copper in specialised mining regions followed a demand-related trend. For example, in the Mitterberg district (Austria) low-quality fahlore copper – mainly mined in the Early BA – was replaced by high-quality chalcopyrite in the Middle BA. In the Late BA (c. 1200 BC), perhaps owing to a surge of demand, both fahlore and chalcopyrite were extracted at the same time (Lutz and Pernicka, 2013). In the British Isles the exploitation of rich local copper ores appears to severely diminish between c. 1300–1200 BC, with internal demand being satisfied by continental metal (Williams & Le Carlier de Veslud, 2019). As for the magnitude of ore extraction, it has been calculated that a single mining district could yield an approximate average of c. 50–100 metric tons of refined copper per year (Pernicka et al., 2016). Provenance studies in other areas of Europe further support the impression that, starting c. 1350–1200 BC, a surge of the demand for metal was satisfied by a limited number of specialised mining regions (e.g. Begemann et al., 2001; Ling et al., 2014).

Copper seems to move independently from the distance of its sources and in spite of the local availability of ores, and thanks to its optimal preservability it is an ideal proxy of the magnitude of production and trade in Europe. Other commodities circulated in the BA, many of which (such as salt, textiles and timber) simply do not leave measurable traces in the archaeological record (e.g. Earle et al., 2015): How did these commodities circulate? The diffusion of balance scales and weights indicates that long-distance trade could rely on widely shared indexes of value to assess and negotiate the prices of commodities (Pare, 2013; Renfrew, 2012). Weighing equipment is first attested in southern Italy in the Early BA (c. 2300–1700 BC), becomes widespread by c. 1350–1200 BC, and by c. 1200–800 BC is adopted virtually everywhere in Europe (Fig. 1); moreover, the same weight units were employed everywhere in the European territory (Ialongo and Rahmstorf, 2019; see below § 3.4). Since the main use of weight systems is the quantification of prices in transactions, weight-based trade belongs to the basic definition of market exchange, whether or not a ‘price-making’ market actually existed in the BA.

2.2. *Fragmentation, hoards and metallic money: three aspects of a faceted problem*

The systematic fragmentation of bronze artefacts – one of the most characteristic and ‘enigmatic’ phenomena of the European BA – is first attested in the Middle BA and becomes progressively widespread in the Late BA (e.g. Bradley, 1990: 114; Hansen, 2016: 197). Towards the end of the 2nd millennium BC, systematic fragmentation assumes the traits of a continental phenomenon. Fragmentation is a key-aspect of the debate on metallurgy in BA Europe, being intimately intertwined with the phenomenon of metal hoarding and with the problem of money (Fig. 2). The interpretation is polarizing: Some scholars see it as a ritual practice, aimed at ‘killing’ an object before ritually burying it, while others envisage an economic purpose aimed at facilitating recycling or exchange (see Brandherm, 2018 for an overview of the debate).

The ritual hypothesis suggests that metal fragments bear traces of ‘aimless violence’ (e.g. Bietti Sestieri et al., 2013; Nebelsick, 2000). Weapons, jewellery, tools and casting waste – some authors suggest – were not simply broken, but they were subject to special treatments, including twisting, bending, folding, heating and, sometimes, partial re-melting. Allegedly, these operations would not fit with utilitarian purposes, but rather be consistent with ritual practices. According to this interpretation, some scrap hoards would be collections of ritually-destroyed artefacts, buried within complex sacrificial ceremonies (Brück, 2016; Hansen, 2016). Empirical studies proposing this interpretation, however, only address very limited samples from arbitrarily selected hoards, and the ritual explanation does not appear suitable to explain the majority of the evidence (Lago, 2020).

According to the theory of temporary storage, the breakage of artefacts had utilitarian purposes. The high incidence of broken objects in Late BA hoards has been interpreted alternatively as proof of massive recycling (e.g. Delfino, 2014), or as evidence of the practice of storing value (e.g. Bradley, 1988; Leonardi, 2016). A recent study – carried out on a big sample with statistical methods – demonstrated that the size of fragments in British Late BA hoards conforms to random distributions (Wiseman 2018). The evidence would argue against the ritual hypothesis: If fragmentation does not follow regular patterns, then hoards are simply the result of random accumulation. Hence, scraps were allegedly accumulated in order to be recycled, and the people who buried the hoards merely failed to retrieve them.

A third theory assumes that metal objects were broken in order to facilitate their circulation as currency (e.g. Peroni, 1998; Primas, 1986; Sommerfeld, 1994). Since the exchange value of metal was assessed through weighing, fragmentation was aimed at obtaining pieces with predetermined mass values, and fragments circulated as money. The starting assumption of this line of research is the following: If bronze objects and fragments comply with weight systems, then there is a fair chance that they were used as currency. However, the results of these studies are generally problematic, since the selection of test-samples is often arbitrary, the analytical methods are merely descriptive and the arguments are often circular (see e.g. critiques in Ialongo, 2019; Pare, 1999). On the other hand, there is one aspect of fragmentation that argues in favour of the commercial hypothesis, i.e. hoards seldom contain two pieces of the same object. The figures for Italy and Central Europe show that, throughout the BA, matching fragments rarely occur in hoards (Fig. 3), as Wiseman (2018) also noted for the British hoards. Except for a minority of special cases, therefore, it is unlikely that the breakage of metal objects was part of an intentional treatment that preceded deposition in a consequential chain of actions, be it either for ceremonial purposes or in order to facilitate re-melting. On the contrary, most fragments rather circulated for a long time before their deposition (e.g. Bernabò Brea and Cavalier, 1980: 738–739; Brandherm, 2018: 53; De Marinis, 2019; Milcent, 2017; Vilaça and Bottaini, 2019: 129). If bronze regularly circulated in fragments, then fragmentation is correlated to exchange, and completely detached from the procedure leading to the deposition of metals. As demonstrated by Wiseman for the British Isles (2018), in the majority of cases hoards simply collect random samples of all the metal that was circulating at the time of their deposition. In other words, if metal circulates mostly in fragments, then fragments will represent most of the metal in hoards.

2.3. *Metal fragments as money*

The spread of weighing technology somehow mirrors the spread of the fragmentation phenomenon. The so-called ‘scrap hoards’ appear in Middle BA in Italy (Lago, 2020) and in Central Europe between the Carpathian Basin and the Loire Valley (e.g. Brandherm, 2004; Hansen, 2016; Nebelsick, 2000). In the course of the Late BA, scrap hoards become increasingly more frequent in these areas, and start being attested almost everywhere in Europe (e.g. northern Germany and Poland: Sommerfeld, 1994; Atlantic France: Coffyn et al., 1981; British Isles: Wiseman, 2018; Spain: Brandherm, 2007; Romania: Rezi, 2011). In this time span, the fragmentation phenomenon hints at a transformation of circulation patterns. In our sample of Italian and Central European hoards, the occurrence of fragmented objects tends to grow steadily in the course of the BA (Fig. 3). The increase in the circulation of light scraps suggests that the volume of individual transactions involving metal tended to become smaller and smaller over time. Interestingly, fragments did not circulate *instead* of complete objects, but *in addition* to them. The average yearly mass of bronze buried in hoards shows that fragments represent a relevant part of circulating metal since around 1350–1050 BC (Fig. 3). In Italy, in particular, the occurrence of complete objects remains stable in the Late BA, while fragments represent the vast majority of the mass of metal in circulation.

The evidence suggests that there is a correlation between the spread of weighing technology, the frequency of fragmentation, and the overall mass of metal in circulation. From this perspective, fragmentation may have represented an incentive for the circulation of metal. In the attempt to explain this correlation, we take a novel perspective on the phenomenon of fragmentation: We propose that the increasing circulation of weight-regulated ‘small change’ may have fostered trade by reducing the average volume of individual transactions, thus granting more and more agents access to the exchange network. The hypothetical use of bronze as money may explain the increasing demand for metal, the subsequent specialisation of mining regions and the fragmentation phenomenon. When a substance is simultaneously money and commodity, the demand for that substance is effectively doubled, since people will seek to obtain it in both states, but for different purposes (Jones, 1976). At the same time, when the desirability of a good increases more people will be interested in obtaining it, which, in turn, will prompt an increase of production.

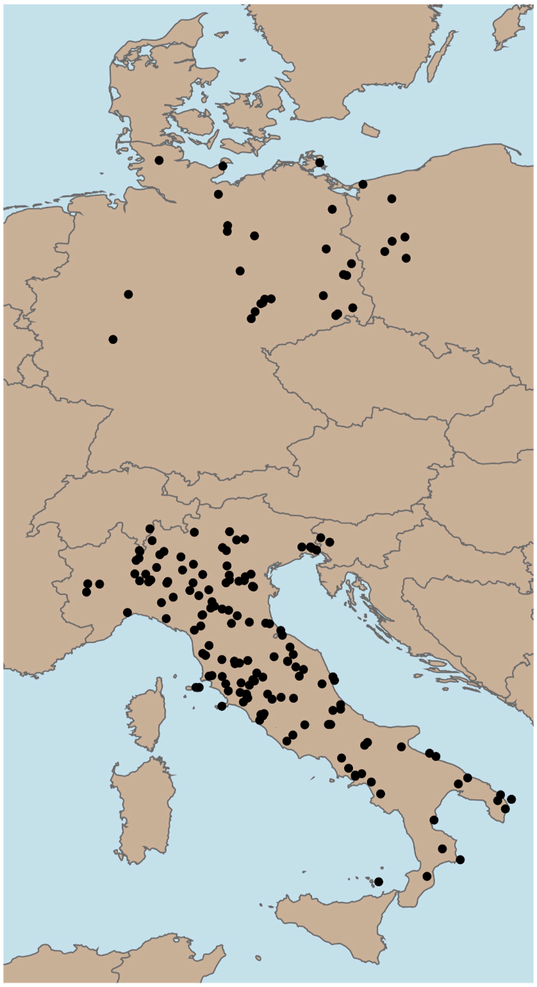

Fig. 4. Geographical distribution of the analysed sample of BA hoards.

3. Testing the money-hypothesis

3.1. *Premise*

The relationship between metals and weight systems is key to solving the problem of pre-coinage metallic money in BA Europe. While we fundamentally agree with the critiques towards the methodological framework of previous studies, we also contend that no proactive effort was ever made to prove the hypothesis false. Critiques always aimed at highlighting flaws and loopholes, but never at developing alternative methods that could factually disprove the hypothesis. Hence, the question still remains unanswered: Do bronze objects and fragments comply with weight systems? Our analysis is designed to provide a clear-cut answer based on statistical tests. The first problem to solve is how to define weight systems. Previous research on the money-hypothesis missed a crucial point, since no one ever considered balance weights as part of the equation. The study of balance weights is the only way to reconstruct prehistoric weight systems. Until recently, the evidence related to weighing equipment in BA Europe was scanty and discontinuous. In the framework of an ongoing research project, all the evidence was collected and significantly expanded with unpublished materials (Ialongo and Rahmstorf, 2019) (Fig. 1).

Table 1

Composition of the analysed sample (items with mass values between 7 and 200 g).

Italy EBA-MBA		
Category	count	Analysed
Complete objects	13	No
Fragmented objects	3	No
Complete ingots	1	No
Fragmented ingots	14	No
Total	31	
Italy LBA		
Category	count	Analysed
Complete objects	156	yes
Fragmented objects	675	yes
Complete ingots	2	no
Fragmented ingots	464	yes
Total	1297	
Central Europe LBA		
Category	count	analysed
Complete objects	622	yes
Fragmented objects	761	yes
Complete ingots	6	no
Fragmented ingots	22	no
Total	1411	

3.2. *The sample*

Our sample includes two regional datasets: the total number of published hoards from Italy (Lago, 2020), and a large sample of hoards from northern Germany and western Poland (Sommerfeld, 1994) (Fig. 4). We exclusively considered objects for which the mass is known. The data have been divided into four categories (Table 1): 1) complete objects (including every functional category except ingots); 2) fragmented objects; 3) complete ingots; 4) fragmented ingots. The Italian subset covers the whole BA (c. 2300–950 BC), while the German subset is limited to the Late BA (c. 1350–800 BC).

3.3. *Cosine Quantogram Analysis*

Cosine Quantogram Analysis (CQA) is the most reliable methodology in metrological studies of the Ancient World. CQA was initially devised in 1974 by the statistician D.G. Kendall (1974). It was employed in weight metrology for the first time in the 1990s (Petruso, 1992), and has been further developed in recent years (e.g. Hafford, 2012; Ialongo, 2019; Ialongo et al., 2019; Pakkanen, 2011).

CQA is a non-inductive method that allows to determine if a sample of metrical observations is the product of one or more basic units, by looking for *quanta* in a distribution of mass values. A *quantum* is a single value for which most of the mass values in a sample are divisible for a negligible remainder. If the sample is 'quantally configured' (i.e., if most of the values are divisible by the same number), then most values will give a rational number (i.e., 2, 5, 8, 1/2, 1/3 …) when divided for the best quantum. All values are divided by a series of quanta and the analysis gives positive results for those quanta that give a negligible remainder for most of the values in the distribution. CQA tests whether an observed measurement X is an integer multiple of a quantum q plus a small error component ε. X is divided for q and the remainder (ε) is tested. Positive results occur when ε is close to either to 0 or q, i.e., when X is (close to) an integer multiple of q:

$$\varphi(q) = \sqrt{2/N}\sum_{i=1}^{n}\cos\left(\frac{2\pi\varepsilon_i}{q}\right)$$

Where N is the sample size, and $\varphi(q)$ is the test-statistic. The resulting graph shows peaks where a quantum gives a high positive value for $\varphi(q)$, which indicates, in turn, that the corresponding quantum is a 'good fit' (Ialongo, 2019; the online version of the article contains a downloadable applet for the calculation of CQA).

3.4. *The Pan-European weight system: orders of magnitude and inaccuracy*

The method – applied to a sample of approximately 600 balance weights – allows to reconstruct the weight systems used in BA Europe with a solid statistical basis. CQA indicates a Pan-European small unit (or *shekel*) of c. 9.4–10.2 g, attested in Italy, Central Europe and Atlantic Europe (Fig. 5) (Ialongo and Rahmstorf, 2019, and a larger unit (*mina*) of c. 420–450 g, attested in Italy and Central Europe (Ialongo and Rahmstorf, 2021).

The concept of a single overarching unit for weights and measurements is a modern idea, and ancient systems of measurement were organised according to different units for different orders of magnitude. According to the standard terminology derived from Mesopotamian metrology, BA weight units are usually divided into four orders of magnitude: The *grain* (less than 1 g), the *shekel* (c. 8–15 g), the *mina* (c. 400–500 g), and the *talent* (c. 20–30 kg) (e.g. Powell, 1987–90). The different units are connected by a system of fractions and multiples that varies from region to region and from period to period. In LBA Europe, there is strong evidence for at least two orders of magnitude that can be approximated to the *shekel* and the *mina*, each with distinct formal types of balance weights (Ialongo and Rahmstorf, 2019). The *shekel*-range spans between 0.16 g and 469.4 g with 95% of the measurements below 152 g, and the *mina*-range spans between 11,8 g–5050 g with 95% of the measurements above 125 g (Fig. 6).

Accuracy is another relevant factor. The accuracy of BA units in Mesopotamia (e.g. Hafford, 2012), the Aegean (Petruso, 1992), and Europe (Ialongo, 2019) has been calculated at c. ± 5% at one standard deviation. The only weighing device known at the time was the equal-arm balance (Hermann et al., 2020). Since the difference between two identical masses being measured on the pans is zero, the error of an equal-arm balance is always proportional to the measured mass. The larger the mass, the larger the error, which will grow proportionally to the mass itself. This means that the approximate error of ±5% will be constant on every weight, regardless of its order of magnitude.

3.5. *Subsampling*

The existence of different orders of magnitude with dedicated units is a crucial factor to be considered if one attempts to compare the metrology of balance weights to the metrology of potentially weight-regulated objects. The boxplot in Fig. 6 compares the distribution of the mass values of balance weights in the *shekel*- and *mina*-ranges to the different classes of metal objects in our sample of BA hoards. It shows that the vast majority of metal objects are heavier than the *shekel* and lighter than the *mina*. This has relevant methodological implications, since CQA can test if the mass values are multiples of the *shekel* but not if they are fractions of the *mina*. In other words, since most of the balance weights in the *mina*-range are heavier than most of the metal objects, we lack a statistically-significant sample to attempt a comparison. For this reason, our analyses are only aimed at testing the probability that the mass values of metal objects in European hoards are multiples of a *shekel* of c. 9.4–10.2 g.

In order to avoid false positives and false negatives, the CQA was limited to a range comprised between 7 and 200 g. Examining the formula in detail clarifies why measurements smaller than the unit will inevitably give false results for the unit-range. The following part of the formula determines how good a quantum fits, for a range comprised between 1 (perfect fit) and −1 (no fit):

$$\cos\left(\frac{2\pi\varepsilon_i}{q}\right)$$

Let us imagine to test a measurement of 19 g for a hypothetical unit of 10 g:

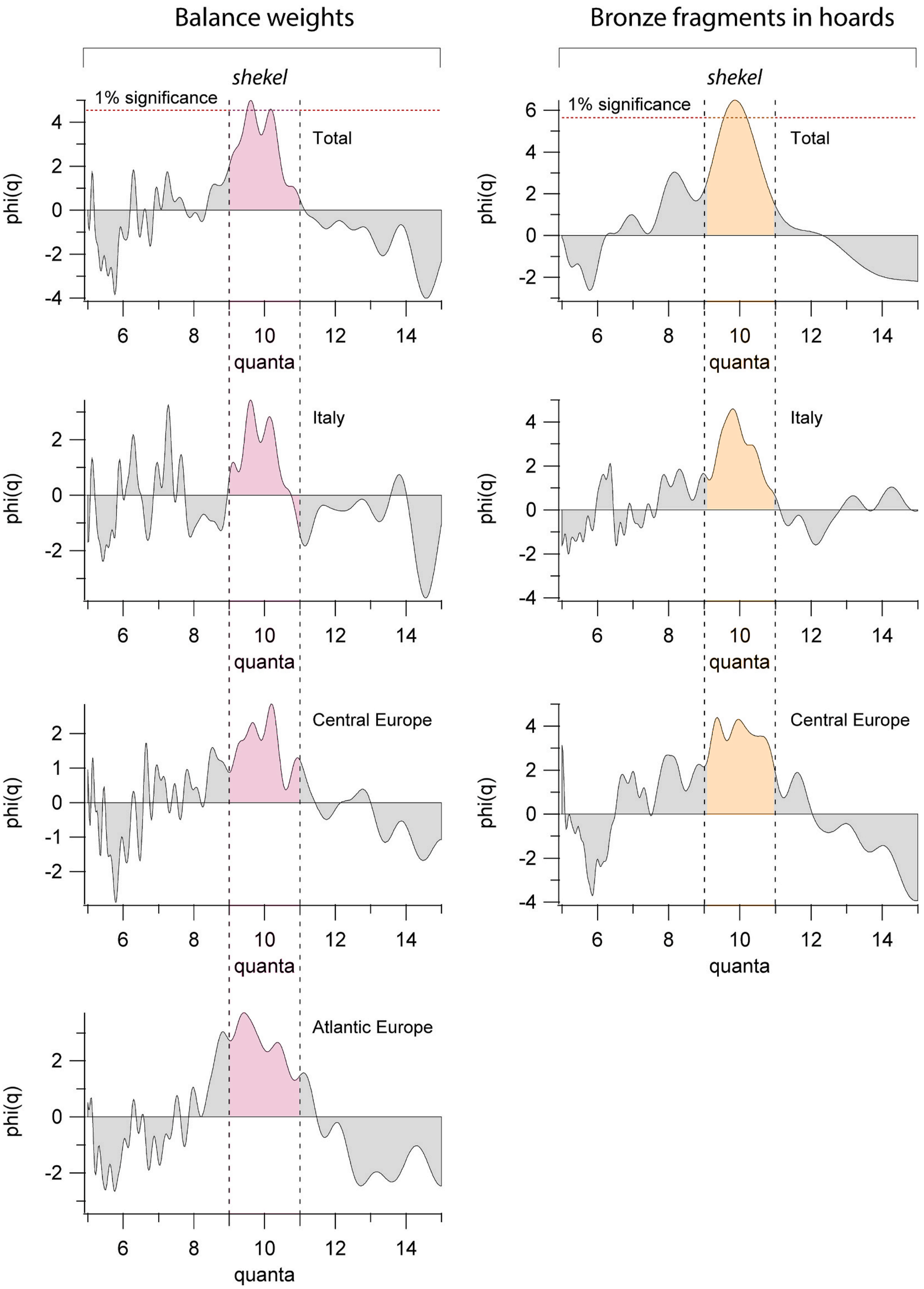

Fig. 5. Cosine Quantogram Analysis. Left column: Balance weights in the shekel-range from BA Europe (based on Ialongo and Rahmstorf, 2019). The complete sample (top) is compared to regional subsets. The analysis includes balance weights with mass values between 7 and 200 g. Right column: Fragmented bronze objects. The complete sample (top) is compared to regional subsets. The vertical lines mark the statistical dispersion of the *shekel*. The dotted red lines show the 1% alpha level, obtained through Monte Carlo tests for statistical significance. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

$$\cos\left(\frac{2\pi 9}{10}\right) = 0.81$$

The result is a very good fit, because the remainder $\varepsilon = 9$ is very close to the quantum 10. Interestingly, for a measurement of 5 g, the result would be −1, despite 5 being exactly half of 10, and hence, in a fractional logic, it should be a very good fit for the unit. This happens because the remainder $\varepsilon = 5$ is as far away as possible from both 10 and 0, being exactly in the middle. This highlights one of the main limitations of CQA, which will always give negative results for multiples of half the unit. Finally, for a measurement of 0.27, the result would be 0.99, because the remainder $\varepsilon = 0.27$ is very close to 0, but it would be a

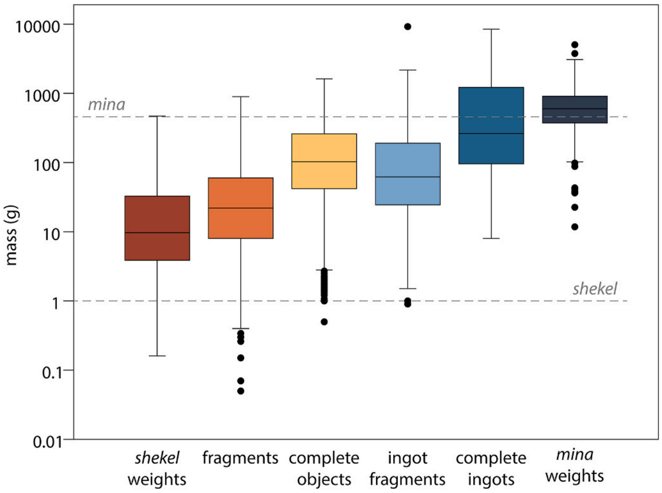

Fig. 6. Box and whiskers diagram of the distribution of mass values of European balance weights and metal objects in hoards. Logarithmic scale.

false positive because every big number can be divided for every small number for a negligible reminder.

On the other hand, the upper limit of the analysis-range is dictated by the issue of the propagation of error. One can imagine a theoretically-exact value of exactly 30 times the unit, e.g. 300 g. According to the accepted error of ±5%, the actual value would range between c. 285–315 g. For the same reasons illustrated above, a test for a quantum of 10 g would give −1 for 285 g, 295 g, 305 g, and 315 g, and negative results for many values in that same range, despite the fact that all those values can hypothetically represent the theoretically-exact value of 30 times the unit.

These considerations show why CQA is not well-suited to identify fractions of a unit, or multiples that are much bigger than the unit itself. When testing a unit of c. 9.4–10.2 g, the range of 7–200 g offers the best compromise between accuracy and inclusivity, providing reliable results while at the same time allowing to maintain a sufficient sample size. The final count for each category of bronze objects included in the analysis is given in Table 1. The part of the Italian subset dating to the Early-Middle BA (c. 2300–1350 BC) was not analysed, since it does not include enough measurements in the 7g-200 g range. Furthermore, Italian complete ingots and German complete and fragmented ingots do not provide enough data, and therefore were not analysed. The analysed sample is thus limited to the Late BA, and is attached as downloadable material to the online version of this article.

3.6. Monte Carlo test for statistical significance

Monte Carlo tests can exclude the occurrence of false positives (Ialongo, 2019; Kendall, 1974; Pakkanen, 2011). The test is based on the reiterated generation of random numbers, in order to check whether random datasets would give better results than the actual sample. The null-hypothesis is that the sample is randomly constituted, i.e., that the observed quantal configuration is only due to chance. Following Kendall's method, we produced a simulation of 1000 randomly generated datasets. The original sample was randomized, by adding a random fraction of ±15% to each measurement. Each generated dataset was analysed through CQA. If equal or better results occur more often than a predetermined threshold (typically 1% or 5% of iterations), it means that it cannot be excluded that the results obtained from the actual sample are simply due to chance, and therefore they should be rejected. For our experiment, we set the threshold (alpha level) to 1%. In other words, if better results occur in less than 1% of the iterations, then the null-hypothesis is rejected and the sample is very likely the result of an intentionally quantal portioning.

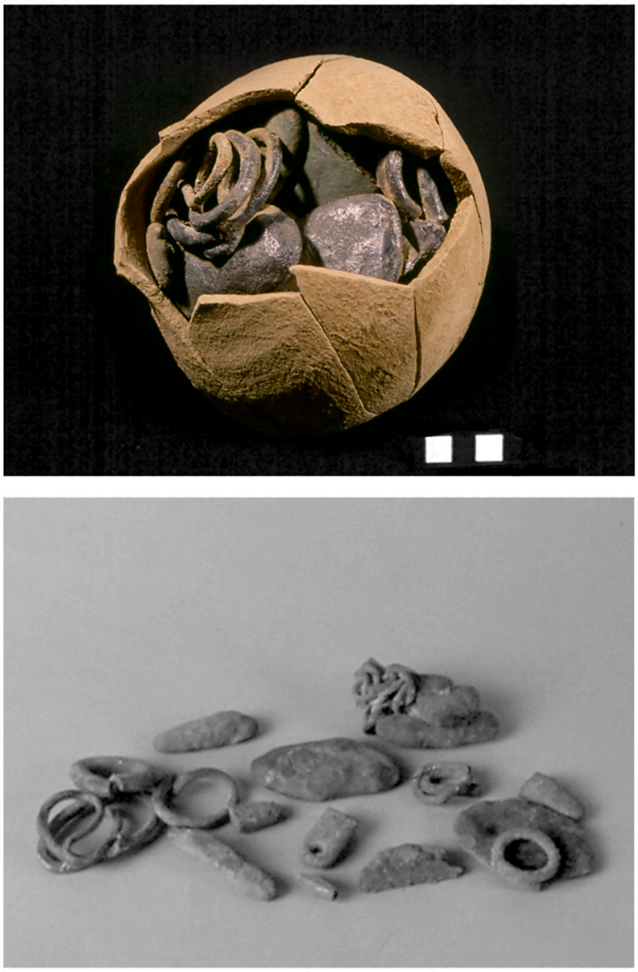

Fig. 7. Tell Mardikh/Ebla (Syria). Hack-silver hoard (c. 2000–1700 BC; from Ialongo et al., 2019; courtesy of Luca Peyronel).

3.7. Expectations

The methodological framework adopted in this paper was initially designed by one of the authors to study the metrical properties of hack-silver money in the Ancient Near East (Ialongo et al., 2019). The high-quality documentation from BA Mesopotamia offers the unique opportunity to address both the abstract and the material properties of the earliest known metal currency. Most importantly, it provides the term of comparison to test the validity of common assumptions about metallic money in BA economies.

The main functions of money are those of 'medium of exchange' and 'standard of value.' The former identifies an object (e.g. a banknote) or a substance (e.g. silver) that is customarily accepted as payment in transactions. The latter implies that such objects or substances serve as customary parameter to quantify economic value. The secondary functions of 'store of value' and 'means of deferred payment' refer, respectively, to the possibility to store money and to use it to pay debts or taxes. In BA Mesopotamia, silver – among other money-stuffs – performed all the functions at the same time, as early as the 3rd millennium BC: medium of exchange (e.g. Powell, 1996), standard of value (e.g. Englund, 2012), store of value (e.g. Steinkeller, 2004) and means of deferred payment (e.g. Garfinkle, 2004), even though it was never officially adopted by central states and neither was it ever cast or struck in any standardized form (Peyronel, 2010). Mass was the standard parameter by which the value of silver, and of most of the other commodities on the market was assessed.

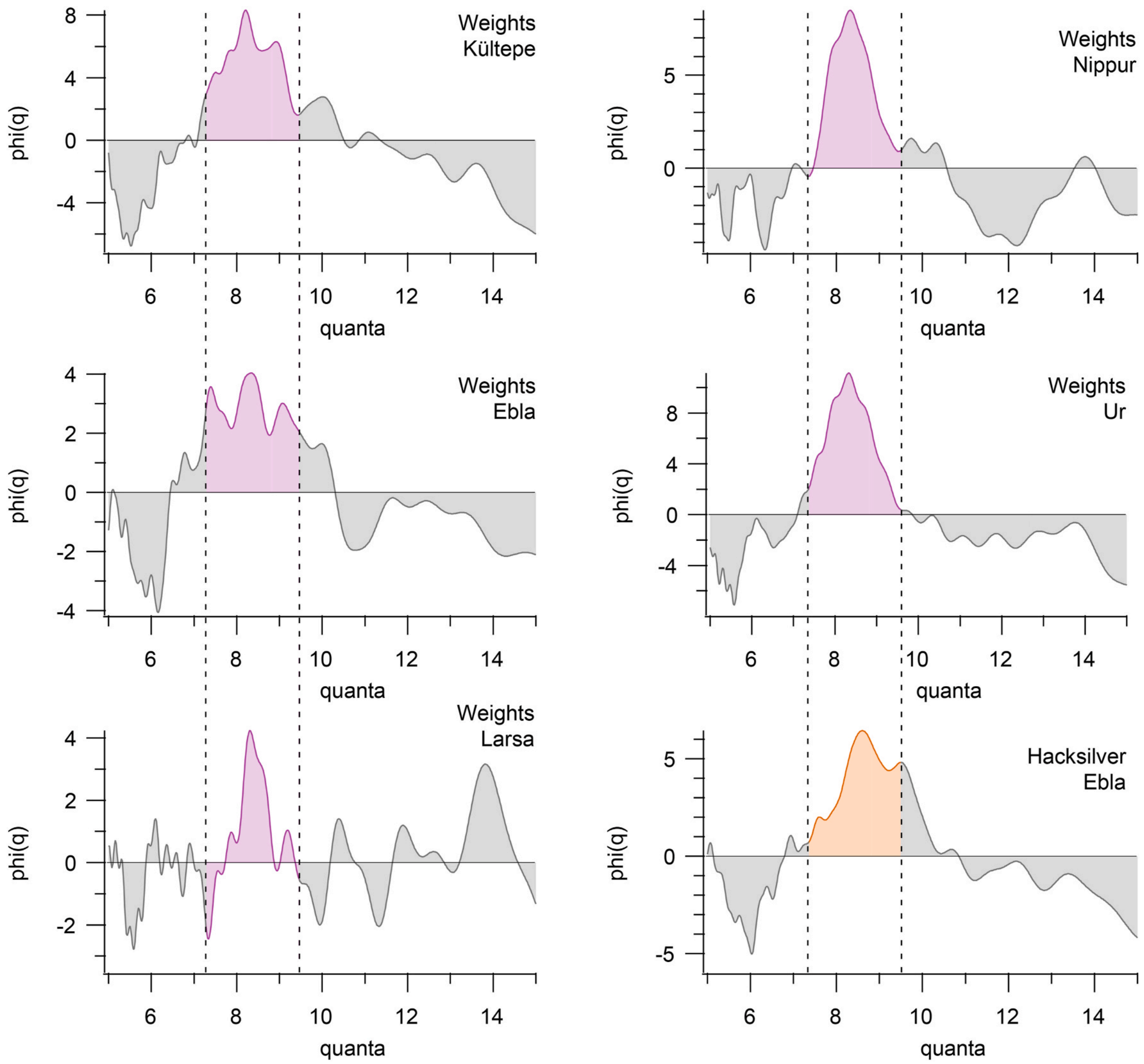

Fig. 8. Cosine Quantogram Analysis of sets of balance weights from different sites in Middle BA Mesopotamia (c. 2000–1700 BC) compared to a hack-silver hoard from Tell Mardikh/Ebla (Syria). The range of the analysis includes items with mass values between 7 and 200 g (data from Ialongo et al., 2019).

The crucial question is how we can identify such functions in the absence of textual evidence. We have shown that the interpretation of hoards is controversial, and hence the evidence of hoarding *per se* cannot be used as proof for the existence of reserves of value. Deferred payments are also invisible in the archaeological record, since we cannot measure the delay by which an object changed hands. Fortunately, the functions of medium of exchange and standard of value are intimately connected, and can leave measurable traces. The assumption to be tested analytically is the following: If metal is regularly used as medium of exchange, then it must be shaped and/or fragmented in order to comply with the standard indexes of value in use in the market within which it circulates. The assumption was tested through the comparison of a hoard of silver fragments from Ebla (Syria; Fig. 7) with sets of balance weights coming from several Middle BA cities (c. 2000–1700 BC) in Turkey, Syria and Iraq (Ialongo et al., 2019). The statistical analysis showed that: 1) A widespread weight system existed at the beginning of the 2nd millennium BC, between central Anatolia and southern Mesopotamia; and 2) The metrical structure of fragmented silver is extremely similar to the metrical structure of balance weights (Fig. 8). The results of the study suggest that the existence of standard frames of reference for the quantification of economic value (i.e. weight systems) strongly influences the materiality of those standard currencies whose value is measured by weight. Based on the Mesopotamian evidence, we can assume that, if a metal is used as money, it is expected to circulate in weighed fragments which, in turn, are expected to comply with standard weight systems. The results proved that the assumption behind the money-theory of fragmentation is valid, and provide the expectations to test the hypothesis on a large sample of European BA hoards.

3.8. Analysis

CQA shows that the metrical structures of balance weights and fragmented objects are the same (Fig. 5). Balance weights produce a bell-shaped concentration of positive values between c. 9–11 g, with a best-fitting quantum of 9.6 g. (Ialongo and Rahmstorf, 2019). This pattern is closely replicated by the quantal configuration of bronze fragments, with a best-fitting quantum of 9.8 g. Monte Carlo tests show that the results of the CQA are statistically significant, with the best-fitting quantum of 9.8 g being well above the 1% alpha level. The results for both individual subsamples of Italian and Central European hoards are consistent with this value. On the contrary, complete objects and fragmented ingots do not produce significant results, with small peaks being rather randomly distributed (Fig. 9).

The Frequency Distribution Analysis (FDA) of the samples of fragmented bronze objects provides further insight into their quantal structure. The graphs in Fig. 10 show the binned distribution of the mass values of bronze fragments, overlaid by the results of a CQA test for the best-fitting quantum of 9.8 g. This comparison shows which

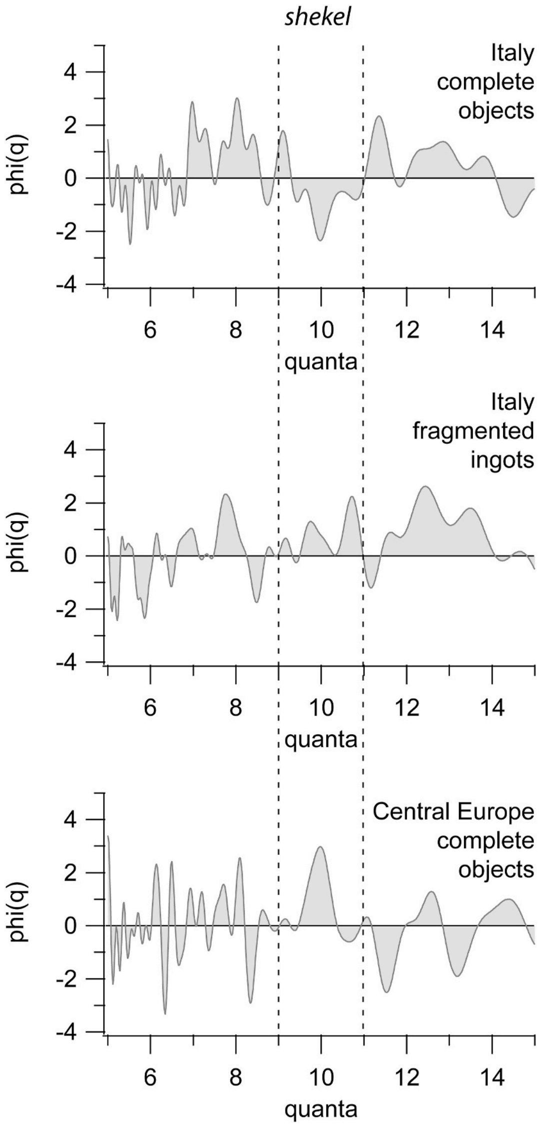

Fig. 9. Cosine Quantogram Analysis of complete bronze objects and ingots from the sampled BA hoards. The vertical lines mark the statistical dispersion of the weight unit.

measurements in the distribution give positive results for the Pan-European *shekel*. The bin-width was arbitrarily chosen in order to be consistent with the CQA test and facilitate comparison. The CQA test gives positive results for small clusters of mass values around c. 10 g, 20 g, 30 g, 40 g, 50 g, 60 g, 70 g, 90 g, 100 g, 120 g, 130 g, 140 g, 160 g, 170 g, 190 g and 200 g. All the clusters have a noticeable statistical dispersion, as it is expected even from supposedly ‘accurate’ sets of proper balance weights (e.g. Hafford, 2012; Ialongo, 2019; Pakkanen, 2011). The results of the CQA are correlated to these clusters: CQA gives a result of c. 10 g because the sample is constituted by a series of concentrations of mass values whose average values are multiples of c. 10 g. As expected, CQA gives negative results for a cluster at c. 15 g (i.e. 1 ½), despite the fact that this value perfectly fits the fractional logic.

Towards the end of the distribution, approximately after c. 160 g, the problems related to the propagation of error start to become evident. FDA highlights two adjacent, normally-distributed clusters, respectively around c. 160 g and 170 g. These clusters are particularly visible, even though they tend to blend into each other. It is interesting to note that CQA gives positive values for almost the entire cluster around c. 160 g, while it gives negative results for the right half of the cluster at c. 170 g. The cluster at c. 170 g shows an overall dispersion between c. 165–180 g, which is entirely expected if one considers a standard error of c. 5% at one standard deviation. CQA, however, cannot correctly identify such a dispersion, and, as expected, gives a false-negative result for the higher range of the cluster, at c. 175 g.

4. Discussion

4.1. Weight regulation

The results of the statistical analysis support the money-hypothesis for Late BA Europe, showing that metal objects were probably intentionally fragmented in order to comply with weight systems. The analogy with the Ancient Near East suggests that bronze fragments in Europe had the same function as silver fragments in Mesopotamia, i.e. they performed the basic functions of money. The joint analysis of balance weights and bronze objects suggests that monetary patterns of exchange existed in BA Europe, that they complied with a Pan-European index of value, and that they were based on the use of metals as standard media of exchange. The actual relevance of the phenomenon is difficult to quantify. For the time being, we can only observe that metal fragments were used as money *frequently enough* to leave measurable traces in the archaeological record; how frequently is still not possible to define. Unlike proper balance weights – that produce sharp, neatly separated clusters of mass values (Ialongo and Rahmstorf, 2019) – bronze fragments produce small clusters that stand out from a diffused background noise. FDA suggest that weight-regulated fragmentation is not very accurate. Based on the statistical analysis, we can derive that systematic fragmentation *tends* to produce fragments with mass values that are multiples of weight units, and that complete objects and ingots were cast with no specific mass prescription. Just like in the Mesopotamian world, the compliance with weight systems is an indirect consequence of trade, rather than a pre-defined regulation. Assessing the actual relevance of the phenomenon will require further research and a larger number of regional samples.

As to *why* fragments tend to assume regular mass values, we can propose a hypothesis. The typical trade situation – documented in Mesopotamian texts – includes two agents, each provided with their own weighing equipment (Peyronel, 2011). Metal fragments do not *need* to be weight-regulated, since each agent can easily quantify the value of the transaction. However, pre-weighed fragments would speed up the operations, by preventing the calculation of a remainder. Breaking bronze objects is relatively simple, and does not require any particular metallurgical knowledge. Experimental results show that a socketed axe made of tin bronze (8%) breaks into pieces with three blows if heated up at c. 560°, the temperature of a medium-sized campfire (Knight, 2017). The required temperature is lower if copper is alloyed with lead (Knight, 2019). In order to produce accurate fragments, one can progressively break off small bits and repeat the weighing until the desired mass is obtained. The repetitiveness of the operation increases the skill of the operator, and skill increases accuracy. Fragmentation can be performed either before or during the transaction, depending on the situation. Archaeological evidence suggests that, at least in the Late BA, bringing along small stocks of metal fragments was a rather common habit. Many burials in central and northern Europe include small boxes of organic materials, containing metal fragments and scraps, blunt tools suited for breaking metals and, sometimes, scale beams and balance weights (Pare, 1999; Roscio et al., 2011). One of such boxes was recently identified among the finds of the Late BA battlefield in the Tollense Valley (Northern Germany, c. 1350–1200 BC) (Fig. 2), which attests that their use was not limited to the burial rite (Uhlig et al., 2019). These containers offer a suggestive picture of how metallic money could be carried around for everyday purposes.

For the complete objects, the absence of weight-regulation has a perfectly logical explanation. The subsample between 7 and 200 g includes every type of ornament, tool and weapon with the only exception of swords, which are exclusively represented in fragments. Since the size

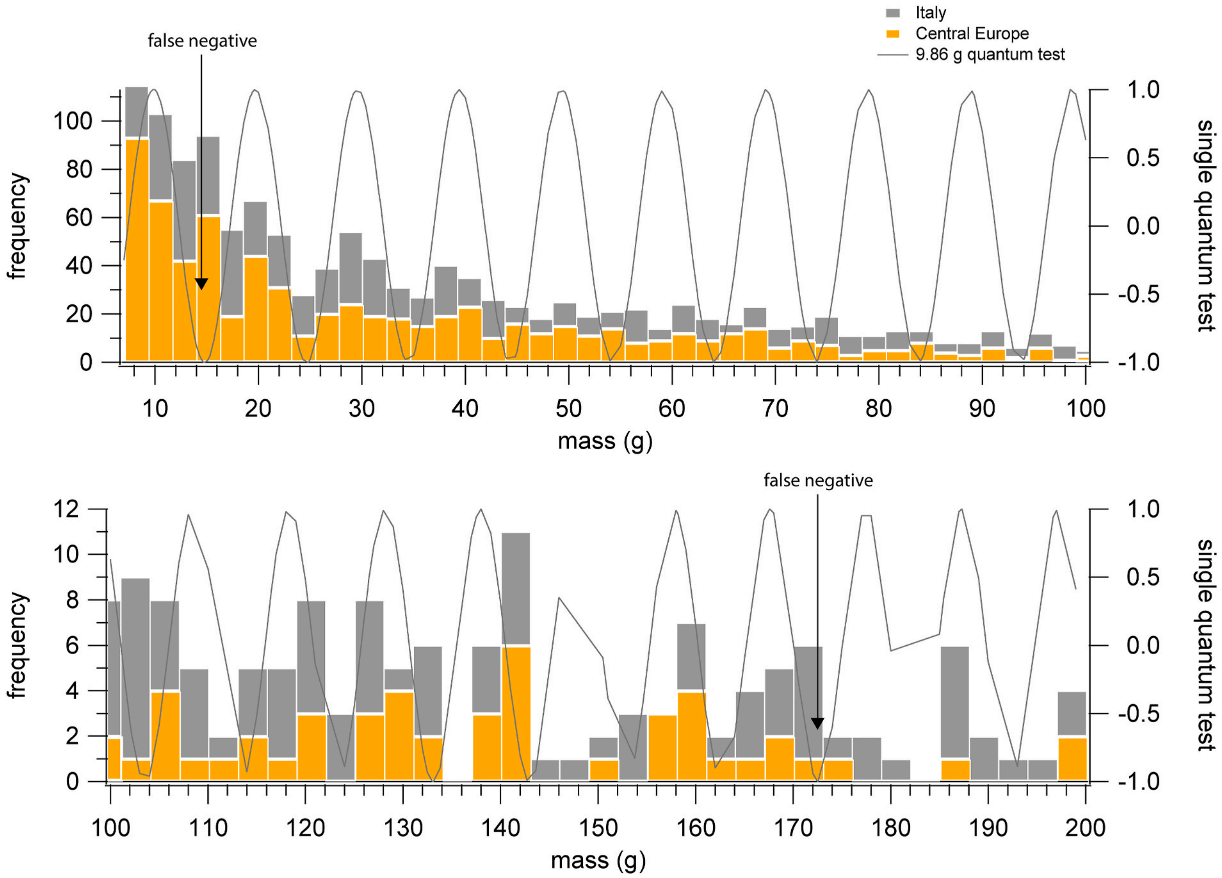

Fig. 10. Frequency Distribution Analysis of that mass values of fragmented bronze objects. The binned distribution is overlaid by a CQA test for the best-fitting quantum of 9.86 g (black line). The bin width was arbitrarily set at 2.3 g (upper graph) and 3 g (lower graph) to facilitate the comparison with the CQA test.

of a useable object is dictated by its function, there is no reason to assume that its mass should be regulated in order to fit a predetermined value.

CQA does not give significant results for ingots and ingot fragments in the *shekel*-range. This can depend on several factors. The fact that ingots are, on average, thicker than any other object in the sample could imply that they are more difficult to break into pieces with a predetermined mass. It could also mean that ingots and ingot fragments were not used as currency. Ingots are usually made of pure copper (e.g. Pernicka et al., 2016), and thus might have been used exclusively as raw material. It should be noted, however, that we could not compare the ingots to the balance weights in the *mina*-range. It is possible that, since they are on average significantly more massive than other object categories, their mass was measured in fractions of the *mina* rather than in multiples of the *shekel*. Finally, one has to consider that the main use of heavy balance weights is to weigh out bulks of goods, rather than single objects. The fact that individual ingot fragments do not comply with weight systems does not rule out the likely possibility that they were traded in weighed bulks. One way to test this could be to analyse the total weight of hoards, and verify if they conform to multiples of the European *mina*. Unfortunately, it is not easy to determine if a hoard is in pristine conditions, or if it underwent modifications before or after its recovery.

4.2. *The value of money*

Our results show that the value of bronze was quantified according to a shared frame of reference. What we define as 'bronze,' however, is an umbrella term for many different copper alloys, mostly containing variable proportions of tin and lead. It is theoretically possible that different alloys had different values, which could somehow hamper the circulation of metals as money. For BA Europe the puzzle is difficult to solve, as we have no direct evidence of value equivalences between different types of bronze and between bronze and other commodities.

An argument in favour of the hypothesis of the different values could be that, since bronze fragments are made of different alloys, their indiscriminate use as currency would hamper or entirely prevent their reuse as raw material. The argument, however, fails to correctly account for the evidence. Substantial quantities of fragments exist in the archaeological record and fragments were undoubtedly exchanged, regardless of whether or not one accepts their monetary use. At the same time, it would seem that metallurgists did not have problems in finding the right alloy for their purposes. This either implies that they were able to determine the alloy of fragments, or that they used fragments in limited quantities and mostly relied on other forms of raw metal, such as ingots. Hence, the argument also fails to acknowledge the relevant role of recycling (e.g. Radivojević et al., 2018). A second argument could be that some metals used in bronze alloys are rarer than others, and thus more expensive. Lead, for example, is alternatively assumed to be expensive (e.g. Johansen, 2016) or cheap (e.g. Needham and Cook, 1988), depending on whether it had to be imported (Scandinavia) or was locally available (British Isles). But if distance played such a determinant role, how can one explain, for instance, the rich metallic record of Denmark, which completely lacks copper and tin sources? The problem of value is extremely complex, and bears far-reaching implications; it basically implies theorising a continent-wide market economy for BA Europe, and cannot be addressed here. Hence, while these arguments are worthy of consideration, they should not play, for now, a decisive role in the interpretation, in one way or another.

An alternative solution could be to assume that the problem of value is not correlated to the diversity of alloys, but rather to different modes of circulation. Different models on the circulation of metals tend to focus perhaps too much on metallurgy: If fragments were mainly exchanged as money their main purpose was to circulate, not to be recycled. Moreover, their circulation was certainly not limited to metallurgists. In theory, a single fragment could circulate for decades without ever ending up in a metallurgist's hands.

Economic theory does not explain why money has value. One way to justify why worthless pieces of paper can have the same monetary function of precious metals (the so-called 'Hahn's problem'; Hahn, 1965) is to admit that '*if people believe that money has value, it does*' (Velde, 2021: 201). Once money is acknowledged to be valuable, however, the market dictates how much value money has. It follows that, if money can be a worthless substance, its market value is not necessarily correlated to the substance of which money is made. Since the value of money (and commodities alike) is regulated by the market, that value will be determined by the most frequent use that the market makes of the substance of which money is made. Hence, if metallurgy is the prevalent use, then it is possible that different alloys will have different values. If monetary use is prevalent, then the difference of alloys will play a minor role in the determination of value.

4.3. The origin of money? Towards a theoretical framework for money in BA Europe

Weighed currency was not the first form of money in Europe. It was, however, the first that could be potentially accepted anywhere, provided that weighing technology was available. In other words, weighing technology does not originate money, but simply provides a universally-valid frame of reference for the quantification of its value (Rahmstorf, 2016). The idea that the origin of money is correlated to technology or to the complexity of socio-economic systems implies an evolutionary paradigm, which hampers our understanding of the functions of pre-modern economies. There is nothing in economic theory that prevents the emergence of money in any given market, in economies of any complexity, and at any point in history (e.g. Jones, 1976; Velde, 2021). Economic evolutionism has been shown to be based on a substantial misunderstanding of the social dynamics that regulate the modern economy (Bloch and Parry, 1989). On the contrary, it has been contended that the modern western economy is still as much embedded in social institutions as only 'primitive' economies were previously believed to be (e.g. Appadurai, 1986), and that the economy in 'primitive' societies is substantially less embedded than the evolutionary paradigm would predict (e.g. Granovetter, 1985). The contemporary approach to prehistoric money owes much to a seminal article by G. Dalton (1965), in which the author traces a sharp distinction between 'primitive' and 'modern' money. Soon after, however, J. Melitz – an economist – demonstrated that Dalton failed to acknowledge that supposedly 'primitive' and 'modern' monies have, in fact, the same functions and limitations (Melitz, 1970). Since then, the functional equivalence between 'primitive' and 'modern' money is generally accepted by most economists, economic historians, and economic anthropologists (e.g. Jones, 1976; Velde, 2021; Zelizer, 2000).

Money is not an evolutionary milestone, but simply a solution to the practical problem of the 'double coincidence of wants' (Jevons, 1875:3), stating that no one can trade with anyone who does not need or does not want whatever it is that they have to offer in payment. For example, if a pig breeder wants wheat and has only pigs to offer, they cannot obtain wheat if the crop farmer does not need or want pigs. The problem can be solved by agreeing upon using a third medium that everyone will eventually come to accept, as it is widely documented in many so-called primitive economies (e.g. Einzig, 1966; Pryor, 1977). Money is not inevitable but it is convenient, as it has no requirements other than being customarily accepted by most agents in a given market. Metals represent only a limited part of all the pre-coinage monies documented either historically or ethnographically, which include perishable materials such as barley (e.g. BA Mesopotamia: Steinkeller, 2004), textiles (e.g. Classic Maya: Baron, 2018), bark-cloth (e.g. Early Colonial West Africa: Pallaver, 2015), and dried fish (e.g. Medieval Iceland: Mehler and Gardiner, 2021). Money is merely a convention, whose embodied physical media can have intrinsic value (such as silver coins) as well as none at all (i.e. banknotes) (Velde, 2021).

Concerning BA Europe, money is often believed to appear in some forms with the spread of mass metallurgy. The so-called *Ösenringbarren* (a type of ingot-like objects shaped as open rings common in Central Europe in the Early BA, c. 2150–1700 BC) are a common example. They show a noticeable regularity in shape, mass, and composition (Lenerz-de Wilde, 1995), and are regarded by some scholars as evidence of the earliest money in Europe (e.g. Pare, 2013; Kuijpers and Popa, 2021). Since they exist several centuries before the introduction of weighing technology in Central Europe, their approximate regularity can be explained by relatively standardised moulds, and by the intuitive ability of experienced users to determine the approximate mass-equivalence of two objects simply by holding them in both hands (Kuijpers and Popa, 2021). If *Ösenringbarren* were indeed money – which we have no reason to doubt – their function was no different from the later, weight-regulated metal currencies. The difference is in their circulation. Since weighing technology was not available (until proven otherwise) there was no way to assess their value objectively or, for example, to calculate fractions and multiples. One can think of *Ösenringbarren* as a form of 'fiduciary money', i.e. a standard medium of exchange whose value is conventionally agreed upon, and whose intrinsic value is not relevant for the quantification of their exchange value. As it was recently proposed, fiduciary currencies can predate the emergence of commodity currencies, contrary to the common belief (Bresson, 2021). Whether classifying different types of money may or may not be the point, we would like to draw attention on the reasons why some monies are accepted in some regions and not in others. The *Ösenringbarren* relied on their recognisable shape, approximate size, and peculiar chemical composition in order to be accepted, because these characters were well-known and understood in the limited area where they were in common use, i.e. between southern Germany and the Czech Republic. The reason why we do not find *Ösenringbarren* outside this area is because those same characters were not recognised as 'valid' elsewhere. The spread of metallurgy undoubtedly expands trade networks, and increases the potential utility of money. The introduction of weighing technology, on the other hand, exponentially expands the user base by providing an objective frame of reference that transcends traditional cultural boundaries. At the same time, weighing technology does not alter the functions of money, and does not imply the erasure of other patterns of monetary and non-monetary exchange. Finally, if weighing technology is not a requisite for money, neither is metallurgy. By the same token, we should not prejudicially rule out a wide range of perishable commodities that are invisible in the archaeological record, but which could have been used as money before, during and after the introduction of metallurgy.

5. Conclusions: a small change revolution?

Based on statistical analyses, we suggest that bronze, in the Late BA, possesses the requisites of a Pan-European money. Metal fragments have regular mass values which, in turn, perfectly correspond to the metrical structure of balance weights. These results represent the first step into a potentially fruitful line of research. The analyses suggest that bronze in BA Europe had the same function as silver in BA Mesopotamia, and cuneiform texts attest that silver performed the basic functions of modern money as early as the 3rd millennium BC.

A Pan-European weight system is mirrored by the metrical structure of bronze fragments, suggesting that the two phenomena are correlated. The widespread use of metals as media of exchange can also explain why local weight systems tend to converge on a continental scale: If metal trade is the main reason behind long-range connectivity, be it in its

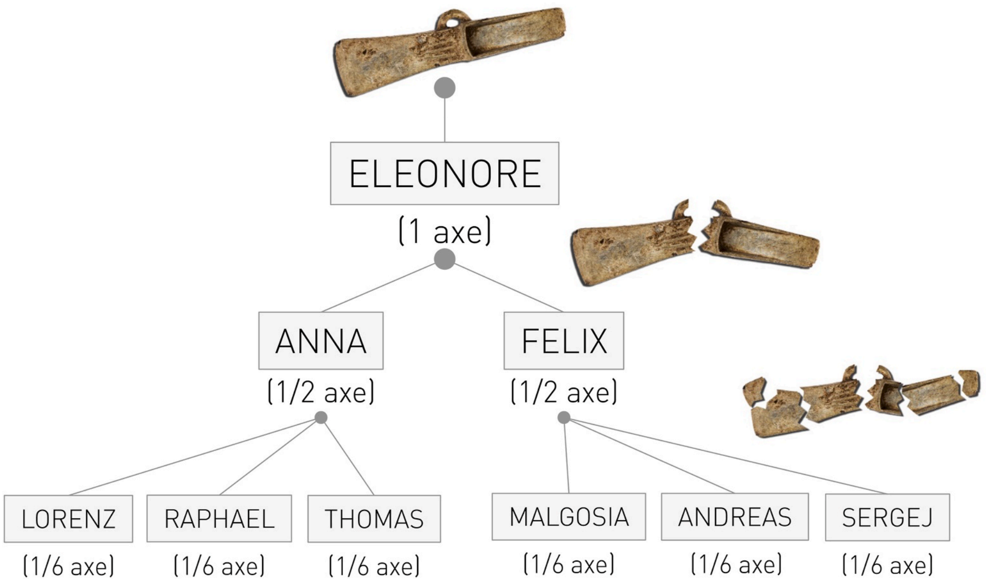

Fig. 11. Schematic representation of the circulation of fragmented objects as 'small change.' The further down the line, the more agents are involved.

commodity- or money-state, then frequent long-distance exchange may have favoured the formation of widespread indexes of value. The progressive relevance of the exchange of fragments may indicate that the focus of metal trade gradually shifted from bulky objects to light items. Moreover, metal circulated simultaneously as commodity and as money. This dual nature effectively doubled the demand for metal, ultimately producing the capillary distribution that we observe all over Europe. Fragmentation does not simply perform a practical function: By intensifying the flow of 'small change', it opens the market to a larger number of economic agents (Fig. 11). Simply put, 'small change' moves faster than bulky objects because it is cheaper.

In this article, our focus on metals is instrumental in addressing the bigger picture of trade in the BA. We focus on metal fragments to demonstrate that the spread of weighing technology profoundly changes the structure of commerce, by introducing a universally-valid frame of reference for the quantification of economic value. With the spread of weight systems, the circulation of a currency whose value can be assessed by weight was not limited anymore to those networks in which that currency was known and customarily accepted. The compliance of metal fragments with weight systems is simply the most archaeologically-visible proxy of monetary patterns of exchange, which could have potentially involved a wider array of commodities.

Acknowledging the existence of monetary patterns of exchange neither implies that metallic money was the only way through which commodities and services were sold and purchased, nor that it was the most frequent one. For the time being, it is impossible to quantify how far different media and means of exchange contributed to the overall amount of transactions. Nonetheless, understanding money in BA Europe can substantially change our perception of economic and social development in prehistory.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2021.105379.

References

Appadurai, A., 1986. Introduction: commodities and the politics of value. In: Appadurai, A. (Ed.), The Social Life of Things. University Press, Cambridge, pp. 3–63.

Baron, J.P., 2018. Ancient monetization: the case of Classic Maya textiles. J. Anthropol. Archaeol. 49, 100–113.

Begemann, F., Schmitt-Strecker, S., Pernicka, E., Lo Schiavo, F., 2001. Chemical composition and lead isotopy of copper and bronze from nuragic sardinia. Eur. J. Archaeol. 4 (1), 43–85.

Bernabò Brea, L., Cavalier, M., 1980. Meligunìs Lipára IV. L'acropoli di Lipari nella preistoria. Flaccovio Editore, Palermo.

Bietti Sestieri, A.M., Salzani, L., Giardino, C., Verly, G., 2013. Ritual treatment of weapons as a correlate of structural change in the Italian LBA communities: the bronze hoard of Pila del Brancon (Nogara, Verona). Rivista di Scienze Preistoriche 63, 155–169.

Bloch, M., Parry, J., 1989. Introduction: money and the morality of exchange. In: Parry, J., Bloch, M. (Eds.), Money and the Morality of Exchange. University Press, Cambridge, pp. 1–32.

Bradley, R., 1988. Hoarding, recycling and the consumption of prehistoric metalwork: technological change in Western Europe. World Archaeol. 20 (2), 249–260.

Bradley, R., 1990. The Passage of Arms: an Archaeological Analysis of Prehistoric Hoards and Votive Deposits. University Press, Cambridge.

Brandherm, D., 2004. Ein neuer Fund eines Langquaidbeils und einer Lanzenspitze aus Speyer: zum Beginn und zur Deutung der Brucherzdeponierungssitte in Süddeutschland. Archaol. Korresp. 34, 357–374.

Brandherm, D., 2007. Sobre el origen del fenómeno de los depósitos en la Península Ibérica: ocultaciones de objetos metálicos de los inicios de la Edad del Bronce". In: Celis, J., Delibes de Castro, G., Fernández Manzano, J., Grau Lobo, L. (Eds.), El hallazgo leonés de Valdevimbre y los depósitos del Bronce Final Atlántico en la Península Ibérica, Junta de Castilla y León y Diputación de León, pp. 177–193.

Brandherm, D., 2018. Fragmentation patterns revisited: ritual and recycling in Bronze Age depositional practice. In: Brandherm, D., Heymans, E., Hofmann, D. (Eds.), Gifts, Goods and Money - Comparing Currency and Circulation Systems in Past Societies. Archaeopress, Oxford, pp. 45–65.

Bresson, A., 2021. Metal-object currency before coinage: China and the West. In: Rahmstorf, L., Barjamovic, G., Ialongo, N. (Eds.), Merchants, Measures and Money. Understanding Technologies of Early Trade in a Comparative Perspective. Weight & Value 2. Hamburg/Kiel, Wachholtz, pp. 289–303.

Brück, J., 2016. Hoards, fragmentation and exchange in the European bronze Age. In: Hansen, S., Neumann D, D., Vachta, T. (Eds.), Heiligtümer in prähistorischen und antiken Gesellschaften. Berlin Studies of the Ancient World, vol. 38, pp. 75–92.

Coffyn, A., Gomez, J., Mohen, J.P., 1981. L'apogée du bronze atlantique. Le dépôt de Vénat, Picard, Paris.

Dalton, G., 1965. Primitive money. Am. Anthropol. 1, 44–65.

Delfino, D., 2014. Bronze recycling during the Bronze Age: some consideration about two metallurgical regions. Metodologias de Trabalho Arqueológico. Campo, Laboratório, Divulgação 1, 121–143.

De Marinis, R.C., 2019. I ripostigli di Soncino (CR) e di Montichiari (BS). In: Maffi, M., Bronzoni, L., Mazzieri, P. (Eds.), le quistioni nostre paletnologiche più importanti…: trent'anni di tutela e ricerca preistorica in Emilia occidentale: atti del convegno di studi in onore di Maria Bernabò Brea. Archeotravo Cooperativa Sociale, Piacenza, pp. 283–292.

Earle, T., Ling, J., Uhnèr, C., Stos-Gale, Z., Melheim, L., 2015. The political economy and metal trade in Bronze Age Europe: understanding regional variability in terms of comparative advantages and articulations. Eur. J. Archaeol. 18 (4), 633–657.

Einzig, A., 1966. Primitive Money in its Ethnological, Historical and Economic Aspects, second ed. Pergamon Press, Oxford.

Englund, R., 2012. Equivalency values and the command economy of the ur III period in Mesopotamia. In: Papadopoulos, J.K., Urton, G. (Eds.), The Construction of Value in the Ancient World, Cotsen Advanced Seminar Series 5. Cotsen Institute of Archaeology Press, Los Angeles, pp. 427–458.

Garfinkle, J., 2004. Shepherds, merchants, and credit: some observations on lending practices in ur III Mesopotamia. J. Econ. Soc. Hist. Orient 47, 1–30.

Granovetter, M., 1985. Economic action and social structure: the problem of embeddedness. Am. J. Sociol. 91 (3), 481–510.

Hahn, F.H., 1965. On some problems of proving the existence of an equilibrium in a monetary economy. In: Hahn, F., Brechung, F.P.R. (Eds.), The Theory of Interest Rates: Proceedings of a Conference Held by the International Economic Association, pp. 297–306. London.

Hafford, W.B., 2012. Weighting in Mesopotamia. The balance Pan weights from ur. Akkadica 133 (1), 21–65.

Hansen, S., 2016. A short history of fragments. In: Material Culture and Identity between the Mediterranean World and Central Europe (Akten der Internationalen Tagung am Römisch-Germanischen Zentralmuseum Mainz, October 22–24 2014). Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 185–207.

Hermann, R., Steinhoff, J., Schlotzhauer, P., Vana, P., 2020. Breaking news! Making and testing bronze Age balance scales. J. Archaeol. Sci. Rep. 32 https://doi.org/10.1016/j.jasrep.2020.102444.

Ialongo, N., 2019. The earliest balance weights in the West: towards an independent metrology for Bronze Age Europe. Camb. Archaeol. J. 29 (1), 103–124.

Ialongo, N., Rahmstorf, L., 2019. The identification of balance weights in pre-literate Bronze Age Europe: typology, chronology, distribution and metrology. In: Rahmstorf, L., Stratford, E. (Eds.), Weights and Marketplaces from the Bronze Age to the Early Modern Period. Wacholtz Verlag, Kiel/Hamburg, pp. 106–126. https://doi.org/10.23797/9783529035401.

Ialongo, N., Rahmstorf, L., 2021. Kannelurensteine – balance weights of the bronze Age? In: Nikulka, F., Schumann, R., Hofmann, D. (Eds.), Circum-Baltic Interactions in the Bronze Age (in press).

Ialongo, N., Vacca, A., Peyronel, L., 2019. Breaking down the bullion. The compliance of bullion-currencies with official weight-systems in a case-study from the ancient Near East. J. Archaeol. Sci. 91, 20–32.

Jevons, W.S., 1875. Money and the Mechanism of Exchange. Appleton, London.

Johansen, J.W., 2016. Heavy metal: lead in bronze Age scandinavia. Fornvännen 111 (3), 153–161.

Jones, R.A., 1976. The origin and development of media of exchange. J. Polit. Econ. 84 (1), 757–776.

Kendall, D.G., 1974. Hunting quanta. Philosophical transactions of the royal society of london. Series A, Mathematical and Physical Sciences 276, 231–266.

Knight, M., 2017. The deliberate destruction of Late Bronze Age socketed axeheads in Cornwall. Corn. Archaeol. 56, 203–224.

Knight, M., 2019. Going to pieces: investigating the deliberate destruction of Late Bronze Age swords and spearheads. Proc. Prehist. Soc. 85, 251–272.

Kristiansen, K., 2018. Theorizing trade and civilisation. In: Kristiansen, K., Lindkvist, T., Myrdal, J. (Eds.), Trade and Civilisation. Economic Networks and Cultural Ties, from Prehistory to the Early Modern Era. University Press, Cambridge, pp. 1–24.

Kuijpers, M.H.G., Popa, C., 2021. The origins of money: calculation of similarity indexes demonstrates the earliest development of commodity money in prehistoric Central Europe. PloS One 16 (1).

Lago, G., 2020. Fragmentation of metal in Italian Bronze Age hoards: new insights from a quantitative analysis. Origini 46 (in press).

Lenerz-de Wilde, M., 1995. Prämonetäre Zahlungsmittel in der Kupfer- und Bronzezeit Mitteleuropas. Fundberichte aus Baden-Württemberg 20 (1), 229–327.

Leonardi, G., 2016. Analisi dei valori ponderali del ripostiglio di bronzi di Merlara (Padova). In: Asolati, Michele, Callegher, Bruno, Saccocci, Andrea, Crisafulli, Cristina (Eds.), Suadente nummo vetere. Studi in onore di Giovanni Gorini. Esedra Editrice, Padova, pp. 431–444.

Ling, J., Stos-Gale, Z., Grandin, L., Billström, K., Hjärtnhner-Holdar, E., Persson, P.O., 2014. Moving metals II: provenancing Scandinavian Bronze Age artefacts by lead isotope and elemental analyses. J. Archaeol. Sci. 41, 106–132.

Lutz, J., Pernicka, E., 2013. Prehistoric copper from the eastern alps. Open J. Archaeometry 1. https://doi.org/10.4081/arc.2013.e25.

Mehler, N., Gardiner, M., 2021. Coinless exchange and foreign merchants in medieval Iceland (AD 900-1600). In: Rahmstorf, L., Barjamovic, G., Ialongo, N. (Eds.), Merchants, Measures and Money. Understanding Technologies of Early Trade in a Comparative Perspective. Weight & Value 2. Hamburg/Kiel, Wachholtz, pp. 35–53.

Melitz, J., 1970. The Polanyi school of anthropology on money: an economist's view. Am. Anthropol. 72, 1020–1040.

Milcent, P.Y., 2017. Valeurs d'usage et d'échange. La dimension prémonétaire des dépôts en Gaule atlantique du XIII^{e} au V^{e} s. av. J.-C. Bulletin de la Société préhistorique française 114 (4), 711–737.

Nebelsick, L., 2000. Rent asunder: ritual violence in Late Bronze Age hoards. In: Pare, C.F.E. (Ed.), Metals Make the World Go Round. The Supply and Circulation of Metals in Bronze Age Europe (Proceedings of a Conference Held at the University of Birmingham in June 1997). Oxbow Books, Oxford, pp. 160–175.

Needham, S.P., Hook, D.R., 1988. Lead and lead alloys in the bronze Age. Recent finds from runnymede bridge. In: Slater, E.A., Tate, J.O. (Eds.), Science and Archaeology Glasgow 1987 (Proceedings of a Conference on the Application of Scientific Tecniques to Archaeology. Glasgow, September 1987), vol. 196. British Archaeological Reports, Oxford, pp. 259–274.

Pakkanen, J., 2011. Aegean Bronze Age weights, chaînes opératoire and the detecting of patterns through statistical analyses. In: Brysbaert, A. (Ed.), Tracing Prehistoric Social Networks through Technology: A Diachronic Perspective on the Aegean. Routledge, London, pp. 143–166.

Pallaver, K., 2015. The african native has No pocket": monetary practices and currency transitions in early colonial Uganda. Int. J. Afr. Hist. Stud. 48 (3), 471–499.

Pare, C.F.E., 1999. Weights and Weighing in Bronze Age Central Europe, Eliten in der Bronzezeit: Ergebnisse zweier Kolloquien in Mainz und Athen. (Monographien des Römisch-Germanischen Zentralmuseums 43). Verlag des Römisch-Germanischen Zentralmuseums, Mainz – Bonn, pp. 421–514.

Pare, C.F.E., 2013. Weighing, commodification and trade. In: Fokkens, H., Harding, A. (Eds.), The Oxford Handbook of the European Bronze Age. University Press, Oxford, pp. 508–527.

Pernicka, E., Lutz, J., Stöllner, T., 2016. Bronze Age copper produced at Mitterberg, Austria, and its distribution. Archaeol. Austriaca 100, 19–55.

Peroni, R., 1998. Bronzezeitliche Gewichtssysteme im Metallhandel zwischen Mittelmeer und Ostsee. In: Hänsel, B. (Ed.), Mensch und Umwelt in der Bronzezeit Europas. Oetker-Voges Verlag, Kiel, pp. 217–224.

Petruso, K.M., 1992. Ayia Irini. The Balance Weights: an Analysis of Weight Measurement in Prehistoric Crete and the Cycladic Islands (Keos 8). Philipp von Zabern, Mainz.

Peyronel, L., 2010. Ancient near eastern economics. The silver question between methodology and archaeological data. In: Matthiae, P., Pinnock, F., Nigro, L., Marchetti, N. (Eds.), Proceedings of the 6th International Congress on the Archaeology of the Ancient Near East (May 5th-10th 2008, Sapienza – Università di Roma 1). Harrassowitz, Wiesbaden, pp. 925–948.

Peyronel, L., 2011. Mašqaltum kittum. Questioni di equilibrio: bilance e sistemi di pesatura nell'Oriente Antico. In: Ascalone, E., Peyronel, L. (Eds.), Studi Italiani di Metrologia e Economia del Vicino Oriente Antico. Herder, Roma, pp. 105–162.

Powell, M.A., 1977. Sumerian merchants and the problem of profit. Iraq 39, 23–29.

Powell, M.A., 1987-90. Masse und Gewichte, Reallexikon der Assyriologie und Vorderasiatischen Archäologie 7. de Gruyter, Berlin, pp. 457–530.

Powell, M.A., 1996. Money in Mesopotamia. J. Econ. Soc. Hist. Orient 39 (3), 224–242.

Primas, M., 1986. Die sicheln in mitteleuropa I (österreich, schweiz, süddeutschland). Prähistorische Bronzefunde 18 (2) (C.H.Beck, München).

Pryor, F.L., 1977. The origins of money. J. Money Credit Bank. 9 (3), 391–409.

Radivojević, M., Roberts, B.W., Pernicka, E., Stos-Gale, Z., Martinón-Torres, M., Rehren, T., Bray, P., Brandherm, D., Ling, J., Mei, J., Vandkilde, H., Kristiansen, K., Shennan, S.J., Broodbank, C., 2018. The provenance, use, and circulation of metals in the European bronze Age: the state of debate. J. Archaeol. Res. 27 (2), 131–185.

Rahmstorf, L., 2010. The concept of weighing during the bronze Age in the aegean, the Near East and Europe. In: Morley, I., Renfrew, C. (Eds.), The Archaeology of Measurement. Comprehending Heaven, Earth and Time in Ancient Societies. Cambridge University Press, Cambridge, pp. 88–105.

Rahmstorf, L., 2016. From 'value ascription' to coinage: a sketch of monetary developments in western Eurasia from the Stone to the Iron Age. In: Haselgrove, C., Krmnicek, S. (Eds.), The Archaeology of Money, (Proceedings of the Workshop, Tübingen October 2013; Leicester Archaeology Monographs 24), pp. 19–42. Leicester.

Rezi, B., 2011. Voluntary destruction and fragmentation in late bronze Age hoards from central transylvania. In: Berecki, S., Németh, R.E., Rezi, B. (Eds.), Bronze Age Rites and Rituals in the Carpathian Basin, (Proceedings of the International Colloquium from Târgu Mureş, 8-10 October 2010), pp. 303–334. Mega.

Renfrew, C., 2012. Systems of value among material things: the nexus of fungibility and measure. In: Papadopoulos, J.K., Urton, G. (Eds.), The Construction of Value in the Ancient World, (Cotsen Advanced Seminar Series 5). Cotsen Institute of Archaeology Press, Los Angeles, pp. 249–260.

Roscio, M., Delor, J.P., Muller, F., 2011. Late bronze Age graves with weighing equipment from eastern France. Archaol. Korresp. 41 (2), 173–186.

Sommerfeld, C., 1994. Gerätegeld Sichel. Studien zur monetären Struktur bronzezeitlicher Horte im nördlichen Mitteleuropa (Vorgeschichtliche Forschungen 19). de Gruyter, Berlin.

Steinkeller, P., 2004. Toward a definition of private economic activity in third millennium Babylonia. In: Rollinger, R., Ulf, C. (Eds.), Commerce and Monetary Systems in the Ancient World: Means of Transmission and Cultural Interaction, (Proceedings of the 5th Annual Symposium of the Assyrian and Babylonian Intellectual Heritage Project, Innsbruck, October 3–8 2011). Franz Steiner Verlag, München, pp. 91–111.

Uhlig, T., Krueger, J., Lidke, G., Jantzen, D., Lorenz, S., Ialongo, N., Terberger, T., 2019. Lost in combat? A scrap metal find from the Bronze Age battlefield site at Tollense. Antiquity 93 (371), 1211–1230.

Vandkilde, H., 2016. Bronzization: the bronze Age as a pre-modern globalization. Praehistorische Z. 91 (1), 103–123.

Vandkilde, H., Hansen, S., Kostakis, K., Kristiansen, K., Müller, J., Sofaer, J., Stig Sørensen, M.L., 2015. Cultural mobility in bronze Age Europe. In: Suchowska-Ducke, P., Scott Reiter, S., Vandkilde, H. (Eds.), Forging Identities. The Mobility of Culture in Bronze Age Europe, British Archaeological Reports, vol. 2771, pp. 5–37 (1), Oxford.

Velde, F., 2021. A functional approach to money in the ancient world. In: Rahmstorf, L., Barjamovic, G., Ialongo, N. (Eds.), Merchants, Measures and Money. Understanding Technologies of Early Trade in a Comparative Perspective. Weight & Value 2. Hamburg/Kiel, Wachholtz, pp. 199–205.

Vilaça, R., Bottaini, C., 2019. Breaking metals and handling ideas about Bronze Age hoards from Western Iberia. Material patterns, invisible behaviors and possible. In: Valera, A.C. (Ed.), Fragmentation and Depositions in Pre and Proto-Historic Portugal, Núcleo De Investigação Arqueológica (NIA) Era Arqueologia. S.A, Lisbon, pp. 125–139.

Williams, R.A., Le Carlier de Veslud, C., 2019. Boom and bust in Bronze Age Britain: major copper production from the Great Orme mine and European trade, c. 1600–1400 BC. Antiquity 93 (371), 1178–1196.

Wiseman, R., 2018. Random accumulation and breaking: the formation of Bronze Age scrap hoards in England and Wales. J. Archaeol. Sci. 90, 39–49.

Zelizer, V., 2000. The purchase of intimacy. Law Soc. Inq. 25 (3), 817–848.