4 Bonze Age weight metrology and the making of a continental market

4.1. Introduction

Weight systems are the most direct, and to date only quantifiable proxy of economic interaction in prehistoric economies, as they emerge from the interaction between economic agents making use of weighing technology to quantify transaction values. Understanding weight systems, then, is a socio-economic problem. At the same time, their identification is a statistical problem. Understanding weight systems is vastly more complex and intriguing than just assigning arbitrary values in grams to ancient units. It requires departing from the classificatory exactitude that is so ingrained in the culture-historical tradition of the pre- and protohistoric archaeologies of the Old World, and embrace an unfamiliar framework grounded in indeterminacy. In practical terms, it requires giving up categorical variables in exchange for numeric ones. The trade-off is worth the price: We may lose the comfort of categories, but we gain the advantages of quantification. The purpose of prehistoric weight metrology is, then, to make sense of (some aspects of) prehistoric economies through quantitative means.

In the first part of this chapter, I will outline a model for Bronze Age weight units that will inform both the methodological and the interpretive frameworks. The model is largely grounded in empirical research I carried out during the last seven years in the framework of the WEIGHT AND VALUE Project, addressing the early manifestations of weighing technology and weight systems across Western Eurasia. The general views expressed in this chapter – especially those regarding the issue of accuracy – are in line with new approaches to Mesopotamian and Aegean Bronze Age metrology (Hafford 2012; Petruso 2019; *e. g.*, Chambon/Otto 2023).

The model's design is largely based on the evidence from Bronze Age Greater Mesopotamia, due to the unmatched quantity and quality of the available documentation, both archaeological and textual. The treatment of the Mesopotamian evidence pivots around the discussion of old but extremely influential models that are by some – although not by all – considered outdated. I would like to clarify that I do not discuss these models because I consider them to be representative of current research on Mesopotamian metrology, but because they are instrumental in making a point. After many conversations I had in the past few years with colleagues and friends who are not specialists in the field of ancient metrology, I have come to realise that such old models are, in fact, very accurate representations of how non-specialists conceptualise ancient weight units through the lenses of common-sense. The point I wish to make, then, is that common-sense is not adequate to understand pre-metric weight units, which instead requires a great deal of counterintuitive reasoning – and some basic statistics – as more and more Bronze Age metrologists are coming to acknowledge.

Some of the hypotheses that constitute the backbone of my model could be tested thanks to experimental research conducted by R. Hermann in collaboration with expert bone carvers and stone masons (Hermann *et al.* 2020; Ialongo *et al.* 2021). The model itself was tested based on a large database of Western Eurasian balance weights, fully published in Ialongo *et al.* 2021.

The chapter continues with the description of the analytical methodology and the illustration of its results. The last two parts are devoted to outlining a model for the origin of weight systems in Western Eurasia, and to explore the connection between weight systems, the origin of money, and the formation of an integrated market in pre-literate Bronze Age Europe.

4.2. The quest for the unit

4.2.1. A unit is not a number

The model outlined in this chapter is based on a simple, fundamental axiom: A unit is not a number. Any attempt to assign an exact value in grams to a pre-metric unit is an entirely arbitrary and largely futile endeavour, doing little more than pretending to 'translate' for a modern audience something that its original users always perceived as '1'. The fallacy of reducing ancient units to the metric system was impeccably introduced by W. Kula (1986, 98-99) in his seminal work on the systems of measurement of Medieval Europe:

[The goal of historical metrology] *will not be achieved if its aims are narrowly restricted in the traditional manner as being "to ascertain precisely the terminology of former measures, to reconstruct the system of measurement, and to calculate the values of the measures of yesteryear, as well as to translate them into the units in use today." For this conception of the scope of historical metrology has, on the one hand, deprived it of the opportunities of tackling problems of the greatest scientific interest and, on the other, has led on occasion to skepticism and cognitive pessimism among its students and, still more, among historians wishing to utilize the data from historical metrology. To convert old time measures into the units of the metric system is often, in fact, not a feasible task, and results of such attempts, however painstaking, are often of little practical use, because even the most meticulous determination of the dimensions of, say, the łan* [*i. e.*, a unit of field measurement in use in medieval Poland] *could not be extensively utilized when even neighboring villages in the same year, more often than not, would have łans of different sizes. The skepticism and the cognitive pessimism were therefore quite often by no means groundless.*

Yet, when the historian succeeds in uncovering the social import of a given measure, although this may not tell him much of what he wants to know then (such as the correct metric equivalent), it may offer him an opening leading to many other, possibly more important, matters.

The concerns expressed by W. Kula (1986) are slowly being incorporated in the scientific discourse on Bronze Age metrology, which has been otherwise dominated by the quest for exact units for roughly a century. As I show in this section, both theoretical modelling and the empirical evidence lead to reject the idea of Bronze Age weight units as exact values, while supporting a model of units as indeterminate intervals.

4.2.2. The many units of Bronze Age Mesopotamia

Bronze Age Mesopotamia is the ideal starting point for a reflection of Bronze Age weight units in Western Eurasia. There is no doubt that the Mesopotamian weight system is the best documented one in the Bronze Age world, thanks to the abundance of written and archaeological evidence. It is a well-known fact that the Mesopotamian weight system – as virtually any pre-metric system of measurement – had different names to identify different orders of magnitude of the same quantity, *i. e.*, mass. The most frequently used orders of magnitude – or 'units,' as they are always designated in common language – were the *shekel* and the *mina*, with the *grain* and the *talent* being somewhat less represented. To simplify an utterly complex problem to its core, the *shekel* – a word of Semitic origin literally meaning 'weight' – was a small unit whose value is conventionally fixed at 60 times the value of the *grain* and $^1/_{60}$ the value of the *mina*, the latter being in turn $^1/_{60}$ the value of the *talent* (Powell 1987).

Trying to determine the exact value in grams of the *shekel* and the *mina* has been a primary focus of research in ancient metrology spanning the last 100 years or so. While most researchers agree that the most frequent value of the *shekel* should be fixed at *c.* 8.3-8.5 g, there are hints that seem to suggest the coexistence of *shekels* of different values. Based on the analysis of a small sample of balance weights from the Bronze Age city of Ebla (Syria; objects dating mostly to *c.* 2000-1700 BCE), A. Archi (1987) proposed the coexistence of three different *shekels*: an 'Eblaite' or 'Syrian *shekel*' of 7.8 g, a 'Levantine *shekel*' of 9.4 g, and an 'Anatolian *shekel*' of 11.75 g. A. Archi's attempt to identify different *shekels* for the Early Bronze Age (*c.* 3000-2000 BCE) and Middle Bronze Age (*c.* 2000-1700 BCE) mirrors a slightly older study by N. Parise (1981), focussing on Mesopotamian weight metrology of the Late Bronze Age. N. Parise identifies exactly the same values and designates them with the names of the cities that would have allegedly adopted them as official: the *shekel* of Carchemish, the *shekel* of Khatti, and the *shekel* of Ugarit. Both A. Archi's and N. Parise's metrological reconstructions of the weight systems of the Ancient Near East have since established themselves as highly influential – equally among supporters and critics – and provided the benchmark for later research.

From a historical perspective, the hypothesis that Early Bronze Age units were created in the very same regions where they eventually became official centuries later is certainly appealing. This hypothesis, however, is based on a biased perception of the nature of ancient weight units, and is not ultimately supported by the evidence. State-of-the-art statistical analyses based on a sample of thousands of balance weights clearly show that there is no ground to assume the existence of any other unit than the so-called 'Mesopotamian *shekel*' of *c.* 8.3-8.5 g in the Early and Middle Bronze Age (Ialongo *et al.* 2021). If we conceptualise Bronze Age units as values expressed in grams, the empirical evidence might then give the impression that the 'right' value of the Mesopotamian *shekel* is 8.3 g, while any other suggested value is 'wrong'. This impression would be profoundly mistaken: All the proposed values – including the supposedly correct one – are, in fact, 'right' and 'wrong' at the same time.

4.2.3. The indeterminacy of Bronze Age units

From a purely mathematical perspective, the most fundamental flaw in traditional approaches to Bronze Age metrology is to conceptualise weight units as 'values' while they are, in fact, 'intervals' (Ialongo 2019; Petruso 2019; Chambon/Otto 2023). Before proceeding, it is crucial to keep in mind that all relative error estimates reported in this book are always intended in terms of Coefficient of Variation (CV) at one Standard Deviation (SD). Since it is a proven fact that the distribution of weight units follows a normal distribution, the CV offers a very accurate estimate of their relative error. This also means that the complete error range must be intended in terms of three standard deviations, as is good practice with normal distributions. For example, a distribution with mean 10 g and CV 5 % will have a total error range comprised between 8.5 g (*i. e.*, 10-0.5*3) and 11.5 g (10+0.5*3). In other words, the complete interval that defines Bronze Age units is always equal to the average value of the distribution plus or minus three times the CV.

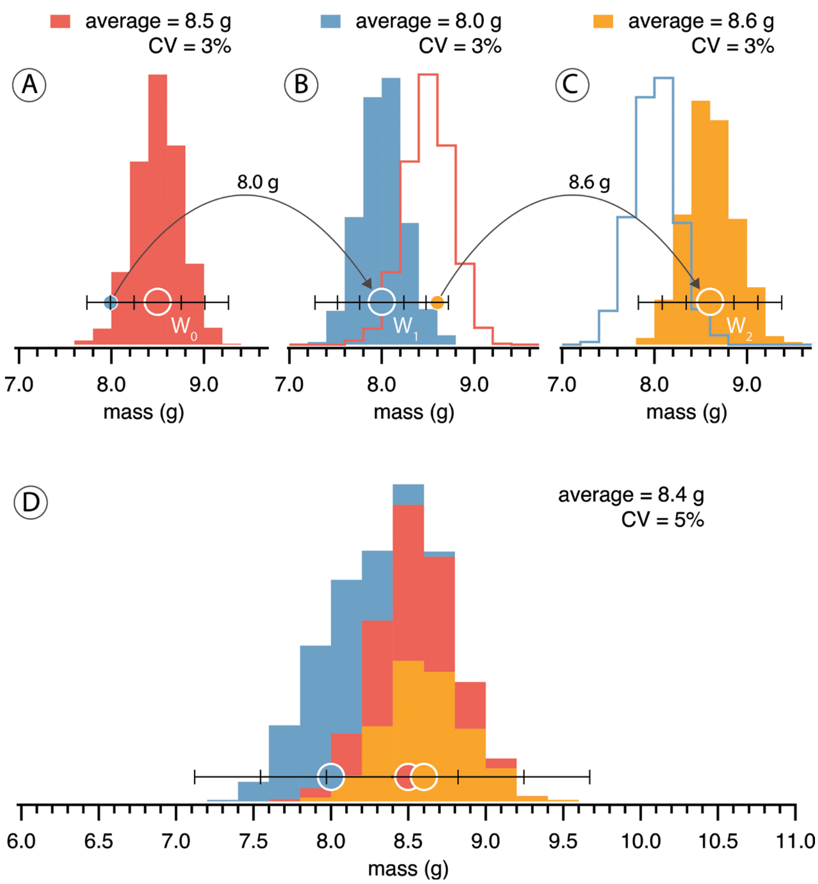
It has been a well-known fact since the dawn of Bronze Age metrology that ancient weight units are arrays of normally-distributed values (Weissbach 1907; 1916; Viedebantt 1917; *e. g.*, 1923). This can be easily demonstrated empirically, simply by plotting the binned distribution of balance weights, as shown in several publications (Parise 1970; *e. g.*, Hafford 2012; Ialongo *et al.* 2018a). More specifically, weight units are distributions of values that are symmetrical about their mean, and whose probability decreases progressively the farther away they get from the mean value, until becoming negligible. Units are ranges of values – *i. e.*, *intervals* – comprised between a minimum and a maximum value that are, in turn, equidistant from, and symmetrically positioned about their median point. Weight units are, in other words, indeterminate by definition.

The next step to frame the nature of Bronze Age units is then to quantify their inaccuracy and identify its causes. Inaccuracy has two prime determinants: instrumental error and propagation of uncertainty. Instrumental error (or systematic error) is an inherent component of any measurement instrument. No matter how technologically advanced, a measurement instrument will always produce a discrepancy between the observed value of a measurable quantity and its 'true' unknown value. Some measurement instruments have an absolute error, *i. e.*, the error remains constant independently from the size of the observed quantity, corresponding to the smallest value that the instrument is designed to measure; a standard ruler, for example, as a systematic error of 1 mm, as 1 mm is the smallest measurable value. Other instruments have, instead, a systematic error that is relative to the quantity being measured. Relative error is crucial to understand Bronze Age weight systems, as it is embedded in the only mass-measuring tool known at the time: the equal-arm balance. Equal-arm balances effectively provide what in hard sciences is called a 'null-measurement', a measurement technique that involves comparing an unknown quantity with a known quantity of the same type – in our case, mass. This comparison is repeated until the instrument registers zero (= null) response – *i. e.*, until the balance beam is in equilibrium – indicating equality between the two quantities. Notably, the systematic error of null-measurement techniques is always relative to the quantity being measured.

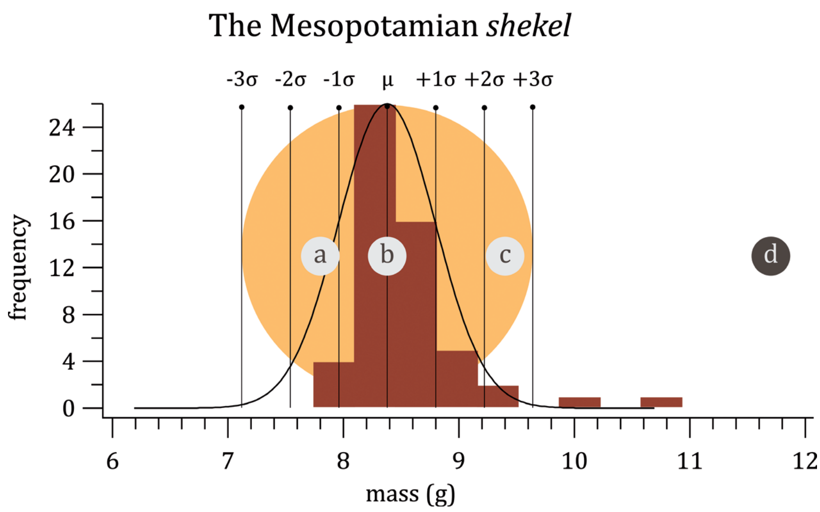
The next problem to solve is how to quantify this error. Ancient users were already well aware of the inaccuracy of their balance scales (Joannès 1989). Based on detailed reports provided by cuneiform texts, the instrumental error of Bronze Age balances can be estimated at *c.* 3 % (Powell 1979). Experiments based on accurate replicas of Bronze Age balance beams and weights confirm this estimation (Ialongo *et al.* 2021).

The inaccuracy of balance scales provides only a partial explanation for the overall statistical dispersion of Bronze Age units. The second determinant factor is the propagation of error caused by the repeated creation of new balance weights. A striking majority of all the Bronze Age balance weights known in Western Eurasia is made of stone. While the available evidence seems to indicate a preference for metal in some areas of Greece in the Late Bronze Age (Petruso 1992), 70 % of the balance weights of pre-literate Bronze Age Europe included in this book and nearly all the weights known between Mesopotamia and the Indus Valley are made of stone (Ascalone/Peyronel 2006; Kulakoğlu 2017; *e. g.*, Ascalone 2022; Rahmstorf 2022). Stone weights, then, make up for most of the statistical variability of the sample, and offer an ideal benchmark to address how the creation of new balance weights affects the overall statistical dispersion of Bronze Age units.

Null-measurements require a reference quantity. Imagine a prototype weight (which we will call W_0) weighing exactly 8.5 g, serving as a reference quantity – *i. e.*, a model – to make new ones. To make a new weight (W_1), we would take a stone of the appropriate material with mass greater than W_0, and carve it down to shape, repeatedly checking the mass of W_1 against the mass of W_0 on an equal-arm balance, until the beam is in equilibrium. Since Bronze Age balance beams have a systematic error of 3 %, the final mass of W_1 will have a normally-distributed probability of falling anywhere within an interval of ± 9 % from the value of W_0, *i. e.*, between 7.735 g and 9.265 g. If we repeat this process, say, 1,000 times, the result will be a normally-distributed sample with average 8.5 and CV 3 % (Fig. 4.1.A). This explains the instrumental error of 3 % affecting all the balance weights produced using exactly the same prototype. This is, however, an extremely unlikely scenario: It is impossible that all the balance weights of the Bronze Age were modelled after the same prototype. The only solution is to assume that potentially any weight modelled after W_0 was subsequently used as a prototype to make new weights, and so on for an indefinite number of prototypes and replicas. Each time a new prototype is picked from one of the 'tails' of the original distribution, the error will propagate,



▲ *Fig. 4.1. Propagation of uncertainty: a visual model of the formation of new weight systems.*
A: formation of a normally-distributed sample of 1,000 balance weights with CV = 3 %, starting from a prototype of 8.5 g (called W0 in the text);
B: formation of a normally-distributed sample of 1,000 balance weights with CV = 3 %, starting from a prototype of 8.0 g (W1, randomly picked from the previous distribution);
C: formation of a normally-distributed sample of 1,000 balance weights with CV = 3 %, starting from a prototype of 8.6 g (W2, randomly picked from the previous distribution);
D: final normally-distributed population, including all previously generated samples, with mean = 8.4 g and CV = 5 %.



▲ *Fig. 4.2. The indeterminacy of weight units. Binned frequency distribution of the unit-value of Mesopotamian inscribed weights of the Early and Middle Bronze Age, obtained by multiplying the mass of each weight by the fractional value indicated by the inscription (full dataset published in* Ialongo *et al. 2021). Mean= 8.4 g, CV= 5 %. Vertical lines indicate the Standard Deviations of the distribution. Exact values of alleged units frequently cited in the literature: A) 'Syrian unit' (7.8 g); B) 'Mesopotamian unit' (8.4 g); C) 'Levantine unit' (9.4 g); D) 'Anatolian unit' (11.75 g).*

consequently enlarging the interval of the unit. Fig. 4.1. illustrates this process. The second prototype is a weight with mass 8 g, picked from the left side of the original distribution. If we use this prototype to build another batch of 1,000 weights, we will have another normal distribution, with the same CV but with mean= 8 g (Fig. 4.1.B). We repeat the process one more time, this time picking a new prototype of 8.6 g from the right side of the distribution, and we obtain yet the same result (Fig. 4.1.C).

At the end of the experiment, we obtain three normally-distributed samples with slightly different means. We can tell that these distributions are in fact slightly different because we obtained them through a controlled experiment, each time using a different prototype and noting down each step carefully, so that we always know exactly which weight was made based on which protype. But what if the experiment was made by someone else, and we did not know which weight was made based on which prototype? Would we be able to make out the three different concentrations, and figure out not only that they were obtained using three different prototypes, but also the exact value in grams of each prototype? The answer is no. Fig. 4.1.D clearly shows that the three distributions seamlessly blend into one another, and that in doing so they create yet another normal distribution, but this time with mean 8.4 g and CV= 5 %.

What I have just illustrated is a simplified model derived from scientific data gathered in a real experiment conducted by R. Hermann in collaboration with an expert stone mason (Ialongo *et al.* 2021). The experiment confirms that the reiterated production of balance weights starting from randomly-picked prototypes propagates the initial instrumental error of 3 % until eventually settling around a CV of *c.* 5 %. This experiment provides the expectations to be tested against the archaeological data. The analysis of the complete dataset of inscribed balance weights in Bronze Age Western Eurasia confirms the expectations. If we divide the mass values of each inscribed weight by the fractional value indicated by their inscriptions, then we can easily quantify the statistical dispersion from the expected value – which, by definition, is always '1' – and the measured value. The results indicate a CV of 5.4 % for Bronze Age units (Fig. 4.1.D) and confirm the expectations derived from experimental replicas.

4.2.4. The 'right' unit

Experimental research and archaeological data demonstrate that Bronze Age units are not exact values, but rather indeterminate, normally-distributed intervals. But how does this help us in our quest for the unit? And how can we use this knowledge to decide which of the many units that have been proposed in the past is 'right,' and which one is 'wrong'?

These questions can now be answered empirically. The graph in fig. 4.2. shows the distribution of the mass values obtained by dividing the observed mass of Mesopotamian inscribed weights of the 3rd and early 2nd millennium by the fractional value indicated by the inscriptions. Inscribed weights undoubtedly represent the best way in which we can reliably identify how ancient users perceived their units of measurements. As expected, the graph shows a normally-distributed concentration with average 8.4 g and CV ≈ 5 %. If we take the exact values of the different units that have been proposed in the past and overlay them on the graph, we can finally answer our question. The 'Syrian' (7.8 g), 'Mesopotamian' (8.4 g), and 'Levantine' (9.4 g) units all comfortably fall within two Standard Deviations from the distribution mean (Fig. 4.2.). The 'Anatolian unit' of 11.75 g, on the other hand, not only falls well outside of the interval, but does not actually correspond to the fractional value of any known inscribed weight. In conclusion, the 'Syrian', 'Mesopotamian', and 'Levantine' units are all randomly-picked values that belong to a normally-distributed interval that its ancient users always perceived as one *shekel*. They are, in other words, *the same unit*. On the other hand, the 'Anatolian' unit of the Early and Middle Bronze Age is, based on the available evidence, a false positive. That the users of weighing technology did not normally differentiate between different competing systems is also indirectly confirmed by the fact that only *c.* 3 % of the Mesopotamian balance weights of the Early and Middle Bronze Age actually bear marks and inscriptions indicating their fractional values (Ialongo *et al.* 2021).

Far from reflecting a historical reality, the proliferation of different units in metrological research is rather an academic artefact, likely depending on the sampling strategy of previous studies. A sample of limited size, as well as a sample drawn from a single site or a single chronological phase, can have been randomly drawn from one of the extremes that compose the overall interval of the unit, and is therefore likely to give biased results. At the same time, this does not imply that these results are necessarily 'wrong'. As far as we know, almost all the values that have been proposed are equally good candidates to represent the 'original unit'. The model in fig. 4.1. shows that the final value of the unit does not precisely correspond to any of the initial values that were used to create it. Which means, in turn, that the 'original Mesopotamian unit' can be one among the ones that have been proposed in the past, as well as none. In more general terms, the Mesopotamian evidence provides the blueprint to frame the nature and the formation of weight units across Western Eurasia in the Bronze Age.

4.2.5. Units and power

Thinking of weight units as indeterminate intervals generated by chance raises a fundamental question: If weight units are the outcome of a random process, how is it possible that their overall dispersion never significantly exceeded a CV of 5 %? The answer, one might argue, is to be found in the regulatory action put in place by central authorities. Before proceeding with addressing the relationship between weight units and power in the Bronze Age, it is first necessary to clarify the cultural-evolutionary context of the appearance of weights and balances.

Weighing technology is one of the great original innovations of the Bronze Age. It was invented *c.* 3100 BCE between Mesopotamia and Egypt, and in the course of the next 2,000 years it spread to then Indus Valley, Anatolia and the Aegean (*c.* 2800 BCE), Italy (*c.* 2300 BCE), Central Europe and the British Isles (*c.* 1350 BCE), and Atlantic Europe (*c.* 1200 BCE). Each time it was adopted in a new region, weighing technology inevitably gave rise to the formation of a new weight system (Ialongo *et al.* 2021). Before weights and balances were invented, no objective frame of reference existed that could allow anyone engaging in an economic transaction to quantify and convert the value of a substance into that of any other substance on the marketplace (Renfrew 2012). This ignited a revolution in trade, whose long-lasting consequences are still very much evident today (Ialongo/Vanzetti 2016).

It is this character of disruptive originality that makes the formation of primary weight systems in Western Eurasia a unique case study in the long history of the relationship between units of measurement and power (Kula 1986), and hence not necessarily comparable with later developments. With the term *'primary weight system'* I designate a weight system that arises in a given region contextually with the first adoption of weighing technology. Hence, in a way, asking whether central authorities plaid a determinant role in the formation of primary weight systems touches on the more general question of the relationship between power and technological innovation.

Outside of Mesopotamia and Egypt, primary weight systems emerged in the Indus Valley, Anatolia, Greece, Italy, Central Europe, the British Isles and the Iberian Peninsula. Each of these regions was characterised by a different and peculiar socio-political setting, and yet in all cases the resulting units never exceeded a CV of *c.* 5 %. This has crucial implications: if the outcome was the same everywhere between the Atlantic and the Indus Valley regardless of cultural peculiarities, it follows that any interpretive model must be equally applicable to all socio-cultural contexts of Bronze Age Western Eurasia, and cannot admit particularisms. This means, in turn, that the agency of central authorities cannot have been the primary determinant factor in regulating the statistical dispersion of weight units, simply because central authorities did not exist in some of these regions during the Bronze Age.

Centralised regulatory action could have occurred in Egypt and Mesopotamia. A determinant role of central authorities is, however, much less likely for western Anatolia and Greece, where centralisation was only at an incipient stage during the Early Bronze Age (Frangipane 2012; Özdoğan 2023). Centralised regulation is ultimately not a viable option for pre-literate Bronze Age Europe – *i. e.*, west of Greece – where far-reaching central authorities simply never existed until the first half of the 1st millennium BCE (*e. g.*, Harding 2000; Kristiansen/Larsson 2005), and even then, only in circumscribed regions of the Mediterranean coast (Pacciarelli 2001; Cardarelli 2018; Stoddart 2020).

There are also reasons to think that, even in Mesopotamia, public authorities did not necessarily play a determinant role in the formation of primary weight systems for roughly a millennium. As both archaeological and textual evidence attest, weight systems appeared and were widespread already on the verge of the 3rd millennium BCE (Powell 1979; Ialongo *et al.* 2021; Rahmstorf 2022). And yet, despite the pervasiveness of weighing technology, there is no evidence of the existence of a 'royal standard' until 2112-2095 BCE, roughly 1,000 after the invention of weighing technology. And even then, the textual evidence does not imply the creation of a new unit, but simply the ratification of a pre-existing one (Frayne 1997; Wilcke 2002; Chambon 2011, 38-41). Evidence of top-down control is also absent for the Indus Valley in the Early Bronze Age, where most balance weights come from domestic contexts, and the very existence of strongly centralised power is questionable (Green *et al.* 2023, 105-147).

The evidence available for profoundly different socio-economic contexts across Western Eurasia suggests that primary weight systems did not require centralised power to flourish. Primary weight units are never created by central authorities, nor are they 'norms' in themselves, although they can be eventually sanctioned by official regulations. Actually, pre-metric units in general are never 'created' by political power, the metric system being as a matter of fact the first – and to date last – instance of a measurement system that was created from scratch under the initiative of a political authority (Kula 1986). Primary weight units, then, are not even necessarily attributes of power, to the extent that they are clearly widespread even where power is comparatively weak.

4.2.6. Units and networks

Since top-down control is insufficient to explain the evidence, bottom-up convergence could offer a viable alternative (Ialongo *et al.* 2018b). A vastly interconnected network of economic agents could effectively regulate the statistical dispersion of weight units by systematically excluding aberrations, and making sure that the overall dispersion did not exceed the customarily-accepted range.

The recent history of units of measurements offers a glimpse into how units can emerge out of custom. In 1866, American oil producers reached an agreement and established the standardized measurement for oil known as the 'oil barrel,' still used today in the US. Prior to this, during the early years of oil extraction in the US, there was no specific container for oil, so it was transported in reused wooden barrels originally used for various goods such as fish and whiskey. These barrels typically held around 42 gallons (approximately 160 l), and were intended to contain approximately 'as much as a man could reasonably wrestle.' The surge in oil production in the early 1860s eventually led to a shortage of wooden barrels, prompting the production of specialized containers for the oil market, which was finally standardized at 42 gallons (AOGHS 2013).

While merely an anecdote, the story of the oil barrel offers a compelling insight into how units of measurement can evolve from customary practices, even in the industrial age. Notably, the 'standard quantity' was already widely used before its official recognition as a unit of measurement, echoing the way ancient Near Eastern reforms solidified pre-existing standards. Organizational convenience drove the adoption of the 42-gallon barrel, as both sellers and buyers were accustomed to the average quantity in which the product was shipped. Therefore, formalizing an already customary measure as the 'official' one likely appeared as the most practical choice for all involved parties. In essence, the endorsement of the unit of measurement served to regulate a specific instance of market exchange already governed by customary norms and a well-established framework of habit and trust.

The notion that official units can emerge from customary standards is not novel in Bronze Age studies. M. Lenerz-de Wilde (1995), C. Pare (2013), R. Peroni (1998), M. Primas (1997), and C. Sommerfeld (1994), for example, all argued that the earliest European standards may have evolved from widely distributed ingot-like objects, such as torcs, axes and sickles, spanning the Early and the Late Bronze Age. As for the Ancient Near East, M. A. Powell (1987) suggests a shared etymology of the term '*shekel*' and the Sumerian word for 'axe', implying that the term initially referred to axes as approximate standards. Additionally, the Sumerian, Akkadian, and Greek words for '*talent*' all essentially mean 'burden/load', hinting that a talent represented 'as much as a man can carry', which in turn closely parallels the origins of the oil barrel, derived from recycled containers and purportedly chosen to hold 'as much as a man could reasonably wrestle'.

Whether the actual likelihood of these 'origin stories' may or may not be the point, the idea of a bottom-up, relationally-defined convergence offers a viable alternative to the top-down normative model. The bottom-up hypothesis is also in line with the increasingly influential idea that Bronze Age Western Eurasia was tied together by a vast, decentralised trade network largely driven by the need to procure tin and cooper (Earle *et al.* 2015; Vandkilde 2016; Kristiansen 2018b; Murray 2023). Finally, the bottom-up hypothesis does not imply that central authorities, where they existed, did not play any role in regulating the statistical spread of weight units. Actually, quite the opposite. Central authorities, to the extent that they themselves constituted economic subjects dealing in weight-based trade, contributed to the bottom-up regulation of weight units proportionately to their economic capacity and relative share of connections within the network. And since strong authorities tend to be outstanding in both aspects, they can be expected to individually contribute more than any other private subject to the overall bottom-up regulation mechanism, even without necessarily relying on normative enforcement.

4.2.7. A model for Bronze Age weight units: recap

The following scheme summarises all the considerations expressed so far, that ultimately constitute the salient traits of my working model of Bronze Age units.

What a weight unit *is not*:

- A weight unit is not a number, and even less an exact value expressed in grams. A weight unit is never 'precise', and its accuracy cannot be quantified in absolute numbers. A weight unit is never created by a political authority (at least, not until the French Revolution), it is not necessarily a norm, and it is not necessarily an attribute of power.

What a weight unit *is*:

- A weight unit is a normally-distributed interval (with conventional CV of *c.* 5 % in the Bronze Age), with all the values included in this interval being always perceived as '1' by their ancient users. Weight units emerge from networks of economic agents (including both private and public ones), and they are customarily regulated from the bottom-up.

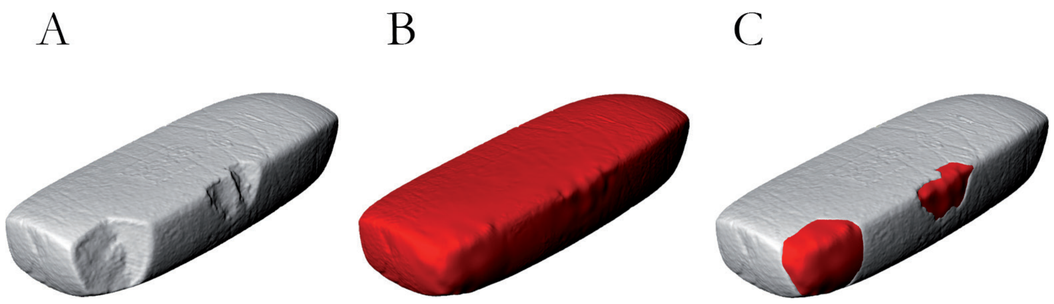


Fig. 4.3. Example of 3D reconstruction of a chipped weight.

This model constitutes the groundwork for the methodological and interpretive frameworks illustrated below.

4.3. Methods

4.3.1. Premise

I have addressed the identification of weight units in pre-literate Bronze Age Europe in several published works. Previous analyses have allowed me to confidently identify two relevant units: a *shekel* of *c.* 10 g (Ialongo 2019; Ialongo *et al.* 2021), and a *mina* of *c.* 450 g (Ialongo/Rahmstorf 2019; 2022). The analyses illustrated here do not add any significantly new result. This book, however, provides the opportunity for an extensive recap of the methodology, a reassessment of its strength and weaknesses, and most importantly an exhaustive discussion of its results.

My choice of using terms like *shekel* and *mina* to identify, respectively, a 'small' and a 'heavy' unit – as well as the choice to assign these units approximate values in grams – is entirely arbitrary and conventional. It is simply meant to aid the reader by reducing a continuous reality to a discrete, simplified framework, that takes its inspiration from a terminology in common use in a field of study – the archaeology of the Ancient Near East – where the values of the *shekel* and the *mina* can be approximately identified thanks to the rich textual record and the occasional occurrence of inscribed weights. Therefore, the use of this terminology should not in any way be taken to imply any direct connection of European units with the Mesopotamian units with the same names.

The sample of balance weights included in this study – its typology, chronology, geographical distribution, and find contexts – have already been described in detail in Chapters 2 and 3.

4.3.2. Reconstruction of chipped weights

The statistical analyses were conducted only on complete and reconstructed weights. For previously published weights, the mass values used for the analyses are the ones given in the original publications. For previously unpublished weights that I documented in museums and excavation storerooms, I used a 2-digit precision balance for objects weighing up to 500 g, and a 0-digit precision balance for weights above 500 g. Chipped weights were subject to 3D scanning, and were digitally reconstructed in order to reconstruct their original mass. This procedure was only applied in case of limited damage, and only when the original shape of the object could be easily reconstructed, such as in the example in fig. 4.3. I used an Artec Spider portable 3D scanner to acquire the 3D models of the objects. The 3D meshes of the scanned objects were modified with the free 3D sculpting software Sculptris. Finally, the volumes of both the original and reconstructed 3D mesh were measured with Rhinoceros 3D, and the hypothetical mass of the reconstructed weight was calculated based on density.

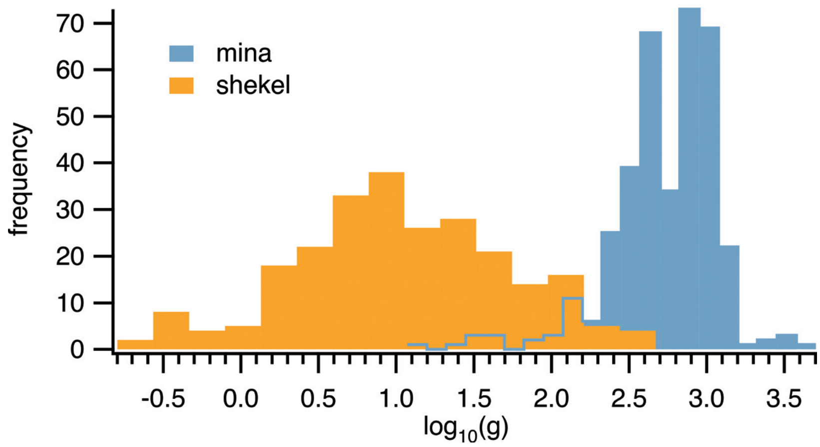
4.3.3. Cosine Quantogram Analysis

Cosine Quantogram Analysis (CQA) is the most reliable analytical technique 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 subsequent years (Pare 1999; Rahmstorf 2010; Pakkanen 2011; *e. g.*, Hafford 2012; Ialongo *et al.* 2021; Poigt 2022).

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 round rational number 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:

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

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 correspond-



▲ *Fig. 4.4. Orders of magnitude of European balance weights. Binned frequency distribution of the logarithms of the mass values of the balance weights in the shekel- and mina-ranges.*

ing quantum is a 'good fit' (Ialongo 2019; the online version of the article contains a downloadable applet for the calculation of CQA).

4.3.4. Subsampling

CQA is characterised by several limitations, that can be overcome through a mindful sub-selection of the sample of balance weights. I will enumerate such limitations, and eventually establish the subsampling value-ranges.

4.3.4.1. *Shekel*-range *vs mina*-range

The presence of different orders of magnitude with dedicated units significantly impacts the analytical strategy. Fig. 4.4. illustrates a comparison between the logarithmic distributions of the mass values of the balance weights in the *shekel* and *mina*-ranges, showing that the two orders of magnitude have neatly distinct concentrations, only marginally overlapping. This data-configuration strongly suggests the existence of two distinct orders of magnitude, and warrants a separate analysis of the two datasets. Since CQA cannot simultaneously address datasets spanning several orders of magnitude, the *shekel* and *mina*-ranges will be analysed separately.

4.3.4.2. CQA can test multiples, but not fractions

One of the limits of CQA is that it can assess potential multiples of a target quantum, but not its fractions. The most direct consequence is that the analysed dataset must be composed of measurements that are approximately equal to or higher than the target quantum.

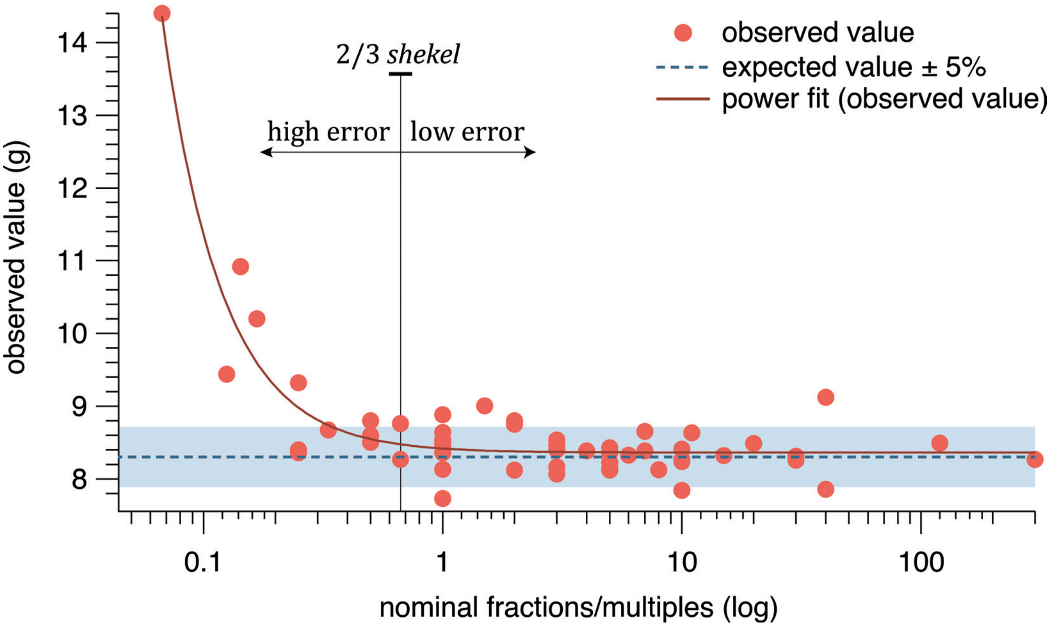
A closer examination of the formula elucidates why measurements smaller than the target quantum invariably yield erroneous results for the unit-range. The formula component determining the goodness of fit for a quantum within a range from 1 (perfect fit) to -1 (no fit) is expressed as

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

For instance, testing a 19 g measurement against a hypothetical 10 g unit yields a result of 0.81, indicating a very good fit due to the negligible remainder of 9 being close to the quantum of 10. However, a 5 g measurement results in -1 despite being exactly half of 10 g, highlighting a limitation of CQA where multiples of half the unit always yield negative results.

4.3.4.3. CQA is based for measurement that are many times bigger than the target quantum

Furthermore, the upper limit of the analysis range is governed by error propagation concerns. For instance, considering a theoretically exact value of 30 times the unit (*e. g.*, 300 g) with an accepted error of ± 5 %, the actual value could range from approximately 285 g to 315 g. Despite these values theoretically representing 30 times the unit, testing with a 10 g quantum would yield -1 for 285 g,



▶ *Fig. 4.5. Size vs accuracy. Y axis: unit-value of Mesopotamian inscribed weights of the Early and Middle Bronze Age, obtained by multiplying the mass of each weight by the fractional value indicated by the inscription (full dataset published in Ialongo et al. 2021). X axis: fractional value indicated by the inscription (logarithmic scale). The graph shows that the distribution of the error becomes asymmetrical at ⅔x the value of the shekel, and rises exponentially for lower values.*

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. As a rule of thumb, in order to obtain meaningful results, the standard error of the highest value of the analysis-range should be at most approximately as big as the target quantum.

4.3.4.4. Measurement error is inversely proportional to size

The graph in fig. 4.5. shows the correlation between the unit value of Mesopotamian inscribed weights (obtained by multiplying the mass of the weight by the fractional value indicated by the inscription) and the fractional value indicated by the inscription. The graph clearly shows that for fractional values higher than $^2/_3$ of the unit the distribution of the error remains stably symmetrical and mostly within one SD from the mean value (8.4 g), while for fractional values equal to or smaller than $^2/_3$ the error rises exponentially. This demonstrates that the smaller the measured quantity is, the higher the inaccuracy becomes. In absolute terms, the threshold can be fixed at *c.* 7 g for Bronze Age units. This outcome is entirely expected, as those sources of error that are irrelevant for bigger quantities – such as the mass of the pans and their chords, the non-perfectly centred fulcrum, the non-perfectly even thickness of the beam, and so on (Poigt *et al.* 2021) – become very much relevant for very small quantities.

4.3.4.5. Subsampling ranges

Considering the caveats illustrated above, the analysis range for the CQA has been set to 7-200 g for the *shekel*-range, and to 300-5,050 g for the *mina*-range, in line with previously published analyses. The final size of all analysed subsets after subsampling is given in tab. 4.1.

4.3.5. Monte Carlo test for statistical significance

Monte Carlo tests can exclude the occurrence of false positives (Kendall 1974; Pakkanen 2011; Ialongo 2019). 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 D. B. Kendall's method, we produced a simulation of 1,000 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.

Shekel	**size after sub-sampling**	**best-fitting quantum**	**phi(q)**	**α=1%**	**α=5%**
Total sample	140	9.6	4.70	3.85	3.31
Phase 1-2	28	9.6	2.77		
Phase 3	51	10.2	3.41		
Phase 4	45	9.6	3.35		
Phase 5	12	9.1			
Italy	62	10.2	2.49		
Central Europe	53	10.2	2.68		
Atlantic Europe	25	9.3	4.57		
Mina					
Total sample	297	445.0	10.09	3.85	3.39
Kannelurensteine (total)	248	447.0	9.94	3.84	3.28
Kannelurensteine (Italy)	84	436.0	6.47		
Kannelurensteine (Switzerland)	142	449.0	7.68		
Kannelurensteine (Germany)	41	112.8	3.21	3.71	3.20
Piriform (total)	40	429.0	3.37	3.40	2.98

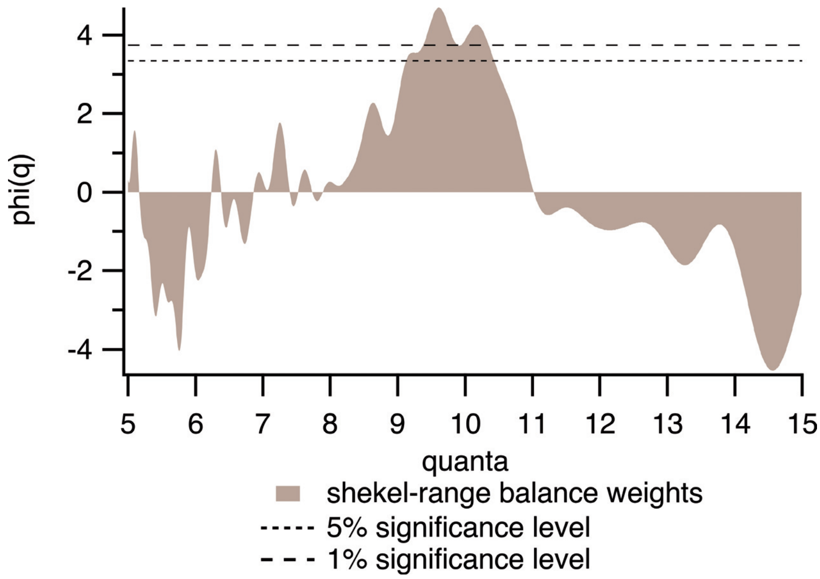
▲*Tab. 4.1. Sub-sample sizes and summary of the results of CQA and Monte Carlo Simulations.*

4.4. Results

The detailed breakdown of sample sizes, best-fitting quanta, φ(*q*) values, and alpha levels for each subsample is given in tab. 4.1.

4.4.1. The shekel

The analysis of the complete sample of balance weights in the *shekel*-range confirms previous results (Ialongo 2019; Ialongo *et al.* 2021). Results highlight a highly significant best-fitting quantum of 9.6 g with ϕ(q)= 4.7, while Monte Carlo simulations indicate ϕ(q) values for 1 % and 5 % significance thresholds of, respectively, 3.85 and 3.31 (Fig. 4.6.). The binned Frequency Distribution Analysis (FDA) offers further insights on the distribution of the sample. The mass values are clearly organized in a multimodal distribution, with a sequence of roughly bell-shaped concentra-



▲ *Fig. 4.6. Cosine Quantogram Analysis of European balance weights of the shekel-range. Complete sample.*

tions corresponding to approximate multiples and fractions of the best-fitting quantum highlighted by the CQA (Fig. 4.7.).

The outcomes of the CQA support the existence of a 'Pan-European *shekel*' of *c.* 9-10 g for the European Bronze Age. They also raise further questions: When and where did the Pan-European *shekel* emerge, and how widespread was it?

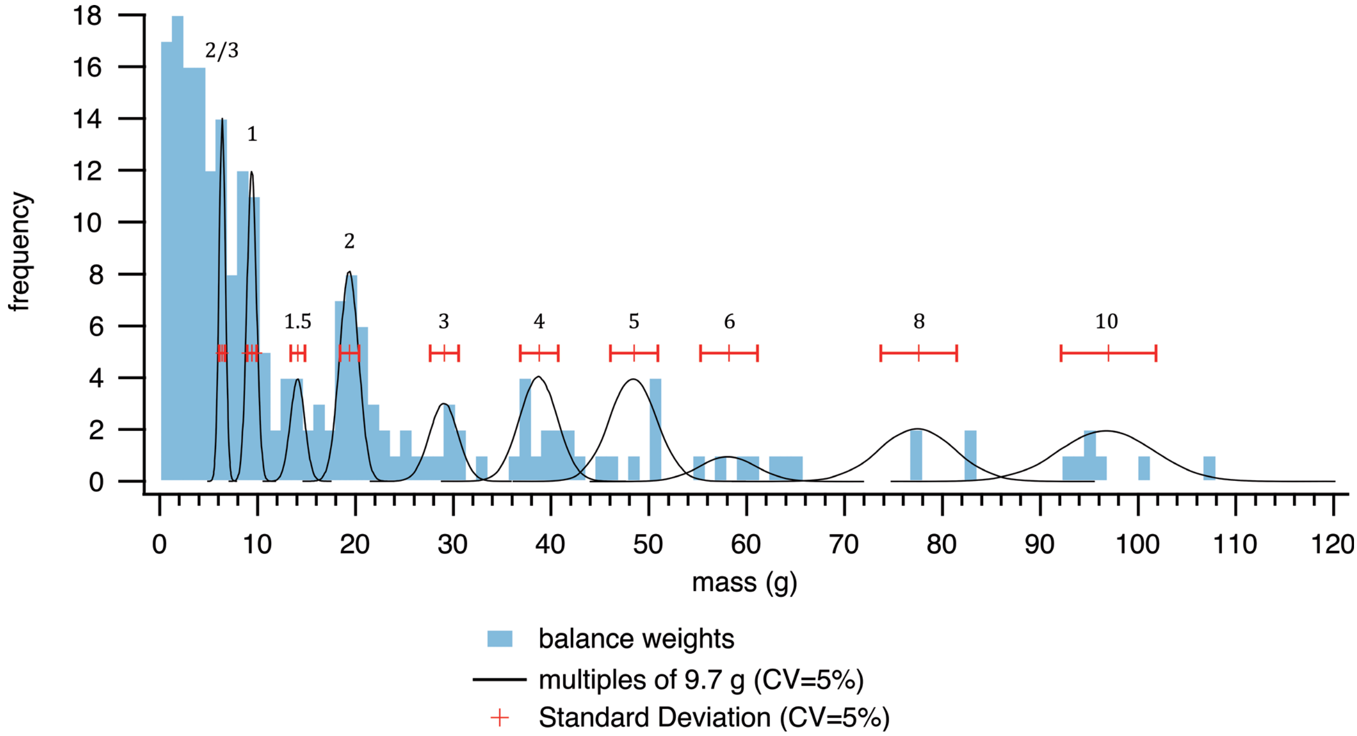
Addressing these questions in detail would require subdividing the sample into smaller subsets, and targeting different European regions in different periods. Unfortunately, the sample is not very big, and dividing it further into narrow geo-chronological subsets would not provide enough data for analyses.

Hence, in order to achieve a compromise between accuracy and sample size, the total sample was divided into two overlapping subsets, one addressing chronology (Fig. 4.8.) and the other addressing geographical distribution (Fig. 4.9.). The chronological phases represented in the graphs are the same used elsewhere in this book; Phases 1 and 2 are analysed together, to make up for the small amount of data. As for the geographical distribution, the sample was divided into three macro regions, roughly corresponding to the already observed diachronic diffusion of weighing technology in Europe: Italy, Central Europe (including Switzerland, Serbia, Czech Republic, Croatia, Hungary, Poland, Germany, and France), and Atlantic Europe (including the British Isles and the Iberian Peninsula).

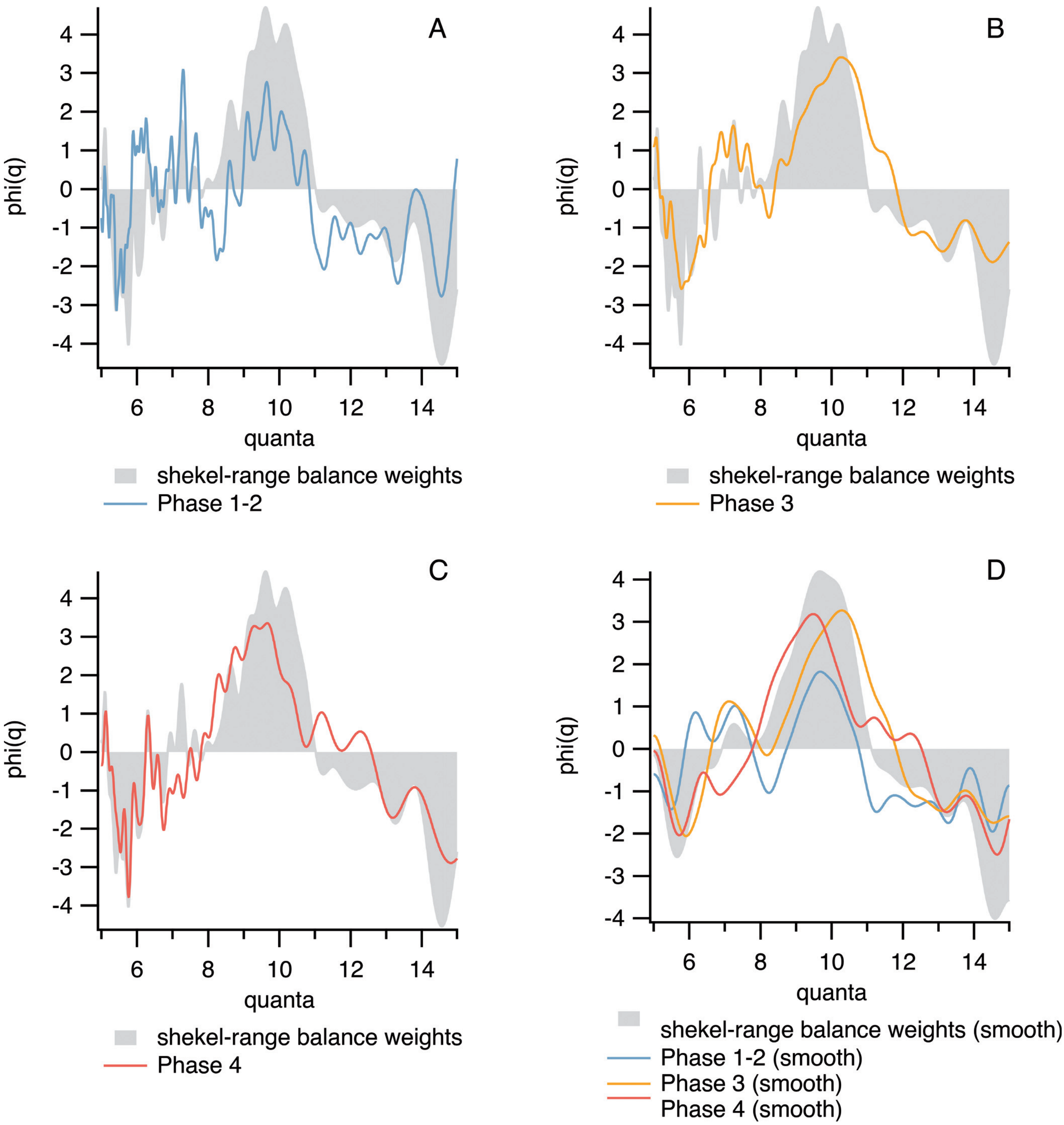
This solution partially makes up for the lack of a more detailed analysis, thanks to the peculiar diachronic and geographical distribution of the sample (see Chapter 2), for example: a) Phases 1 and 2 entirely correspond to Italy; b) Phase 3 is mostly represented in Central Europe (especially Germany and France); d) the Iberian Peninsula is only represented in Phases 4-5.

Results indicate three recurrent best-fitting quanta, all belonging to the statistical dispersion of the same theoretical unit:

- a best-fitting quantum of 9.3 g for Atlantic Europe in Phase 4 (Fig. 4.8.C; 4.9.C);



▲ *Fig. 4.7. Binned Frequency Distribution Analysis of the complete sample of European balance weights of the shekel-range (cut at 120 g). The black curves indicate multiples of the best-fitting quantum identified by CQA (9.6 g), represented as normally-distributed intervals with CV=5 %. The red lines indicate the Standard Deviation of each multiple.*



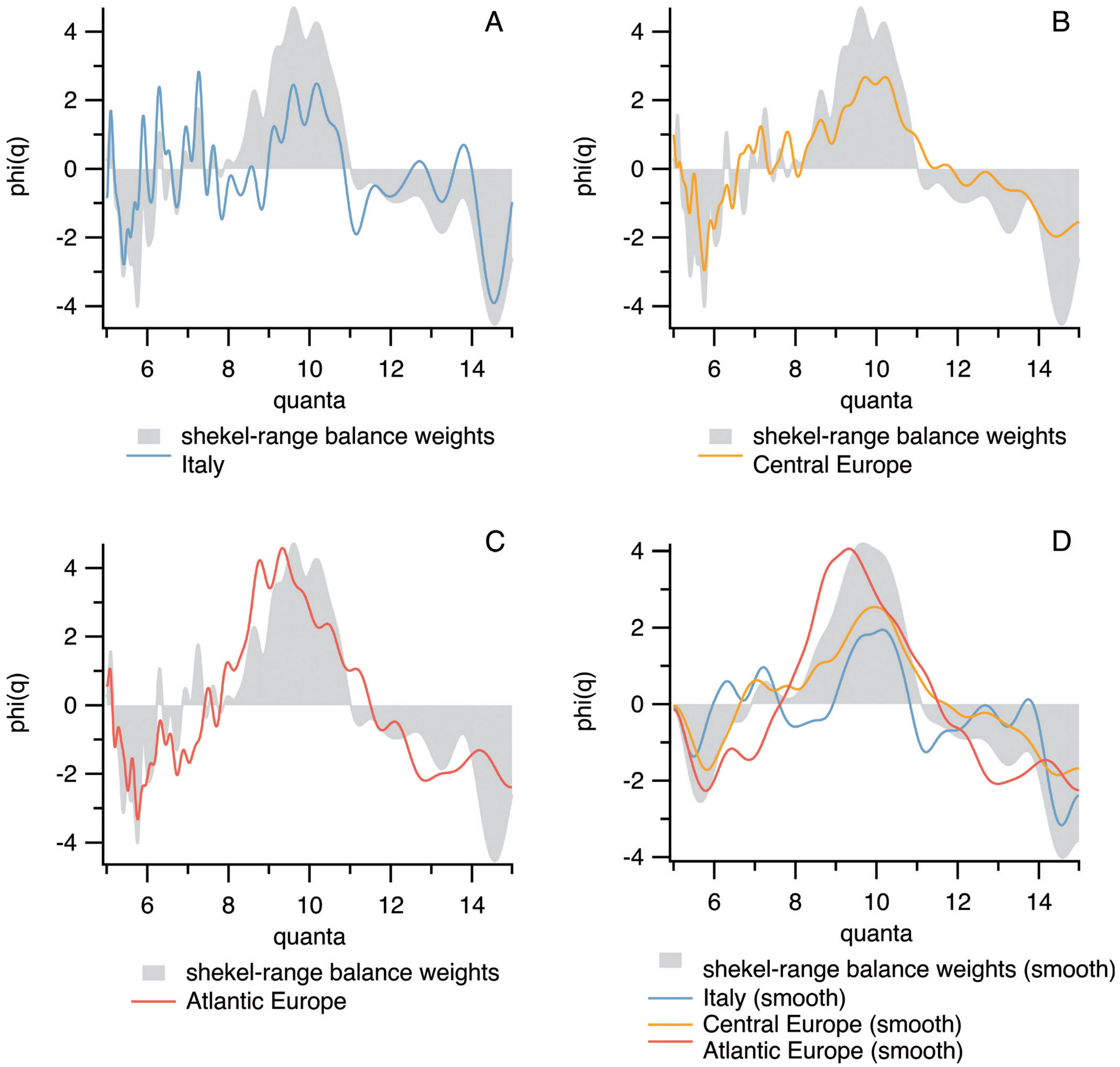
▲ *Fig. 4.8. Cosine Quantogram Analysis, shekel-range: diachronic analysis. A: Phase 1-2 (c. 2300-1350 BCE); B: Phase 3 (c. 1350-1150 BCE); C: Phase 4 (c. 1150-800 BCE). D: comparative chart; the curves were smoothed out to enhance visibility.*

- a best-fitting quantum of 9.6 g for Phases 1-2 in Italy, and for Phase 4 across Europe (Fig. 4.8.A,C; 4.9.A);
- a best-fitting quantum of 10.2 for Phase 3 in Italy and Central Europe (Fig. 4.8.B; 4.9.B).

In conclusion, the results of the statistical analyses for both the diachronic and geographical subsets confirm that the Pan-European *shekel* of *c.* 9-10 g remains relatively stable in Europe throughout the Bronze Age, gradually spreading hand in hand with the diffusion of weighing technology (see Chapter 2). All subsets consistently show roughly bell-shaped concentrations corresponding to the same interval of significant quanta highlighted by the analysis of the total sample. Individual best-fitting quanta in this interval range between 9.3 g and 10.2 g – respectively recorded in in Phase 4 and 3 – with the Italian subset of Phases 1-2 remaining roughly in between.

4.4.2. The mina

The analysis of the complete sample of balance weights in the *mina*-range are in line with previously obtained results (Ialongo/Rahmstorf 2019; 2022). CQA highlights a highly significant best-fitting quantum of 445 g with $\phi(q)$= 9.88, while Monte Carlo simulations indicate $\phi(q)$ values for 1 % and 5 % significance thresholds of, respectively, 3.85 and 3.39 (Fig. 4.10.A).

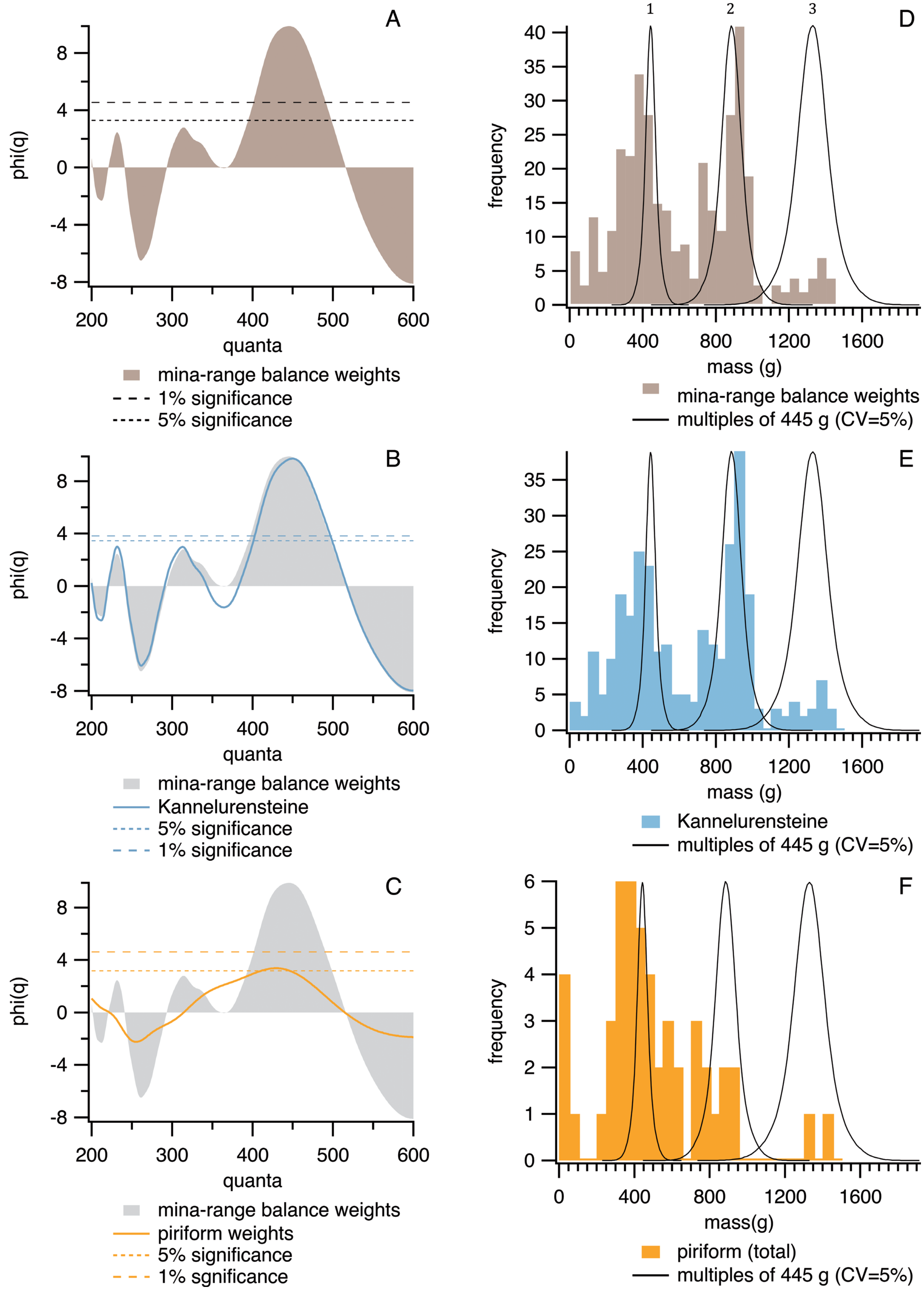


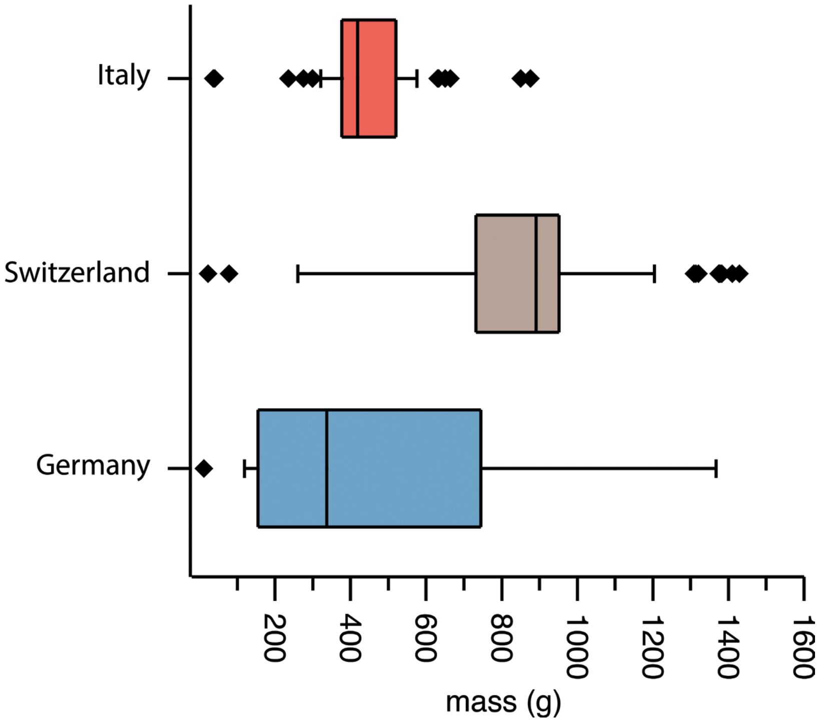
▲ *Fig. 4.9. Cosine Quantogram Analysis, shekel-range: geographic analysis. A: Italy; B: Central Europe; C: Atlantic Europe. D: comparative chart; the curves were smoothed out to enhance visibility.*

The separate analysis of *Kannelurensteine* (Fig. 4.10.B) and piriform weights (Fig. 4.10.C), representing respectively 82 % and 15 % of the total sample, gives comparable results. As *Kannelurensteine* represent the vast majority of the sample in the *mina*-range, it is no surprise that their quantogram very closely mirrors the results obtained for the total sample. The FDA shows two very well-clustered bell-shaped concentrations around 2x and 3x the value of the best-fitting quantum (Fig. 4.10.E). The concentration around the alleged unit value, however, is rather spread out: While the mode of the concentration corresponds to the best-fitting quantum of 445 g, the left part of the concentration stretches as far as to include the $^1/_2$ fraction. This fuzziness is easily solved by the separate analysis of regional samples, illustrated below.

The CQA for piriform weights shows somewhat less-sharp results, but still highlights a significant best-fitting quantum that is consistent with the overall results (432 g). The FDA shows similar concentrations to the ones observed for the *Kannelurensteine*: two concentrations corresponding to 2x and 3x the value of the best-fitting

▶ *Fig. 4.10. Mina-range: Cosine Quantogram Analysis (A-C) and Binned Frequency Distribution Analysis (D-F). CQA: A) complete sample; B) Kannelurensteine; C) piriform weights. FDA: D) complete sample; E) Kannelurensteine; F) piriform weights. The black curves overlayed on the FDA indicate multiples of the best-fitting quantum identified by CQA (445 g), represented as normally-distributed intervals with CV= 5 %.*


A
phi(q)
quanta
mina-range balance weights
1% significance
5% significance
B
phi(q)
quanta
mina-range balance weights
Kannelurensteine
5% significance
1% significance
C
phi(q)
quanta
mina-range balance weights
piriform weights
5% significance
1% sgnificance
D
1
2
3
frequency
mass (g)
mina-range balance weights
multiples of 445 g (CV=5%)
E
frequency
mass (g)
Kannelurensteine
multiples of 445 g (CV=5%)
F
frequency
mass(g)
piriform (total)
multiples of 445 g (CV=5%)



▲ *Fig. 4.11. Regional samples of Kannelurensteine: boxplot.*

quantum, and a fuzzier concentration around the alleged unit value (Fig. 4.10.F).

In line with the results of previous research (Ialongo/Rahmstorf 2019; 2022), the structure of the European *mina* appears characterised by a greater degree of variability than that of the *shekel*. While the unit value remains relatively stable, a closer analysis of the frequency distribution of the mass values of *Kannelurensteine* highlights observable shifts across time and space. Dividing the *Kannelurensteine* sample into three regional sub-samples (Italy, Switzerland, and Germany) offers a first look at these chronological and geographical differences.

The boxplot in fig. 4.11. shows that: a) the Italian sample is roughly symmetrically distributed about the alleged unit value, b) the Swiss sample is roughly symmetrically distributed about 2x the alleged unit value, and c) the German sample shows a right-skewed distribution, with the highest density below the alleged unit value. In short, most *Kannelurensteine* in Switzerland are rather heavy, most of those from Germany are rather light, while the Italian ones are approximately in between. Furthermore, if one considers that most *Kannelurensteine* from Italy are dated to Phase 2-3, and all those from Switzerland and Germany date to Phase 4, it appears that the geographical shift also reflects a chronological one.

The quantograms of Italian and Swiss *Kannelurensteine* reveals that both samples give best-fitting quanta that are consistent with the alleged unit of *c.* 445 g (Fig. 4.12.A-B). If the CQA shows comparable quantal structures, the FDA reveals a peculiar difference: While the near complete sample of *Kannelurensteine* from Italy clusters around the value of the best-fitting quantum (Fig. 4.12.D), the Swiss sample shows relevant concentrations around 2x, 3x, and $^1/_2$x that value, and almost no measurement in the interval that theoretically belongs to the alleged unit of *c.* 445 g (Fig. 4.12.E).

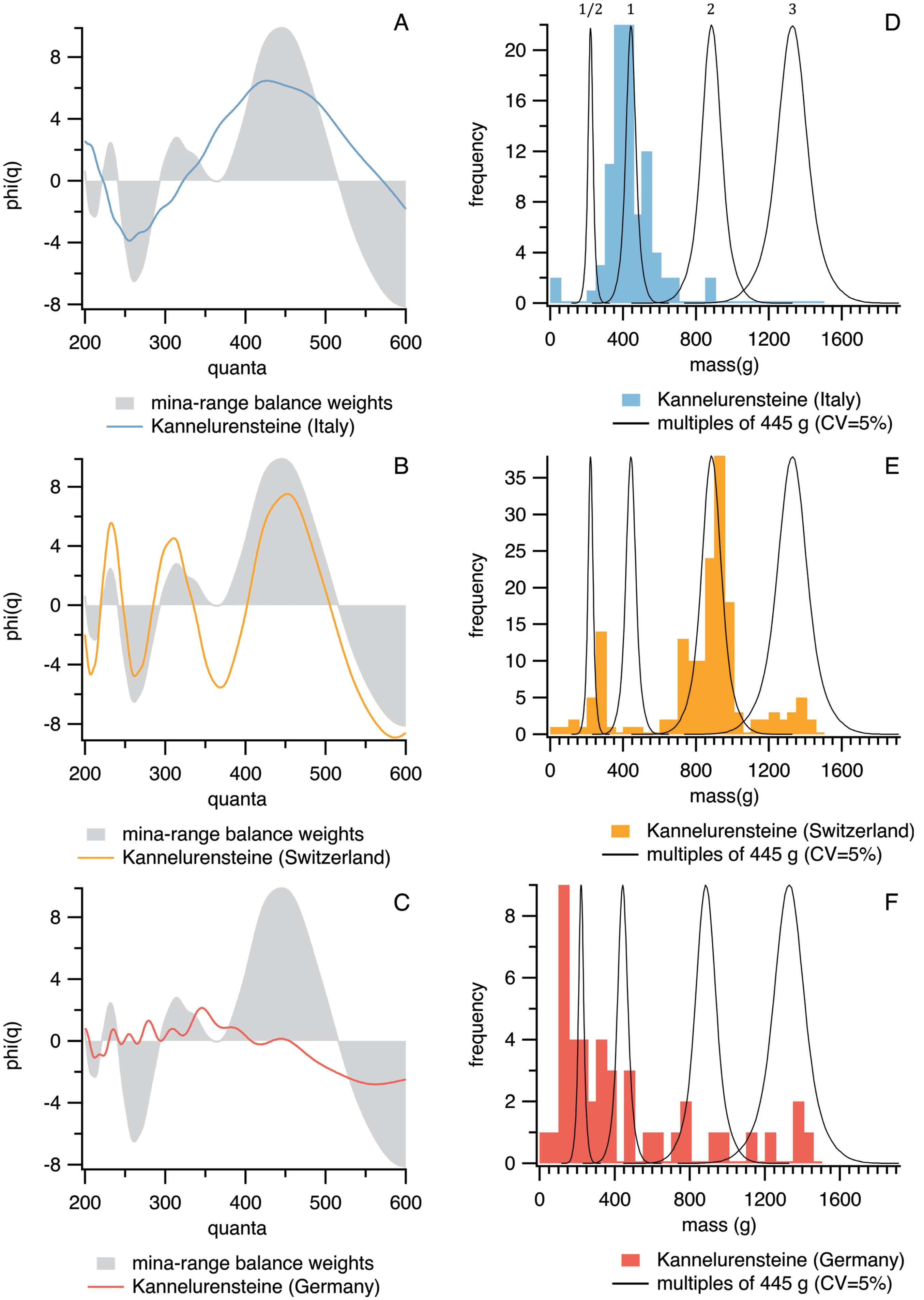
The analysis of the German sub-sample reveals yet a different pattern. CQA, for instance, does not indicate any relevant quantum in the analysis range (Fig. 4.12.C). The FDA, however, detects small and loose concentrations around 1x, 2x, and 3x the value of the alleged unit, but most measurements cluster below the unit value (Fig. 4.12.F). A more detailed analysis of the German sub-sample, however, reveals a pattern that is still consistent with the alleged unit. Repeating the CQA with a lower starting point for the analysis-range (*i. e.*, 100-1,500 g, instead of 300-5,050 g), identifies a significant best-fitting quantum of 112.8 g, *i. e.*, almost exactly $^1/_4$ of the best-fitting quantum of 445 g obtained for the total sample (Fig. 4.13.A). In line with this result, the FDA shows relevant concentrations around $^1/_2$x and $^1/_4$x the alleged unit value (Fig. 4.13.B).

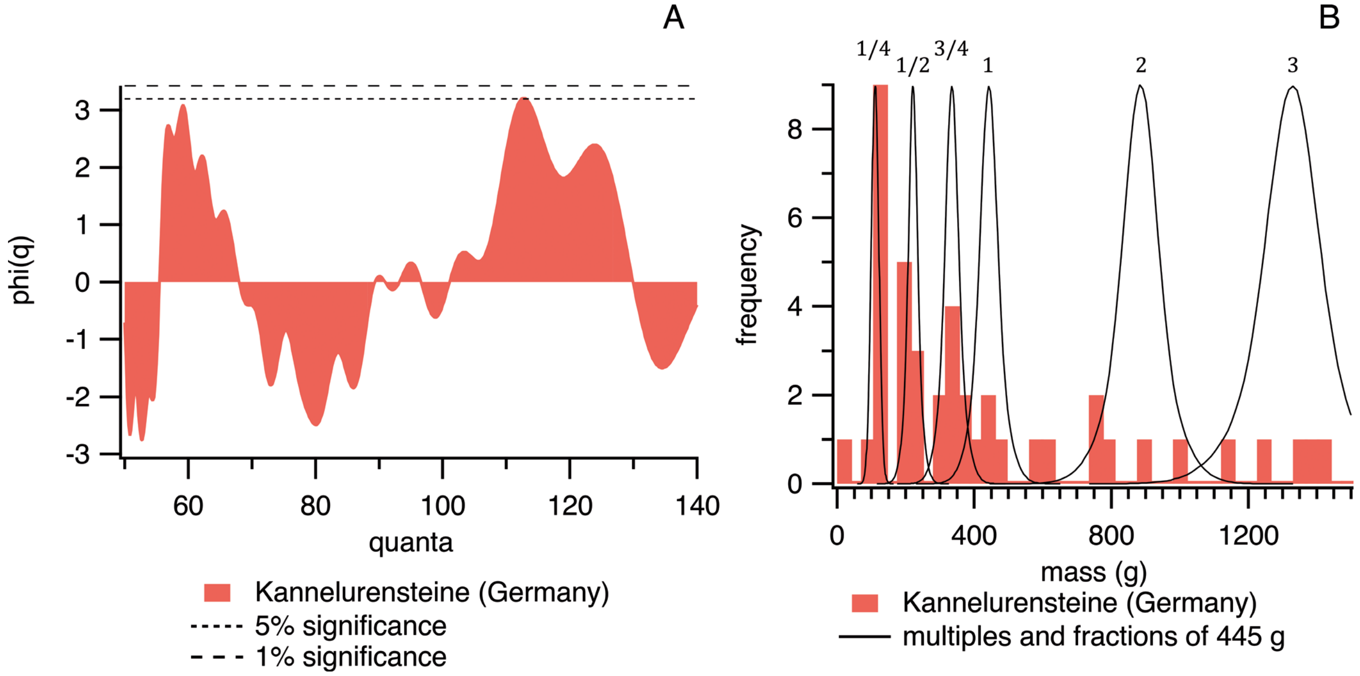
In conclusion, the comparative analysis of the different sub-samples of *Kannelurensteine* confirms the existence of a European *mina* whose theoretical value corresponds to *c.* 445 g or *to one of its multiples and fractions*, the difference being merely a matter of subjective perception. Based on available evidence, the distribution of the European *mina* is limited to Italy in Phase 2-3, and extends to Central Europe in Phase 4.

4.4.3. Towards the Iron Age: the balance weights of Phase 5 (c. 750-600 BCE)

A small sample of twelve balance weights, all belonging to the *shekel*-range, comes from find contexts datable to the 8th and 7th centuries BCE (Phase 5) (Fig. 4.14.). A much larger sample of Iron Age weights spanning the 1st millennium BCE was analysed in T. Poigt (2022). The Iron Age weights analysed here represent the 'residue' of the chronological screening of the complete sample collected during the research; they only come from Sardinia and the Iberian Peninsula, and they are in no way a significant sample of weighing devices for their period of reference. I decided to include them in this study because they are the only reliably datable weights coming from early Phoenician settlements in Europe, or from local settlements that entertained contacts with Phoenicians in the 8th and 7th centuries BCE.

▶ *Fig. 4.12. Kannelurensteine, regional samples: Cosine Quantogram Analysis (A-C) and Binned Frequency Distribution Analysis (D-E). CQA: A) Italy; B) Switzerland; C) Germany. FDA: D) Italy; E) Switzerland; F) Germany. The black curves overlayed on the FDA indicate multiples of the best-fitting quantum identified by CQA (445 g), represented as normally-distributed intervals with CV=5%.*


A
phi(q)
quanta
mina-range balance weights
Kannelurensteine (Italy)
D
1/2
1
2
3
frequency
mass(g)
Kannelurensteine (Italy)
multiples of 445 g (CV=5%)
B
phi(q)
quanta
mina-range balance weights
Kannelurensteine (Switzerland)
E
frequency
mass(g)
Kannelurensteine (Switzerland)
multiples of 445 g (CV=5%)
C
phi(q)
quanta
mina-range balance weights
Kannelurensteine (Germany)
F
frequency
mass (g)
Kannelurensteine (Germany)
multiples of 445 g (CV=5%)

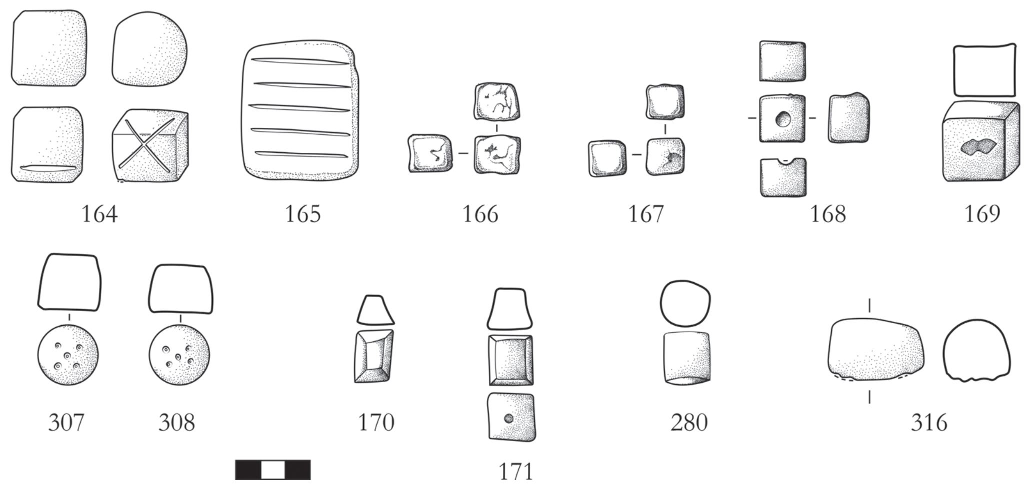


▲ *Fig. 4.13. Kannelurensteine from Germany. A: Cosine Quantogram Analysis; B: Binned Frequency Distribution Analysis. The black curves overlayed on the FDA indicate multiples of the best-fitting quantum identified by CQA (445 g), represented as normally-distributed intervals with CV= 5 %.*

All these weights except one (Fig. 4.14.316; sphendonoid with flat base) have peculiar formal types, that are never attested in Bronze Age contexts. Furthermore, six of them – five from Sardinia (Fig. 4.14.164-165,168,307-308), and one from Spain (Fig. 4.14.171) – bear incised signs that are often interpreted as quantity marks. Unfortunately, the analysis of quantity marks does not give clear results (Tab. 4.2.). Three Sardinian weights – one from the hoard of Forraxi Nioi (Fig. 4.14.165) and two form the settlement of Santu Brai (Fig. 4.14.307-308) – bear five incised signs, suggesting a unit value between *c.* 4.7 g and 5.4 g (Tab. 4.2.). Another weight from Santu Brai (Fig. 4.14.164) and one from Nuraghe Sant'Imbenia (Fig. 4.14.168), however, yield respectively 63.37 g and 45.52 g. Finally, a lead weight from Huelva in south-western Spain indicates a potential unit of 9.54 g (Fig. 4.14.171). Based on the marks, the only correspondence can be found between the three weights with five incised marks from Santu Brai and Forraxi Nioi, indicating a unit interval around 5 g. However, another weight from Santu Brai indicates a completely different unit (63.37 g), as well as the two remaining ones from Sant'Imbenia (45.52 g) and Huelva (63.37 g).

A unit of 11.75 g was proposed for the Sardinian weights (Zaccagnini 1991; Lo Schiavo 2006). If this value sounds familiar it is because it is directly derived from the so-called '*shekel* of Khatti', which I discussed in the first part of this chapter in connection with the 'Anatolian *shekel*' of the same value. This interpretation, however, is problematic: Let alone that none of the actual and reconstructed mass values comes even close to the alleged 'Microasiatic unit', any attempt to use exact values in metrological reconstructions is, as it should be clear by now, always bound to produce meaningless results.

Despite the small sample size, we have then no other choice than turning to statistics. CQA shows a best-fitting quantum of 9.1 g (Fig. 4.15.A), which is compatible with the results obtained from a larg-



▶ *Fig. 4.14. Balance weights of Phase 5 (c. 750-600 BCE). Stone: cat. no. 164-165, 307-308, 316. Lead: cat. no. 166-169, 170-171, 280.*

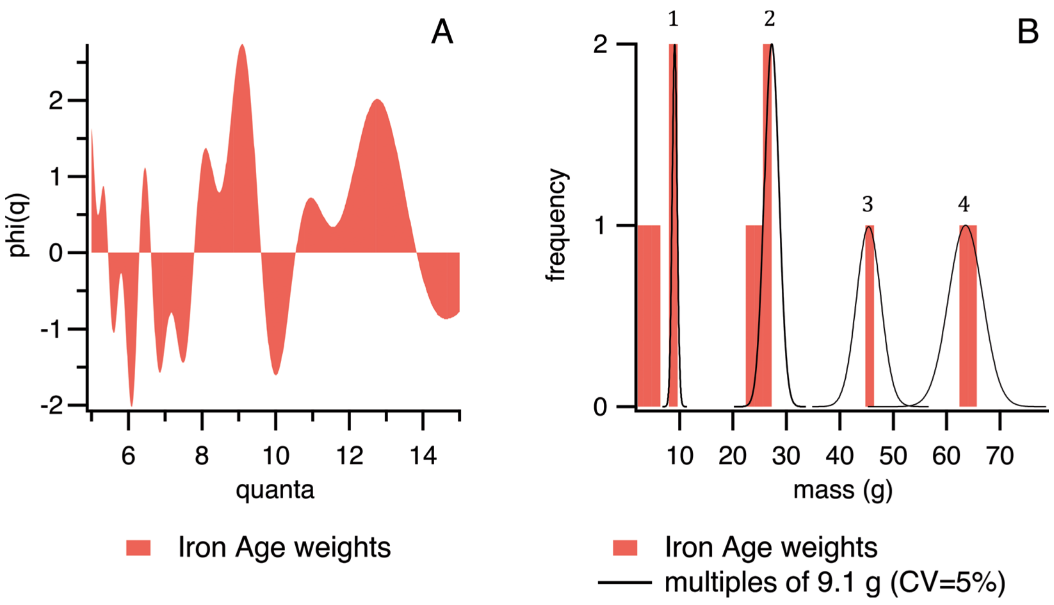
Cat.n.	Site	Region	Material	Mass (g)	Mark description	Inferred multiplier	Resulting unit
167	Quinta do Almaraz	Portugal	Lead	2.63			
170	Huelva - Plaza de las Monjas	Spain	Lead	4.45			
166	Quinta do Almaraz	Portugal	Lead	6.38			
171	Huelva - Plaza de las Monjas	Spain	Lead	9.54	Circular indentation on the base	1	9.54
280	Huelva - Plaza de las Monjas	Spain	Lead	9.59			
165	Forraxi Nioi	Italy (Sardinia)	Stone	23.87	Five incised lines on one face	5	4.77
308	Santu Brai	Italy (Sardinia)	Stone	25.17	Five incised dots on the flat face	5	5.03
169	Huelva - Plaza de las Monjas	Spain	Lead	26.62			
307	Santu Brai	Italy (Sardinia)	Stone	26.8	Five incised dots on the flat face	5	5.36
168	Nuraghe Sant'Imbenia	Italy (Sardinia)	Lead	45.52	Circular indentation on one face	1	45.52
164	Santu Brai	Italy (Sardinia)	Stone	63.7	Single incised line on one face; two crossed lines across two faces	1	63.70

▲ *Tab. 4.2. Balance weights of Phase 5 (c. 750-600 BCE).*

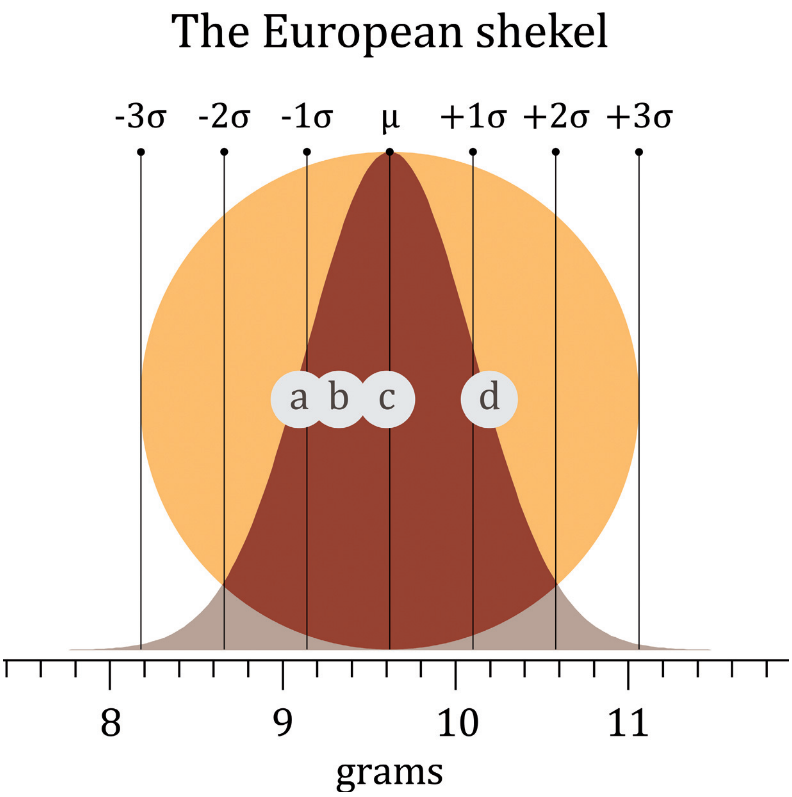
er sample of later Iron Age weights from the Iberian Peninsula (Poigt 2022, 253-258). This result is further clarified by the FDA, showing small but consistent concentrations around 9 g, 25-27 g, and 64-65 g – respectively *c.* 1x, 3x, and 7x the value of the best-fitting quantum – plus an isolated value at *c.* 45 g (5x) (Fig. 4.15.B). In conclusion, while the small sample size urges caution, the results of the statistical analyses suggest a best-fitting quantum that is still compatible with the interval of the Bronze Age *shekel*.

4.4.4. The weight units of pre-literate Bronze Age Europe

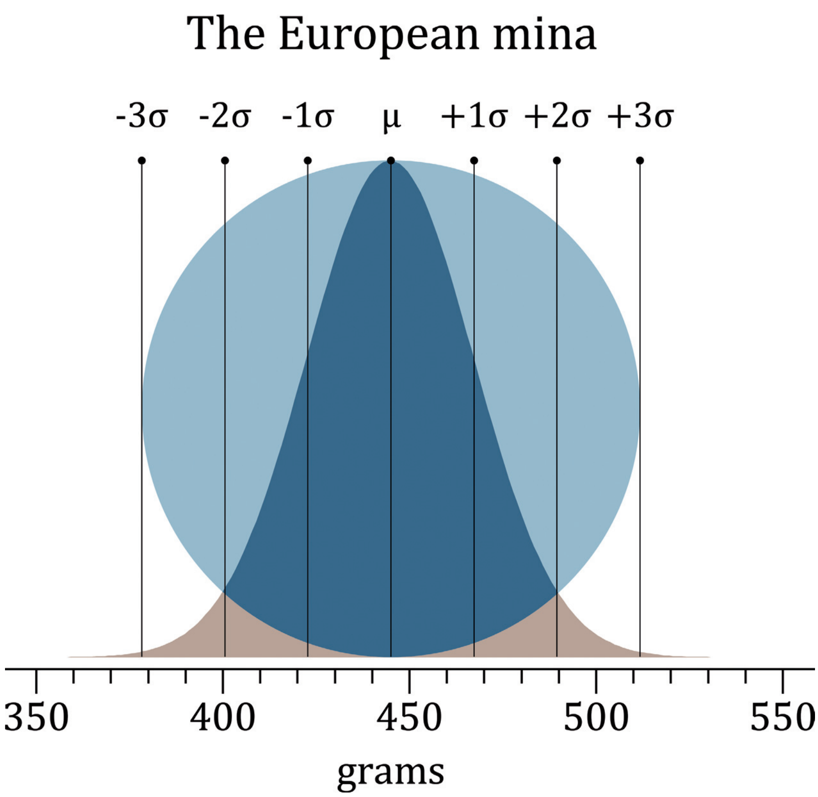
The results of the statistical analyses identify two weight units, widespread in Europe throughout the Bronze Age: a small unit of *c.* 9-10 g – the 'Pan-European *shekel*' – and a *mina* of *c.* 450 g (Tab. 4.1.). As already illustrated in the introduction to this chapter, the more or less exact values in grams that we use to designate ancient weight units are merely labels that may facilitate communication, but they actually bear little significance. Weight units – and units of measurement in general – are by definition intervals, whose statistical dispersion depends on many factors, chiefly among which the accuracy of measurement tools. For the Bronze Age world, the overall error margin of weighing technology was *c.* 5 % in terms of Coefficient of Variation which, considering the full range of three standard deviations that defines normal distributions, amounts to a total range of ± 15 %. Considering the full error range makes it possible to have a more accurate representation of European Bronze Age units, with



◀ *Fig. 4.15. Balance weights of Phase 5 (c. 750-600 BCE). A: Cosine Quantogram Analysis; B: Binned Frequency Distribution Analysis. The black curves overlayed on the FDA indicate multiples of the best-fitting quantum identified by CQA (9.6 g), represented as normally-distributed intervals with CV= 5 %.*



▲ *Fig. 4.16. The Pan-European shekel (mean= 9.6 g, CV= 5 %). Vertical lines indicate the Standard Deviations of the distribution. Best-fitting quanta identified by CQA: A) 9.1 g (Phase 5); B) 9.3 g (Atlantic Europe); C) 9.6 g (total, Phase 1-2, Phase 4); D) 10.2 g (Phase 3, Italy, Central Europe).*



▲ *Fig. 4.17. The European mina (mean= 445 g, CV= 5 %). Vertical lines indicate the Standard Deviations of the distribution.*

the *shekel* being equal to *c.* 8-11 g, and the *mina* to *c.* 360-520 g (Fig. 4.16.-17.). When addressing the significance of Bronze Age units, one must always bear in mind that any value within these ranges was potentially perceived as '1' by their users. It is also crucial to consider that the best-fitting quanta given by the CQA are only approximations that are dependent on the actual distribution of mass measurements, and that slightly different results for different datasets in no way mean slightly different units. A closer examination of the several, slightly different best-fitting quanta obtained from different subsets of the *shekel*-range, for example, clearly shows that each value is perfectly compatible with the overall interval of the Pan-European *shekel*, regardless of chronology and geographical distribution (Fig. 4.16.).

This way of conceptualising weight units fundamentally affects the way of conceptualising how primary weight systems emerged in Bronze Age Western Eurasia, contextually to the first adoption of weighing technology in a region where weights and balances were previously not used (Ialongo *et al.* 2021).

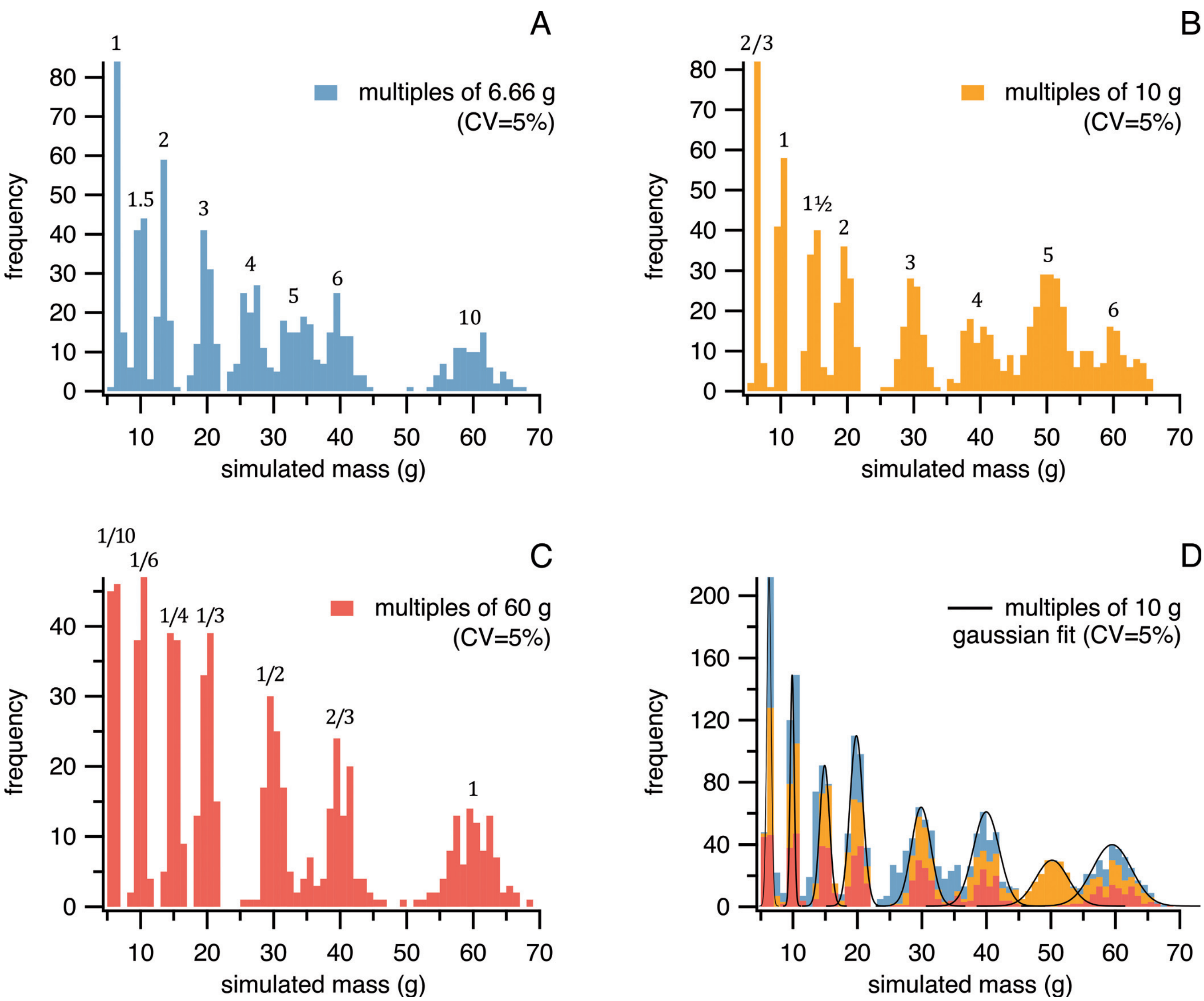
4.5. The origin of European weight systems

4.5.1. The myth of the 'imported unit'

The analysis of the European sample of balance weights indicates a best-fitting quantum of *c.* 10 g which – for the sake of simplification – I have been referring to as a 'unit'. Previous studies based on smaller samples have suggested an alternative unit of *c.* 6.1-6.7 g (Pare 1999; Cardarelli *et al.* 2001), representing, in turn, *c.* $^{1}/_{10}$ of the alleged 'Aegean unit' of *c.* 58-65 g (Petruso 1992). In early studies on the spread of weight systems it was generally assumed that weight units in pre-literate Bronze Age Europe were imported 'as-is' from the Aegean, together with weighing technology.

At this point, one may ask if we can really exclude that the Pan-European *shekel* was 'imported' from the Aegean. Which, again, boils down to the question of the 'true value' of pre-metric units. Here I will illustrate a thought experiment that demonstrates how ill-formulated this question is.

Imagine a hypothetical region of the Bronze Age world in which three different weight units were in use at the same time. Now, imagine that these units correspond to the three alleged units proposed by different authors: The 'Pan-European *shekel*' of 10 g, and the 'Aegean units' of 6.6 g and 60 g. I simulated a hypothetical scenario in which we possess a large sample of balance weights which we can aprioristically and precisely assign to each of these three different units. I randomly generated three subsets of *c.* 1,000 measurements. Each subset is a multimodal distribution, composed by a series of normally-distributed concentrations of randomly generated numbers, each concentration corresponding to multiples and fractions of the respective unit with a Coefficient of Variation of 5 %, *i. e.*, the inherent



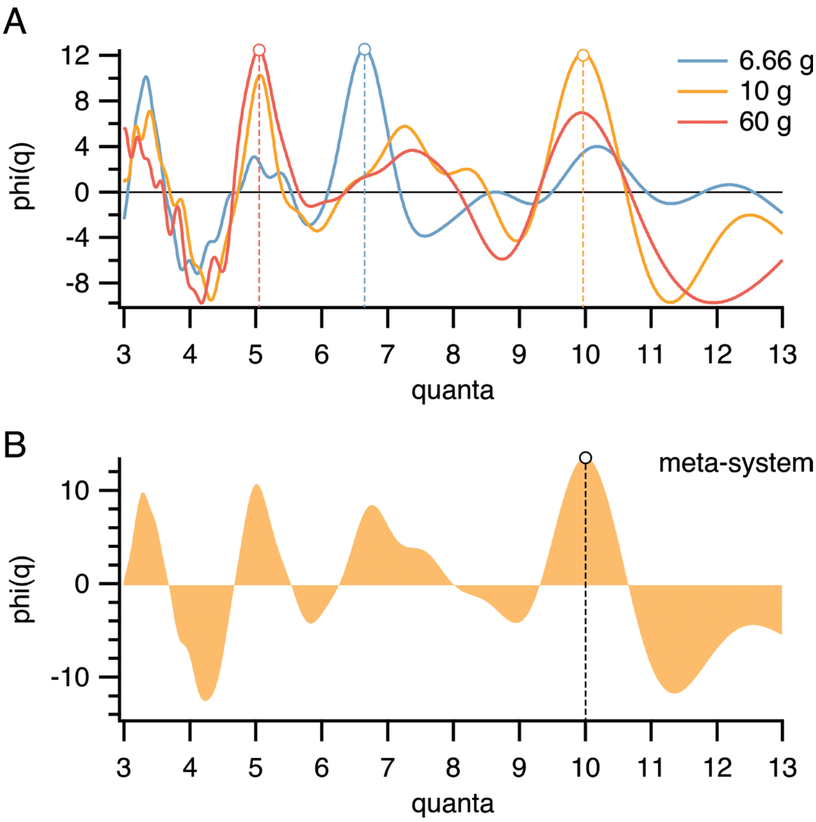
▲ *Fig. 4.18. Hypothetical meta-system (FDA). A) multiples of 6.66 g (CV=5%); B) multiples of 10 g (CV=5%); C) multiples 60 G (CV=5%). D) meta-system: complete distribution. The black curves overlayed on the FDA indicate multiples of 10 g, represented as normally-distributed intervals with CV= 5 %.*

error margin of Bronze Age units. The simulated subsets show very neatly-separated concentrations, each easily ascribable to their unit of reference (Fig. 4.18.A-C). As expected, the CQA correctly identifies the unit of each subset, showing best-fitting quanta at 6.66 g, 10 g, and 5 g (*i. e.*, $^{1}/_{12}$ of 60 g) (Fig. 4.19.A).

So far, the simulation suggests that, if we are able to attribute each balance weight to its respective unit *before* the statistical analysis, we will likely be able to identify different units as well. Unfortunately, this is never the case with real archaeological data. In Bronze Age Western Eurasia balance weights are almost never inscribed, and typology alone is not reliable to pre-emptively assign each balance weight to a particular unit. This is, after all, precisely the reason why we need statistical analyses: to identify the potential existence of weight systems in an apparently chaotic sample of measurements.

If we want to simulate a real research scenario, then, we need take all our simulated subsets, analyse them all together, and see if we can detect the existence of three different systems. Surprisingly, the Frequency Distribution Analysis of the complete datasets now identifies only concentrations that are multiples of 10 g (Fig. 4.18.D). In the same way, the CQA now univocally identifies 10 g as the best-fitting quantum (Fig. 4.19.B). Truth be told, this outcome is not surprising at all. The nominal values of the three units are all multiples and fractions of one another, therefore it is simply inevitable that their respective multiples and fractions will exactly correspond many times over, and even when they do not, the distance will be so small that the respective dispersions will overlap to the point where they are impossible to discern. The reason why the analysis of the complete dataset only highlights the unit of 10 g is simply because 10 g is the Greatest Common Divisor of the complete dataset.

Which one, then, is the 'true' value of the unit of Bronze Age Europe? All considered, the only possible answer is: *All of them, and possibly even more*. Elsewhere, I dubbed this way of conceptualising the seamless intersection between nominally different, but factually analogous units the 'meta-



▲ *Fig. 4.19. Hypothetical meta-system (CQA). A: separate analysis of the samples illustrated in fig. 4.18. B: comprehensive analyses of all samples at once.*

system model' (Ialongo *et al.* 2018a; 2018b). The meta-system model clarifies, at the same time, the limits of the analytical methods and the nature of Bronze Age weight units. CQA does not reveal 'the unit', but simply a common denominator. This means that, as far as pre-literate societies are concerned, we will never be able to positively identify 'the unit'. The good news is that 'the unit' is a purely theoretical concept, and a largely irrelevant factor in understanding the structure of prehistoric systems of measurement, their empirical application, and their impact on economic and social systems.

4.5.2. One, No One and One Hundred Thousand units

From both a theoretical and empirical point of view, once we identify a significant quantum in a distribution of metrically-configured objects we know that the mass values of those objects were seamlessly convertible into one another through a simple system of fractions and multiples, independently from the exact value of 'the unit', and even regardless of the coexistence of different units. It follows that, as long as at least a single quantum was shared, each region, settlement, and even each single individual could have theoretically used a different unit, and this would make no difference – neither to ancient users, nor to modern archaeologists.

Imagine, for example, a system with 100 agents, each using a nominally different weight unit: Common sense would tell us that this system would be too chaotic to function. Now imagine that each of these units was a round multiple of, say, 5 g, *i. e.*, 5-10-15-20-25-30…500 g. In this scenario, the existence of 100 nominally different units would make no difference whatsoever, as all these supposedly different units can be instantly and effortlessly reduced to the common denominator of 5 g. In an international trade network in which 'official units' could not exist because there was no far-reaching centralised authority that could sanction, let alone enforce them, a weight system with a similar structure would have provided virtually frictionless conversion factors, even with the simultaneous presence of a multitude of different units. This could also explain why inscriptions and quantity-marks are so rare in some regions (only 5 % of the balance weights from Mesopotamia has inscriptions or marks; Ialongo *et al.* 2021) and completely absent in others (such as Bronze Age Europe), and even why sometimes marked weights from the same period, region, and culture seem to be based on completely different units (such as in the Iberian Peninsula and Sardinia in the Iron Age; see above, also Poigt 2022): In a typical transaction-scenario it does not matter which fraction or multiple one's weight *objectively* represents, as long as each agent *subjectively* agrees on the value of the transaction.

The structure of the European *mina* represents an emblematic case study on the nature of customary weight units in pre-state societies, while also offering an instructive perspective on the biased perception that modern observers tend to have on ancient systems of measurement. If we look at the frequency distribution of the mass values of *Kannelurensteine*, we observe that the Italian sample has a main cluster around 450 g, the Swiss sample around 900 g, and the German sample around 112 g. Even if we assume that the unit is the most attested value, then we would have that the Italian unit is exactly 4x the German one, the Swiss unit is exactly 2x the Italian one, and the German unit is exactly ⅛x the Swiss one. Which is tantamount to having exactly the same unit in all three territories.

4.5.3. How did weight units 'move'?

A unit can 'move' only on very particular conditions. For a unit to 'exist' in the first place, it needs to be somehow fixed in time and space, with a conventional value (or range of values) that is, in turn, sanctioned by an institution – either private or public – with the authority to enforce it. To be simply embodied in balance weights, as we have seen, is not enough, since that would not necessarily mean that the unit was one and unique.

Once this requisite is met, there are basically two scenarios for an existing unit to be 'transferred' to a new region. The first scenario is *adoption*: The unit must be adopted by an institution with the same enforcing authority, that can sanction its value and make it 'official', also in the framework of a formal international agreement with the authority of the unit's region of origin. The second scenario is *imposition*: The institution sanctioning the unit in its region of origin must extend its authority to the new region, either peacefully or violently. These scenarios are more or less explicitly advocated in some studies attempting to draw historical considerations based on weight units, conceived as exactly-determined, inherently-normative entities (Massa/Palmisano 2018; Rosenswig 2024). None of these two scenarios, however, applies to Bronze Age Europe.

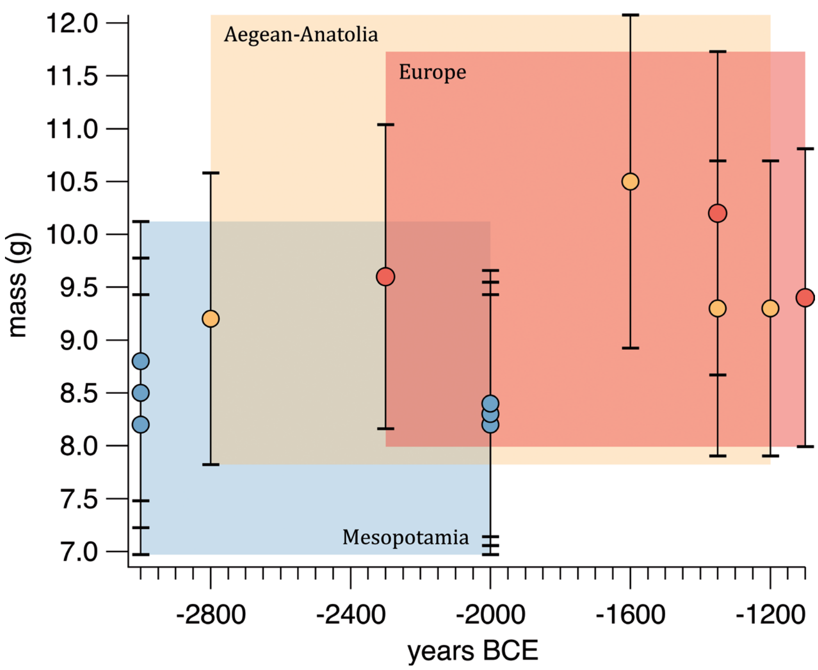
Eastern states never established any form of direct or indirect control over Europe. There is not even evidence of direct contacts between Europe (west of Greece) and the Levant, at least not until the end of the 2nd millennium BCE (Berger *et al.* 2022; Eshel *et al.* 2022), roughly 1,000 years after the first appearance of weighing technology in southern Italy, and even then the evidence is not conclusive. Perhaps even more importantly, there was no single authority in Europe that was in the condition to negotiate treaties with Eastern states, let alone imposing and enforcing them on a continental scale. It is even debatable whether or not, in the Near East, weight units were actually 'officially enforced' in the first place. Official overseeing was mainly enacted by public officers in instances of reallocation of goods that took place within the palace's precinct (Durand 1987; Joannès 1989, 127; Arkhipov 2012, 183), while private merchants usually worked out reciprocal controversies on their own (Stratford 2017).

A weight unit can be regulated by official norms, but is not a norm in itself. A weight unit is not a 'number' either, that can be copied as-is and transferred to another location. It is not even an object that can be moved, or 'imported'. If weight systems are not movable objects, they can however move *with* objects. Independently from whether a single unique unit exists or many interconnected ones, balance weights are the embodiment of the abstract concept of weight, and enclose within themselves all the necessary material properties to preserve, replicate, and even create weight systems. Simply put, weight units do not move; people do, and balance weights move with them.

When weighing technology appears in a new region it does not emerge spontaneously, but it is brought by people carrying along their tools – weights and balances – that are eventually 'copied' and used by other people. Since weights and balances are trading tools, the most likely scenario of the appearance of weighing technology in a new region is via trade. Merchants from a 'weighing region' (say, the Aegean) entertain trade relationships with a 'non-weighing region' (say, southern Italy). The weighing merchants quantify their incomes and expenditures according to the system they are best acquainted with – *i. e.*, weighing – but they find themselves struggling when it comes to negotiate prices with their non-weighing partners, who have different systems to account for value. Eventually, the non-weighing merchants will see the practical advantages of the new technology, and they will start using it for themselves. The next logical step would be to borrow one or two weights from their tech-savvy partners, and simply use them as models to make new ones (Petruso 2019). It is worth noting that there is nothing preventing this process from happening anywhere within a given trade network: Weighing technology does not need to be brought from one region to another by their original users, but it can be also learned by the eventual new users when travelling to the region where the technology is already in use.

The formation of new weight systems in the Bronze Age world can then be modelled as follows: Balance weights are borrowed and replicated, and since balance weights are physical manifestation of abstract units, the units move along with them. Replicas are, in turn, also replicated, and a new weight system eventually emerges in a new region.

As both empirical and textual evidence unequivocally demonstrate, however, balance weights are by definition never 'precise'. No matter how meticulously one strives for accuracy, a single balance weight will always have a normally distributed probability of falling anywhere within the unit's statistical dispersion-range (see above, Fig. 4.1.-2.). Far from being a merely theoretical exercise, the inherent indeterminacy of weight units bears fundamental consequences on how new units are born. If the initial array of 'borrowed' weights, constituting the model for the new weight system, is picked from one of the two 'tails' of the unit's normal distribution, the value-range of the new unit will be inevitably slightly different from the value-range of the unit from which it originated from. And since this process is repeated again and again each time



▲ *Fig. 4.20. Bronze Age weight systems between Mesopotamia and Europe. Each dot shows the best-fitting quantum of the relative regional sample and its chronology (the earliest date of the interval is indicated). The vertical lines indicate the three Standard Deviations range of each best-fitting quantum.*

the technology reaches a new region, the statistical error will spread, and the final result will be a normally-distributed value-range that randomly oscillates between slightly less and slightly more than the original value-range. This model of random propagation of Bronze Age units was successfully tested based on a dataset of thousands of balance weights spanning Mesopotamia Europe between the 3rd and the 2nd millennium BCE (Ialongo *et al.* 2021).

The graph in fig. 4.20. shows the observed values of all the weight units in the *shekel*-range that can be identified between Mesopotamia and Europe in the 3rd and 2nd millennium BCE. The graph clearly shows that the overall error-range of all the units largely overlaps throughout the whole time-span, and across a total distance of roughly 5,000 km. This means, in turn, that regardless of how different the theoretical values each unit might appear at first glance, all these systems were largely interoperable.

4.6. Weight systems and market integration

4.6.1. Premise: the relational nature of weight units and the problem of markets

The random-propagation model raises a fundamental question: If the formation of new units is governed by chance, and if there was no authority capable of regulating their statistical dispersion, then how come the weight systems of pre-literate Bronze Age Europe remained stable for over a millennium?

Common sense cannot explain the stability of primary weight systems, as the common-sense conceptualisation of primary weight units as 'numbers,' 'norms' and 'objects' is not supported by the evidence. The nature of Bronze Age units is neither objective nor normative. It is *relational*: Weight units can be defined as *relational constructs*, as they emerge from, and are consolidated by relationships between people, and hence they are more closely assimilable to the notions of 'habit' and 'custom' than to that of 'norm'. The regulation of weight systems was about people constantly engaging in transactions, haggling over price, working out controversies, and ultimately figuring out how much they could deviate from an implicitly understood custom before breaking one another's trust.

Bronze Age weight systems remain stable over wide territories for long periods of time because they are upheld by a formidably dense network of trading agents constantly negotiating prices, watching over potential frauds, discarding contentious weights, and ultimately assuring that the statistical dispersion of the unit does not exceed the socially-accepted threshold of the trade network *as a whole*, no matter how big it was. In other words, the spread of Bronze Age weight units is regulated by the market.

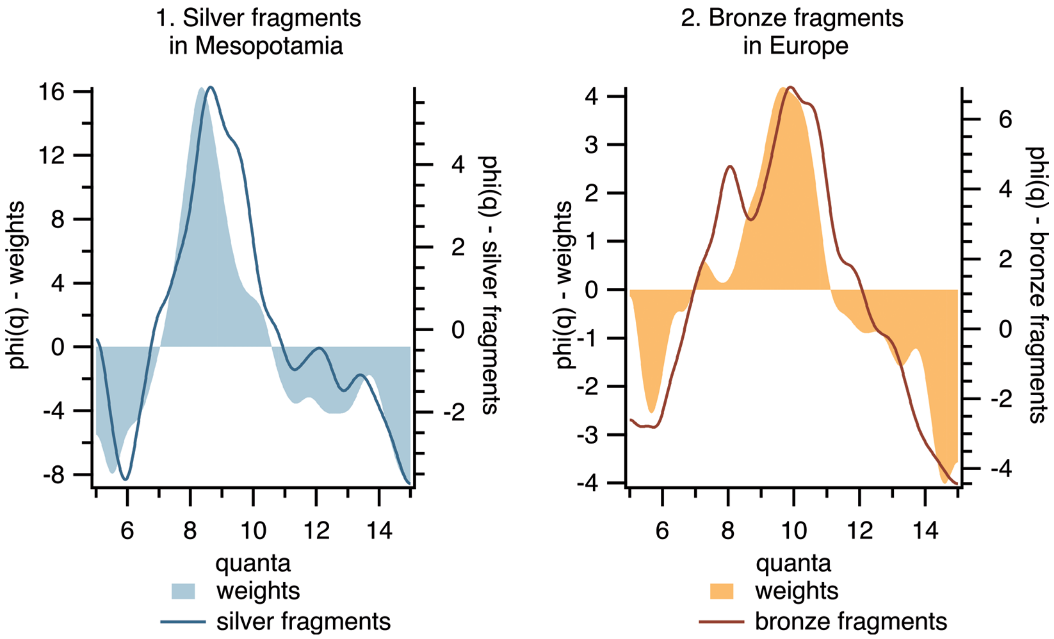
Talking about 'markets' in the Bronze Age is often met with scepticism, as their existence would be, allegedly, theoretically impossible in pre-modern economies (*e. g.*, Bruck 2016; Fontijn 2019; Jung 2021). Let alone that economic anthropology has abandoned the arbitrary distinction between 'primitive' and 'modern' economies long ago (Bourdieu 1977; Granovetter 1985; Appadurai 1986) – and that contemporary archaeological theory is finally acknowledging the compatibility of the market model with prehistoric societies (Baron/Millhauser 2021; Blanton/Feinman 2024) – the question is not whether or not markets are 'theoretically possible,' but rather whether or not the evidence supports the existence of markets. If it does, then the theory must be modified, and a role for markets needs to be created.

We sometimes tend to forget that 'the market' is not an 'external force' endowed with its own agency, but it is simply a model that describes what happens when a multitude of people in a vast territory creates connections in order to secure the supply of goods that they need or want to obtain. These connections can be direct or indirect, regular or occasional, high- or low-volume, but eventually they determine the emergence of an exchange system in which all agents are to some extent interdependent. This system is, as a matter of fact, indistinguishable from what is more or less universally referred to as the 'Bronze Age Western Eurasian trade network' (Earle *et al.* 2015; Vandkilde 2016; Kristiansen 2018b; Murray 2023). Imagine countless different agents spread out across Europe periodically engaging in economic transactions, each time with different partners in different places, for different quantities of different goods, every day all year long. Whether we call it a 'market' or a 'network' really makes very little difference. What matters for the subject at hand is that, once we eliminate the normative hypothesis, the market model is the only option left to explain why, in the absence of international authorities, the interval of Bronze Age weight systems remains approximately constant across roughly a millennium.

4.6.2. Weight-regulated money in Mesopotamia

Before concluding this chapter with the outline of a distributed-network model for market exchange in pre-literate Bronze Age Europe, I will introduce the problem of pre-coinage money in Bronze Age economies. The theoretical literature on the 'origin' of money is vast, stratified and complex. It traditionally involved many competing approaches from the fields of economics, anthropology, history and archaeology, which seldomly engage in interdisciplinary debate and among which there is no established consensus, not even among scholars in the same field (Bohannan 1959; Dalton 1965; Melitz 1970; Jones 1976; *e. g.*, Bloch/Parry 1989; Zelizer 1989; Haselgrove/Krmnicek 2012).

At the same time, it is perhaps puzzling to realise that, in the face of such an impressive corpus of theoretical literature on the subject, empirical re-



◀ *Fig. 4.21. Weight-regulated money in the Bronze Age. Cosine Quantogram Analysis of metal scraps compared with balance weights. 1) silver fragments in Mesopotamia (data for silver in* Ialongo *et al. 2018); 2) bronze fragments in Europe (data for bronze in* Ialongo *et al. 2023).*

search on the pre-coinage currencies used by those very economies that eventually 'invented' coins – as opposed to ethnographically-documented ones – is traditionally rather scarce. This is to say that virtually all the competing theories on the 'origin of money,' intended as a hypothetical historical process, remain to date largely untested. Fortunately, a recent surge of interest in the archaeological problem of pre-coinage money in pre- and protohistoric economies raises hopes that the debate can finally move on from its merely theoretical dimension, and embrace a data-grounded perspective (Baron 2018; Baron/Millhauser 2021; Ialongo/Lago 2021; 2023; Kuijpers/Popa 2021; Rahmstorf *et al.* (eds.) 2021; Montalvo-Puente *et al.* 2023; Rosenswig 2024). Since the problem of money is only tangential to the aims of this book, I will limit the discussion to the empirical evidence, as it is closely related to the origin of weight systems.

Whether arguing over the nature of money may or may not be the point, there is substantial evidence that Bronze Age economies between Mesopotamia and Europe at least partly relied on lumps and fragments of weighed metal as means of payment in economic transactions. In Mesopotamia, such a function was largely fulfilled by silver scraps at least since the 3rd millennium BCE (Powell 1996), with evidence becoming clearer and clearer by the beginning of the 2nd millennium BCE, thanks to the precise documentation found in business letters and bookkeeping accounts of private merchants (Stratford 2017; Barjamovic *et al.* 2019; Dercksen 2021). According to many surviving documents, silver fulfilled the function of medium of exchange, standard of value, reserve of value, and means of deferred payment (Garfinkle 2004; Steinkeller 2004; Englund 2012; Dercksen 2021), even though it was never officially adopted, let alone 'issued' by any central authority (Peyronel 2010; Rahmstorf 2016a).

The value of silver was quantified through weighing, which in turn makes its monetary function very much recognisable empirically through the very same methodology employed to reconstruct weight systems based on balance weights. A recent study showed that the silver lumps and fragments contained in a hoard found in the Bronze Age city of Ebla, Syria (*c.* 2000-1700 BCE), have the same metrological structure as the balance weights of the same period (Ialongo *et al.* 2018a). More in detail, CQA shows that both balance weights and silver scraps comply with the 'Mesopotamian *shekel*' of *c.* 8.3-8.5 g (Fig. 4.21.1).

Since there was no enforced 'norm' that prescribed that silver scraps complied with weight systems, the fact that they do requires a different explanation. Just like for balance weights, the apparent weight-based regulation of silver scraps can be explained by a bottom-up, customary process mostly dictated by convenience. Simply put, since most transactions values were quantified in multiples of the *shekel*, silver would have been most conveniently broken down to match those values, hence minimising the potential friction caused by the high incidence of remainders, which in turn eventually produced quantally-configured datasets that CQA can very easily detect. Note that, just like for balance weights, the outcome needs to be neither regular nor precise in absolute terms, but only regular and precise *enough* to produce statistically-significant quantal variability.

As it is always the case in ancient as well as in modern economies (Dalton 1965; Melitz 1970; Pryor 1977; Bloch/Parry 1989; Haselgrove/Krmnicek 2012; Rosenswig 2024), there were many different currencies circulating at the same time in Bronze Age Mesopotamia. Silver is the most 'visible' one simply because it was the most used by those subjects – *i. e.*, public administrations and wealthy merchants – that produced the largest share of the textual and archaeological evidence that survived to be collected and studied by philologists and archaeologists. Grains, for example, were probably one of the most used everyday currencies in local markets, as well as non-precious metals such as copper, lead and tin (Powell 1996; Steinkeller 2004; Sallaberger/Pruss 2015). Just like bronze coins in the Roman Republic were used in local markets by agents that could not normally afford – or did not have much use for – silver mints (Kemmers 2016; Stannard 2021), one can imagine local currency-systems largely relying on less-than-noble metals. We may not see conspicuous traces of these local markets in Mesopotamia simply because their protagonists were average 'commoners' who, unlike wealthy private merchants engaging in long-distance trade, did not have the need to produce detailed written documents to keep track of their businesses. After all, nearly all we know about the private economy of Bronze Age Mesopotamia comes from the site of Kültepe/Kanesh, in Anatolia; if, by an unfortunate coincidence, this single site had gone unexcavated, we would probably doubt that a private economy even existed in the first place (Steinkeller 2004).

While the widespread monetary circulation of non-precious metals remains for now an untestable hypothesis for the Near East, substantial evidence suggests that bronze scraps fulfilled in pre-literate Bronze Age Europe the same monetary function that silver did in Mesopotamia.

4.6.3. Weight-regulated money in Europe

The analysis of a very large sample of more than 20,000 bronze objects from more than 1,000 Bronze Age hoards distributed between Italy and Germany reveals that fragments start complying with the Pan-European *shekel* starting *c.* 1500-1350 BCE (Fig. 4.21.2). Before then, bronze fragments show no sign of weight-based regulation, while complete objects simply never do (Ialongo/Lago 2021; 2023).

This is not the appropriate space to discuss the fragmentation phenomenon of Bronze Age Europe, which has been widely addressed in archaeological literature in last 100 years or so (Primas 1986; Sommerfeld 1994; Bruck 2016; Hansen 2016; *e. g.*, Brandherm 2018; Vilaça/Bottaini 2019; Lago 2020). Suffice it to say that starting *c.* 1500-1350 BCE, the vast majority (*c.* 75 % of the total) of the metal objects we find in European hoards were intentionally fragmented. The results of the statistically analysis strongly imply that these objects were intentionally broken down to match multiples of a weight unit, and, based on the analogy with silver fragments in Mesopotamia, they circulated as weight-regulated money. The premises, results and implications of this research, as well as the sample on which it is based have been discussed at length in recent publications (Ialongo/Lago 2021; 2023). What is important to note for the subject at hand, is the remarkable chronological correlation between the emergence of the fragmentation phenomenon, the beginning of the weight-based regulation of bronze fragments, and the appearance of weighing technology in Central Europe. These three continental-scale phenomena are clearly interconnected, and bear strong implications for the monetary circulation of metal fragments, the emergence of primary weight systems, and the formation of a continental trade network in pre-literate Bronze Age Europe.

In the same way as silver in Mesopotamia, bronze objects were broken down to match transaction values. Contrary to silver, however, bronze was an extremely common and widely available material, and the fact that it circulated in a monetary fashion implies exchange patterns that did not necessarily involve affluent agents. The generalised compliance of metal fragments with weight systems – both in Europe and Mesopotamia – is a secondary consequence of the monetary circulation of metal, and it is precisely for this reason that the weight-based regulation of metal fragments is the single most important outcome of the spread of weighing technology in the Bronze Age world. Metal fragments do not comply with weight systems because it was 'mandatory,' but because it was convenient. Just like the regulation of weight systems, the weight-based regulation of media of exchange is the material consequence of emergent economic behaviour, consistently enacted on a continental scale through half a millennium, and it is therefore a quantifiable proxy of that same behaviour. In a typical scenario, two trading partners negotiate a transaction. If credit or payment 'in kind' are not feasible, for whatever reason, the partners will agree on a price to be paid in metal, as the seller knows that they will be available to exchange that piece of metal for something else that they want or need in a future transaction. The buyer then chips off a piece of metal from their stock, whose mass corresponds to the transaction value both agents agreed upon, and the transaction is concluded.

What is especially intriguing about transactions paid with bronze fragments in Europe is their extremely low average value. The mass values of bronze fragments in European hoards are log-normally distributed (meaning that low values are vastly more represented than high ones), with *c.* 50 % of them weighing between *c.* 0.5-20 g, and 75 % below *c.* 70 g (Ialongo/Lago 2021; 2023). If Mesopotamian prices are any indication for Bronze Age Europe, bronze was significantly less valuable than silver. An unsystematic review of price equivalences spanning the Early and the Late Bronze Age indicates that the value of bronze was approximately one order of magnitude smaller than the value of silver (Gelb *et al.* 1991; Englund 2012; Stratford 2017; Dercksen 2021). If we piece

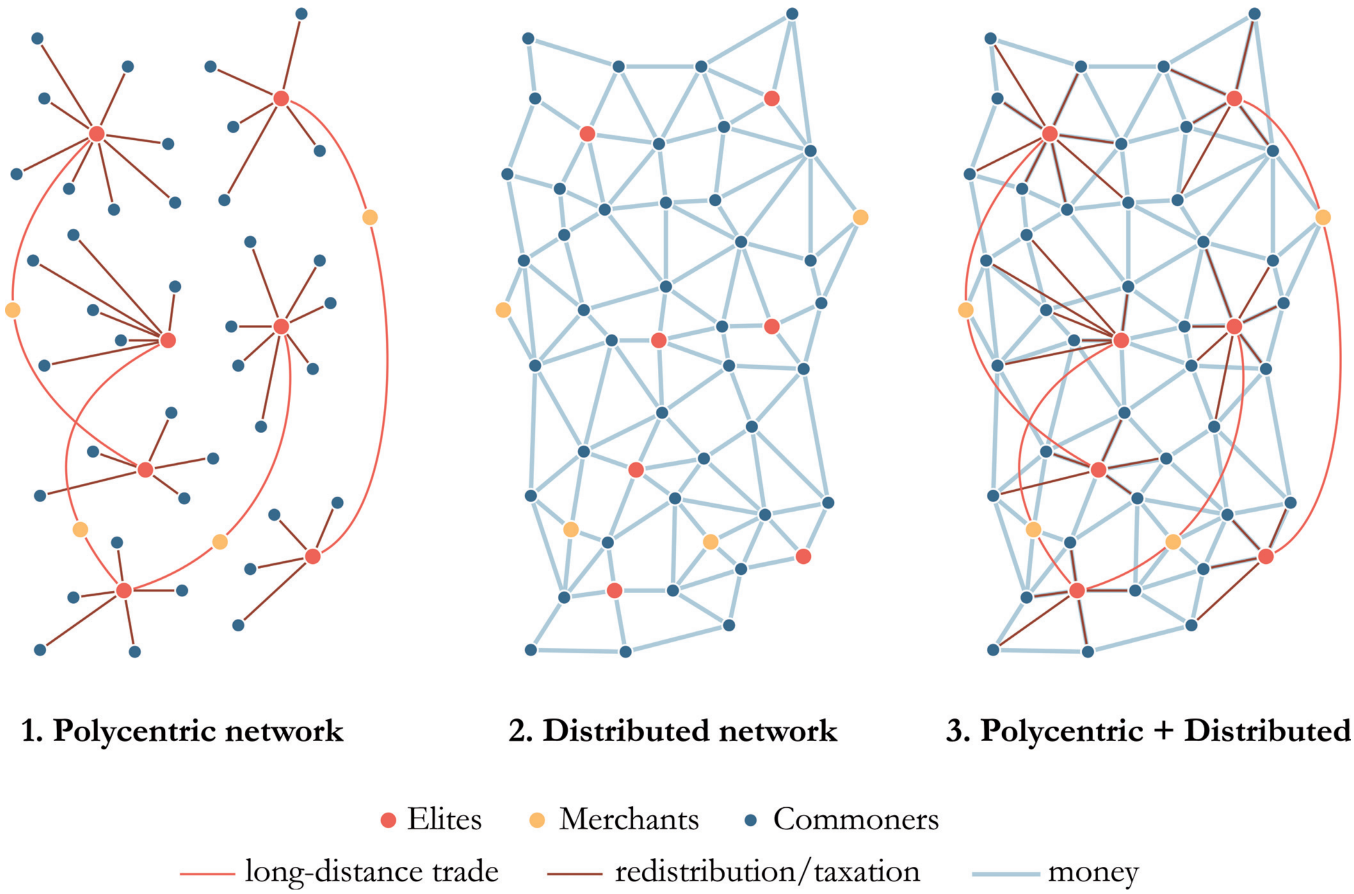


Fig. 4.22. Network models compared. The distribution of nodes is identical in all three versions.

together these bits of information with the price equivalences for different commodities, one can derive that a quantity of bronze in the same range as the most attested mass values of bronze fragments in European hoards (*c.* 1-100 g) could purchase goods that are compatible with the everyday needs of a modest household, for example: *c.* 1-10 g of tin, 10-100 g of wool or salt, or 1-10 kg of cheese, lentils, or garlic. While these figures are obviously not verifiable in any systematic way, it is nonetheless rather striking that the vast majority of metal objects that show signs of weight-based regulation in Bronze Age Europe clearly belongs to a mass-range that a large part of the population did not realistically struggle to come by. In other words, the systematic compliance of bronze fragments with weight systems seems to be a proxy of small-scale transactions in local markets.

The indirect weight-regulation of metal fragments is so systematic and widespread, that it hints at a widely diffused phenomenon. The fact that weight fragments circulated as weighed currency is simply a proxy of the frequency of small-scale transactions in local markets; whether all of these transactions were 'monetary' in nature or not makes little difference. In conclusion, metal fragments comply with weight systems. And just as in the case of balance weights, once the top-down hypothesis is eliminated, the market model is the only viable explanation left.

4.6.4. Weight systems, money, and the formation of an integrated market in Bronze Age Europe

What was the role of weight-regulated money in the formation of trade networks in Bronze Age Europe? In order to find a role for money in prehistoric economies, we must first ask who had a use for it. Today, the most influential models for Bronze Age Europe are mainly concerned with exploring how power controls the economy in a top-down fashion, whereas 'power' is identified with elites operating within different degrees of polycentric chiefdom-like societies (*e. g.*, Earle *et al.* 2015; Kristiansen 2018b; Ling *et al.* 2018).

Local and chronological peculiarities aside, the polycentric model rests on two fundamental assumptions: 1) Western Eurasia is globally entangled in a trade network fuelled by the need to procure raw materials, especially tin and copper, and 2) in Europe, regional elites control local production and long-distance exchange. As a corollary, long-distance trade happens between peer elite groups or individuals, through a system of alliances and reciprocal dependencies (Fig. 4.22.1). The main actors are usually ranked in a four-tier scheme: 1) The elites, controlling and organising production and trade, extracting resources through tributes and redistributing wealth, and funding long-distance expeditions, *e. g.* by building and maintaining ships (Ling *et al.* 2018); 2) merchants, usually acting on behalf of elites as vectors, although recently having been acknowledged a certain degree of entrepreneurial freedom (Vandkilde 2021); 3) commoners, working under the control of elites to fulfil their economic planning; and 4) slaves, at the same time part of the workforce and valuable commodity.

Let alone slaves, full economic agency is only acknowledged to elites and partially to merchants, while commoners appear as passive recipients of a redistribution mechanism, with no agency on their own. All the attention is directed towards long-distance directional trade, and local markets play barely any role, while money is sometimes mentioned, but its function never defined.

Theoretically speaking, one could argue that in a model that frames economic initiative almost exclusively as private negotiations between distant elites, money can safely have no role at all. Be it European elites (Earle *et al.* 2015; Kristiansen 2018b; Ling *et al.* 2018) or Near Eastern states and merchants (Barjamovic *et al.* 2019; Benati *et al.* 2021), the common consensus is that high-tier subjects in the Bronze Age engaged in long distance exchange of a wide variety of different commodities, shipped in diversified bulks. Affluent subjects may not have had much use for money simply because they had at the same time ready availability of, and high demand for a wide range of different goods. Hence, it would be relatively easier for them to find partners that have what they want, and want what they have. Such a *'Double Coincidence of Wants'* is the minimum requirement for any transaction to take place, and is in turn the key-concept on which functional approaches in monetary theory build their models for the bottom-up origin of money in local markets (Jevons 1875; Jones 1976; Graeber 2011).

The reliance on money, in fact, becomes increasingly pressing the more the range of demanded goods exceeds the range of available products to offer in exchange. On the opposite end of the social spectrum, small producers – such as farmers and shepherds – may have struggled finding potential partners in local markets that met the requirements for the 'Double Coincidence of Wants,' and hence could have enormously benefitted from the existence of a standard medium of exchange to mitigate friction and facilitate transactions. In this scenario, the circulation of 'small change' sustains a distributed network, where each agent can potentially interact with any other provided that they are close enough, regardless of their status (Fig. 4.22.2). Monetary exchange in local markets could then simply facilitate the satisfaction of basic needs and wants, such as diversifying diets and procuring clothing, tools and novelty items (Ialongo/Lago 2023).

While the polycentric and distributed models may appear radically different at first glance, they are in fact perfectly superimposable (Fig. 4.22.3). After all, the elites do not exist outside of the economic sphere, but they are part of it. In this perspective, weight-regulated money simply reveals a vast sector of the economy of Bronze Age Europe that has gone so far largely unnoticed to prehistoric research: small-scale, short-range transactions in local markets, a dimension of Bronze Age economies that is gaining more and more prominence in recent research (Knapp *et al.* 2022; Murray 2023; Powell *et al.* 2022).

In conclusion, whether or not the economy of Bronze Age Europe was a 'monetary economy' is not really relevant. What I have tried to argue in this conclusive chapter is rather that the diffusion of weighing technology and the formation of weight systems produced a wealth of quantifiable archaeological data, that offer a unique and so-far vastly unexplored perspective on prehistoric economies in Western Eurasia.

4.7. Chapter highlights

- Bronze Age weight units are not precise values, but indeterminate, normally-distributed intervals with Coefficient of Variation of *c.* 5 %.
- Weighing technology progressively spreads westward during the Bronze Age, and primary weight systems emerge contextually wherever the technology is adopted for the first time. By the end of the 2nd millennium BCE, weight systems exist everywhere between the Indus Valley and Atlantic Europe.
- Bronze Age weight systems are *relational constructs*. They are never 'created' by central authorities, but emerge in a bottom-up fashion from economic networks.
- Bronze Age weight units are neither fixed values nor physical entities, hence they cannot be 'imported'. The emergence of new weight systems is a process governed by statistical randomness, which in turn is the consequence of the physical replication of balance weights.
- The weight system of pre-literate Bronze Age Europe emerges around 2000 BCE, and remains stable throughout the 2nd and early 1st millennium BCE.
- The European weight system is organised around two basic units. These units can be conventionally defined as a *shekel* (*i. e.*, a small unit) of *c.* 9-10 g – attested in Italy, Central Europe, the British Isles and the Iberian Peninsula – and a *mina* (*i. e.*, a big unit) of *c.* 445 g (or alternatively, 2x or ½x of this value), attested in Italy and Central Europe.
- The statistical dispersion of Bronze Age weight systems is largely regulated by the market. Central authorities can play a role in regulating statistical dispersion, but only where central authorities existed in the first place. In pre-literate Bronze Age Europe, there is no evidence that such authorities ever existed.
- Metal fragments comply with weight systems, and circulated as weighed currencies: silver in Mesopotamia, bronze in Europe.
- The monetary circulation of bronze in Europe suggests frequent small-scale transactions in local markets.