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ORIGINAL ARTICLE

Making money out of making money in ancient Athens

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Abstract

The observed weights of ancient coins are usually less than the nominal "ideal" weights of the coin standards to which they belong because state authorities took a fee—"seigniorage"—for minting coins to cover costs and to make a profit. The basis for calculating the amount taken by the state and the way it administered manufacture are not well understood. Here we analyze the weights of 1344 of the earliest coins of Athens (c. 550–479 BCE). We reveal a parabolic relationship between the cost of the silver and the weights of the coins whereby a progressively higher proportion was taken as the denomination decreased, meaning that the smaller the coin, the larger was the proportion of silver taken from it. There was tight control of the minting process and mathematical sophistication in precisely adjusting the silver content from the first introduction of coinage. It also made minting a profitable business. Changes in minting practice can be detected with the introduction of the Athenian "owl" coins, when the percentage of silver taken by the state increased and the spread of weights widened to include coins weighing more than the nominal weight. The latter indicates a significant shift toward monetization of the economy.

KEYWORDS

Athens, coin standards, coin weights, coinage, owls, Peisistratos, seigniorage, *Wappenmünzen*

INTRODUCTION

The observed weight of ancient Athenian coins varies from the nominal (ideal) weight required by the standard. However, the amount by which they differed has hitherto not been quantified, and no one has suggested the basis upon which the state decided how much to take. In this paper, we present the results of an analysis of 1344 early Athenian coins by denomination and weight and provide an answer to these questions. We comment on the implications of our findings in the vexed debate about the introduction of money into a silver-using barter economy and its transition to monetization.

Coinage was introduced to Athens in the second half of the 6th century BCE under the tyrant Peisistratos (Sheedy et al., 2012) with a series of *Wappenmünzen* coins, so called because early numismatists erroneously considered them to have "heraldic" designs (Seltman, 1924), but the name has stuck. The Attic silver coin-weight system was based upon a talent weighing approximately 26 kg, comprising 6000 drachmas with an ideal weight of 4.35 g (Van Driessche, 2009, pp. 73–74). As with all coinages, the state determined the standard and had the power to enforce its use in its territories and took a premium over the same amount of silver weighed as bullion (Kroll, 2011, p. 19, n. 41). Minting commenced with the didrachm (a stater of two drachms), drachm and obol (1/6 of a drachm) denominations, but the weights are not in the proportions of 2, 1 and 1/6, respectively. Toward the end of the series, a larger coin, the tetradrachm (distater) with a gorgon type and an image on the reverse was introduced, as well as a trihemiobol (1/4 of a drachm) and a hemiobol (1/2 of an obol). Around 520 BCE, a substantial change was made with the introduction of the famous owl type series issued primarily in tetradrachms. This change was closely associated with commencement of exploitation of the Lavrion silver mines located in the southeast of Attica and predated the democratic reforms of 508/7 BCE (Sheedy & Davis, forthcoming). The fineness of the coins was consistently high, with 95% of the coins having greater than 95% pure silver (Davis, Sheedy, & Gore, 2020).

There has been much debate about how coinage came to be invented (Balmuth, 2001; Craddock & Cahill, 2020), and the process by which it was introduced into an economy. Clearly, it was related to weight systems, which often bear the same name (shekel, drachma). A persuasive model for the development of weight systems in the Bronze Age proposes that the diffusion of weighing technology occurred through merchants' interactions based on the "random propagation of error constrained by market self-regulation" rather than intervention by political authorities (Ialongo et al., 2021). A weight system (as distinct from a coinage weight system) was used by a state or imposed upon it for a variety of historical, commercial and military reasons (Psoma, 2015) and would be used for the weighing of bullion, but the decision to strike coinage required something more proactive. In a key paper, Kim and Kroll (2008) analyzed the hoard that pinpoints the time in the second half of the 6th century BCE when the Greek polis of Colophon on the coast of Asia Minor started producing minute fractional coins although concurrently using bullion. They speculated that the state must have been prepared to bear the considerable cost and effort of minting to facilitate minor market transactions by obviating the need to weigh small amounts; but they saw it as a commitment to the "economic needs of the entire community" rather than just the elite, notwithstanding that the latter dominated the political scene. Our evidence questions this conclusion, and we propose a more pragmatic explanation.

DATA AND METHODS

We obtained the weights of 944 *Wappenmünzen* and 400 owl coins. Numismatic data are derived from exhaustive scrutiny, scanning and recording of information about relevant coins in the comprehensive collection of coin catalogues maintained by Basil Demetriadi (Athens)

and from examination of coins held in museums around the world and thus represent most known examples. Only coins too heavily damaged to determine their types and fragments of coins were excluded. The data will be published in Sheedy and Davis (forthcoming). The weights and photographs were taken as given in the catalogues. In the museums, the coins were measured for weight with a portable jeweler's scale with a precision of 0.01 g. Scale accuracy was checked daily against a 50.0 g calibration weight. Coins were photographed on both sides and in some cases on the edge. All known details were recorded in a FileMaker (FileMaker Inc.) database.

The plots, histograms and cumulative distribution functions were produced from a home-made MATLAB code (available on request from the authors).

RESULTS

Table 1 summarizes the analysis of the coins divided into denominations. The first row shows owl tetradrachms with an average weight that is 2.6% less than the ideal weight. Subsequent rows represent the various denominations in the chronologically earlier *Wappenmünzen* series. The largest denomination issued late in the series was the tetradrachm with a gorgon on the obverse. These are 2% less than ideal weight. The didrachms are 3.2% less than the ideal weight. The remaining rows are so-called fractions (drachms and smaller); these were minted primarily for domestic use such as paying local taxes, which simplified government administration, as well as more generally in the marketplace (Kroll, 2021, p. 264). Even though the absolute amount of missing silver decreases with weight, the relative silver markdown increases as the weight increases and reaches 20.3% The relationship between the denomination of the coin is regular, which cannot be coincidental. To put it another way, although the price per coin decreases on account of the relative weight of each denomination, the price per gram goes up considerably from only 0.18 per gram for the owl tetradrachms to 1.16 per gram for the hemiobols.

The results are plotted in Figure 1, where the intercept of the line can be seen as the seigniorage. The heavier denominations (tetradrachms and didrachms) cluster close to zero. Each denomination plots further to the upper right along the parabola as its weight decreases.

Figure 2 provides histograms of all the types and denominations. In each case there is a sharp peak a little under the nominal weight. All denominations have a tail of coins of significantly lesser weight comprising specimens with holes drilled in them so they could be worn in

TABLE 1 Analysis of early Athenian coins subdivided into denominations. The tetradrachms in the top row were part of a new series minted after the *Wappenmünzen* series which comprises the gorgon tetradrachms and all remaining rows. The table shows the amount in grams and percentage by which the average of the observed weight differed from the ideal weight. It then shows the price per coin and the price per gram.

Denomination	Number of coins	Ideal weight (g)	Average weight (g)	Amount missing (g)	Percent missing	Price/coin	Price/g
Tetradrachm (owl)	424	17.4	16.95	0.45	2.6	0.083	0.18
Tetradrachm (gorgon)	31	17.4	17.06	0.34	2	0.070	0.21
Didrachm	142	8.7	8.42	0.28	3.2	0.060	0.22
Drachm	145	4.35	4.15	0.20	5.1	0.046	0.21
Trihemiobol	16	1.09	0.98	0.11	10.1	0.020	0.18
Obol	549	0.72	0.64	0.08	13.9	0.032	0.32
Hemiobol	61	0.36	0.29	0.070	20.3	0.084	1.16

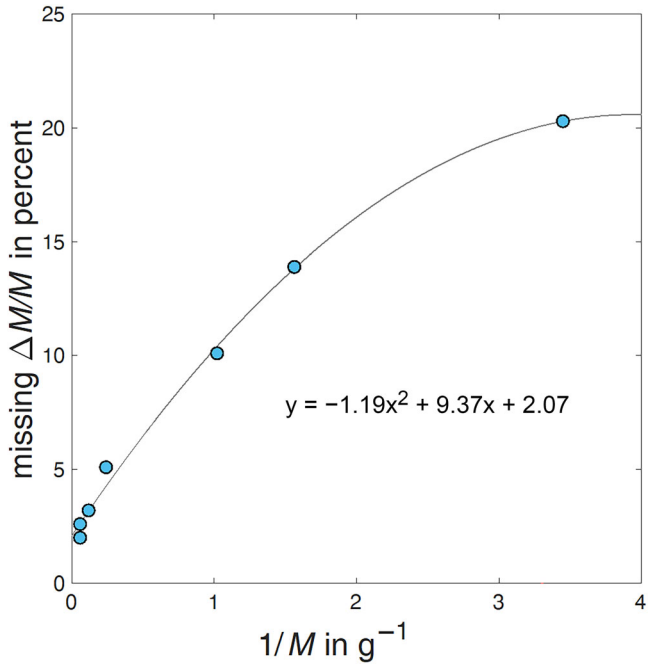

FIGURE 1 Graphic representation of Table 1 showing that the relationship between the denomination of the coin and the percentage of silver taken can be approximated by a parabola. The higher denominations plot closer to zero. The y-axis represents the relative deficit $\Delta M/M$ and is plotted versus $1/M$. When M (mass) ≥ infinity, $1/M \geq 0$. The slope s of the curve ($s = -0.024x + 0.094$) is an alternative expression of the silver weight missing ΔM with respect to the denomination. The point slightly off the curve (4th circle up from the left) represents the trihemiobols, which are an anomaly because they comprise two populations averaged here.

modern times and/or reflecting poor conditions of deposition or wear. The data are considerably denser for the owl tetradrachms ($n = 424$) than for the gorgon tetradrachms ($n = 31$). However, the spread of weights is much greater for the owls than the gorgons with many of the coins over the ideal weight, something which does not occur with any of the *Wappenmünzen*.

Figure 3 presents the information as cumulative distribution functions (cdf), which have the advantage of being independent of bin choices and look smoother than regular histograms. The characteristic of all these plots is to be bottom heavy—that is, characteristically not symmetrical with respect to 50% (median). A normal "Gaussian" distribution is therefore not appropriate.

t-Tests were carried out on the various denominations, which showed, with rare exceptions, no significant difference among die populations. The exceptions are the trihemiobols, for which there are only two dies (see discussion below), and a specific wheel variety that was minted underweight across all denominations. The reasons for this are unknown; the anomalous wheel variety is discussed in Sheedy and Davis (forthcoming).

DISCUSSION

There are many reasons why the observed and ideal weights vary. First, there was a margin of tolerance within which a batch of coins needed to be minted, which could be achieved by adjusting the weight of the batch itself *al marco* or of individual coins within the batch *al pezzo* (Stannard, 2011). The tolerance was surprisingly precise when required (de Callataÿ, 2019), set

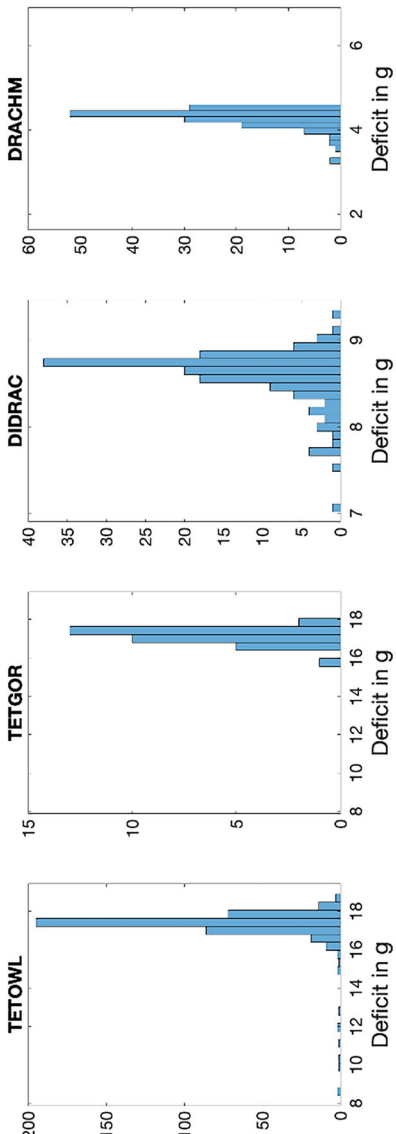

FIGURE 2 The weight in grams showing the deficit from ideal weight of all the denominations. The number of coins is on the *y*-axis and the deficit is on the *x*-axis.

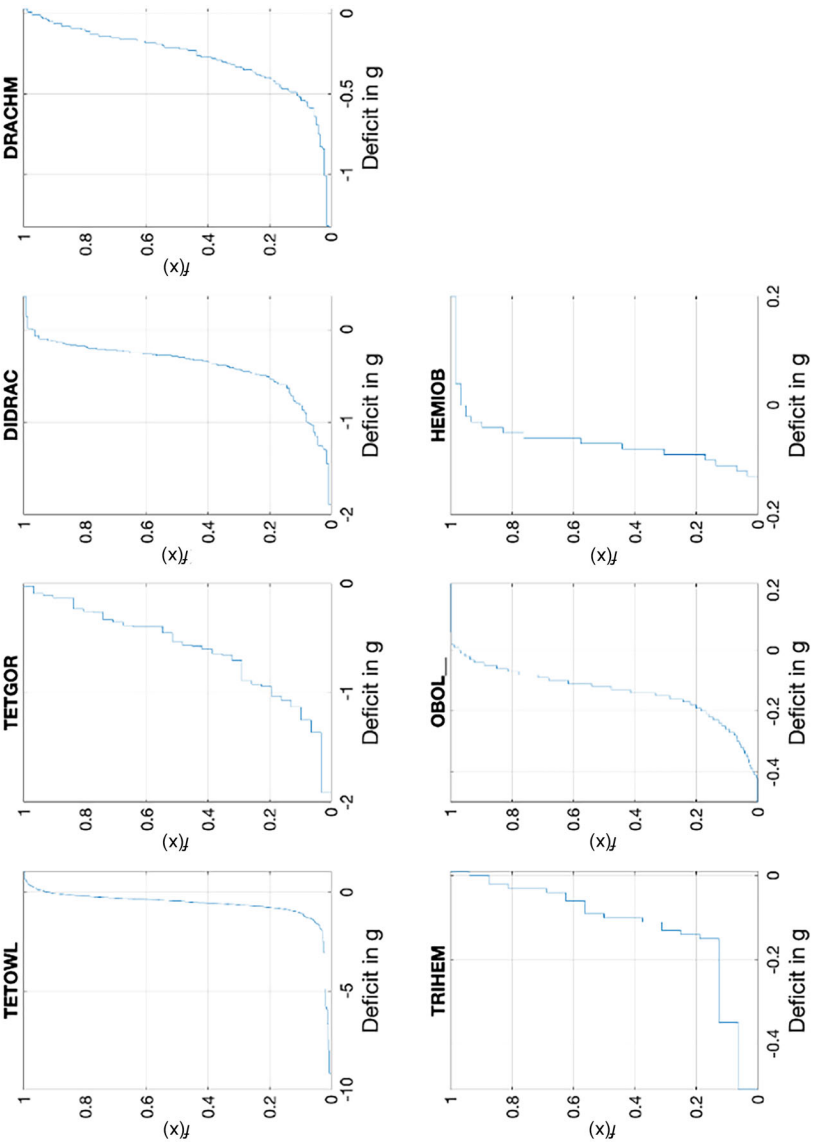

FIGURE 3 Plot of the cumulative distribution functions (cdf) of the data (stepwise increasing functions). The functions are not symmetrical about the median, which indicates that the population is not normal.

at 1.67% in the case of the Delphic Amphyctiony (Doyen, 2011). Second, all metal artifacts suffer some loss of mass through deposition in the ground for millennia. Some elements preferentially leach out and others come into the patina (Gore & Davis, 2016). However, this factor might be expected to be consistent across all coin denominations. Third, coins lose mass from use. Delamare (1994) proposed that this is proportional to duration of circulation, but, although small coins may change hands more frequently than large ones, time is not a variable relevant to this question, and a coin could stay in circulation for a very long period. In any event, an examination of the denominations broken down into types shows very little difference in weight irrespective of wear suggesting that this factor is of minimal importance (Sheedy & Davis, forthcoming). Finally, there may be a deliberate decision by the minting authorities acting on behalf of the state to reduce the weight to cover the cost of minting, but also, right from the inception of minting by the Lydians in the late 7th century BCE, to make a profit (Davis, in press). This practice is referred to as seigniorage.

The reasons why coined money was introduced to Athens are unknown. There is some evidence that Athenian merchants were using silver (Davis, 2012; Kroll, 1998) and coinage was beginning to be established across the Greek world. This study shows unexpected elements of planning right from the first striking that were consistently maintained for the duration of the series.

A state decision to bank on a reduced weight of coins from the standard might be expected to be consistent across all denominations resulting in a "reduced standard," or at least a reduction that was consistent between the larger coins and the fractions whereby all the fractional coins were struck at the same reduced percentage. However, the results demonstrate that the percentage of silver missing increased as the denomination decreased, which plots as a regular curve along the arc of the parabola. The plot shows that the Athenian state set the weight of each coin denomination separately and variably. It does not mean that every coin in a particular denomination weighed the same, as occurs with modern coins, but the batch minted by each pair of dies totaled a set weight. This demonstrates that the authorities had formulated a rule to determine the percentage that they would take on each denomination. The small range of values for all denominations in Figure 3 shows the tightness of control over the minting process.

The state's reduction in silver content made the fractional coins expensive. For a hemiobol, it amounted to one-fifth of its content, while the heavier coins all cluster close to zero. This is probably because the big coins were being weighed and acted as stores of wealth and would not have been accepted if substantially less than their face value in what might be described as a "bullion-using monetary economy" (Le Rider, 2001). The state took a higher percentage from small fractional coins, relying on guaranteeing value and capacity to enforce use within their territory. Thus, while all coins were less than their weighed bullion value to the extent that the coin standard gave a fixed premium to the state for minting, the fractional coins were fiduciary and could only be used for exchange locally.

Three factors point to a change in minting policy between the gorgon and owl tetradrachms, probably related to the fact that the silver used in the former came from non-domestic sources, while the silver in the latter came mostly from Lavrion (Davis, Gore, et al., 2020). First, the owls weigh more than the gorgons, presumably to bring them up closer to ideal weight to succeed in the export market. Second, the fee charged for minting the tetradrachms increased from 2% to 2.6%. This was less than the usual 3% or 5% cost to change money (*IG*I^3 1453 = Melville-Jones, 2007, 50–1, no. 78, Section 5; the number is lost on the document but the letters only permit two possibilities). The cost would have been acceptable in what was effectively an export business of silver bullion with the commodity guaranteed by the Athenian state when struck into coinage; it represented commercial reality. Third, there is a greater spread of weights for the owl tetradrachms compared with the gorgon tetradrachms (Figure 2). Some of the owls weigh more than their ideal weight. Arguably, this points to minting by batch and a crucial shift to counting coins from weighing them since the coinage was now fungible, all coins being equally exchangeable.

The trihemiobols (Figure 1) diverge slightly from the parabola on the graph. This is because there are only two pairs of dies, with averages of 1.06 and 0.98 g. The latter would fit precisely on the plot. Little is known numismatically about the trihemiobols since they have only just been identified in a current study (Sheedy & Davis, forthcoming). They were minted in the *Wappenmünzen* series on a very small scale ($n = 16$ coins) and discontinued after only one further issue in the subsequent owl series. As such, they were an experiment and needed to be fitted into the pattern by the mint.

CONCLUSION

Coinage was introduced into a bullion-using economy in which merchants had previously controlled exchange. We demonstrate that right from the start of minting the state had a clear and well-executed policy whereby it extracted proportionally more silver as the denomination reduced. This seigniorage taken by the state can be fitted to a parabola. Thus, although the various denominations of fractional coins were all intended primarily for internal use, the same percentage of silver was not taken. The extraction of a higher proportion of silver from smaller denominations than larger ones would have been readily justified by the increased cost of minting the coins in relation to their value. Whether this practice was unique to Athens is currently unknown but should be looked at in future mint studies, with a particular focus on fractions. It is likely that in some other early mints fractions predominated and there was a similarly strong incentive to take a greater percentage of seigniorage from them.

A change in state minting policy can be detected with the introduction of the owl tetradrachms, when the state increased the percentage it took, and the spread of coin weights widened to include coins over the ideal weight. This demonstrates increased monetization of the economy because each coin no longer needed to be weighed but could be counted and exchanged equally with any other coin.

A state guarantee of value made the coinage fiduciary. The fractional coins were probably minted to meet the needs of the state for small payments, a topic that is explored in Sheedy and Davis (forthcoming). It points to the ability of the authorities to enforce the use of its coins in areas under its control. Minting coinage filled the twin purposes of maximizing profitability and control domestically while preserving the accountability and reputation of the larger coins that could trade externally. It demonstrates that, contra Kim and Kroll (2008), minting was not being done altruistically to aid the poorer members of society. At its heart is the understanding that then, as today, mints make money out of making money!

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are being published in Sheedy and Davis (forthcoming).

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