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Nicholas Holmes

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Minting technology responds to one or both of two objectives regarding weight: to make coins that are individually of a certain weight, within a narrow range (the 'tolerances'); and to obtain a fixed number of coins from a fixed weight of metal. Weight adjustment of individual coins is *al pezzo*; adjustment by relating a fixed count of coins to a fixed weight of metal, without overmuch care about the weight of individual coins, is *al marco*.

Any form of adjustment increases labour costs, *al pezzo* more than *al marco* adjustment.[1] For ancient coins, we need to ask whether anything constrained a mint to adjust individual issues and, if so, what type of adjustment was used. We have two types of evidence: physical marks on coins resulting from adjustment practice, and statistical analysis of coin populations.

Two types of fraud forced mediaeval and later mints to assume the costs of tight adjustment: clipping[2] and culling.[3] Ancient coin fraud, however, concentrated on plated coins: clipping was not common until the thin *siliquae* of the fourth century AD, and I know no evidence that ancient fraudsters culled coins.

In 1993 I showed that many Roman Republican *denarii* issues between 123 and 49/48 BC were adjusted *al marco*;[4] this was possible because of the visible traces of the technique used to adjust the flans before striking, by gouging slivers of metal off the surface with a scorper. This produces characteristic undercut lunate 'judder' marks, belly-forward across the cut. The metal of the judders folds over, and the judder is usually visible, even when the cut itself has been quite obliterated (**Pl. I, 1**).

The gouges proved that the flans had been adjusted. Statistical analysis of large samples then showed that adjustment had been *al marco*, by a combination of abnormalities in the distributions of gouged issues: negative skew[5] (the heavy leg of distribution is reduced), and high kurtosis[6] (the centre of the distribution is raised). Table 1[7] shows these abnormalities.

TABLE 1: Roman Republic *denarii* adjusted *al marco*

*Sampl*e	N	mean	stDev	skew	kurt	CV%
Gouged pieces	166	3.86	0.11	-1.14	5.21	2.85
Cosa hoard	997	3.88	0.17	-0.79	2.63	4.38
ANS	707	3.83	0.15	-1.61	4.39	3.92

Acknowledgements: I thank Wolfgang Fischer-Bossert and the American Numismatic Society for the decadrachm illustration; Classical Numismatic Group for the gouged *denarius* and Amisos bronze illustrations; and Peter van Alfen and Bernhard Woytek for the electronic files of their data.

[1] Cf. Stahl 2004, pp. 194-95, for the balance between minting costs and security in the Venetian mint.

[2] Cutting metal off the edge.

[3] Sorting out and melting over-heavy coins.

[4] Stannard 1993.

[5] A measure of the asymmetry of the probability distribution.

[6] A measure of the 'peakedness' of a probability distribution.

[7] From Stannard 1993, p. 48. Normal skew = 0; normal kurtosis = 0. I have added CV% = coefficient of variation, or the standard deviation expressed as a percentage of the mean (stDev/mean*100), to provide a measure to compare the 'tightness' of adjustment across issues. 'Gouged pieces' = all the gouged denarii I then knew; 'Cosa hoard' = the denarii of gouged issues in this hoard (Buttrey 1980); 'ANS' = the denarii of gouged issues in the ANS.

Gouging, with negative skew and high kurtosis, made it possible to postulate the following parameters:

> 'In the Cosa hoard sample, the difference between the mean[8] and the mode,[9] multiplied by the number of coins ((3.90-3.88)*997), gives a weight of 19.94 g recovered from the original overall weight of 3,888.3 g., equivalent to the weight of about five *denarii* a thousand. If we assume, on the basis of the observed distributions, that the average weight of blanks sorted out for gouging was about 4.25 g., then an average weight of about 0.37 g. per coin (4.25-3.88) was cut away. We can then estimate the number of blanks gouged at 19.94/0.37, or 53, or about 5.3%.'[10]

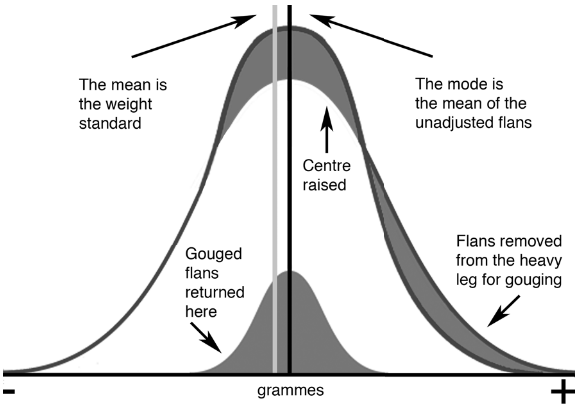

Fig. 1. Model of an issue adjusted *al marco*

Fig. 1 models such adjustment. A block of flans is cast at an average weight slightly heavier than the target. They follow a normal distribution, where the mean and mode coincide. The number of flans required from the overall weight-target are counted out and put on a scale. Flans are taken out - mostly obviously heavy pieces - gouged, and returned, until the overall weight-target is reached. This causes negative skew and the high kurtosis. The mode, or 'weight peak', of the adjusted distribution remains that of the unadjusted distribution, but the mean is now lighter than the mode.

There is an important theoretical implication: the weight-standard is the mean, *not* the mode; to take the weight peak of an *al marco*-adjusted issue as the weight standard is wrong, because it suggests a slightly too heavy standard: in the Cosa hoard coins, for example, there is a difference of about 0.5% between mode and mean. The tiny difference between the mode (the mean of the unadjusted flans) and the mean (the target weight) - about 2.06% of the target weight: ((3.90-3.88)/3.88*100) - shows the large sample one needs for significant results.

Wear is usually the most important factor influencing a coin population after it has left the mint. Random wear will not change the normality of a distribution, *in a single age-class*; it will spread the curve, and shift both the mode and the mean lower, but the distribution will still be normal, if it started normal; and it will still show negative skew and high kurtosis, if these were characteristics of the original population. In a long-lived circulating population composed of successive age-classes, the older age-classes will have worn more, and their individual distributions have spread more.[11] The distribution of the composite population is the sum of the age-classes, and the resulting distribution will show negative skew and low kurtosis. This theoretical picture needs to be tested on real populations. Figure 2 models such a population.

[8] The sum of the weights divided by the number of coins.

[9] The most frequent value in a data set or a probability distribution.

[10] Stannard 1993, p. 49. These figures are, of course, only indicative.

[11] Greater coin-loss of earlier age-classes must also be allowed for.

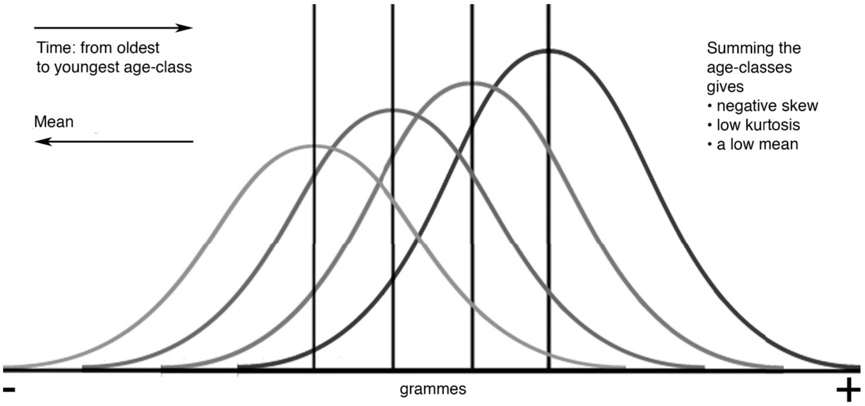

Fig. 2. Wear in a population composed of successive age-classes

In addition to the general incidence of gouging in Roman Republic *denarii*, I knew, in 1993, a few examples of a single gouged coin in some other series (**Pl. I, 2-5**).[12] An Athenian decadrachm with a cut and judders on the owl's breast has now appeared (**Pl. I, 6**). Numismatists now seem more willing to postulate adjustment *al marco* for ancient coins. In publishing the decadrachm, Wolfgang Fischer-Bossert remarked that:

> 'This is minting *al marco*. The flans were not meticulously adjusted, as is usual with gold coins (minting *al pezzo*).'[13]

In analysing Trajan's gold, Bernhard Woytek remarked that:

> '*Aurei* of the Roman Principate were not struck *al pezzo*, but *al marco*, so that individual weights could differ substantially.'[14]

This note attempts to outline the evidence needed to evaluate such assertions, which I think are correct, but which are not yet proved.

Casting and adjusting flans is a two-step process,[15] whether *al marco* or *al pezzo*. I suspect that all ancient precious metal issues were adjusted, because it is virtually impossible to cast flans directly so as to obtain the correct number of flans of accurate average weight from the correct overall weight of metal. I doubt reconstructions of ancient minting practice that do not include adjustment, and suspect that the failure to allow for adjustment is behind the suggestion that the correct weight of metal for each flan was first weighed out and then melted. This would be labour-intensive (particularly if it is postulated that the metal was first prepared in granular form) and unlikely.[16]

A single gouged piece in an issue does *not* in itself show that an issue was adjusted, whether *al pezzo* or *al marco*. Moreover, it is possible that both *al pezzo* and *al marco* adjustment may have

[12] Stannard 1993: (1) Lycia, stater, c. 460 BC, Spier (1987), pl. VI.5. (2) Hyele, Lucania, didrachm, c. 390-275/250 BC, *SNG ANS* 1292. (3) Audoleon, King of Paeonia, tetradrachm, c. 315-286 BC, *SNG Cop*. 1382, *BMC* 4. (4) Constantine I, aureus, *RIC* 126.

[13] Fischer-Bossert 2008, p. 13.

[14] Woytek 2008, p. 439.

[15] Some issues were made by cutting a flan from sheet metal and trimming it to within the tolerances, a one-step process. Cf. *RRC* 441/1.

[16] Faucher *et al.* 2009, pp. 60-61, show experimentally that such a process is labour-intensive, and that about 0.1 g. of metal par flan is lost.

been used in a single issue; the overall weight of a block of coins adjusted *al pezzo* may have been heavy, which was remedied by removing metal from a small number of pieces.

A crucial starting point is evidence that certain bronze issues were *not* adjusted; this is a basic datum against which the statistical evidence from precious metal issues can be evaluated. For example, Roman Republican cast libral bronze follows a normal distribution, as Table 2[17] shows.

TABLE 2. Unadjusted Roman Republic libral cast bronze

Sample	N	mean	StDev	skew	kurt	CV%
As	1168	268.01	13.67	0.02	0.84	5.10
Semis	3132	134.54	9.49	0.27	0.59	7.05
Triens	392	89.44	7.46	0.24	0.61	8.34
Quadrans	266	67.6	4.64	0.33	0.58	6.86
Sextans	208	43.38	3.47	0.20	0.93	8.00
Uncia	184	21.78	2.11	0.42	2.78	9.69

The large sample of struck imperial *quadrantes* from the River Tiber[18] in Table 3 is also perfectly regularly distributed: because of the low metal value and fiduciary character of these coins, adjustment of any type was obviously unwarranted.

These bronze samples include many age-classes, with some degree of wear; that they still follows a normal distribution shows that random wear does not much alter the *shape* of the curve.

TABLE 3. Unadjusted struck imperial *quadrantes* from the River Tiber
(Augustus, Gaius, Claudius together)

N	*mean*	*StDev*	*skew*	*kurt*	*CV%*
670	2.41	0.47	-0.01	0.08	19.50

The coefficient of variation - which measures the care taken in preparing flans - is instructive. The tighter the coefficient, the more labour goes into adjusting the flans.[19] It is larger in both bronze samples than in the precious metal issues analysed here; precious metal flans were generally worked with more care.

Table 4 analyses the known population of Athenian decadrachms,[20] firstly with the coins from the Elmalı hoard, and secondly without. The negative skew and the high kurtosis are consistent with *al marco* adjustment, but the population is too small for statistical certainty.

TABLE 4. Athenian decadrachms

Sample	*N*	*mean*	*StDev*	*skew*	*kurt*	*CV%*
With the Elmalı hoard	36	42.26	1.31	-2.60	7.59	3.11
Without the Elmalı hoard	25	42.00	1.52	-1.97	4.40	3.61

[17] From Guey and Carcassonne 1978, p. 76.

[18] King 1975, pp. 82-85; analysed in Stannard 1993, p. 49.

[19] It may also vary with flan size, with smaller flans more variable.

[20] Fischer-Bossert 2008, p. 13.

For comparison, I analysed the numerous Athenian pi-style tetradrachms recently published by Lisa Anderson and Peter van Alfen[21] (Table 5). The sample includes many worn, chopped and punched coins, and includes many age-classes, but the overall pattern, with negative skew and high kurtosis, suggests *al marco* adjustment. I have never seen gouging in Athenian tetradrachms.

TABLE 5. Athenian pi-style tetradrachms

N	*mean*	*StDev*	*skew*	*kurt*	*CV%*
360	16.81	0.29	-2.63	13.48	1.74

Small samples bedevil this research. The difficulties can be illustrated by analysing various samples of the Roman Republican Mars/eagle sixty-As gold issues, anonymous and with various symbols (Table 6).[22] A hoard from Agrigento includes 34 anonymous sixty-As pieces;[23] Bahrfeldt had earlier assembled the weights of known specimens, with and without symbols.[24] While the Agrigento hoard distribution might appear to suggest *al marco* adjustment, other samples do not confirm this. I doubt that the samples reflect different adjustment practices, and conclude that the sample is insufficient for argument. I can advance no useful argument as to whether or not these coins were adjusted *al marco* or *al pezzo*. It seems a tightly adjusted issue, because the coefficient of variation is uniformly low.

TABLE 6. Roman Republican sixty-*As* Mars/eagle gold

Sample	*N*	*mean*	*StDev*	*skew*	*kurt*	*CV%*
Agrigento	34	3.36	0.02	-1.80	6.35	0.67
Agrigento & Bahrfeldt	90	3.36	0.03	-0.12	-0.12	0.78
All Bahrfeldt	56	3.35	0.03	0.45	-0.12	0.84
Bahrfeldt, no symbols	38	3.36	0.03	0.67	-0.32	0.01
Bahrfeldt, with symbols	18	3.35	0.03	-0.03	0.45	0.84

Bernhard Woytek recently published large samples of Trajan's gold issues,[25] which I analyse in Table 7. The low coefficient of variation indicates careful adjustment. Despite the often large samples, there is little uniformity. The issues of AD 101-102, 107-111, 112-114 and 114-116 all have the negative skew and high kurtosis that, in Roman Republican *denarii*, I associate with adjustment *al marco*; but the other issues do not. This is paradoxical, as it is unlikely that some issues were adjusted *al marco* and others *al pezzo*. It requires further investigation. One possibility is that, in some issues, the raw flans were closer in average weight to the weight-target than in others, so needing less adjustment.

[21] Anderson / van Alfen 2008, Appendix 1, pp. 189-98.

[22] *RRC* 44/2, without symbol; 50/1, anchor; 88/1, spearhead; 105/1, pentagram, and 106/1, staff; 211-208 BC.

[23] Caccamo Caltabiano 1990, p. 2.

[24] Bahrfeldt 1923, pp. 16-17.

[25] Woytek 2008, pp. 440-50.

TABLE 7. Gold issues of Trajan

Sample	*N*	*mean*	*StDev*	*skew*	*kurt*	*CV%*
c. Feb.-Oct., AD 98	53	7.48	0.14	-0.64	0.26	1.91
c. Oct? AD 98-99	50	7.31	0.17	0.40	-0.26	2.33
AD 100	53	7.21	0.12	-0.35	0.28	1.73
AD 101-102	141	7.15	0.18	-1.87	11.30	2.51
AD 103-107	127	7.15	0.12	-0.13	-0.31	1.71
AD 107-111	334	7.15	0.15	-1.09	9.14	2.16
AD 112-114	353	7.14	0.17	-2.10	9.80	2.32
AD 114-116	281	7.17	0.17	-3.57	25.94	2.40
AD 116-117	214	7.17	0.14	-0.52	0.23	1.99

A key challenge is to look for evidence of the way in which metal was removed from flans, if not by gouging. One possibility would be cutting metal from flan edges, but there are few traces of this. Examples, such as the Kroton stater of **Pl. I, 7**,[26] are probably usually the result of overstriking coins of a heavier weight-standard, and first adjusting these.

Filing metal from the face of flans is a further possibility. This was the commonest adjustment method in early modern coinage. The ancient examples I know are all bronze (cf. **Pl. I, 8**),[27] and it is possible that such filing was to flatten flans, rather than to adjust weights; the statistics of such issues should be investigated.

It would also have been possible to compose a block of correct overall weight *al marco* by replacing heavier flans with lighter, or lighter with heavier, but this seems improbable, because - if the parameters I postulated above for Republican *denarii* applied (where adjustment required something in the order of reducing the weight of 5.3% of flans by 3.79 g.) - it would mean weighing large numbers of individual flans and melting others.

Adjustment *al pezzo* could have been effected by weighing flans from the initial casting, selecting those that fell within the tolerances, rejecting light flans and adjusting those that were too heavy. The Dutch Mint used such procedures (with flan-filing) for gold ducats as late as 1974, with tolerances of 0.002 g. on either side of 3.499 g., and with 90% of flans from each melt discarded and remelted.

> 'Two men work to salvage as many blanks as possible. If a blank weighs light it is remelted. If it is slightly heavy, it is tossed into one of four boxes, numbered one to four, calling for one, two, three passes of a file over the flat surface of a blank. Such removal of gold will bring the blank into acceptable tolerance levels, it is hoped. If too much gold is removed in the filing operation, it is rejected when weighed again. If too heavy, it is filed again.'[28]

[26] *c.* 480-430 BC, *HN Italy* 2001, pp. 168-69, 2102; cf. similar edge-cuts on *SNG ANS* 275.

[27] Pontos, Amisos, 109-88 BC, *SNG BM Black Sea* 1167.

[28] Coffing 1975, p. 60, quoted in Stannard 1993, p. 50, n. 1.

The method is labour-intensive. If employed in ancient mints, tolerances would have been much wider. The statistical signature of such procedures would probably be a very low coefficient of variance and very high kurtosis, without negative skew.

This note is the beginning of a programme of research, not an end product. At this stage, I make the following conjectures:

1. All or most precious metal issues in antiquity were adjusted, which is why the resulting distributions are not normal. The normality of the distributions of some bronze issues proves this.

2. Tight adjustment was not necessary, because neither clipping nor culling was common. Most adjustment was *al marco*, because it required less labour, and resulted in lower fire-loss in remelting. It is probable that the practice was to cast blocks slightly heavy, and adjust by removing metal from some over-heavy flans.

3. All coin weight standards in antiquity were probably expressed as a fraction - the '*taglio*' - of the weight unit. *Taglio* and *al marco* go together. Abstract weight standards, not linked to a *taglio*, are an artefact of modern, *post hoc*, thinking.

4. In discussing weight standards, we should always start by asking whether there was adjustment and, if so, whether it was *al marco* or *al pezzo* or something else.

5. In *al marco* adjustment, the average, *not* the weight peak, is the standard.

Statistical analysis is an important tool, but much thinking and work is still needed before we move to a higher degree of certainty. I would be most grateful if anyone who has large weighed samples of issues in any metal would be kind enough to let me use them.

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PLATE I

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