GINI, THEIL, AND THE TRADE-OFF BETWEEN OPTIMAL AND EFFICIENT GROUPING OF INCOME DATA*

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Abstract

This paper deals with the effect of various methods of grouping income data in brackets on Theil and Gini indexes. Although optimal brackets result in the smallest underestimation errors, the differences between the methods in the case of 28 brackets are negligible. So, simple Dutch CBS groupings are preferred on efficiency grounds as they have rounded brackets and do not differ with the distribution of incomes or with the index used. Neither income nor population fractiles are preferred as far as the computation of Theil and Gini indexes is concerned.

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* The authors are indepted to Professor J.S. Cramer and Professor J. Hartog for helpful comments.

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1. Introduction

Published income statistics are typically tabulated in grouped form, the individual incomes having been aggregated into either brackets or fractiles. This is done mainly for reasons of efficiency and privacy.

A major disadvantage of such aggregation for the analysis of income inequality is that it results in a certain loss of information. The differences between incomes that are grouped in the same bracket (or fractile) can no longer be observed. As a consequence, indexes of income inequality that are computed from the aggregated data underestimate the true income inequality.

The relative importance of the underestimation error depends on the underlying income distribution, the way in which the aggregation has been performed and the inequality index under consideration. For the Theil index, Theil himself (1967) computed the maximum possible underestimation error caused by grouping. While the neglect of the inequality within brackets yields an unambiguous lower bound for the true Theil index, Theil's assumption of maximum unequally distributed incomes within each bracket yields an unambiguous upper bound. Gastwirth (1975) has made an attempt to bring these lower and upper bounds closer together by assuming the probability density function of the income distribution to be decreasing above the mode. Odink & Van Imhoff (1984) showed that the assumption of a linear density function within each income bracket gives an approximation of the Theil index that differs only .1% from the true value for the Dutch CBS frequency distribution.

Similar results hold for the Gini index. In Gastwirth (1972) formulas are given for strict lower and upper bounds to the true Gini index for grouped data, as well as for modified bounds under the assumption of a unimodal probability density function. Again, approximation with a linear density function within brackets results in negligibly small errors (Odink & Van Imhoff, 1987).

Aghevli & Mehran (1981) derive conditions for the grouping of individual income data to be optimal in the sense that the resulting underestimation error is minimized, given the number of income brackets. The purpose of our present paper is to compare optimal grouping in the Aghevli & Mehran sense with actual grouping as performed by the Dutch Central Bureau of Statistics, as well as with grouping in population fractiles and income fractiles. The various grouping methods are compared with respect to both the Theil index and the

Gini index. The data on which our calculations are based are a subsample of some 29,200 wages from the Dutch CBS "Loonstructuur-onderzoek 1979" (CBS, 1983).

2. The effect of grouping on observed income inequality

The effect of grouping on observed income inequality can be derived from decomposition formulas for the inequality index under consideration. Both T and G are decomposable (Theil, 1967, pp. 94-95; Gastwirth, 1972), although the latter's decomposability holds only if the grouping is ordered.

The Theil index for the individual income data equals:

$$T = \Sigma_k((X_k/Y)\ \ln(X_kN/Y)) =$$

$$= \Sigma_i\, y_iT_i + \Sigma_i(y_i\ \ln(y_i/n_i)) \qquad (1)$$

where

X_k=k^{th} income, $k = 1,\dots,N$
Y = total income
n_i= share of group i in total number of incomes, $i = 1,\dots,M$
y_i= share of group i in total income
T_i= Theil index for inequality within group i.
N= number of incomes
M= number of groups

For the Gini index, with the incomes both within and between groups ordered from low to high:

$$G = \frac{1}{2N^2(Y/N)}\Sigma_k\Sigma_l|X_k-X_l| =$$

$$= \Sigma_iy_in_iG_i + \Sigma_i\Sigma_{r>i}\ |n_iy_r-n_ry_i| \qquad (2)$$

where G_i = Gini index for inequality within group i.
The value of the inequality index computed from grouped data equals the inequality between brackets, given by the second term in (1) and (2), respectively. Grouping results in the disregarding of the first term in (1) and (2), which is the inequality within the groups. When all individuals earn the same income (complete equality), both T and G are equal to zero; when one

individual earns all income, the other individuals earning nothing at all (complete inequality), G equals $(N-1)/N$ and T equals $\ln N$.

According to Kakwani (1980, pp.65-69) inequality measures ought to lie in the range of zero to one. The Theil coefficient does not satisfy this requirement. In our opinion the requirement of upper bounds equal to one is not an essential issue. Besides, as Theil (1967) argued, for the inequality it makes a difference if one person out of two or one out of a million earns all income. So it is not unreasonable that the maximum inequality increases with the number of individuals.

Besides lowering the measured income inequality, an additional effect of grouping of individual data is that the number of "units" is reduced. In the case of M groups with equal number of incomes (population fractiles) the maximum value of T is, according to (1), equal to $\ln M$. For this reason one might be inclined to conclude that an equal number of fractiles is necessary for the mutual comparability of different income distributions. However the maximum value of T is far greater than the actual value of T (for Dutch income data the ratio is about 75:1). Therefore the reduction of the maximum T as a consequence of grouping is virtually irrelevant for the order of magnitude of the aggregation error. Indeed, as our calculations bear out, the use of an equal number of fractiles for different income distributions (as suggested in Massizzo e.a., 1969) does not guarantee that the underestimation errors are of the same order of magnitude.

In addition, a substantial part of the underestimation error is caused by the highest, open income bracket. Suppose for instance that the incomes are Pareto-distributed. In that case the incomes in the highest bracket are also Pareto-distributed with the same α. As T is then a function of α only (see Theil, 1967) the inequality within the M^{th} bracket (T_M) is equal to T. The proportional underestimation error due to the M^{th} bracket then equals

$$\frac{y_M T_M}{T} = y_M,$$

the income share of the highest bracket. For population deciles this share may vary from .2 or less to .5 or even more.

Starting from the decomposition formulas (1) and (2) one can derive conditions for the determination of the grouping criteria which are optimal in the sense that the resulting underestimation error is minimized. For the grouping of N ordered incomes in M groups the grouping criteria give rise to M-1 group limits $a_1,..,a_{M-1}$. Aghevli & Mehran (1981) showed that the optimality conditions for T and G, respectively, are given by:

$$a_i = \frac{(Y_{i+1}/N_{i+1}) - (Y_i/N_i)}{\ln(Y_{i+1}/N_{i+1}) - \ln(Y_i/N_i)} \qquad i=1,...,M-1 \text{ for T} \tag{3}$$

$$a_i = \frac{Y_i + Y_{i+1}}{N_i + N_{i+1}} \qquad i=1,...,M-1 \text{ for G} \tag{4}$$

where

Y_i = income of group i

N_i = number of incomes of group i

Given a sample of individual income data the optimal group limits can be found by an iterative search process. Unfortunately the A&M conditions do not yield a unique set of group limits: although the conditions are necessary for the grouping to be optimal, they are not sufficient. Constructing a suitable algorithm for the computation of Aghevli & Mehran (A&M) groupings was hard and laborious. For the final version of our calculations we have used an algorithm that proceeds along the following lines:

- choose some initial group limits $a_1,....,a_{M-1}$;
- determine the optimal a_i, keeping the other group limits constant, for i=1,.....,M-1;
- repeat the previous step until convergence is reached.

Convergence was reached in all experiments, and all final groupings satisfied the A&M conditions. However, the groupings obtained in some cases varied with the initial conditions, although the differences in the corresponding inequality index were small. For the calculations in section 3 we have in each case tried four sets of starting values: CBS brackets (if available); income fractiles; population fractiles and population fractiles; where cases with equal wages are counted as one observation. We have chosen the grouping with the highest value of the inequality index under consideration.

3. Actual and optimal grouping compared

The Dutch CBS uses different brackets for different purposes. The income frequency distributions are usually presented in 32 brackets or in deciles, the wage distributions in 17 brackets and incomes in consumer surveys in only 7 brackets (see Van Praag, et al., 1983). The question arises whether the underestimation due to grouping can be reduced by changing the brackets and whether such a change is efficient. The Aghevli & Mehran optimality conditions are given for G and T in equations (4) and (3), respectively.

Unfortunately the conditions are different for the different inequality measures. In addition the brackets vary not only with the number of groups and the inequality index but also with the income distribution as such. So there are no standard optimal income brackets. The main advantages of CBS brackets are standardization for different distributions and rounded brackets.

The CBS-classifications in 7 and 32 brackets are used for the grouping of yearly incomes. In order to make these classifications suitable for the grouping of weekly wages we have rescaled the bracket limits using a scaling factor of 1/56 (52 weeks per year + 4 weeks supplementary allowances). See also the Appendix. The highest three brackets and the lowest bracket of the 32-groups CBS-classification remained empty, as the CBS did not ask for monthly wages above 11 500 Duch guilders, and as there are no negative wages.

Table 1 gives the underestimation of Gini and Theil for 7, 10, 17 and 28 brackets, for CBS groups, A&M groups, population fractiles and income fractiles. A&M brackets give of course the lowest underestimation, being at most 4.9% for Theil in the case of 7 groups, while for income fractiles and CBS groups the underestimation of Theil is more than 15%. In the case of 10 groups for Theil A&M (2.6%) is still far better than population (6.7%) or income (10.4%) deciles, while for Gini the results are less impressive: 1.3% for A&M against 1.9% for population deciles. In the case of 17 groups A&M is for G hardly better than population fractiles, while for Theil the improvement is still substantial. The relatively bad results for the 17 CBS-groups are due to the fact that the brackets were intended for full-time wages only, so that for data which include part-time wages the brackets are too crude for the lower wages. In the case of 28 groups the results for the CBS groups are quite remarkable, the difference with A&M is reduced to 0.1% or less, the underestimation error being only .5% for Theil and .3% for Gini. For Theil the CBS groups are much better than population (1.6%) or income (3.6%) fractiles, while for Gini all brackets fit very well.

Table 1 Underestimation (in%) of Gini and Theil due to grouping (LSO 1979, N=29 271, all wages)

	Theil	%	Gini	%
individual data	.13688	-	.27872	-
7 A&M-T groups	.13010	4.9	.26815	3.8
7 A&M-G groups	.12762	6.8	.27117	2.7
7 CBS groups	.11066	19.2	.24389	12.5
7 population fractiles	.12194	10.9	.26862	3.6
7 income fractiles	.11632	15.0	.26414	5.2
10 A&M-T groups	.13333	2.6	.27351	1.9
10 A&M-G groups	.13183	3.7	.27502	1.3
10 population deciles	.12728	6.7	.27350	1.9
10 income deciles	.12266	10.4	.27039	3.0
17 A&M-T groups	.13559	0.9	.27704	0.6
17 A&M-G groups	.13470	1.6	.27742	0.5
17 CBS groups	.12412	9.3	.27133	2.7
17 population fractiles	.13256	3.2	.27677	0.7
17 income fractiles	.12867	6.0	.27505	1.3
28 A&M-T groups	.13639	0.4	.27803	0.3
28 A&M-G groups	.13584	0.8	.27822	0.2
28 CBS groups	.13626	0.5	.27796	0.3
28 population fractiles	.13464	1.6	.27795	0.3
28 income fractiles	.13201	3.6	.27704	0.6

Although A&M grouping gives better results for all cases it must not be forgotten that A&M grouping is different for Gini and Theil. In the case of 28 groups the CBS brackets give (slightly) better results than A&M-G for T.

So, as the A&M results for a larger number of groups are hardly better than CBS grouping the question arises whether optimal brackets are preferred to efficient brackets, which have rounded income intervals and do not differ with the distribution of the incomes or the index used. For the case of 28 groups the answer will be negative.

Table 2 Underestimation (in%) of Gini and Theil due to grouping (LSO 1979, N=23 484, full-timers)

	Theil	%	Gini	%
individual data	.07853	-	.21291	-
7 A&M-T groups	.07489	4.6	.20506	3.7
7 A&M-G groups	.07355	6.3	.20720	2.7
7 CBS groups	.05190	33.9	.16828	21.0
7 population fractiles	.06908	12.0	.20437	3.8
7 income fractiles	.07203	8.3	.20571	3.4
10 A&M-T groups	.07667	2.4	.20896	1.9
10 A&M-G groups	.07590	3.4	.21011	1.3
10 population deciles	.07235	7.6	.20865	2.0
10 income deciles	.07445	5.2	.20909	1.8
17 A&M-T groups	.07777	1.0	.21118	0.8
17 A&M-G groups	.07759	1.2	.21192	0.5
17 CBS groups	.07692	2.1	.21130	0.8
17 population fractiles	.07545	3.9	.21129	0.8
17 income fractiles	.07653	2.6	.21145	0.7
28 A&M-T groups	.07823	0.4	.21216	0.4
28 A&M-G groups	.07819	0.4	.21244	0.2
28 CBS groups	.07798	0.7	.21202	0.4
28 population fractiles	.07690	2.1	.21227	0.3
28 income fractiles	.07759	1.2	.21235	0.3

As the wages of part-timers may play a part in the results, the outcomes for wages of full-timers only are given in table 2. For full-timers the level of inequality is much lower than for part-timers, in percentages: 43 for T and 24 for G. All the same, the A&M groups give in all cases slightly better proportional results. The underestimation is for population fractiles in all cases greater and for income fractiles smaller than in table 1. While for all wages population fractiles do better than income fractiles for all groupings, the opposite is true for wages of full-timers only. For the CBS groupings the results are very different. For 7 groups the underestimation is now 34% for T and 21% for G. On the other hand, for 17 groups there is a substantial improvement, the underestimation of T is now only 2.1% (against 9.3% in table 1), being smaller than for population fractiles (3.9%) and income fractiles (2.6%). For G the CBS grouping is very good, as all grouping methods are (less than 1% underestimation). Finally for 28 CBS groups the underestimation error remains very low, .7% for T and .4% for G, although it is slightly higher than in table 1. The reason is that the within-group inequality hardly changes, while the between-group inequality is much lower.

So, again the question arises whether optimal brackets are efficient brackets. For the case of 28 groups the answer will still be negative. But also in the case of 17 groups the advantages of rounded and uniform brackets seem to outweigh the advantage of optimal brackets in the Aghevli and Mehran sense.

In tables 3 and 4 the upper limits of the brackets are given for 7, 10, 17 and 28 groups for the different grouping methods. The brackets show great variation, not only between CBS, fractiles and A&M brackets, but also between A&M for Theil and Gini and for wages of all as opposed to full-timers. In all cases the lowest upper limit is for A&M-T lower and the highest upper limit higher than for A&M-G. For instance: for 7 groups A&M-Theil varies from the first to the sixth bracket from 162 to 1352, while A&M-Gini only varies from 237 to 1032. The reason is that Gini is relatively more sensitive to changes between the mid incomes (Champernowne 1974). The effect of leaving out part-timers is very substantial: for 7 groups the upper limits of the first and the sixth brackets are now 373 and 1522 for A&M-T.

The difference between population and income fractiles is of course due to the fact that the lowest population fractile earns the smallest income share while the highest earns the largest income share. Nevertheless, it is remarkable that the upper limits of all the lowest groups are lower for A&M-G and -T than for fractiles and all but three (out of 32) of the next highest group are higher (the upper limits of A&M-G were lower than those of income fractiles in the case of all wages for 7, 17 and 28 groups). In general it can be stated that, from the point of view of measuring income inequality, there are too many data in the lowest as well as in the highest fractile group, not only for calculating T but even for G. For population fractiles this error is more serious for the highest and for income fractiles more serious for the lowest

Table 3 Brackets for different grouping methods (LSO 1979, N= 29 271, all wages)

upper limit		A&M-T	A&M-G	CBS	Pop.	Inc.
7 groups	1	163	237	179	269	439
	2	345	404	232	426	528
	3	517	514	304	507	603
	4	683	617	375	579	685
	5	928	754	446	664	808
	6	1352	1032	625	819	1074
10 groups	1	136	197	-	216	396
	2	266	335	-	343	480
	3	386	443	-	436	537
	4	501	516	-	493	589
	5	611	586	-	543	644
	6	744	662	-	594	707
	7	932	763	-	655	791
	8	1208	924	-	740	941
	9	1649	1228	-	914	1203
17 groups	1	73	125	400	137	320
	2	140	221	450	239	414
	3	217	292	500	317	464
	4	292	363	550	383	501
	5	370	419	600	432	533
	6	440	461	650	468	563
	7	500	499	700	499	593
	8	559	538	750	528	627
	9	620	578	800	557	659
	10	688	623	900	589	697
	11	770	673	1000	623	743
	12	874	735	1100	659	800
	13	1009	816	1200	707	879
	14	1189	932	1300	769	985
	15	1432	1108	1400	869	1146
	16	1838	1403	1500	1075	1412
28 groups	1	42	87	36	94	258
	2	73	150	71	165	344
	3	105	213	107	227	409
	4	140	259	143	269	439
	5	178	305	179	320	466
	6	213	348	214	359	488
	7	243	390	250	403	508
	8	274	422	286	426	528
	9	308	447	321	450	548
	10	347	469	357	470	566
	11	390	489	393	489	584
	12	430	508	429	507	603
	13	464	527	464	524	624
	14	497	547	500	543	644
	15	533	567	536	560	662
	16	571	590	571	579	685
	17	613	613	607	598	713
	18	657	640	643	619	739
	19	705	669	679	644	773
	20	764	704	714	664	808
	21	840	747	804	693	858
	22	939	801	893	723	913
	23	1066	869	1071	767	982
	24	1221	959	1250	819	1074
	25	1409	1080	1429	896	1178
	26	1663	1262	1607	1019	1333
	27	2037	1549	1786	1223	1580

Table 4 Brackets for different grouping methods
(LSO 1979, N= 23 485, full-timers)

upper limit		A&M-T	A&M-G	CBS	Pop.	Inc.
7 groups	1	373	406	179	423	476
	2	512	502	232	497	555
	3	639	587	304	557	626
	4	810	683	375	624	709
	5	1077	827	446	708	836
	6	1522	1121	625	871	1104
10 groups	1	337	375	337	389	445
	2	444	463	444	457	509
	3	530	535	530	504	560
	4	621	586	621	546	610
	5	730	650	730	590	663
	6	872	727	872	639	726
	7	1072	835	1072	697	818
	8	1359	1008	1359	787	967
	9	1808	1307	1808	973	1235
17 groups	1	301	315	400	330	412
	2	387	395	450	413	459
	3	460	448	500	444	497
	4	523	490	550	473	528
	5	586	529	600	501	557
	6	650	566	650	525	587
	7	719	604	700	552	616
	8	792	644	750	575	647
	9	870	687	800	602	680
	10	958	738	900	632	717
	11	1064	801	1000	662	767
	12	1187	882	1100	701	824
	13	1317	989	1200	750	906
	14	1465	1127	1300	816	1020
	15	1689	1315	1400	924	1168
	16	2064	1617	1500	1132	1444
28 groups	1	246	285	36	289	359
	2	298	347	71	351	418
	3	347	404	107	401	452
	4	396	443	143	423	476
	5	444	479	179	445	498
	6	486	509	214	464	517
	7	528	539	250	481	537
	8	569	567	286	497	555
	9	613	595	321	512	572
	10	657	625	357	527	590
	11	702	654	393	543	607
	12	754	686	429	557	626
	13	812	719	464	574	644
	14	870	755	500	590	663
	15	929	791	536	605	684
	16	989	832	571	624	709
	17	1046	877	607	644	732
	18	1106	929	643	660	763
	19	1167	991	679	681	793
	20	1227	1060	714	708	836
	21	1289	1136	804	735	882
	22	1361	1219	893	770	945
	23	1450	1311	1071	811	1017
	24	1561	1421	1250	871	1104
	25	1702	1537	1429	954	1205
	26	1899	1721	1607	1079	1361
	27	2217	1996	1786	1298	1605

income group.
Here is the reason why income fractiles give better results for wages of full-timers and population fractiles for all wages.

As far as the CBS groupings are concerned, the reason that the 7 groups classification is not suitable for measuring income inequality is obvious: the upper limit of the sixth group is much too low, being 625 instead of far more than 1000. The simple 17 CBS brackets work very well for full-timers (for whom they are intended) as stated above. For all wages the upper limit of the lowest group is far too high: 400 instead of 73 (A&M-T) or 125 (A&M-G). Finally the 28 CBS groups do very well. In the case of full-timers only (for whom they are not intended) there are far too many lower brackets, the upper limit of the seventh bracket being 250, while that of the first A&M-T bracket is 246 and for A&M-G 285. Nevertheless the underestimation of the inequality indexes remains very small (see above).

4 Conclusions

Inequality indexes computed from grouped income data underestimate the true value of the measure. The extent of underestimation varies with the number of groups, the brackets used, the distribution of the incomes and the inequality measure. In this paper Dutch CBS brackets, optimal brackets in the sense of Aghevli & Mehran (1981), population and income fractiles are compared with respect to both the Gini index and Theil index for 7, 10, 17 and 28 groups of income data.

Calculations based on a comprehensive sample of individual wages, including part-timers and full-timers, lead to the following conclusions:

- A&M brackets give of, course, the lowest underestimation error in all cases; the proportional error for full-timers is slightly lower than for all;
- as Gini is more sensitive to changes between the mid-incomes, the lowest and the highest A&M bracket both contain more wages for G than for T;
- as A&M-G and -T differ, A&M-T for G and A&M-G for T are not in all cases better than CBS brackets or fractiles, although the differences are negligibly small;
- according to A&M, classification in fractiles leads to too many wages in the lowest as well as in the highest bracket; for population fractiles this error is more serious for the highest, and for income fractiles more serious for the lowest bracket;
- as a result, population fractiles do better than income fractiles for all

wages, the opposite being true for wages of full-timers only;

- the 7 CBS brackets are not suitable for computing income inequality, while 17 simple CBS brackets do very well for full-timers (for whom they are intended), and are preferred to fractiles;
- the underestimation error for 28 simple CBS brackets is negligibly small so that on efficiency grounds they are preferred to A&M brackets as well as to fractiles.

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Appendix - The data

CBS bracket		number of wages	
per year	per week	all	full-timers
0 - 2000	0 - 36	148	0
2000 - 4000	36 - 71	487	3
4000 - 6000	71 - 107	641	0
6000 - 8000	107 - 143	511	2
8000 - 10000	143 - 179	482	6
10000 - 12000	179 - 214	625	56
12000 - 14000	214 - 250	772	231
14000 - 16000	250 - 286	803	395
16000 - 18000	286 - 321	924	567
18000 - 20000	321 - 357	853	546
20000 - 22000	357 - 393	842	599
22000 - 24000	393 - 429	1385	1162
24000 - 26000	429 - 464	1666	1470
26000 - 28000	464 - 500	1934	1782
28000 - 30000	500 - 536	2075	1952
30000 - 32000	536 - 571	2108	2004
32000 - 34000	571 - 607	1961	1902
34000 - 36000	607 - 643	1581	1514
36000 - 38000	643 - 679	1568	1525
38000 - 40000	679 - 714	1365	1349
40000 - 45000	714 - 804	2075	2046
45000 - 50000	804 - 893	1280	1251
50000 - 60000	893 - 1071	1445	1413
60000 - 70000	1071 - 1250	753	741
70000 - 80000	1250 - 1429	435	427
80000 - 90000	1429 - 1607	268	259
90000 - 100000	1607 - 1786	136	136
100000 - 150000	1786 - 2679	148	147

Source: CBS (1983)

Ontvangen: 04-02-1987
Geaccepteerd: 04-09-1987