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Bernard Grofman
University of California, Irvine

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Comparing the Compactness of California Congressional Districts Under Three Different Plans: 1980, 1982, and 1984

Thomas Hofeller and Bernard Grofman

Gerrymandering is the drawing of boundaries of districts, so as to advantage candidates of one political or racial group at the expense of another. While ill-compactness has often been proposed as the hallmark of a gerrymander, we believe that it is better seen as a potential indicator of gerrymandering. In our view, analysis of ill-compactness must be coupled with an analysis of the political (racial) consequences of boundary manipulations if it is to be relevant to a determination of probable partisan (racial) gerrymandering (Grofman, 1983a; Niemi et al., 1990).

Gerrymandering is based on the wasting or weakening of the votes of what is usually the minority political party or racial interest group. This is accomplished by packing minority voting strength in a limited number of districts, and/or by fracturing smaller areas of concentrations of minority voting strength and submerging them in districts with just enough majority voting strength to render them ineffective. Usually both of these methods of dilution are present in gerrymanders involving large numbers of districts. The gerrymander does not require the construction of irregularly shaped districts in all situations. There are many instances, particularly in racial gerrymandering, when very compact districts can, if cleverly drawn, result in plans that are dilutive of minority voting strength.

While irregular boundaries can result from an attempt to follow neutral criteria, it is unlikely that a plan with a significant number of irregularly shaped districts does not have some of its irregularities due to gerrymandering. The combination of ill-compactness and other evidence of gerrymandering intent, when combined with indicia of gerrymandering effects, should shift the burden of proof to those drafting (or defending) a plan to explain why districts are not compact. (Cf. the view of Justice Stevens in *Karcher v. Daggett (I)*, 462 U.S. 725 (1983).)

We look at the compactness of three congressional plans for a single state, the state of California: the Masters' Plan, adopted in 1973 and used for the 94th through the 97th Congress (43 seats); the plan adopted in 1981 (commonly known as Burton I in honor of the late Congressman Philip Burton who was its chief drafter) and used for only one election (1982, the 98th Congress), because it was subsequently rejected by voter referendum (45 seats); and the plan adopted in 1982 (commonly known as Burton II), which was used in the 1984 and 1986 elections (the 99th and 100th Congress) and will be used for the rest of the decade absent court intervention, also a 45-seat plan.

A necessary starting point is the specification of compactness scores so as to identify ill-compact districts or ill-compact plans. There are three key issues involving compactness. First, how is the term to be defined? Second, how can we best measure compactness? Third, are judgments of compactness to be made about individual districts or about plans (or large geographic areas) as a whole?

DEFINING AND MEASURING COMPACTNESS

Webster defines the adjective compact as "occupying a small volume by reason of efficient use of space" or "having parts or units closely packed or joined." This definition is a useful starting point in terms of redistricting. The ideal shape, in terms of these definitions, would be a circle. A circle is the geometric figure that is the most compact, that is, having the largest area possible within the shortest boundary (perimeter).[1]

There are two conceptually distinct ways in which a district can fail to make efficient use of space; one is by having an area that is unduly "spread out"; the other is by having a perimeter that is large relative to the minimum perimeter needed to contain the same area. We refer to measures of these two distinct aspects of ill compactness as *dispersion measures* and *perimeter measures*, respectively (Niemi et al., 1990). Perimeter measures penalize for irregularities in the shape of boundaries, for example, sawtooth edges. Dispersion measures are not affected by irregular boundaries unless the irregularities have substantial effects on how large an area is contained in the district.

We will make use of one standard dispersion measure of compactness, the ratio of the district area to the area of the smallest circle that contains (circumscribes) the district;[2] and one standard perimeter measure of compactness, the ratio of the district area to the area of the circle whose circumference is identical to the district perimeter.[3] We will refer to the first of these measures as the *circumscribing circle measure*, and the second as the *perimeter circle* measure.

As noted by Niemi and Wilkerson (chapter 12), the circumscribing circle and perimeter circle measures are each invariant with respect to the units (e.g., miles, kilometers) in which district boundary is being measured. Both vary between zero and one, assigning zero to the least compact and one to the most compact district. For both measures a circle is perfectly compact. However, except for extreme cases, the two measures will usually assign different scores to a given district; although both measures are likely, in practice, to be similar in the way they rank order districts as to compactness (see further discussion of this point in Niemi et al., 1990). The circumscribing circle model, unlike the perimeter circle model,[4] does not require extreme accuracy in entering the perimeter of the districts into the computer.[5]

We will also make use of a third measure of compactness, one based on population dispersion rather than a real dispersion or perimeter irregularities. Population dispersion measures form an important third type of compactness measures. What measures of this type penalize for are excessive extrusions and indentations that actually reach out for or are drawn to exclude significant centers of population.

The *population polygon* measure of population compactness calculates the ratio between the population of each district and the population of the area inside the polygon with the shortest possible perimeter length that completely surrounds the district.[6] This method takes into account both extrusions and intrusions. The real advantage of this measure, however, is that it only punishes for irregular shapes that bypass voters—not geographic areas that may contain few people (see, however, discussion of this method in Niemi et al., 1990).[7]

It is the fracturing or packing of voters that comprises the fundamental element of the gerrymander. Any model that does not take into account the distribution of population may miss gerrymandering even in many cases in which visual examination would clearly indicate its presence. Consider an example in which portions of one or more geographically large but sparsely populated rural counties are combined with a portion of densely populated city. There could be an extremely intricate gerrymander present in the geographically small (but highly populous) urban portion of the district; yet, because the portion of the district affected by this gerrymander is extremely small in comparison to either the total geographic area of the district or the total perimeter length of the district, neither the circumscribing circle model nor the perimeter circle model might indicate any aberration.

Each of the three measures described above has limitations, and we urge that none be used in mechanical fashion to reject districts (or plans) that lie below some preset threshold. For example, the perimeter measure of compactness penalizes for irregular boundary lines that may result due to natural features such as winding coastlines, rivers, ridge lines of mountain ranges, or governmental boundaries of political subunits such as cities or counties. Such factors might provide the basis for rebuttal to claims of ill-compactness. Also, what is on average possible for a plan as a whole may vary from jurisdiction to jurisdiction. We believe it useful to compare alternative plans for the same jurisdiction to see what overall level of compactness is feasible. That is why we are comparing three different plans for California.

DATA ANALYSIS

The application of the perimeter-circle model produced values that were generally in the .3% to .5% range, with only one district above .6% out of the 212 districts analyzed. The application of the circumscribing-circle model produced values that were generally in the .3% to .5% range, with no district above .6% out of the 212 districts analyzed. The application of the population polygon model produced values that were generally in the .5% to .8% range, with districts running from a high of .96 to a low of .26. See Table 14.1.

Now we turn to a comparison of plans. Looking at the perimeter circle measure, the range of scores in the Masters' Plan was .15 to .72 with a mean of .38 and a standard deviation of .11. In contrast, in Burton I the range was .05 to .40, the mean was .19, and the standard deviation was .09; for Burton II the range was .06 to .39, the mean was .20, and the standard deviation was .09. Thus, it is apparent that, in terms of the perimeter circle measure, the Masters' Plan was far more compact than either of the other two plans, but that there was little to choose between Burton I and Burton II.

Looking at the circumscribing circle measure, the range of scores in the Masters' Plan was .13 to .60 with a mean of .40 and a standard

TABLE 14.1. Comparison of Measures of Compactness for California Congressional Plans 1974–1986

	Perimeter Circle			Circumscribing Circle			Population Polygon		
District Plan	94 Masters'	98 Burton I	100 Burton II	94 Masters'	98 Burton I	100 Burton II	94 Masters'	98 Burton I	100 Burton II
CD01	.57	.17	.17	.59	.22	.17	.84	.66	.83
CD02	.23	.17	.29	.18	.36	.39	.96	.72	.77
CD03	.53	.36	.39	.55	.53	.54	.87	.86	.88
CD04	.30	.21	.22	.39	.43	.42	.40	.45	.44
CD05	.34	.40	.39	.37	.51	.34	.87	.87	.73
CD06	.49	.17	.26	.49	.30	.43	.55	.32	.61
CD07	.30	.24	.30	.38	.34	.36	.67	.67	.66
CD08	.30	.11	.16	.55	.22	.30	.86	.66	.69
CD09	.29	.19	.24	.30	.29	.28	.61	.59	.57
CD10	.25	.21	.30	.30	.32	.40	.86	.74	.80
CD11	.42	.17	.24	.43	.40	.41	.85	.83	.93
CD12	.44	.10	.14	.55	.26	.32	.78	.28	.30
CD13	.33	.13	.17	.45	.35	.36	.51	.67	.70
CD14	.33	.21	.21	.35	.34	.24	.55	.26	.33
CD15	.41	.21	.23	.49	.50	.41	.51	.52	.52
CD16	.35	.24	.19	.27	.27	.25	.78	.83	.81
CD17	.37	.20	.29	.42	.53	.52	.89	.56	.53
CD18	.32	.11	.13	.45	.27	.30	.66	.45	.45
CD19	.35	.27	.27	.38	.34	.34	.59	.79	.81
CD20	.37	.14	.17	.56	.28	.28	.67	.59	.40
CD21	.42	.10	.10	.33	.30	.37	.80	.42	.33
CD22	.38	.11	.14	.39	.26	.41	.59	.35	.47
CD23	.50	.10	.07	.48	.40	.19	.83	.68	.60
CD24	.52	.26	.29	.46	.42	.40	.84	.76	.78
CD25	.49	.16	.19	.40	.26	.29	.83	.71	.67
CD26	.29	.05	.09	.33	.36	.44	.51	.57	.61
CD27	.15	.06	.06	.13	.15	.13	.50	.46	.52
CD28	.38	.17	.24	.35	.37	.38	.84	.67	.74
CD29	.58	.22	.19	.52	.36	.31	.80	.74	.69
CD30	.30	.09	.11	.38	.21	.20	.76	.54	.54
CD31	.32	.18	.16	.29	.40	.38	.78	.64	.65
CD32	.39	.08	.08	.46	.18	.24	.69	.64	.56
CD33	.25	.13	.17	.21	.39	.38	.52	.27	.37
CD34	.35	.09	.10	.34	.28	.31	.75	.66	.62
CD35	.45	.33	.38	.51	.33	.48	.92	.34	.34
CD36	.48	.09	.11	.46	.34	.35	.85	.79	.74
CD37	.72	.37	.38	.60	.26	.26	.79	.71	.77
CD38	.29	.17	.09	.29	.37	.25	.74	.71	.64
CD39	.52	.36	.27	.52	.57	.50	.88	.87	.81
CD40	.39	.21	.24	.35	.49	.47	.70	.59	.64

(continued)

TABLE 14.1. (*Continued*)

District Plan	Perimeter Circle			Circumscribing Circle			Population Polygon		
	94 Masters'	98 Burton I	100 Burton II	94 Masters'	98 Burton I	100 Burton II	94 Masters'	98 Burton I	100 Burton II
CD41	.31	.15	.18	.34	.42	.38	.55	.68	.66
CD42	.34	.10	.08	.46	.23	.22	.81	.50	.38
CD43	.37	.29	.29	.32	.37	.35	.44	.86	.89
CD44		.12	.12		.33	.37		.68	.77
CD45		.31	.33		.36	.37		.42	.36
Average	.38	.16	.20	.40	.34	.34	.72	.61	.62
Stan. Dev.	.11	.09	.09	.11	.10	.09	.15	.17	.17

deviation of .11. In contrast, in Burton I the range was .15 to .57, the mean was .34, and the standard deviation was .10; for Burton II the range was .13 to .54, the mean was .34, and the standard deviation was .09. Thus, it is apparent, in terms of the circumscribing circle measure, that the Masters' Plan was more compact than either of the other two plans, but that again there was little to choose between Burton I and Burton II.

Looking at the population polygon measure, the range of scores in the Masters' Plan was .44 to .96 with a mean of .72 and a standard deviation of .15. In contrast in Burton I, the range was .26 to .87, the mean was .61, and the standard deviation was .17; for Burton II the range was .30 to .89, the mean was .62, and the standard deviation was .17. Thus, it is again apparent that, in terms of the population polygon measure, the Masters' Plan was more compact than either of the other two plans, but there was little to choose between Burton I and Burton II.

Hence, whichever compactness measure we choose, the Masters' Plan is more compact than either Burton I or Burton II.[8] Grofman (1983a) has shown that a number of the ill-compact aspects of these two plans are directly related to attempts to achieve partisan advantage through concentration or dispersal gerrymandering techniques.

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NOTES

1. Of course, an area cannot be packed with contiguous circles. Nonetheless most measures based on other geometric figures such as squares or hexagons can in general be treated simply as mathematical transformations of measures based on circles (Manninen, 1973; Niemi et al., 1990).
2. This measure is identified as "Dispersion 2" in Niemi et al. (1988). It is almost always identical to the "longest axis" measure used by Niemi and Wilkerson (chapter 12). See Niemi et al. (1990) or Manninen (1973) for details of possible differences between the two measures. In the political science literature this measure is often called the Reock measure, although Reock (1963) was not in fact the first to propose it.
3. This measure is what Niemi and Wilkerson (chapter 12) and Niemi et al. (1990) refer to as "Perimeter 2." The area of a circle with circumference equal to the perimeter, P, of the district is found by solving $R = 2\pi r$ in terms of r, the radius of the desired circle, and then substituting that value in the formula for the area of a circle, Πr^2. Doing so we obtain $p^2/4\Pi$. Dividing the area of the figure, A, by that fraction, we obtain the formula $4\Pi A/p^2$.
4. Data used are "digitized" district boundaries expressed in terms of very small line segments. A digitizer is a piece of computer graphics input hardware that registers "x" and "y" coordinates into the computer each time the end of a straight-line segment is passed in order around the district's boundary. Using this methodology, we must be sure that the computer properly "closes" the polygon that represents the outside perimeter of the district, and that the program is fed the "x" and "y" coordinates in correct order around the polygon. There are various other technical issues. For example, when "digitizing" district boundaries, extreme care must be used to enter in all the details of the perimeter of each district. There is a real possibility that use of maps of different scales will mask details in "rural" districts, since urban districts are shown in more detail on a smaller scale map. This, in turn, will result in better ratios for the rural districts in comparison to the urban districts, which are usually drawn on much more detailed maps. What non-attention to this technical requirement amounts to is unintentional and inconsistent line-smoothing. Of course, in comparing plans, if rural and urban districts are treated similarly in calculating values for each of several different plans the bias imposed is apt to be minimal to nonexistent.
5. The circumscribing circle measure requires a somewhat complex algorithm to calculate if the circle using the longest axis of the district as diameter is not large enough to circumscribe the district. The first step in this process is to determine which two points on the perimeter are the greatest distance away from one another. This requires calculating a pairwise distance matrix. A circle is then computed that has its center midway between the two maximally distant points and a radius equal to half the distance between those points. After the first circle has been calculated, each point on the district perimeter is tested to see if any point is

outside the circumference of the circle. If not, then the first circle is the correct circumscribing circle. If one or more points are outside, the point furthest outside is used with the two original points to calculate a new circle center. The three new points then form a triangle. A new circle center is determined which is the point equidistant from the three points of the triangle. A new circle is calculated and all the points on the perimeter of the district are again tested to see if all are inside or tangent to the circle. This process is then repeated as often as needed.

Calculations of the circumscribing circle measure using data of different standards of precision should, nonetheless, generally be comparable. Moreover, a very good approximation to the circumscribing circle can often be determined visually, as can the length of a district's longest axis.

6. If the shape of the district were to be cut out of a sheet of wood, and a rubber band were to be stretched around the sides of the cut-out shape, roughly speaking, the rubber band would form the smallest possible polygon in terms of total length. This model is not without some problems in terms of its practical applications. Considerably more data are required to run the model than for either the perimeter circle or circumscribing circle model. Not only must the boundaries of the districts be accurately entered into the computer, but the model also requires that populations within small units of census geography (e.g., enumeration districts or census blocks) be specified. However, population centroid data may be substituted for exact boundaries, and this considerably simplifies the computational problems.
7. One distinct advantage of this model is that it can realistically give rise to values at or near 1.0. For example, a straight line bisecting any state will produce two districts with 1.00 values (areas outside state lines are not counted for population purposes). If either of those two districts is bisected by another straight line, the compactness value for each of the districts will still be 1.00.
8. Comparing alternative plans helps to judge whether deviations from compactness are in fact mandated by geographic necessity, as defendants of a plan sometimes claim. Sometimes, however, detailed inspection of specific districts and their possible justifications is also called for. For example, in California, cities such as Fresno and San Jose have extremely irregular boundaries. Thus, following city boundaries may decrease compactness. Burton II, however, has districts that divide these cities. If irregular city boundaries were the primary reason for irregular district boundaries in metropolitan areas in Burton II, then the portions of the perimeters of the districts that run through the interior of these cities and through unincorporated areas should be relatively smooth; this is simply not the case.