

What are Judicially Manageable Standards for Redistricting? Evidence from History

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Abstract

In the 1960s the courts adopted population-equality measures as a means to limit gerrymandering. In recent cases, the courts have begun to use geographical compactness standards for this same purpose. In this research note, I argue that unlike population-equality measures, compactness standards are not easily manageable by the judiciary.

I use a variety of compactness measures and population-equality measures to evaluate 349 district plans, comprising the 3390 U.S. Congressional districts created between 1789 and 1913. I find that different population-equality measures, even those with poor theoretical properties, produce very similar evaluations of plans. On the other hand, different compactness measures fail to agree about the compactness of most districts and plans.

In effect, the courts can use any convenient measure of population equality and obtain similar results, while the courts' choice of compactness measures will significantly change the evaluations in each case. Since there is no generally accepted single measure of compactness, this disagreement among measures raises concerns whether compactness is a readily operationalizable notion, to use a social scientific formulation, or a judicially manageable one, to employ terms from law.

1. Redistricting rules and electoral results

It has long been recognized that the way that election districts are created can affect who wins in an election. A number of recent studies have shown that redistricting has powerful effects. (Gelman and King 1994; Kousser 1995), and several scholars blame redistricting for much of the heavy Democratic loss in the 1992 and 1994 congressional elections. (Hill 1995; Swain 1994) Many scholars who are concerned with these issues have asserted that we can limit the influence of redistricting on elections by requiring that districts satisfy formal geographic properties such as contiguity, compactness and population equality. (Polsby and Popper 1991; Stern 1974)

Many judges seem to share the opinion of such scholars that the electoral effects of redistricting can be controlled through formal rules for drawing districts. Contiguity, compactness and population equality are near the heart of many of the recent legal battles over district maps. In particular, the Supreme Court, in two recent redistricting decisions, *Shaw v. Reno* (1993) and *Miller v. Johnson* (1995), makes arguments that are closely tied to redistricting mechanisms. In both cases, the Court held that the failures of the legislature to use “traditional” criteria when it created the districting plans was a ground for subjecting the plan to strict scrutiny. The decision in *Shaw* even seems to require that district appearance be constitutionally assessed, in and of itself (Pildes and Niemi 1993), although *Miller* may mark a retreat from this requirement.

Population equality has been applied by the Court to districts since the 1960’s, culminating in *Karcher v. Daggett* (1983), in which the Supreme Court overturned New Jersey’s congressional districting plan because of a 0.698 percent population deviation between the largest and smallest districts. Compactness, on the other hand, has never been held to be a principle that affects the constitutional permissibility of a plan. It has become important recently because the Court used it as a criterion for qualifying challenges to district plans under the Voting Rights Act (V.R.A) *Thornburgh v. Gingles* (1986), and as an indication of narrow tailoring in *Shaw v. Reno* (1993) and

Miller v. Johnson (1995). Even so, the courts have evaluated compactness only in a vague and imprecise manner.

Political and legal scholars have made extreme claims about the value of compactness criteria: Polsby and Popper, strong proponents of compactness, claim in the *Yale Law and Policy Review* that such a standard could virtually eliminate gerrymandering, or, at the least, “make the gerrymanderer’s life a living hell.” (Polsby and Popper 1991, 353)² At the same time, opponents of compactness measures claim that these standards are at best ineffective (Grofman 1985; Musgrove 1977), or at worst often contrary to substantive principles of representation. (Cain 1984; Lijphart 1989; Lowenstein and Steinberg 1985; Mayhew 1971)

Should compactness standards come to play the same critical role in redistricting that population standards play now? I argue that they should not: compactness standards raise troubling problems of judicial consistency and manageability that were not raised by population standards. In this paper, I use United States congressional districts from 1789 through 1913 to compare malapportionment standards and several compactness standards. I have argued in earlier theoretical papers that most compactness measures are inconsistent because there are many ways of manipulating electoral boundaries, and, at most, that compactness measures capture varied and isolated aspects of electoral manipulation (Altman 1995). Does the data from real political districts support this previous theoretical analysis? Do the various compactness measures fail to agree with each other when they are calculated for real districts?

2. Data Sources

No single source contains all geographical and population data for U.S. congressional districts over the entire period from 1789 through 1912; for different periods I turned to several different sources. Data on the geography of election districts is available from several overlapping data series.

²In addition, Wells and Stern make claims which are nearly as strong. (Stern 1974; Wells 1982)

For election districts used between 1789 through 1912, I extracted geographical data from the *United States Congressional Districts and Data* series (Parsons, Beach and Hermann 1978; Parsons, Dubin and Parsons 1990; Parsons, Beach and Dubin 1986).

I extracted the tabular data using an optical character recognition system, in addition to manually entering data.³ Extracting compactness data from the district maps was more complicated: First, I digitized each district map using an optical scanner⁴. Second, I used image processing software⁵ to identify the boundaries of each district and to estimate its geographical properties. Third, I used image analysis software to apply standard mathematical formulas (described in section 3.1) that calculate compactness scores.

3. Evaluating Districts: Compactness and Population Measures Compared

3.1 Quantitative Measures of Malapportionment and Compactness

There are a number of different methods to measure malapportionment used in the scholarly literature and by the courts. The most popular early measures of population variation were the difference between the largest and smallest districts (divided by the mean), the population variance ratio, which is the ratio of the largest to the smallest district, the maximum (or average) percent deviation from the mean, and the electoral percentage, which is the minimum percentage of the population represented by a

³I used the commercial character recognition package Omnipage 3.0. All numerical data was independently double-checked to ensure correct entry.

⁴I used a HP-Scanjet III optical scanner operating at various resolutions ranging from 150–600 d.p.i. I used the higher level resolution when maps were particularly small and finely detailed.

⁵I used the software package NIH-Image (version 1.6), a program in the public domain developed by the National Institute of Health especially for mathematical analysis of two-dimensional digital images. This program has built in routines that remove noise from images, that automatically identify the outlines of selected shapes (districts in this case), and that measure perimeter, area (etc.) of a selected shape. It was necessary, however, to guide the program in its selection of districts, and to correct defects in the district maps, such as boundary lines that were obscured by text markers or map symbols, boundary lines that overlapped solely because of line-weight, and the like.

bare majority of seats.⁶ Later court cases have tended to stress the difference between the largest and smallest districts, and this measure was emphasized in *Karcher v. Daggett* (1983).

These measures have a number of theoretical faults, and Foster (1985) argues cogently that such measures as the Gini index, Theil's measure of entropy, and the coefficient of variation have more desirable theoretical properties (Foster 1985). Foster shows that these measures belong to a small group that are guaranteed to be Lorenz-consistent: if the Lorenz curve for distribution *A* dominates the Lorenz curve⁷ for distribution *B*, all of these measures will rank *A* higher than *B*. Because of this consistency property, I expected these measures to agree more often than the other set of measures.

In this analysis I use both popular measures and the theoretically compelling measures. I measure the population coefficient of variation⁸, the Gini⁹ coefficient, Theil's entropy measure¹⁰, the ratio of maximum and minimum district populations, the maximum deviation from the average district population, and the electoral percentage¹¹.

I included this last measure for the sake of completeness, but not without qualms. There are a number of problems that result from applying the electoral percentage to congressional district plans of individual states. First, as Dixon (1968) argues, this measure runs into numerical problems when a plan

⁶See Dixon (1968) chapter 17, section 4 and chapter 18, section 2.

⁷A Lorenz is the graph of the cumulative distribution, expressed as a percentage of the total distribution, of a sorted distribution.

⁸This is the standard deviation divided by the mean. Think of it as a measure of the average deviation.

⁹The Gini coefficient is twice the area under the Lorenz curve.

¹⁰I use the first of Theil's measures, which is given below, where $T(\mathbf{x})$ denotes the entropy of the inequality measure of a set of districts, and $|\mathbf{x}|$ denotes the total population of those districts:
$$\frac{1}{|\mathbf{x}|} \sum_{i=1}^n \frac{x_i}{|\mathbf{x}|} \ln \frac{x_i}{|\mathbf{x}|}$$

¹¹The electoral percentage is the minimum percentage of the population in a state needed to win a majority of the districts. Since all of the measures besides the electoral percentage increase as malapportionment increases I use $|50\% - \text{e.p.}|$ for this measure of malapportionment, where e.p. is the electoral percentage.

has few districts — in a state with two congressional districts the electoral percentage is necessarily 100 percent.¹² Last, the electoral percentage was defined with legislative districts in mind, and when we apply it instead to congressional districts it loses much of its political meaning, since capturing a bare majority of a state's congressional seats does not have the same direct political implications as does capturing a legislature. Consequently, I expected that the electoral percentage would perform poorly in these circumstances and could not be consistent with the other measures.

Contiguity is the most often mentioned geographic principle. It is a simple idea in theory, but is less so in practice. In the context of redistricting, contiguity is meant to be a signal of the political manipulation of districts, not just a formal and accidental property of district shapes. If we are to use contiguity in this fashion two hurdles must be overcome. First, mathematical contiguity does not reflect a constraint on electoral manipulation, as any given noncontiguous district (or set of districts) can be made contiguous by adding arbitrarily thin connecting lines, without materially changing the results of an election held in that district. (Sherstyuk 1993) Second, breaches of contiguity may be difficult or impossible to avoid because of geographic obstacles, such as large bodies of water, and such discontiguities occur in the absence of any political manipulation.

To overcome these hurdles, I divided districts into three categories in order of divergence from real-world contiguity: practically contiguous, questionably contiguous, and non-contiguous. All districts that are formally contiguous, or that only deviate from contiguity because of islands off the coast of the district I put in the first category. Into the second category I put districts that were otherwise contiguous but that contained islands that were not directly off the coast of the district, districts that were non-

¹² Dixon also argues (see Chap. 7, sec. 7.a) that this measure does not adequately reflect the realities of controlling an election, and I agree with him. It is also true that the other population measures fail to directly assess political power; but unlike the electoral percentage, the other measures can be argued to capture the formal, intrinsic value of an individual vote (see Lowenstein, 1990).

contiguous but could be connected by straight bridges, and districts that were connected only by “points”¹³. In the non-contiguous category, I put all other violations of formal contiguity. See Figure 1.

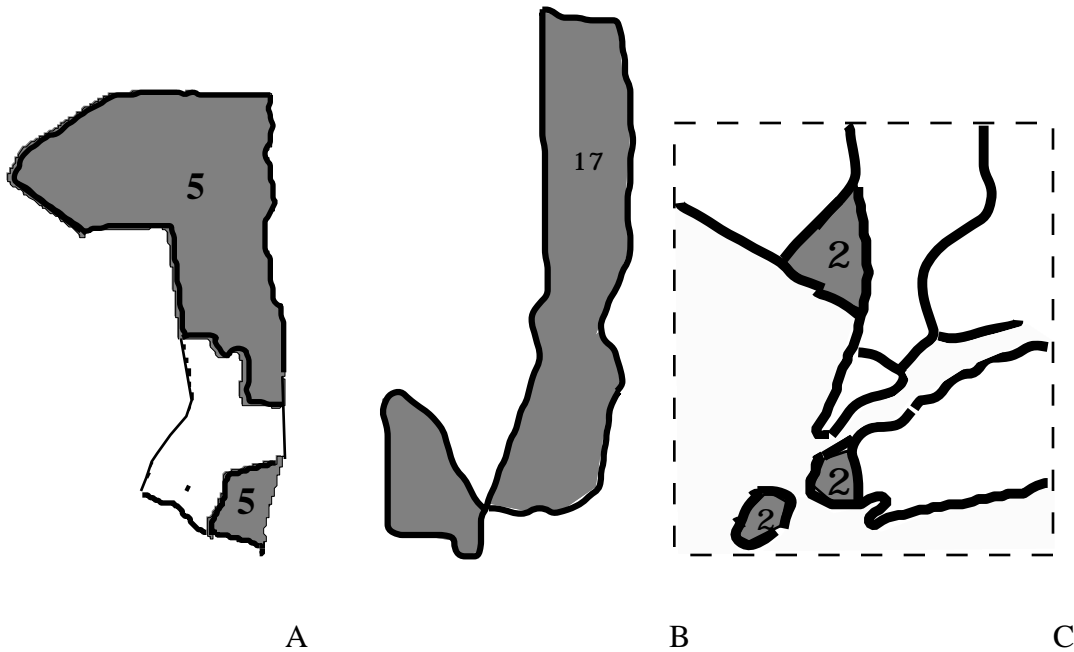


Figure 1: Three Odd District in Early New York Congressional Districting Plans. Part A shows the plainly non-contiguous fifth district in New York's first (1788) congressional districting plan. Part B shows the seventeenth district in the thirteenth (1812) Congressional district plan; this plan is of questionable contiguity because it is connected only at a single point. Part C shows district two in the twenty-third (1832) Congressional districting plan. The light shading shows areas covered with water. This district is of questionable contiguity because the island portions of the district are not joined to the nearest mainland district.

The literature contains many more ways of measuring the compactness of a set of districts than it does for measuring the malapportionment in those districts: Recent surveys of compactness criteria list over thirty-six different measurement formulas.¹⁴ While there are a plethora of different measurements, and many assertions as to their effectiveness, the vast majority of criteria are developed using *ad hoc*

¹³More formally, I classified a district as questionably contiguous when more than ten percent of the district's area was connected to the rest of the district by a passageway no longer than one percent of the district's length.

¹⁴See Niemi, et al., (1991) for the most comprehensive listing. (Also see Flaherty & Crumplin 1992; Frolov 1974; Young 1988 for alternative examinations of a variety of criteria.)

criteria¹⁵, and most measures have been criticized for making arbitrary or nonsensical distinctions between districts. (Altman 1995; Young 1988) Some advocates of compactness argue that the particular measure that we choose is irrelevant since most measures will lead to similar overall evaluations of different districts (Polsby and Popper 1991). The questions remain, how consistent are these measures in practice, and does it matter which measures the courts choose?

Geographically-based compactness measures fall into three rough categories: measures that compare the perimeter of a district to its area, measures that compare the length of a district to its width, and measures that compare the area of a district to the area of an idealized shape that encloses the district. I use four popular measures selected from among these categories (see Table 1)¹⁶.

<i>Name</i>	<i>Measurement</i>	<i>Comments</i>
Area/Perimeter (AP)	$A/0.282P$	See (Flaherty and Crumplin 1992).
Normalized Area/Perimeter (Norm)	$A/(0.282P)^2$	See (Flaherty and Crumplin 1992).
Area of Circle (AC)	The ratio of the district area to area of minimum circumscribing circle (Normalized to the [0,1] interval.)	See (Frolov 1974).
Length/Width (LW)	The length of the minor axes/major axes for the best fitting ellipse. ¹⁷	

Table 1: Compactness Measures

3.2 Comparing Different Measures

¹⁵For exceptions see Blair & Bliss (1967) and Altman (1995).

¹⁶Compactness measures can also be computed based upon population distribution instead of geographical distribution (See Altman 1995 and Niemi, et. al 1991 for a survey). State laws, constitutional provisions, and court cases, however, stress the geographical measures almost exclusively.

¹⁷Measures that compare length and width are common (see Niemi, et al. 1990) but these measures tend to be overly influenced by outlying points and are not necessarily orientation independent (Young 1988). By fitting an ellipse to the shape and measuring the axes of the ellipse both of these problems are reduced:

I calculate the best fitting ellipse by using the ‘ellipse of concentration’ (see (Cramer 1946)) which equates the second order central moments of the ellipse to those of the distribution of points in the district, and then adjust the resulting ellipse slightly so that it has the same area as the district being measured.

To see how well, in practice, these various measures of malapportionment and compactness agreed with each other I first used each measure to score all of the districting plans that were created between 1789 and 1913 and that contained two or more districts. One statistic that describes the strength of linear relationships between variables is the correlation coefficient. For reasons that I will explain shortly, this measure is not a good measure of the level of agreement between different methods of judging. But because of this statistic’s familiarity, and to contrast it with better ways of evaluating scoring methods, I calculated the correlation coefficient among all of these scoring methods for this data. See Table 2.

	<i>(Max-Min) /Mean</i>	<i>Pop. Variance Ratio</i>	<i>Coeff. of Variation</i>	<i>Gini Coeff</i>	<i>Theil’s Entropy</i>
<i>Pop. Variance Ratio</i>	0.63				
<i>Coeff. of Variation</i>	0.87	0.44			
<i>Gini Coeff.</i>	0.77	0.38	0.86		
<i>Theil’s Entropy</i>	0.17	0.12	0.20	0.62	
<i>Electoral Percentage</i>	-0.25	-0.07	-0.08	-0.08	0.19

Table 2: Correlation between malapportionment scores for multi-district plans: 1-62nd Congresses (349 observations)

These correlations seem to show that most of the malapportionment measures produce somewhat similar patterns of scores. Correlations are somewhat misleading in this case, however, because we are interested not in the scores themselves, but in how they are used to rank plans, and the correlation measure can produce either underestimates or overestimates of the level of agreements between rankings. Two malapportionment measures that are not linearly related may not correlate well, but can produce identical evaluations about districts. For instance, in this case Theil’s entropy measure correlates poorly with other measures simply because it uses a logarithmic scale. Conversely, two scoring methods that disagree most of the time can have a very high correlation if they contain high-valued outliers that are in agreement. Since the absolute score will vary arbitrarily with the measure being measured, when the courts compare two plans, they should not ask “How do these plans

score?”, “Which plan is best?”¹⁸ The answer to this question depends not on the raw malapportionment scores, but on the ordinal rankings produced by these scores. Kendall’s τ_β directly measures this similarity among ordinal rankings produced by different cardinal scores¹⁹.

Kendall’s measure is an intuitively appealing way of directly measuring the level of agreement between two scoring systems. First, for each pair of measures I count the number of concurrences, C , or times where both measures agree that one plan is more malapportioned than the other, I calculate the number of strict disagreements, D , and the number of unilateral ties under each malapportionment measure, T_x & T_y . Kendall’s τ_β is then simply ²⁰:
$$\tau_\beta = \frac{C - D}{\sqrt{(C + D + T_x)(C + D + T_y)}}.$$

Using Kendall’s Tau we can see that the level of agreement among malapportionment measures is even higher than the Pearson Product-Moment Correlation coefficients indicate (see Table 3). With the exception of the *electoralpercentage* measure, all of the measures agree in at least three quarters of all possible comparisons.

Table 3 bears out our expectations about these population measures. As expected, the electoral percentage measure seems to have little connection with any other measure of population equality. Also as expected, the three Lorenz-consistent measures agree more closely among themselves (0.89–0.94) than they do with other measures

¹⁸TFor each measure of malaportionment, the courts could specify a minimum acceptable score. Because the level of compactness that can be achieved varies with state geography, the number of districts in a plan, and the geographic distribution of population in a state, however, the courts will not be able to set a reasonable and effective minimum compactness levels (Altman 1995).

¹⁹There are three variations of Kendall’s Tau, which differ only in how they treat ties. I use Kendall’s Tau Beta because it penalizes measures for disagreement over ties. In this paper, the choice of variations was irrelevant because there were only a minuscule number of tied rankings.

²⁰See Liebetrau (1983) for a guide to Kendall’s measures and to other measures of association.

	<i>(Max-Min) /Mean</i>	<i>Pop. Variance Ratio</i>	<i>Coeff. of Variation</i>	<i>Gini Coeff</i>	<i>Thiel's Entropy</i>
<i>Pop. Variance Ratio</i>	0.96				
<i>Coeff. of Variation</i>	0.77	0.76			
<i>Gini Coeff.</i>	0.81	0.80	0.89		
<i>Thiel's Entropy</i>	0.80	0.79	0.91	0.94	
<i>Electoral Percentage</i>	-0.28	-0.28	-0.14	-0.18	-0.16

Table 3: Kendall's τ between population equality scores for multi-district plans: 1-62nd Congresses (349 observations)

Surprisingly, despite theoretical qualms about how best to measure malapportionment, all but one of these measures seem to be measuring the same underlying concept. The courts can use any popular measure of malapportionment and they will come to the same conclusions in the vast majority of cases. This should give us confidence that these standards are being applied consistently, and that these standards are judicially manageable.

Unfortunately, we cannot be so confident about measuring compactness. Compactness measures do not seem to be measuring the same thing. Many of the measures of compactness in this study disagree more often than not. Table 4a and 4b shows the level of agreement (τ) over scores for different compactness plans, while Table 5 shows the level of agreement among scores for individual districts; neither shows the same level of consistency that was shown by malapportionment measures.²¹

	<i>AC</i>	<i>AP</i>	<i>LW</i>
<i>AP</i>	0.08		
<i>LW</i>	0.56	0.09	
<i>NORM</i>	0.53	0.07	0.27

Table 4a: Kendall's τ between mean compactness scores for multi-district plans: 1-62nd Congresses (349 observations)

²¹ Here, my results disagree with those in (Niemi, et al. 1990). There are five reasons for this disagreement: Niemi, et. al. compare some compactness measures that come from the same class of general measures, they use a much more limited range of district data, their district plans are have more districts (15–100 districts) than the average congressional plan, and they use two measures of correlation, Pearson's ρ and Spearman's ρ , that measure agreement less directly than Kendall's Tau. (see Liebtrau 1983 for a discussion of the relative merits of these measures)

	<i>AC</i>	<i>AP</i>	<i>LW</i>
<i>AP</i>	0.23		
<i>LW</i>	0.51	0.29	
<i>NORM</i>	0.45	0.26	0.16

Table 4b: Kendall's τ between minimum compactness scores for multi-district plans: 1-62nd Congresses (349 observations). Here, the compactness of a plan is defined by its least compact district.

	<i>AC</i>	<i>AP</i>	<i>LW</i>
<i>AP</i>	0.11		
<i>LW</i>	0.54	0.08	
<i>NORM</i>	0.51	0.09	0.28

Table 5: Kendall's τ between compactness scores for individual districts: 1-62nd Congresses (3390 observations)

Furthermore, although in theory sufficiently compact districts will be contiguous²², in practice compactness and contiguity are often at odds. Table 6 shows two different measures of concordance between contiguity and compactness scores.²³ While I have included Kendall's measure for consistency in presentation, all but 58 districts are contiguous, which causes an extreme percentage of ties across the contiguity category and distorts Kendall's measure. A more appropriate measure in this case is Somer's d , which is very similar to Kendall's measure except that it looks only at pairs of districts which differ in their levels of contiguity. Using Somer's d , we can see that when we compare two districts with different levels of contiguity, the least contiguous district will most often be the more compact of the two.

		<i>Somer's d</i>

²² Compactness implies contiguity only for "well-behaved" measures of compactness, and even then only at some threshold level. See Altman 1995.

²³ I divided districts into three categories of contiguity, as described in section 3.1.

<i>AC</i>	0.06	0.32
<i>AP</i>	0.08	0.44
<i>LW</i>	0.05	0.28
<i>NORM</i>	0.06	0.34

Table 6: Comparison between level of contiguity (contiguous, questionable, and non-contiguous) and compactness scores for individual districts: 1-62nd Congresses (3390 observations) All but 58 of these districts were practically contiguous.

Discussion

At the time that the Supreme Court decided *Reynolds v. Sims* (1964), there were a number of competing population inequality standards. The justices did not decide on a standard at that time, but in their decision, they used three measures: the percentage deviation from the ideal district size, the population variance ratio, and the electoral percentage. By the time that the Supreme Court decided *Karcher v. Daggett* in 1983, deviation from ideal size had come to the forefront, and the justices used it exclusively in their decision. While theoretically flawed, this measure has proven to be simple to evaluate, judicially manageable, and relatively uncontroversial. This paper shows why.

Despite theoretical misgiving about some popular measures of population inequality, all but one of the malapportionment measures that I tested produced very similar evaluations over a large set of real districts. In effect, the courts can use almost any convenient measure of population equality and obtain consistent results. Because of this, the courts were free to pick an easily calculable and manageable population measure, this choice of measures was relatively uncontroversial, and the courts' resulting measurements of malapportionment have been predictable.

Unfortunately, this cannot be said of compactness measures. The measures of compactness in this study, which are typical examples of the three most popular types of geographical compactness measures, disagree more often than not. Compactness measures disagree even when we look only at the "worst" districts in each plan. And compactness measures can disagree with assessments of practical contiguity.

Population equality is often held to be intrinsically valuable. The principle of “one person one vote” is enforced by the courts on its own merit, as well as in its instrumental role in creating fair outcomes. This intrinsic value lends strength to the concept of population equality and seems to make it easier to measure. On the other hand, if there is some intrinsic value to geographic compactness, the majority of proponents for compactness leave it unarticulated, and this study shows that numeric measures fail to agree on it.

This study raises questions about the Supreme Court’s designation of compactness as a “traditional districting criterion” in *Miller*. The term “compactness” has historically entered into both state and congressional districting legislation, but it has not often been numerically defined. So although there may be some historical precedent for the use of compactness standards in redistricting, these historical precedents offer no guidance as to which measure to use.

More important, this disagreement among measures raises concerns about the judicial manageability of compactness standards. The disagreement that I find among compactness evaluations contradicts Polsby’s and Popper’s (1991) assertion that compactness measures generally lead to the same results , and it supports Young’s (1988) conclusion that compactness is still a “hazy and ill-defined concept” (pg. 114) , and Lowenstein’s and Steinberg’s (1985) contention that measuring compactness is neither simple nor straightforward.

Unlike malapportionment standards, the judge’s choice of compactness measures will greatly affect the type of districting plans that she accepts. To make matters worse, dozens of compactness measures have been proposed, and there is little theoretical or scholarly agreement over which measures are best. Since we lack a precise understanding of precisely how and how much geography affects elections, our measures of compactness are remote and clumsy instruments. Current definitions of geographic compactness are not based upon models of electoral manipulation, but on intuitions about “odd” shapes. Thus there is a danger of judicial arbitrariness when the courts choose a measure, and of inconsistent application of the law if different courts choose different standards.

Some proponents of compactness might argue, however, that such arbitrariness is inconsequential, that the benefit of compactness is primarily prophylactic — to gain this benefit the Court need only arbitrarily pick one measure of compactness and rigidly enforce it. In a limited formal sense, this argument is valid: Almost any compactness measure that is very strictly enforced will define a very small set of possible districting plans (Altman 1995).

In a more important sense, however, this argument is misplaced. An arbitrary restriction on gerrymandering is just that. Such a standard could be used to eliminate gerrymandering, but the courts could achieve the same effect more easily by creating districts from names drawn at random from a state's telephone directories. Both procedures come at the cost of effectively negating the districting process altogether, and both procedures are likely to have predictable and unequal effects for the representation of identifiable political groups. Before compactness can be used “arbitrarily” there must be a reasonable assurance that they will not unduly interfere with legitimate redistricting goals.²⁴

Issacharoff (1993) argues that the High Court's misplaced belief that it could develop meaningful standards for managing redistricting has led to confusion and “politically charged ad hoc adjudication of redistricting claims” . I agree, and I can find no better example of such misplaced attempts to control redistricting than the courts attempts to use geographic compactness as a constitutional standard. Geographic compactness should be rejected as a standard for redistricting, or limited to extreme cases in which a wide variety of compactness measures agree.

²⁴This is not to say that compactness is useless. Where multiple compactness measures concur in their evaluations, or where deviations from compactness are extreme, the court would have a strong reason to suspect that plan was drawn purposefully. The Court might then examine the plan further to determine whether or not that purpose was legitimate.

Appendix: Corrections to and Omissions from the Data

No source of data is perfect, and this data is limited in four ways. First, population estimates for each district are based on decadal census data, and this data inevitably represents the population at the beginning of the decade more accurately than the population at the end of the decade.

Second, some districts contained political units for which no precise census data exists, either because the political unit was created after the census for that decade, or because the political unit subdivides one or more census aggregation units. In these cases, I adopted the district estimates found in the data source, or, if this was unavailable, I estimated the demographic data myself using census data aggregated at the county level.

This limitation particularly affects districts in major urban areas (primarily Baltimore, Philadelphia, New York City, Boston, St. Louis and Chicago) after 1860, because it was at about this time that many of these ceased to be created entirely from whole counties. For most of these districts it is possible to determine total population accurately by using census information aggregated at the ward level, but other demographic variables have to be estimated (Parsons, et al. 1986).

Third, partially because of this estimation problem, the available demographic data series extends only through the districts of the 62nd congress, and does not resume until the U.S. Census created the Congressional District Data Book (and Atlas) series for the 87th and later congresses. Of course it would be possible to reconstruct reasonably accurate apportionment data for most districts during this gap²⁵, using the statutory descriptions of districts found in Martis and Rowles (1987) and ward-level data from the 13th–16th Censuses of the United States; unfortunately, this is a project well beyond the scope of this paper.

²⁵Estimates of more detailed demographic data for urban districts would necessarily be questionable at best, and perhaps useless.

Fourth, the level of detail in district maps varied across time and across sources. I attempted to use the most detailed maps available, but in a few cases lack of detail in the available district maps²⁶, or differences in detail in different data sources has affected the accuracy of my measurements.²⁷

In this paper I relied heavily on the the *United States Congressional Districts and Data* series (Parsons, et al. 1978; Parsons, et al. 1990; Parsons, et al. 1986) for districts in the period of 1789–1913. In using this data, however, I discovered a number of omissions and errors, most of which I was able to correct using other sources.

This data series omits a number of district maps; the vast majority of these are of urban areas. For many of these maps used the district maps in Martis & Rowles (1982) for the following districts (Table A-1):

²⁶In all of the cases where the primary data source contained several maps of the same district, I used the map which captured the most detail, as long as the complete boundaries for that district could be reconstructed from it.

²⁷In general, sources were in agreement on the overall shapes and areas of each district, but the perimeter of convoluted districts could vary significantly with the level of detail contained in each map. This problem is a result of the differences in information that are contained in different maps, and is not an artifact of the methods used to extract the data and is in large part unavoidable because perimeter measurements are, in general, sensitive to the accuracy of the measuring device; furthermore in the case of natural, fractal, boundaries, the "real" length of a shape may be indeterminate.

For example, suppose you were trying to measure the length of a section of the California shoreline, perhaps the section between San Francisco and Los Angeles. If you used a coarse approximation, perhaps by measuring the length of Route 1, which runs along the shore nearby, you would guess that the shoreline is several hundred miles long. If you tried to make more precise measurements by walking along the beach, your path might expand to several thousands of miles. Finer measurements will reveal the shore to be of ever-increasing length.

This problem is of most concern when comparing perimeter-based compactness measurements across districts that were measured at widely different scales.

Congress	State and Districts
3rd	PA-1
18th	IN-1-13
23th	PA-1 -PA-3
28th	NY-2-6, PA-1-4
30th	IA-1-2
33rd	MD-4, NY-3-8, PA-1-3
38th	MD-3, PA-14
43rd	MA-3-4, NY-11-14, PA-1-4
44th	PA-1-5
50th	IN-1-15,OH-50-51
58th	NY-18

Table A-1, Redistricting Plans Reconstructed from Other Sources

This data series also omits maps and population data for a number of minor redistrictings. I was able to reconstruct most of these redistrictings using county-level data for the following state plans: New Jersey's redistricting for the 29th congress, Ohio's redistricting for the 29th congress, Georgia's redistricting for the 31rst congress, Indiana's redistricting for the 50th congress, and Kansas's redistricting for the 53rd congress. There were a number of omitted minor redistricting plans that I was unable to reconstruct, since they involved extensive changes at the ward level; population variables for the following districts was marked as missing in the data-set²⁸ (Table A-2):

Congress	State and Districts
52th	MD-2-5
55th	MD-1
56th	MA-9-11,MD-3-5

Table A-2, Redistricting Plans Partially-Reconstructed from Other Sources

I corrected a number of obvious typos and inconsistencies in the population data and maps: the two most significant errors were that the population of Tennessee's 5th district in its plan for the 53rd

²⁸ In addition, there were several changes to New Hampshire's redistricting plan for the 32nd congress, in which a few towns were shifted among districts districts. I was unable to reconstruct these districts, but since these changes were very minor I chose to ignore them.

Congress, and New York's 6th district in its plan for the 28th Congress were listed as ten times their actual size. Also, a typo shows Howard county in Indiana's 50th congressional map as belonging to two different districts. I corrected these errors.

Finally, the base maps for Maine and Rhode Island changed across time; maps of these states in the data series show them to have much longer coastlines before 1842 than afterwards, which causes identical districts to appear to have different perimeters and thus different degrees of compactness. To fix this inconsistency, I reconstructed all of the earlier districts for these two states upon a base map created from the post-1842 maps.

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