Geographic Information Systems and the Spatial Dimensions of American Politics

Wendy K. Tam Cho[1] and James G. Gimpel[2]

[1]Departments of Political Science and Statistics, and National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801; email: wendycho@illinois.edu

[2]Department of Political Science, University of Maryland, College Park, Maryland 20742; email: jgimpel@gvpt.umd.edu

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Abstract

In research on American politics, the use of geographic information systems (GIS) is most often thought of in connection with redistricting and the study of election results. In the past ten years, political scientists have realized that GIS can help them address many research questions and data analysis tasks quite apart from these traditional applications. These include the analysis of point patterns and the detection of clustering; the study of diffusion of influence; and the measurement of spatial relationships involving key constructs such as proximity and distance, flow, and interaction. GIS tools also prove to be the exploratory complements to the suite of tools being used in spatial econometrics to test explicit hypotheses about the impact of geography and spatial arrangement on political outcomes.

INTRODUCTION

A picture is worth a thousand words. Although research findings are often conveyed with extensive description in scholarly journals, most of us have experienced the power of visualization through maps, charts, and figures. These "picture forms" summarize relationships, patterns, and trends in data by transforming data into a format that is quickly digestible and easier to understand than descriptive text. Human beings are better at interpreting data when it is displayed visually than when it is organized, for example, in tables or arrays of numbers. An idea that may take pages of text to describe can often be powerfully captured by a well conceptualized and clearly constructed graphic representation, and this advantage has long been recognized by scientists. Visualization of data became a regular feature in scientific journals as early as the 1830s (Beniger & Robyn 1978).

A map has been aptly described as "a graphic representation of the milieu"—or all aspects of the cultural and physical environment (Dent et al. 2008; Robinson & Petchenik 1976, pp. 16–17). In research with a sociospatial dimension, mapping is a tool for discovery and analysis throughout the investigation and is not merely a decoration for the resulting manuscript (Steinberg & Steinberg 2006, Monmonier 1993, p. 12). Maps are commonly used for purposes of data exploration and theory construction because social processes operating in space produce patterns. Most social science phenomena are neither randomly nor evenly distributed in space but exhibit some type of spatial structure. Examination of mapped relationships assists in developing theories because objects and events that are geographically proximate are often related, whether through causation or correlation.

Colocation, like covariation, is important because it offers clues as to causes. A well-known example is John Snow's mapping of cholera deaths in London in 1854, which led to the discovery of a contaminated water source. When that water supply was cut off, the contagion subsided (Longley et al. 2001; Steinberg & Steinberg 2006, p. 18). The well was not the literal first cause, of course, but "bad" drinking water proved to be a valuable link in the causal chain. Without mapping the mortality data together with features of the built environment (e.g., streets, households, water wells), Snow would have had great difficulty identifying the proximal source of the epidemic.

At the end of the research process, once spatial relationships have been identified, mapping is also used to communicate results and conclusions to readers. As much art as science, cartography facilitates this communication. The convenience of contemporary software tools has facilitated map production but has also led to the proliferation of many poor-quality maps. A well-designed map takes time and considerable trial and error. Fortunately, experts have catalogued an extensive set of best (Peterson 2009, Dent et al. 2008) and worst (Monmonier & deBlij 1996) practices.

In political science, the use of visualization objects, especially maps, has recently been bolstered by the rapid development of geographic information systems (GIS). Advancement in this field has resulted in new tools for creating rich and detailed images in cartographic form. Our enthusiasm for data mapping is long standing, but accessible technology always lags a step or two behind the desire to put it to use (Fotheringham et al. 2000, p. 31). GIS has been, and continues to be, the technological answer to our aspiration for visualization enhancements.

Mapping is important for political scientists because pinpointing where a particular political phenomenon occurred often provides clues as to why it occurred. However, mapping capability is just the tip of the iceberg of GIS. The best geographic software systems include a rich set of spatial analysis tools for managing spatial data, identifying spatial relationships, measuring spatial concepts, and making spatial predictions. These resources have greatly advanced our ability to use spatial data in the social sciences, a less recognized boon of the GIS revolution. The capability to represent georeferenced data with a map is central to the purpose of GIS, but geographic analysis increasingly involves the investigation and measurement of spatial interaction, flow, density, scale, shape, distance, and proximity conducted without the display of maps (Lloyd 2010, Fotheringham et al. 2000).

GEOGRAPHIC INFORMATION SYSTEMS AND POLITICS

Redistricting of electoral units is an obvious application of GIS in political science. Depicting, defining, and redefining district boundaries and studying the substantive impact of alternative districting schemes are certainly in the province of GIS, but hardly exhaust the GIS toolkit. Instead, the varied instruments in the GIS toolbox are versatile and applicable to many other political inquiries, as the last decade of research has revealed. While it may be premature to say that political science has been transformed, it is fair to say that the capabilities of GIS have touched the field and that its full reach has yet to be felt. As a discipline, we are just beginning to realize how many of our theories are spatial in nature, whether inherently or explicitly, and how GIS tools will greatly augment our ability to understand politics. Some foundational theories have been set forth, but corresponding empirical examinations have lagged behind.

The potential of GIS is particularly significant in political science because politics is, after all, inherently spatial. In the United States, governing jurisdictions (e.g., states, counties, US House of Representatives seats, school districts, etc.) are defined by clear geographic boundaries. Not surprisingly, then, we have created political institutions that govern and represent populations within explicitly defined territories. US Senators represent states. Members of the US House represent geographically contiguous districts within states. Governors, state representatives, mayors, aldermen, and city council members represent geographically and spatially defined areas. On the flip side of political representation, the individuals being represented are unambiguously situated in one district or another by place of residence. Because the district distinctions and "belongingness" are sharp and geographically defined, individuals develop identities based on where they live and the characteristics of these places. Political campaigns accentuate and reinforce these geographic identities by crafting strategies with geography in mind: battleground areas receive customized and more frequent messages whereas other areas can be largely neglected (Shaw 2006, Chen & Reeves 2011, Gimpel et al. 2007). In addition to the role of long-standing geographic entities (informal ones such as sociocultural regions, as well as those institutionalized by Designated Market Area boundaries) in structuring outreach efforts and steering electoral strategy, places also reinforce particular patterns of socialization, shape information flow, inculcate habits of thought and action, and influence the creation and sustenance of social networks.

Historical precedent has an enduring impact on neighborhood characteristics. It is difficult, even with sustained effort and determination, to make large-scale changes in neighborhoods over short periods. Once neighborhoods take on particular qualities, a number of continuing forces bond together to sustain local conditions. Thus, geography is essential to the understanding of politics and political behavior. Relatedly, social context matters in politics. Even apart from the inherently geographic political system, politics has never been regarded as a set of unrelated individual actions but is instead a set of interrelated social phenomena. A corollary of this claim is that people are influenced by the context in which they find themselves. Indeed, it is not hard to imagine circumstances under which colleagues and neighbors would be influential in the formation and expression of political beliefs or would be the impetus behind the emergence of some type of political action. Although people can and do maintain relationships that span great distances, the principal source of influential interaction is physical and spatial proximity.

One of the primary advantages that accrues from incorporating and analyzing the sociospatial dimension is that we can move away from theories that incorporate only individual decision making, whether across time or in a singular incident, in an isolated realm. That is, the individual no longer needs to be seen as an atomistic actor. Instead, we can consider theoretical frameworks that place an individual's actions in the context of his neighborhood, where behavior can be compared to, influenced by, and observed in relation to that of proximate others. The change in theoretical perspective here is plainly significant. The "social" in social science has been neglected, not because of deficient theories but because we have not been equipped to rigorously test our theories. Advances in GIS allow us to meld our theories with our methods of data analysis.

For numerous and varied reasons, then, the development of GIS has important implications for the study of politics. Geographic concepts such as location, environment, distance, and proximity are intricately related to our theories about individual behavior, directly shaping how we understand political participation and voting behavior. When we couple this insight with the spatial aspects of our political systems, institutions, and electoral districts, we see that politics cannot be understood well when the geographic dimension is ignored. For our understanding of campaigns, elections, institutions, and policy, the gain from incorporating spatial relationships is measurably large.

PIONEERING EFFORTS AND CONTEXTUAL THEORIES

It is clear from the literature in American politics that we have long understood the importance of geography. Indeed, pioneering studies in political behavior articulate the need for understanding and envisioning the spatial aspects of politics. The older research is not vastly different in focus from behavioral research today—arguably the earlier researchers just had fewer tools. Maps were used long before before desktop GIS computing came along. The ability to draw maps has been enhanced by software and computing technology, but the absence of these tools did not deter the determined data visualizers from moving forward with their own painstakingly drawn illustrations.

V.O. Key, Jr. was an innovator of spatial perspectives in the study of elections and political behavior. Key is perhaps best known for his seminal work, *Southern Politics in State and Nation*, which explores the ground-level workings of southern political institutions and the role of race in unifying a region he thought would otherwise be cleaved by socioeconomic status, and even radical given its pervasive white poverty. Following Reconstruction, the South sought to disenfranchise the newly freed slaves. The movement toward white supremacy led to white-dominated political institutions that heavily favored Democrats, and this post-Reconstruction white dominance hindered the development of a two-party system in the region. Key first examined the one-party control in each southern state in great detail, analyzing social structure and political leadership. Key creatively used maps to display the spatial nature of local voting allegiances and the irrelevance of party cues for voters. In so doing, Key introduced the idea of "friends and neighbors" voting: the concept that a candidate receives a large share of the vote from localities that are close to his home base simply because of regional loyalty and name recognition. In maps from elections in Alabama, South Carolina, Mississippi, and Florida, Key demonstrated that the home counties and the counties immediately surrounding them produced the biggest vote shares for "native son" candidates.

Figure 1 shows Key's map of the Thurmond (Dixiecrat) vote in Arkansas in 1948. The map depicts the strength of the Thurmond vote in areas of black concentration. As Key noted, this ecological correspondence was not a sign that blacks voted for Thurmond, but that whites living proximate to large black populations were especially likely to support Thurmond. Key also unearthed other interesting spatial patterns that exhibited historical cleavages dating back to the Civil War and showed uneven support for economic and social conservatism across geographic areas. In primaries, Black Belt counties—the historical loci of plantation agriculture and slave ownership—often voted in opposition to the lower-income white counties in the "up-country"

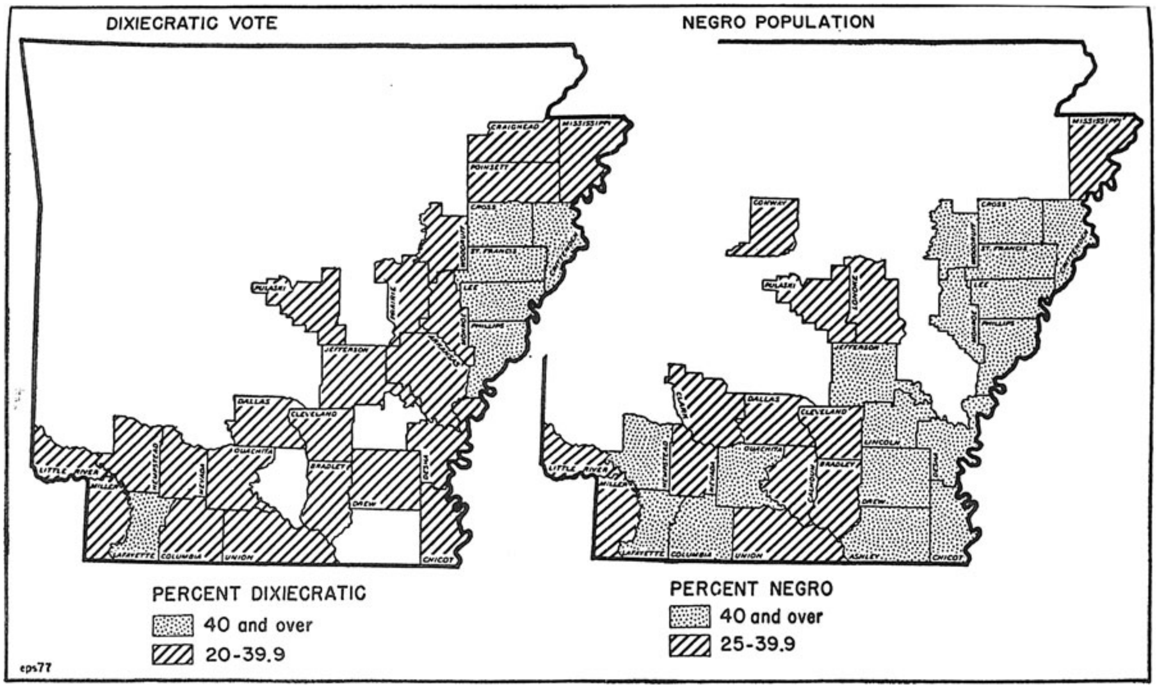

Figure 1

The Black Belt and the Thurmond vote in 1948: the case of Arkansas (Key 1949). Notice the quality of the map, which had to be drawn by hand rather than by GIS software or any other form of automation.

areas, which were often mountainous rural regions with less agriculture and little to no history of slave holding. But in general elections, these two economically disparate groups were unified by their common racial views, obstructing the emergence of a class-based and issue-oriented politics of the kind that could be found in northern two-party competitive states.

Although scholars such as Key generated some enthusiasm for spatial analysis, this initial excitement primarily stimulated the collection of geographic data about politics. The more influential and lasting growth has been in the development of social theories of behavior that motivate such analysis. Theories rooted in place and social context have been a part of the literature for some time but undoubtedly found their inspiration in the spatial relationships revealed by maps. These theories have varied but typically center on a set of dominant themes. One is the role of neighborhood influence and social interaction. In this vein, Eulau (1986) examined what he called the "self and society dualism" and premised his book on the insight that the "most significant factor in the environment of a person is another person" (p. 9). Berelson et al. (1954) began with a similar theoretical orientation in their classic study of residents of Elmira, New York. In addition to considering individual factors such as socioeconomic status on one's voting decisions, they explored the role of social conditions or influence. They held that the majority view in a neighborhood has a disproportionate impact on gaining and holding previously nonaligned adherents because majority partisans dominate the geographically constrained flow of information in the locale. Putnam (1966) provided further evidence of the influence of local political environments on individual attitudes and behavior by exploring the role of community groups in sustaining support for traditional political stands. Sensitivity to the local climate of opinion turns out to be greater for citizens who are well-networked in the community. Community influence is conveyed to individuals through their participation in local organizations.

LISA: local indicators of spatial autocorrelation

Illustrating another research strategy to test a related theory, Huckfeldt (1979) combined survey and aggregate data on neighborhoods to examine the role of social context, especially high- versus low-status contexts, on individual political involvement. Huckfeldt & Sprague (1995) and their students have sustained interest in social influence processes as critical to the acquisition and maintenance of political attitudes and as a factor in political mobilization. The key geographic premise in this work is that individuals are limited in the extent of their social interactions by space. Distance imposes limits on human interaction that have not been overcome by technology and mass communication. As a whole, this literature seeks to place the individual within his social context and to understand individual political beliefs and behaviors in relation to the behavior of proximate and networked others.

The concept of friends-and-neighbors voting that Key first introduced was accepted as conventional wisdom. Subsequent scholars examined the idea further and sought to provide other empirical evidence to supplement the maps that Key had drawn. Tatalovich (1975) focused on elections in Mississippi from 1943 to 1973. He examined counties surrounding the home county and computed a correlation coefficient for the percentage of the county's vote for a candidate and the distance of that county from the home county. This method foreshadowed current measures of spatial autocorrelation such as Moran's *I* and LISA (local indicators of spatial autocorrelation) statistics, which are now programmed into GIS packages. Lewis-Beck & Rice (1983) extended the idea of friends-and-neighbors voting to presidential elections and home-state advantages. Rice & Macht (1987) examined friends-and-neighbors voting in gubernatorial and senatorial elections from 46 states from 1976 to 1982. Gimpel et al. (2008) extended the study of these substate advantages, noting the diffusion of support beyond the home county as well as the gradual decay of regional advantage as a function of distance from the candidate's home town. Others have also noted this type of localism in other elections (Black & Black 1973, Bryan 1981) as well as in the area of campaign finance (Thielemann 1993).

The study of racial politics in both political science and sociology is traceable back to Key's seminal study and his insight into the geographically structured nature of racial attitudes. An extensive literature examining the role of context in racial attitudes has emerged that seeks to adjudicate between two hypotheses. A key issue is how the size of proximately situated outgroups affects prejudice. Specifically, do larger outgroup populations reduce or increase prejudice toward these groups? Those who hold to the contact hypothesis posit that larger outgroup populations result in more positive attitudes toward these outgroups because the larger numbers facilitate increased cross-group interpersonal interactions, which in turn dispel stereotypes developed in the absence of these interactions. Others, who hold to the threat hypothesis, posit that as the outgroup population increases, so do negative attitudes toward that group because of the increasing economic, political, and social risks to the interests of a superordinate group. Both theories embrace the notion that geography, proximity, and social interaction are critical components in the formation of racial attitudes.

Another strand of literature that has advanced through the use of GIS has emerged in the field of policy studies. This literature focuses on the diffusion of policy adoption by different states. The study of state policy making has a long history (Walker 1969, Gray 1973). The testing of theories of diffusion, whereby state action is influenced by actions in neighboring states, is more recent. For instance, Berry & Berry (1992) extend the work of Walker and Gray by examining the effect of neighboring states using event history analyses. At the same time, they recognize the limitations of their empirical analyses and call for more sophisticated measures of neighboring states that are able to move beyond the contiguous neighbor measure that they employed. In subsequent work by Berry & Baybeck (2005), GIS tools were deployed specifically to measure the size of state populations living along the border with neighboring states. These border populations were theorized to be the most likely to play a bordering state's lottery, and if sufficiently large, the revenue lost across the border would be targeted for recapture by the home state through adoption of its own lottery. The authors found that as a nonlottery state's population near the border with a lottery state increased, the probability that the nonlottery state would adopt its own lottery also increased. Although competition with neighboring states is not the only factor behind the spread of state lotteries, the point here is that these underlying ideas of diffusion and neighbor behavior have an unmistakable parallel with the literature discussed above on the influence of social context and proximity on individual behavior.

Across a wide variety of research questions, scholars have illuminated the central role of geography. All of the works described above emphasize the role of spatial context, distance, and proximity, exemplifying an acute awareness of the role of space in individual behavior. The methods employed may not be perfectly aligned with the theory, but the spatial component in the theories themselves could not be more clear. The advances in GIS are relatively recent, and the earliest foundational studies were not able to take advantage of the GIS tools that have become available over the past decade. At present, we are in the midst of another wave of research centered on the same substantive questions but employing tools that are more finely tuned for answering them. As GIS advances and this toolbox continues to grow, our ability to form deeper and fuller understandings of political phenomena will likewise advance.

RANGE OF APPLICATIONS

The confluence of recent, significant advances in GIS and the proliferation of research methodologies and tools for spatial analysis has created conditions that are ripe for a new and more methodologically sophisticated wave of spatial analyses of political data. The international relations subfield has led the way in advances in this type of scholarship. Their early-adopter status owes something to geographers who were interested in the study of conflict (Anselin & O'Loughlin 1990, 1992; O'Loughlin & Anselin 1991, 1992, 1996). This research spilled over into the work of political scientists and has continued to grow (Ward & Gleditsch 2008). Although scholars of American politics were slower to the starting blocks, the range of GIS applications within this subfield has expanded greatly in the past decade or so. These types of analyses have become increasingly sophisticated as the suite of tools has been developed.

Exploratory Spatial Analysis

V.O. Key's workload would have been greatly eased, and his ability to examine more data greatly increased, by two specific breakthroughs in GIS. The first is the ability to geocode data. Geocoding is the process of attaching geographic coordinates (usually as latitude and longitude or as x–y coordinates) to data that are in more traditional geographic formats, such as, for example, street addresses, zip codes, district numbers, county identifiers, or FIPS (Federal Information Processing Standard) codes. When traditional identifiers are converted to geographic coordinates, the associated content can be mapped and understood by GIS software. This process is now fully automated and no longer requires the diligent attention of the researcher to complete it by hand. In addition to address matching or the capability to geocode, this development allows researchers to measure constructs such as distance and proximity with precision that could not be easily obtained otherwise. Geocoding has been used by a variety of researchers to develop data sets amenable to their intended analysis (Sui & Hugill 2002, Baybeck & Huckfeldt 2002, Cho 2003, Gimpel et al. 2008).

The second advance is the ability to easily create choropleth maps. These are thematic maps where areas are shaded to indicate regional differentiation in value. The main purpose of a choropleth map is to display data that are aggregated over some geographic region. Choropleths are quite common. V.O. Key constructed a large number of them by hand. Although the term choropleth may not be part of the vernacular, the maps themselves are popular and easily recognizable. Presidential election night broadcasts, for instance, center on the choropleth map of the United States where states are shaded red if their vote is tending Republican and blue if they favor the Democrats. One can immediately see that such a representation is imminently more "readable" and conveys pertinent information much more clearly than an extensive table with vote proportions listed for each of the 50 states. The choropleth provides a simple way to visualize the political landscape, highlighting clusters, showcasing variability, and simply exhibiting the geographic distribution of data values. These maps are commonly used to display results but also, much like scatterplots, are often used for exploratory spatial analysis that will later inform a more traditional analysis or lead to further spatial econometric modeling.

In studies of American politics, choropleth maps have been used to display election returns by precinct (Kohfeld & Sprague 2002), residuals from count models (Kohfeld & Sprague 2002), kriging prediction values and variances (Cho & Gimpel 2007), normal votes by county (Cho & Nicley 2008), sociodemographic variables by tract (Cho & Baer 2011), coefficients from geographically weighted regression (Cho & Gimpel 2009, 2010), G_i^* statistics (Gimpel & Cho 2004), campaign contributions by zip code (Gimpel et al. 2006), news consumption by designated market area (Althaus et al. 2009), partisanship by precincts, and LISA statistics (Darmofal 2006), to name but a few examples.

The choropleths that are presented in published work are often a display of results, but countless other choropleth maps are used by researchers in an exploratory stage simply to gain some initial insight into the data. **Figure 2** displays the geographic distribution of the American Recovery and Reinvestment Act of 2009, otherwise known as the Obama stimulus package. The bottom panel displays unemployment rates as a choropleth map. Green pentagons overlay the map to indicate areas with the highest rate of home foreclosures. The top map displays stimulus spending. Most counties in the United States are shown in desert tones, reflecting that most received less than the mean amount. Greener shades symbolize counties whose populations received more generous funding through the stimulus. The locations shaded as light and dark green are scattered throughout the United States, but they are especially prevalent in the Plains and the Mountain West, in many cases in counties that had markedly low levels of unemployment and home foreclosures. Visual inspection of the two maps generates the overriding impression that there was no special concentration of funding for areas hardest hit by the recession. Notably, there were very few concentrated allocations of stimulus money anywhere in the struggling industrial Midwest. This type of information is critical to the exploratory data analysis that informs spatial econometric modeling. Maps provide an amazing resource in this realm.

Various spatial statistics are now included in the most recent GIS software programs. Indicators of spatial autocorrelation Moran's I and Geary's c fit in this genre. These measures have been presented on their own, without the accompaniment of maps, but are more often used as exploratory tools in conjunction with maps to facilitate a more focused and detailed analysis of the data (Cho 2003, Darmofal 2006, Gimpel et al. 2006, Cho & Nicley 2008, Althaus et al. 2009). LISA statistics also fulfill the same purpose but focus on a more localized set of observations (Anselin & Cho 2002, Cho 2003, Darmofal 2006, Cho & Nicley 2008). In general, their use helps the researcher to visualize the spatial structure in the data.

In the attempt to measure and ultimately understand the role of spatial autocorrelation, others have used point pattern analysis. Sui & Hugill (2002) use the Getis-Ord G_i statistics to examine the distribution of voters at the precinct level. They created choropleth maps to identify areas where there was clustering, either high or low. They found that the extent of neighborhood effects in local elections was heavily influenced by voter turnout. Gimpel & Cho (2004) similarly examined the settlement concentration of ethnic groups in New England using choropleths and the G_i^* statistic. The G_i^* statistic is similar to local Moran's I or LISA statistics in that they are all used to assess local clustering of values or spatial autocorrelation. A positive G_i^* value indicates a cluster of high values; a negative G_i^* value indicates a cluster of low values. Middling values of the G_i^* imply random or unsystematic clustering of values. Mapping these statistics revealed the persistence of historical settlement patterns of white ethnic groups and suggested that ethnic bloc voting endures for multiple generations in many towns despite changing political and economic conditions.

Ripley's K and Besag's L are related tools. The purpose of these statistics is to test the null hypothesis of spatial randomness or a lack of spatial clustering. Ripley's K is calculated by dividing the number of neighboring observations by the average density of observations in a defined area. That is, it quantifies concentration or dispersion by considering each point and its neighbors within a certain distance. Sui & Hugill (2002) use Ripley's K to examine the pattern of voters. Gimpel et al. (2006) conduct a similar analysis using Besag's L, which is a straightforward normalization of Ripley's K. Besag's L is generally preferred over Ripley's K because the normalization makes it easier to interpret. Using these statistical tools, Gimpel et al. (2006) examine the clustering of new Arab-American voter registrants at various spatial scales both before and after 9/11. At each distance, the statistic indicates the amount of spatial clustering evident at a radius of that distance for each individual voter. They present a number of plots to indicate the differences in the emergence of new Arab-American voter registrants at various distance scales. The evidence was consistent with the notion that spatial surges in new Arab-American registration result from information flow within neighborhoods, and among kin, about the importance of political involvement. Even so, the authors found that political mobilization is not necessarily reliant on high ethnic concentration, and frequently ethnic concentration is itself a sign of recency of immigration and noncitizen status, obvious inhibitors of registration and voting. The events of 9/11 broadened Arab-American political influence beyond traditional areas of Arab-American settlement, but also within them. New Arab-Americans were mobilized as part of the broader Arab-American voting public in the suburban and exurban locations that were examined, but Arab-Americans gained voting power relative to the general population in the largest US cities.

Including Spatial Constructs in Traditional Analyses

In some studies, spatial constructs are used to inform more traditional "aspatial" analyses, such as a linear model or a limited-dependent-variable model. One such tactic is to use GIS capability either to attach a geographic characteristic to data units or to construct distance or proximity measures that will take the form of a traditional explanatory variable in a statistical model. For instance, Gimpel et al. (2008) examine the relationship between a congressional candidate and campaign donors who reside inside and outside the candidate's district. They began with the campaign finance data available from the Federal Election Commission (FEC) that lists the addresses of campaign donors and provides geographic information on the donation recipient. They then use GIS to locate zip codes (from the FEC data) within congressional districts to determine the origin of the contributions, and they track the donations to the destination district. GIS was instrumental for managing the data and creating new variables, as well as for describing the results using maps to depict the funding flows.

Baybeck & Huckfeldt (2002) conduct a multilevel analysis of information and communication. Spatial units—in this case, neighborhoods—were used to aggregate individuals into geographic clusters. These units were then used to define social networks. Their conclusions associated the level of dispersion in the networks with the type of information diffusion that manifested within the networks. Reeves & Gimpel (2012) use a hierarchical model to reason that various local contexts, defined in terms of both official and unofficial boundaries, have substantially similar effects on how citizens draw on local economic conditions to judge the health of the national economy during an election period. These studies are but two examples of a large set of research projects that incorporate a geographic construct into a multilevel model. Hierarchical or multilevel models have a long history, and many employ geographic "neighborhoods" for the purpose of grouping individual-level units. There are other types of groupings, to be sure, but geographic aggregation is natural and common given the influence of proximity on human interaction.

Spatial Econometric Analyses

To summarize, geographic data analysis has a number of successive levels, just as traditional data analysis does. First, there is simple description—using GIS tools to visualize and describe spatial structure in the data and to make simple queries. The next level involves using the capabilities of GIS software for exploratory spatial data analysis—exploring covariation and colocation, developing theories, and advancing hypotheses. The third level is to test hypotheses—specifying spatial statistical models of processes to explain and predict spatial outcomes.

Spatial econometric models should be viewed as a natural extension of simpler GIS analyses. The estimation of these models is increasingly discussed in conjunction with spatially oriented social science data. Spatial econometric models deviate from the class of multilevel models in their treatment of the spatial units. In a multilevel model, we recognize that individuals are often part of a larger group populating a classroom, a precinct, a neighborhood, or some other unit of aggregation. This membership arrangement poses problems for the basic linear-model assumptions of homoscedasticity and independence. Individuals in the same group share the attributes of the group and so are less likely to be independent than individuals from different groups. Error components exist for the group as well as for the individual. Random coefficient models are one way to alleviate these problems and also can be a way of incorporating geographic information. To incorporate information about higher-level or group variables, however, researchers turn to multilevel models. In these models, we can make statistical corrections to account for assumptions of homoscedasticity and independence while also incorporating known information about the groups.

Although multilevel models can integrate the spatial component at the group level, they are not explicitly concerned with identifying the spatial processes. In a spatial econometric model, we focus more on the role that spatial processes play and less on the nuisance that they create for statistical analyses. For instance, how much of the variation in the dependent variable arises from a diffusion or contagion process? In addition to the effect of various independent variables, what is the effect that arises specifically from geography?

Spatial lag and spatial error models. As we have discussed, social scientists have long been interested in the influence of geography on political behavior. We have theorized and put forward hypotheses about this role but lacked the ability to make precise empirical statements about the influence of context. The auspicious coupling of the development of GIS technology and the maturation of the literature involving spatial statistical analysis is sparking renewed interest in the study of social context and its relationship with political behavior. The more recent analyses incorporate increasingly sophisticated tools, and the insights gathered on a wide range of topics are increasingly rich. Some of these analyses involve spatial regimes and spatial regressions that employ a spatial lag or a spatial error term (Cho 2003, Gimpel & Cho 2004, Gimpel et al. 2006, Cho & Rudolph 2008, Althaus et al. 2009, Cho & Baer 2011).

These studies typically aim to examine the theories of political behavior that have explicitly advanced the notion that context matters in politics. In contrast to studies that use spatial constructs in traditional analyses, the concept of spatial dependence is tested. In the former case, the researcher expects to find unique patterns in different geographic units, but the behavior in the geographic units is not necessarily believed to depend on the behavior of neighboring units. The latter studies, however, set out to test whether the behavior in geographic units is somehow related to and affected by behavior in nearby areas.

This type of spatial dependence can take different forms. The two general classes of models are spatial lag models and spatial error models. If we control for a set of covariates and our spatial variable remains significant, then we have evidence that the pattern we observe is consistent with a neighborhood effect or is attributable to an unobserved or unmeasured variable. In the former case, we would use a spatial lag model, whereas the latter case is more properly captured with a spatial error model.

A spatial lag model is most consistent with contagion theories or a diffusion process. The explicit inclusion of a spatial lag term implies that the influence of a neighboring unit is not an artifact of measured or unmeasured variables but that the neighbor's behavior has a direct effect on an individual's behavior. Note that the evidence of a diffusion or contagion effect is indirect. The spatial regression models cannot identify the specific mechanism that produces the spatial effects. Instead, the value added is that if the observed phenomenon were actually characterized by a diffusion process, then we would expect to see these spatial imprints emerge. The discovery of spatial effects, then, obliges future research to place some emphasis on uncovering the mechanisms that would produce diffusion. A spatial error model, on the other hand, implies that the spatial patterning is the result of unmeasured covariates. Choosing whether to employ a spatial lag or spatial error model as the proper specification is not a matter of convenience nor completely driven by theory. The choice should be determined through the proper use of a set of diagnostics.

Cho (2003) applies spatial econometric models to examine the area of campaign finance. Prior to her work, campaign finance research focused on the attributes of individual donors (e.g., education and income) to explain the impetus of campaign contributing. The concept of a contribution network had not been empirically examined, although the idea was not foreign. Her spatial analysis, employing both spatial lag and spatial error models as well as incorporating spatial regimes to account for spatial heterogeneity, revealed that patterns of campaign donations are geographically clustered; they exhibit both spatial dependence, which implies a neighborhood effect, and spatial heterogeneity, which implies a regional effect. Cho also found that this clustering cannot be explained completely by socioeconomic and demographic variables. Although sociodemographic characteristics are important components of the dynamic underlying campaign contributions, there is also evidence consistent with a contagion effect whereby ethnic contribution networks are directing funds to candidate treasuries.

In the racial politics literature, the concept of neighbor influence is pervasive. Individuals form their racial attitudes partly as a function of their attributes, but perhaps even more as a function of their neighbors' attitudes and the demographics of their geographic region. This literature has long employed geographic identifiers but has also failed to reconcile decades of research arriving at different conclusions. Cho & Baer (2011) revisit a long-running debate about the role of racial context in shaping racial attitudes. They highlight issues that arise with geographic analyses, particularly the "modified areal unit problem," in which the results of data analysis are influenced by the number and sizes of the geographic units or zones used to organize the data. They also demonstrate that meticulous attention must be paid to the construction of spatial units through carefully conducting spatial exploratory analysis and using that information in constructing a spatial lag regression.

It may seem that spatial lag models are more informative and consistent with the geographic processes that are implied by our preliminary hypotheses, but several studies have demonstrated the value of spatial error regressions as well. In some cases, spatial autocorrelation is present even when diffusion processes are not at play. In these instances, spatial models are still important. Statistically, if spatial processes underlie the behavior of interest but are not accounted for in the model, inferences will be inaccurate and coefficient estimates may be biased. Erroneously ignoring spatial dependence (in the form of a spatial lag) may create bias and inconsistency in the same way that we understand the omitted-variable problem to affect ordinary least squares (OLS) estimates (Anselin 1988). Alternatively, when the spatial error structure is ignored, simple inefficiency is apparent in the estimates, but the standard errors are biased (Anselin & Griffith 1988). Hence, even if one is interested only in the aspatial effects, omitting the possibility of a spatial aspect from the model may affect the interpretation of the results, spatial and otherwise.

Several authors have used spatial error regressions when their data were spatial, but spatial dependence did not take the form of a spatial lag parameter. For instance, Darmofal (2006) examines the spatial dependence in macro-level turnout from the advent of Jacksonian democracy to the election of 2000. He incorporates the spatial dimension as a complement to factors such as competition and voting laws. The spatial component is not the central defining feature of his data, but he demonstrates through a series of maps and spatial autocorrelation statistics that spatial dependence is a prevalent theme in the data. Gimpel & Cho (2004) also employ a spatial error regression when they examine the role of ethnic ancestry in explaining the political divide in presidential voting in more than 1500 New England towns. Again, although spatial dependence is evident in the data, it appears to originate in unmeasured covariates rather than in a contagion or diffusion process.

Cho & Rudolph (2008) examine the spatial structure of political participation in the United States using spatial econometric techniques. The different spatial specifications have substantive implications for the interpretation of their results, which they analyze in a unique way. They constructed a spatial lag model, but the focus of their paper is on the remaining spatial autocorrelation in the data after the spatial lag is incorporated. There is none. Their interpretation is that all of the spatial autocorrelation was accounted for and thus was not the result of any unmeasured covariates. The lack of remaining spatial autocorrelation allowed them to refine further the theory of behavioral contagion.

Geographically weighted regression models. As with all types of econometric modeling, spatial specifications can be widely variable. For spatial models, one important modeling decision centers on the manner in which one might specify the extent of spatial autocorrelation. In spatial lag and spatial error models, spatial dependence is explicitly part of the specification, but although the extent of spatial dependence may vary, it is considered fixed across the study area. One might incorporate the "contiguous neighbor" as the extent of dependence among units. Alternatively, one might use a distance decay measure where spatial autocorrelation is assumed to be strongest within a certain distance band and to decrease as units are located increasingly far from the unit of interest. For any choice, this decision extends to all units in the study and thus implicitly assumes that the extent of dependence is "stationary," that is, it does not vary across the study area.

One could imagine a scenario, however, wherein the extent of spatial dependence might differ depending on the characteristics of the local geography. For instance, in an urban area, one's neighborhood might be quite small in square mileage but encompass many people. In a rural area, the opposite may be true: a neighborhood might be conceived of as vastly larger but include only a handful of people. In this way, neighborhood definitions might be more dependent on population density than geographic area. In cases of spatial nonstationarity such as this, underlying processes are believed to affect the reach of spatial autocorrelation in different parts of the study area.

In instances where one cannot identify a specific geographic range that defines neighborhoods or areas of influence, one might opt for a geographically weighted regression (GWR) approach rather than a spatial lag or spatial error model (Calvo & Escolar 2003; Darmofal 2008; Cho & Gimpel 2009, 2010). GWR is part of a growing trend in GIS toward local analysis as a means for understanding spatial effects in greater detail. A GWR allows for the possibility that neighborhoods vary in size. Perhaps an even more attractive feature, however, is that GWR allows one to dispense with the notion of spatial stationarity in the coefficients. That is, the flexibility in these models allows one to model heterogeneity in the contextual processes so that one can capture the larger and smaller contextual effects that are simultaneously at play across the study area. Not surprisingly, GWR models often have smaller residuals with less spatial dependency, providing better fits to data, even after accounting for added model complexity and a larger number of parameters.

Cho & Gimpel (2010) found that a GWR was most appropriate for their data because they hypothesized that the patterns of political participation based on various local population attributes would vary across the state of Texas. From their GWR they established that high-income neighborhoods, for example, are associated with stronger effects on propensity to donate to a campaign at some locations than at other locations. Darmofal (2008) employs a GWR to examine voting patterns during the 1928–1936 Democratic realignment. The GWR reveals extensive geographic variation in how political and demographic factors influenced voting during the New Deal realignment. Calvo & Escolar (2003) advocate a GWR approach for making ecological inferences. Anselin & Cho (2002) highlight ecological inference as a type of problem that exhibits extreme spatial heterogeneity—values that vary widely across units of observation. Calvo & Escolar provide empirical evidence for their claim and demonstrate how a GWR, if properly specified, could help model the extreme spatial heterogeneity in ecological inference problems by allowing for a different coefficient for every geographic unit.

GWR is intended to capture local variation in effect size. If a researcher is not interested in local effects but only in the aggregation of local effects to estimate a global effect, then the value of GWR is diminished. However, for all researchers, it is instructive to acknowledge that traditional analyses, such as OLS or logit and probit models, and spatial econometric models, such as spatial lag and spatial error models, report coefficients that are global, i.e., spatial averages. Although the coefficients may differ in different parts of the study area, the coefficient reported is an average of all of these effects. When the local effects are highly variable, the average is less informative than when the area is more homogeneous. Moreover, if large variation exists, one might be interested in understanding this variation and in empirically modeling it through a GWR rather than subsuming the variation into an average value.

Semivariograms and kriging. We have, up until this point, largely skirted the issue of how one assesses the extent of spatial autocorrelation. Defining the weights matrix that characterizes which observations are considered neighbors of other observations is a key component of any spatial analysis. Theoretical guesswork and exploratory trial and error are not the only alternatives. Cho & Baer (2011) discuss some spatial exploration strategies for determining the proper weights matrix. Others, especially those who engage in spatial prediction or "kriging," have used a semivariogram to assess the extent of spatial autocorrelation. The semivariogram is defined as $\gamma(s_i, s_j) = \frac{1}{2}\text{Var}[Z(s_i) - Z(s_j)]$, where s_i and s_j represent two locations and $Z(s_i)$ is some attribute at location s_j. At close locations, we expect attributes to be similar. As s_i and s_j become farther apart, we expect their attributes to be less similar and the variance to increase. In this way, the semivariogram provides a measure of spatial similarity. Researchers can use a semivariogram to assess the distance at which spatial autocorrelation begins to level off in a particular data set.

Kriging is a class of geostatistical methods that originates from earth science applications, and specifically from the work of Matheron (1963). The technique got its name from D.G. Krige, a South African miner and engineer who pioneered its use in the field (Cressie 1993). Through kriging, the researcher can predict values at unsampled points based on known values in surrounding areas. Such GIS tools are critical for many research applications because it is costly or impractical to visit every location. The output from these models enables the creation of a prediction surface for the sampled phenomenon. The method has a well-established history in applied science settings, where it has been used to study animal populations, disease epidemiology, environmental risks to health, and similar georeferenced phenomena. Across social science fields, kriging has been used to estimate population, settlement density, housing values, income, charitable and political contributions, and other spatially based and socially networked phenomena.

What these applications have in common is that the variables of interest are regionalized, i.e., they are distributed in space. Regionalized variable theory suggests that the variation in a spatially distributed variable can be explained by three components: (*a*) a structural component characterized by a constant mean, or trend; (*b*) a random but spatially dependent component, which is the variation of the regionalized variable; and (*c*) spatially uncorrelated random error. With kriging, one can make spatial predictions by constructing a random field using known observations and interpolating the values at the unknown points of interest. In this way, one can predict values at these unknown points of interest. Cho & Gimpel (2007) employ kriging to study campaign contributing. Given the geographic concentration of wealth in the United States, and the dependence of political campaigns on wealthy donors, Cho & Gimpel (2007) suggest the value of this type of interpolation for predicting where a campaign might most successfully prospect for contributions.

Applications. In general, great strides have been made in recent years in many fields of study by employing spatial methods of data analysis. We have highlighted some pioneering initial studies using a variety of these methods. We expect related investigations to proliferate in the near future. A swell of interest is increasingly evident in the growing number of conference papers and journal submissions. The study of policy diffusion began with relatively simplistic conceptions of neighbor influence and how diffusion evolves. These early studies were not particularly sophisticated in their methodological choices and especially their measures. Saavedra (2000) was among the first to apply a more rigorous empirical analysis to the policy diffusion question. He used spatial econometric methods to specify a reaction function in which the Aid to Families with Dependent Children (AFDC) benefits in a given state were a function of the AFDC benefits in neighboring states as well as socioeconomic characteristics. Rom et al. (1998) examined AFDC and welfare policy by using a spatial lag model to capture diffusion. Friends-and-neighbors voting has also been reexamined with spatial tools suited to a more nuanced view of the phenomenon. Gimpel et al. (2008), for instance, use a distance decay measure in their examination of the friends-and-neighbors effect. In general, as we have seen from the large number of papers cited above, numerous applications of spatial methods to substantive questions in the subfield of American politics have already emerged in studies of voter turnout (Kohfeld & Sprague 2002; Sui & Hugill 2002; Gimpel et al. 2004, 2008; Cho & Rudolph 2008), voter geography (Darmofal 2006, 2008), vote choice (Peterson et al. 2008, O'Loughlin et al. 1994), donor geography (Cho 2003; Cho & Gimpel 2007, 2010; Gimpel et al. 2006, 2008), policy diffusion (Berry & Berry 1992, Berry & Baybeck 2008, Rom et al. 1998, Saavedra 2000), ecological inference (Anselin & Cho 2002, Calvo & Escolar 2003), campaign strategy (Cho & Gimpel 2007), and the origins of racial attitudes (Cho & Baer 2011).

FUTURE APPLICATIONS

GIS will have a continuing and expanding role in the measurement of important social scientific constructs relating to interaction, location, distance, proximity, and scale. With the GIS capacity to position events and individuals within their environments or neighborhoods, it is possible to study the relationship of behavior to social and political milieu at multiple scales, likely revealing dissimilar effects at each level of observation. Of course, the "modifiable areal unit problem" needs to be considered, but having the capacity to investigate the same phenomenon at multiple scales vastly expands our understanding of the way geographic influence works.

Present scholarship in political behavior, both observational and experimental, is concerned with the role of social networks in communication, opinion formation, and political engagement. In the near future, GIS will be used to assess the extent to which social network influence is constrained by distance and regular face-to-face interaction. GIS will also be important in measuring the extent of spatial autocorrelation in opinions and behavior across friendship and discussion networks. Such studies will advance the earlier work by Huckfeldt & Sprague (1995) on the socially embedded and geographically bounded nature of political viewpoints and activity. This trajectory of fascinating research is likely to teach us a great deal about the genesis and development of social movements and of collective action in forms such as political protest.

In policy-related research, GIS has the capacity to guide discussion and decision making not just about redistricting schemes, but about the optimal location of important public services such as hospitals, schools, fire stations, polling places, and new infrastructure. These are technically called point location problems. An entire class of optimizing tools, called location-allocation models, is already widely used in engineering and planning but has been little used by policy analysts working within political science. Exciting developments using GIS to depict and study the multiple dimensions of space and time are well under way. Panel data remind us of the importance of adding the time dimension to spatial analysis, and models to handle the complexity of estimating space and time effects simultaneously are being developed. These models will not only shape future scholarship on contemporary themes but will also provide a new avenue for research with historical data. The work of political historian Richard White (2010, 2011) and the "spatial history" project at Stanford University stand out as pioneering the use of GIS with archival and recently digitized records dating to the nineteenth century.

As we have indicated, the demand for maps as instruments of data visualization predates the development of GIS in all social science fields. But GIS tools have certainly made mapping much more accessible for a wide array of political science topics. More than that, GIS has greatly improved the measurement of critical social science constructs, as well as the management of data that are spatially arranged, whether observations are adjacent to each other, nested, or positioned in some other geographic relationship. Finally, GIS as it has developed within political science is closely linked to the ever-increasing use of spatial statistics and econometrics for hypothesis testing. Whether a researcher is interested in geocoding individuals from surveys to nest them within neighborhoods, or examining the adoption of policy across political jurisdictions, the development of spatially related theories has made it imperative to have software tools that can precisely gauge and depict the geographic associations and linkages among observations. The gains are not just realized in more exacting measures of familiar constructs, although these certainly constitute an important advance. Entirely new work can move forward because of the data management and measurement capabilities in GIS. This essay has pointed to a small subset of the work that has been done using GIS during the past decade or so. As in any developing science in its nascent stages, we can confidently conclude that the best is yet to come.

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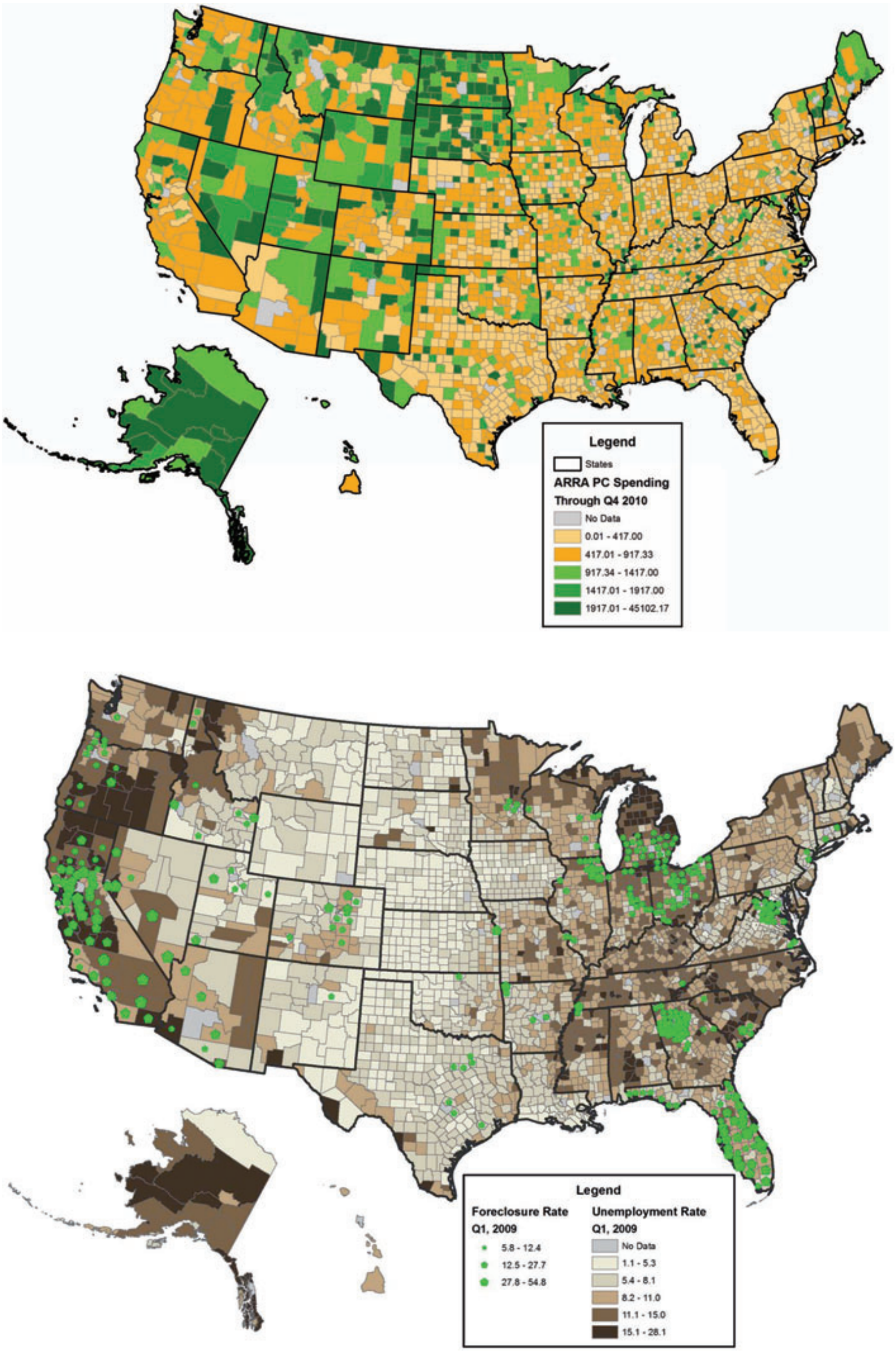

Figure 2

Distribution of the Obama stimulus package (the American Recovery and Reinvestment Act of 2009, ARRA) compared with indicators of unemployment and home foreclosure at the time of enactment. *Top*: stimulus package spending; *bottom*: unemployment rates.