A Spatial View of How United States Cesarean Section Rates Changed from 1990-2014

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Abstract

The overuse of cesarean sections (c-sections) in the United States is a contested issue. The rate of c-section births in 2015 at 32% was over double the World Health Organization recommendation of 10-15%. We employed spatial statistical methods and data visualization techniques to assess the temporal and spatial trends in c-section rates by county across the US. While the national rate of c-section remained stable at the beginning and end of this study period, an increase in rates from 1997 to 2009 was reflected simultaneously in national, state, and individual county rates. Local indicators of spatial dependence did not show spatial clustering as being connected to, or driving, the change, yet the visualization methods used here show details on individual county deviance from local temporal trends. By highlighting counties which do not follow the trends of their neighbors, we identify exceptional locations which could help further the study of the determinants of changing c-section rates in the United States.

Keywords; Cesarean sections, Exploratory spatial data analysis, Medical geography, Spatial statistics

Introduction

Due to the number of factors contributing to the rate of c-section use it is difficult to find a primary driver of changing US c-section rates. For this reason, an understanding of the spatial patterning of c-section rates over time could help to create hypotheses about what may be influencing increasing rates of c-sections in the U.S. To search for differential geographic trends, visualization can be incredibly efficient in highlighting spatio-temporal patterns that may not be seen otherwise. The aim of this paper is to understand the temporal and spatial patterning in c-section rates from in US counties from 1990-2014 to identify common patterns in the national rise in c-section rates during that time and to identify individual counties which establish unique c-section rate patterns over time compared to their immediate neighbors and national trends. This paper is not intended to identify the determinants of c-section rates, but rather to generate hypotheses for further analysis.

Literature Review

In 2010, cesarean sections (c-sections) were the most commonly performed major surgery in the United States (Pfuntner, Wier, & Stocks, 2013). While c-sections have consistently been one of the most frequently performed major surgeries, the U.S. saw a rapid increase in c-sections from 21 percent of all births in 1996 to 32 percent in 2007 (Menacker, Hamilton 2010). The increase in c-section rate, as represented by percent of births delivered through c-section, is concerning because c-sections are associated with increased risk of maternal morbidity (Curtin et al 2015), c-section rates differ by racial and ethnic groups (Ehrenberg, Durnwald, Catalano, & Mercer, 2004, Braveman et al 1995), and unnecessary surgery has a societal economic burden (Gibbons et al 2010). The increase in c-section rates is also observed for premature deliveries, which are associated with adverse health effects in later life, whether delivered by c-section or not (Menacker, Hamilton 2010, Wilmink et al., 2010). The increase in preterm c-section deliveries is concerning because of questions about whether c-sections are necessary for preterm delivery and because rates of preterm delivery are associated with maternal race (Demissie et al., 2001).

The situations in which c-section deliveries are performed can be described in three ways: (1) emergency, in which a mother has started labor before it becomes apparent that she will need a c-section, (2) planned, in which the need for a c-section is anticipated for medical reasons and acted on before labor, and (3) elective, in which a c-section is planned, even though the risk is low enough to not be considered medically necessary. An additional c-section definition of importance is “Low Risk”, which could be placed in any of the former three categories, in which a c-section is performed for a first-time mother, at term, with the child oriented head first and the pregnancy is with one child. The last definition does not differentiate by maternal and provider preference or maternal and fetal health. The increasing rates of c-section are in part due to increasing rates of elective c-section (Meikle, Steiner, Zhang, & Lawrence, 2005) as well as increasing rates of low risk c-section (Osterman, Martin 2014). The increase in low risk and elective c-section deliveries has occurred even if this delivery method has the potential to induce larger medical costs and increased risk of morbidity for the mother compared to if the birth had been vaginal (Bost, 2003; Curtin et al. 2015). However, if an emergency occurs during regularly planned vaginal birth, emergency c-sections are associated with more severe and frequent maternal morbidity, psychological disorders, and higher expenses when compared to planned c-sections (Ryding, Wijma, & Wijma, 1997).

Since only 11.3% of subsequent births to women who had a previous c-section were vaginal in 2014 when our study period ended (Centers for Disease Control, 2014), a major determinant of c-section rates is the method of a woman’s first delivery, referred to as primary delivery. Rates of primary elective c-section rose from 19.7% of all primary c-sections in 1997 to 28.3% in 2001 and is cited as being a large contributor to the overall rise in c-section rates in the US (Meikle et al., 2005). This also comes during a period when the American College of Obstetrics and Gynecology (ACOG) released a clinical review in 2000 stating that the risks and rewards of c-section delivery have reached a point where delivery method could be a choice rather than a necessity (Harer, 2000). This stance was later amended by the ACOG in 2013, saying that without medical indicators, vaginal birth should be recommended (American College of Obstetricians and Gynecologists, 2013). While a body of literature has proposed that rising c-section rates are due to maternal request, this has been described as understating physicians' influence on the decision-making process (Gamble, Creedy, McCourt, Weaver, & Beake, 2007).

There are numerous ways in which the medical field can influence the c-section rates including the practices of individual physicians, hospitals, and payment methods. Individual physicians' rates of c-section delivery vary widely even when they are in the same practice (Metz et al., 2016) and are associated with provider attitudes towards perceived safety practices during birth (White VanGompel, Main, Tancredi, & Melnikow, 2018). The difference in amount paid to physicians and hospital for vaginal or c-section birth has also been identified as a determinant of c-section use (Gruber et al., 1999, Grant, 2009), however the size of the effect has been questioned (Grant, 2009). Hospitals are also seen as influencing the c-section rates through associations such as type of hospital ownership, obstetric policies and staffing (Huesch, Currid-Halkett, & Doctor, 2014; Lundsberg et al., 2017).

There is also evidence to suggest that changing maternal characteristics could medically necessitate an increase in c-section rates. For example, diabetes, maternal weight, and higher maternal age all increase the risk for c-section delivery and these maternal characteristics all became more prevalent during the period of increasing c-section rates (Ehrenberg et al., 2004, Luthy et al. 2003). While none of these conditions explicitly mandate the use of a c-section, they can lead to conditions such as hypertension which is a medical reason for a c-section. C-sections have been seen to occur at higher rates in southern states (Clarke & Taffel, 1996) where rates of obesity are also high (Michimi & Wimberly, 2010). This geographic overlap reinforces the idea that changing health patterns may be one of many drivers of increasing rates of c-section deliveries.

Methods

The data for this study come from the publicly available Centers for Disease Control and Prevention (CDC) Vital Statistics birth data from the years 1990 to 2014 (CDC, 2015). Two subsets of this dataset were used, one of state-reported totals and one of county-reported totals. Due to privacy issues in health data sharing, the CDC only provides data for counties with populations greater than 100,000 in the public use county data. Including only counties from the continental United States, the counties fulfilling the 100,000-person threshold changed over time, with 375 counties in 1990 and over 570 counties in 2014 for a total of 12,004 cases over the 25-year study period (Figure 1). To ensure data quality, we removed cases (n=183) where the number of total births reported were substantially (7.3%) different (greater than ± 2 standard deviations from the mean difference between the reported total and the summed total values by delivery method (c-section, vaginal)). All analysis for this study was done using Statistical package R (R Core Team, 2017.) We merged the c-section rates at the county and state level with the 2014 United States Census Bureau county and state cartographic boundaries (United States Census Bureau 2015). Since the data we used were de-identified, contained only state or county-level data, and were publicly available, this study was deemed to be non-human subjects research by the Institutional Review Board at the University of Colorado, Boulder.

Initial exploratory analysis was performed by comparing average and median c-section rates by state, county, and year to search for temporal trends. The increase in rates was visualized in Figure 1 and mapped in Figure 2.

We began our spatial analysis by calculating global Moran's I using various weights matrices based on distance, where all counties within a certain threshold distance were neighbors, using thresholds of 50, 100, 150, and 200 miles. We also investigated K-nearest neighbor thresholds of 2, 3, 4, and 5 nearest neighbors. The results presented below are for those with D=150 miles for county-level data because this matrix had the highest number of years with a significant global Moran's I, and K=3 for state-level data due to the larger scale.

To assess local spatial autocorrelation of percent c-section, we mapped Local Moran's I_i values as the absolute value of the Moran's I_i Z-score and plotted Moran's I (LISA) scatterplots for each county for each year with a first order spatial lag (direct neighbors with d=150 miles) (Figure 3). Outliers were defined as cases which show influence or leverage on the regression used to calculate the Moran's I. The outliers in the Moran's I scatterplots were identified as showing significance in any one of a number of standard regression diagnostics, including Cooks Distance and the diagonal measure of a hat matrix (Anselin 1995). We then used a visual clustering technique to compare Local Moran's I_i scatterplots, initially proposed by Murray et al. (2012). In this application, we observed a year-to-year comparison of how each county changed its relative location in the Local Moran's I_i scatterplot (Figure 4). In addition to exploratory data analysis, we reviewed relevant literature to identify national trends and exceptional locations to highlight in this study.

Results

The national rate of c-section changed most rapidly from 23.94 percent in 2001 to 31.24 percent in 2007 (Figure 1). County-level comparisons showed a difference of 33.27% between the highest and lowest county c-section rate in 2014, with Washington County, Utah having the lowest 2014 rate of 15.55% and Rapides, Louisiana having the highest rate of 48.82%. Using exploratory data analysis on aggregated averages by year and state, we found differences between state-reported data and state-aggregated county-reported data (when only counties with > 100,000 people were included). Specifically, the temporal trends remained consistent, but individual state ranks of highest and lowest rates were different between the two datasets. Because of these differences, it is important to recognize that the results presented below apply only to the most populous counties (populations > 100,000) in the US.

When comparing the spatial distribution of the county-reported rates by year, the global Moran's I test showed significant positive autocorrelation only in 1991 and 2004 (Table 1), meaning a county's c-section rates are similar to their neighbors (i.e., counties with high c-section rates are more likely to be neighbors of counties that also have high c-section rates and vice versa).

Local Moran's I_i was assessed using Local Moran's I_i maps and Moran's I scatter plots. The Moran's I scatter plots (Figure 3) showed no exceptional clustering during any of the observed years, however counties such as Brown county, WI which were highlighted in our literature review, did appear as outliers. The Local Moran's I_i maps did not show exceptional clustering for any of the years studied, and individual counties which showed high |z. I_i| cluster values changed over time.

Together these results do not support the hypothesis that spatial connectivity was a major determinant of changing state or county-level c-section rates during our study. However, directional movement plots showed distinct trends (Figure 4). This visualization showed annual changes to the clustering of c-section rates at a local scale, which could potentially highlight if there were groups of counties whose trajectories were counter to the overall trend, thus influencing our observed global Moran's I values. During the period of increasing c-section rates from 1997-2009, more counties exhibited positive co-movement (movement to higher c-section rates and higher similarity to neighbors), than negative co-movements (movement to lower c-section rates and lower similarity to neighbors) with the strongest transitions towards positive co-movement taking place each year from 2000 to 2006 (Figure 4C). Since there was a general trend towards higher c-section rates and higher similarity to neighbors over this time period, positive spatial autocorrelation in the global Moran's I value was expected, yet the values were not significant for most years. In Figure 4C, the directional plot from 2003 to 2004, we see a strong general movement towards positive co-movement, suggesting a transition towards positive spatial autocorrelation which corresponds to the value of the global Moran's I for 2004. However, the shift from 1990 to 1991 (Figure 4A) does not show any distinct movement pattern correlating to the positive global Moran's I value seen in 1991.

Figure 4C also shows a cluster of counties moving counter to the national trend and towards low c-section rates at a higher magnitude than others moving into the quadrant. Although this cluster of counties moving towards lower rates from 2003 to 2004 are not geographically clustered, they did follow similar patterns of c-section rate over time during the same period. These counties included Comanche, OK; Jackson, MS; Stearns, MN; and Manatee, FL. The results of our literature search of exceptional counties did not reveal these counties as unique, however when examining the history of these counties specifically, we did find reports for Comanche, OK that referred to its lower c-section rate compared to other counties in its state (Lewin Group, 2014).

Our literature review found a series of studies in which researchers directly observed hospitals in Green Bay, a city in Brown County, WI. These studies identified low rates of c-sections in 1990 and 1992 to be naturally occurring without any formal intervention, despite higher rates in 1986 and 1988 (Sandmire & DeMott, 1994). We observed that during the study period, Brown County, WI began as an outlier in the Moran's I scatterplot, before integrating into the main cluster in 2003 (Figure 3). Although Brown County, WI maintained lower than average c-section rates, it transitioned over time from being an outlier in its low rates and high similarity, to fitting in with national trends of moderate rates and moderate similarity. In this way, Brown County followed the temporal trend of increasing rates and enacted the spatial standard of moderate similarity.

Discussion

Our findings contribute to the literature on changing rates of c-section in the US as well as the literature on the spatial influence on health and medicine by highlighting the lack of evidence for county-level spatial exchange among c-section rates. The findings also show a possible application of a novel data visualization method in health and medical geography. The lack of evidence for local similarity, together with our observation of the bulk of individual counties changing according to national patterns, suggests that localized spatial exchange (i.e., a diffusion process) at a county-level was *not* a primary reason for increasing c-section rates in the US from 1990-2014, and we found that neighboring counties changed together, but only as a reflection of national trends.

The directional movement plot visualizations highlighted counties which acted differently from national trends between years, and visualized changes in spatial connectivity over time. Here, the strong positive-comovements in the directional plots were seen as corresponding to positive autocorrelation in 2004 which could indicate underlying geographic trends between 2000 and 2006 during which strong positive co-movements were also seen. However the directional plots did not have any distinct patterns leading to the positive global Moran's I value in 1991. The strong positive co-movements from 2000 to 2006 also coincided with the most rapid increase in c-section rate from 2001 through 2007. This rapid increase in c-section rate during this time period could explain the positive co-movement as the national c-section rate was unanimously rising during this period. It doesn't explain why the global Moran's I was only positive for one of these years. The discrepancy in the timing of the significant global Moran's I values compared to the timing of observable patterns in our visualizations indicate the possibility of geographic patterning not observed in this analysis.

Our literature review did not uncover any notable programs or initiatives related to c-sections for the counties identified as experiencing large unexpected drops in c-section rates from 2003-2004 (Figure 3). However, there is evidence of these counties moving towards and/or maintaining lower c-section rates. For example, reports showed that Comanche County, OK had low rates of medically unnecessary c-sections compared to its neighbors (Lewin Group 2014). This was seen in our data as Comanche County saw a decrease in rate of 4.08 percent from 2003-2004. While it may or may not be beneficial to rapidly decrease the c-section rate, understanding how or why the c-section rates declined so rapidly in these counties compared to their neighbors could help in future initiatives to lower c-section rates in other counties.

Brown County, WI was identified from the literature because its largest metropolitan area, Green Bay, had a large decrease in c-section rate from 13.3% in 1986 to 10.2% in 1992 (Sandmire & DeMott, 1994). This reduction happened without formal c-section curtailment programs. However, Green Bay was the setting of the Green Bay Cesarean Section Study, which spanned from 1985 until 1994, in which researchers interacted with practitioners to understand c-section decision making and rates. Interestingly, during the period of overlap between our study and the Green Bay Cesarean Study from 1990-1994, Brown County showed a trend similar to the national trend where the rate dipped slightly before rising again. However, at this time the Moran's I plots show Brown county as an outlier compared to its neighbors despite following national trends. In 2003, Brown county then transitioned away from being an outlier as measured by c-section rate and similarity, and followed national trends for the rest of the study period (Figure 3A-D). The undetermined traits that kept Brown county's c-section rate significantly lower than those of its neighbors initially appeared to disappear when the national rate, and also Brown county's rate, began to increase in 1998. Not only did Brown County's c- section rate increase, but it also became more similar to its neighbors before losing its outlier standing in 2003.

This is contrasted with counties like Utah County, UT which also maintained a low c-section rate and high similarity to its neighbors during the period when national rates were increasing, yet also maintained significantly different rates of c-section and similarity to be considered an outlier on the Moran's I plots. This identification of counties which exhibit lower c-section rates than their neighbors should lead to more targeted research into what caused individual counties to maintain or lower their c-section rates.

The simultaneous rise in rates shown by the majority of US counties still leaves questions about what the drivers of individual county-level rates are. Future research should include a comparative analysis of the locations which deviated from national trends. This work can also be expanded by using new data at different scales, such as at the city or state level, or data using different levels of contiguity such as the inclusion of all counties or only city level data. While it can be difficult to find individual drivers of changing health patterns, looking to locations which defy local standards can direct targeted research into potential determinants of c-section rates.

Conclusions

Although our spatial analysis did not uncover spatial connections as significantly driving US c-section rates, the novel approach for geographic visualization used here highlights area of further interest for understanding changing patterns of c-sections over time and space. While spatial clustering was not observed in our analysis, we identified a visualization method that could be useful in highlighting periods with distinct trends, as well as counties which did not act in the same way as their neighbors over time. Counties like Brown County, WI, which was previously identified as being an outlier, acted in accordance to national trends, while counties like Comanche County, OK deviated from national and local trends in a way that may have been beneficial to population health. Together these observations can indicate the role of geographic analysis in supporting and generating questions on drivers of health status. With a goal of using spatial analysis to highlight positive deviance in relation to US maternal care, the foundations established in this study have the potential to benefit initiatives exploring c-section rates and other health endpoints of population health interest.

Table 1. Annual median rates of c-section compared to the global Moran's I. (*) Indicates a P-value of less than .05

Year	**Median**	**Moran's I**	**Year**	**Median**	**Moran's I**	**Year**	**Median**	**Moran's I**
1990	22.32	0.0034	**1999**	21.31	0.0203	**2008**	31.48	-0.0131
1991	21.97	0.0632*	**2000**	22.05	0.0033	**2009**	31.93	0.0150
1992	21.67	-0.0059	**2001**	23.69	-0.0009	**2010**	31.74	-0.0165
1993	21.30	0.0202	**2002**	25.21	0.0056	**2011**	32.09	0.0085
1994	20.65	-0.0122	**2003**	26.63	0.0126	**2012**	32.08	-0.0144
1995	20.31	-0.0162	**2004**	28.32	0.0341*	**2013**	32.02	-0.0231
1996	20.21	0.0174	**2005**	29.42	-0.0121	**2014**	31.65	0.0086
1997	20.12	-0.0068	**2006**	30.15	-0.0269			
1998	20.28	0.0073	**2007**	30.74	0.0061			

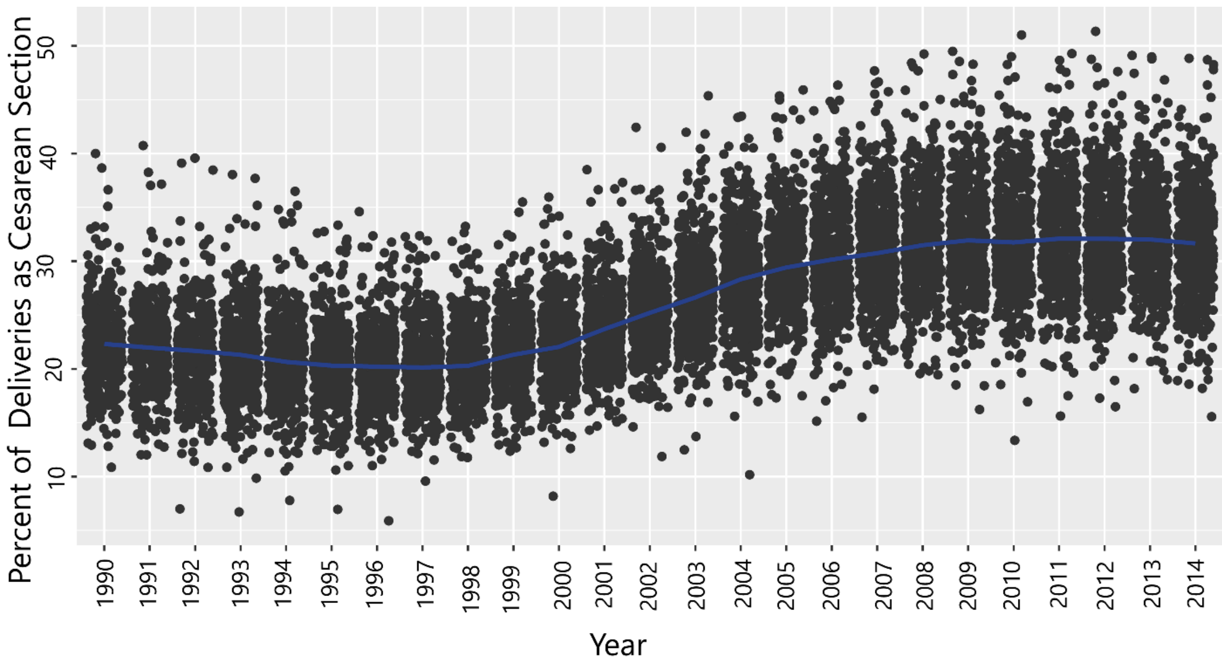

Figure 1: Annual changes in c-section rate by county, with the median rate in blue, for U.S. counties with populations greater than 100,000.

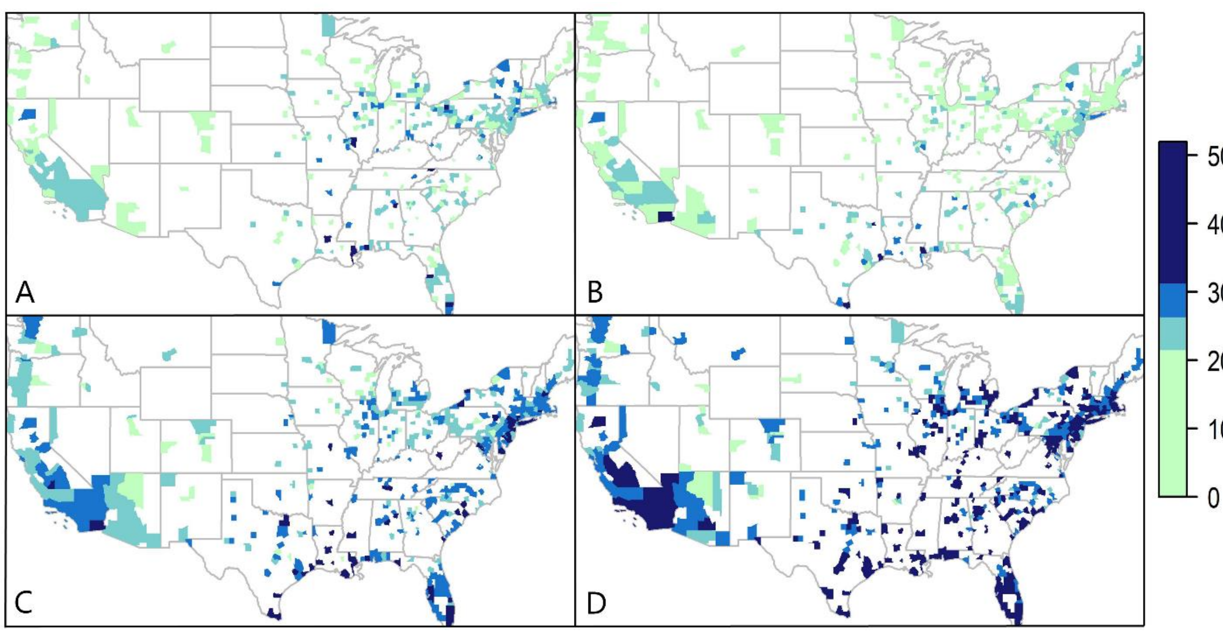

Figure 2. The c-section rate for counties greater than 100,000, by quantiles calculated on the data for all years. A. 1990, B. 1997, C. 2003, D. 2014.

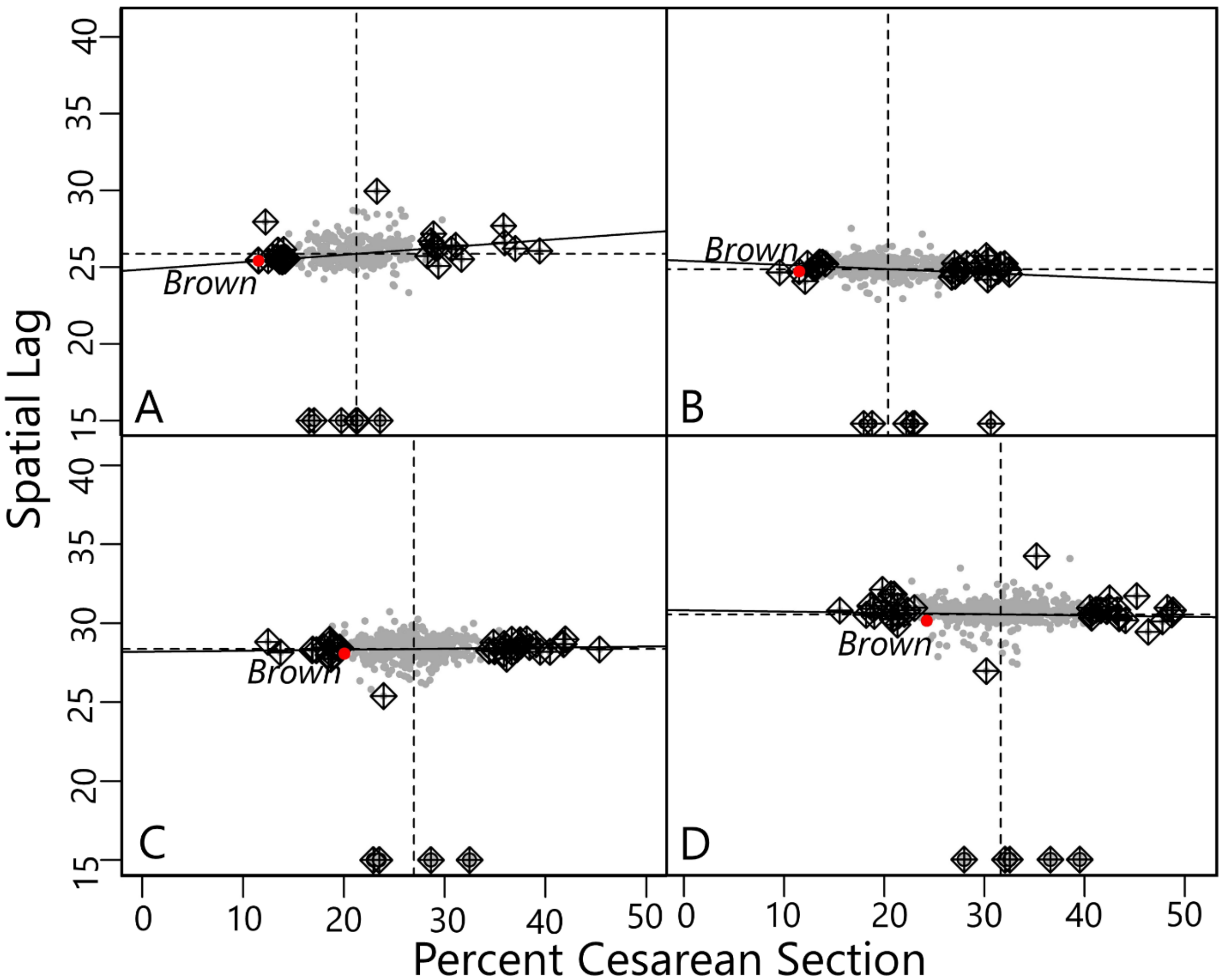

Figure 3 A-D. Moran's I scatter plots comparing local indicators of spatial autocorrelation for years A. 1990, B. 1997, C. 2003, D. 2014, with Brown County Wisconsin labeled.

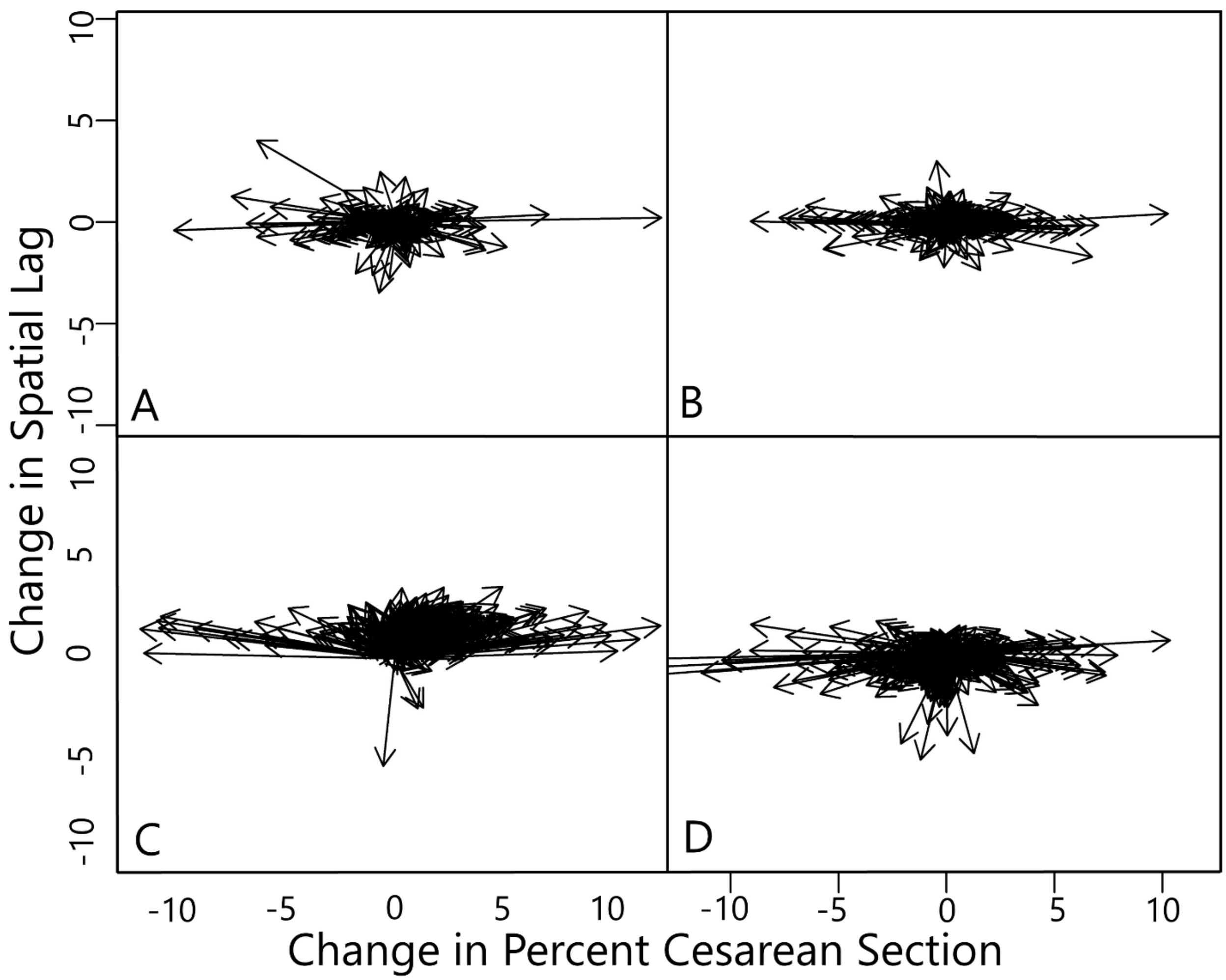

Figure 4 A-D. Directional Moran's I scatter plots showing annual changes of local indicators of spatial autocorrelation by county for years A. 1990-1991, B. 1997-1998, C. 2003-2004, and D. 2013-2014. In these diagrams, a steady state is represented by an evenly distributed circle of arrows (Figure 4D).

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