The Spatial Patterns of Low Birth Weight and Infant Mortality and Associated Risk Factors at the County-Level: Using Spatial Analytical Techniques*

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Abstract

In this paper, we use spatial analytical techniques to visualize spatial variation in low birth weight rates (LBWRs) and infant mortality rates (IMRs) at the county level and provide the improved understanding of the underlying mechanisms of differentiating outcomes of interest across areas. We utilize the 2002 Area Resource File. The result shows a clear spatial pattern of LBWRs and IMRs. The spatial autocorrelation is clearer for LBWRs than IMRs. The concentration of high LBWRs is observed in the southeastern and middle northeastern regions of the U.S., while the southeastern regions show the high-level of IMRs. The spatial regression model shows that the aggregate socioeconomic aspects of areas play an important role in determining the county-level of both the LBWRs and IMRs. Physical features (i.e., humidity, temperature, and elevation) exert great role in determining the county LBWRs, while health care relevant resources (i.e., states' Medicaid eligibility, per capita physician supply) have substantial influences on the county IMRs.

INTRODUCTION

Infant mortality rates (IMRs) have been seen as the most sensitive marker of the population's quality of life and well-being, which make them a powerful presence in both the academic and public policy areas (Gortmaker and Wise 1997; Frisbie 2005; Wise 1999, 2003). In comparison to U.S. economic standing, medical advances and health care expenditure, however, the US IMR ranks poorly internationally. The greatly increased risk of infant death among low weight births, a critical measure of infant morbidity at birth and the strongest predictor of infant survival, has been found to be the major contributing factor behind the relatively poor position of the US IMR in comparison with other developed countries (Gortmaker and Wise 1997; Paneth 1995). Given that few issues are of greater importance for a society than the infant health and mortality, the reduction in LBW rates and IMRs becomes a top priority for the U.S. health objection as is clear from the Healthy People 2010 (2000).

An important feature of the infant morbidity and mortality burden in the U.S. is that there exist substantial area variations (i.e., states, counties, urban and non-urban, and other small units of areas). Many researchers have documented that the geography itself reinforces their positive and negative impacts on the individual overall life chance and well-being through leading to various by-products (i.e., the different amount and quality of social services and infrastructure and polarized norms, attitudes and behaviors to health and mortality differentials of residents) (Ellen 2000; Massey 1996; Massey and Denton 1993; Williams and Collins 2001; Wilson 1987). Given the extremely high level of spatial segregation across the meaning social groups, this spatial segregation have definitely impacted regional infant health and mortality conditions due to the characteristics of the individuals living in such areas, in combination with the characteristics that relate to space itself. Therefore, the contextual impacts of infant health and mortality outcomes could become multifaceted and complex. Yet, past studies have narrowly focused on one or a few dimensions of the local context, mainly socioeconomic features.

The overall purpose of this study is to examine the spatial disparities in the LBW and infant death rates at the county level and to understand the underlying mechanisms of differentiating population at risk across areas. Different from the prior ecological studies, I utilize the spatial analytical technique. Despite the wide use and the proven usefulness of the spatial analytic technique for the ecological studies (Anselin 1988, forthcoming; Boscoe et al. 2004; Patrick 2000; Ricketts 1994; Rushton 2003), few attempts have been made to utilize it to identify the geographic distribution and the spatial process (i.e., spatial dependence) of the infant health and mortality outcomes. For this project, the county is the unit of analysis as "the county, as the local extension of the state's policy power, became the most common political body either willing or situated appropriately to apply public health policies." (Ricketts 2002) Given that the level of infant health and mortality have been largely driven by the social and public health programs and the perinatal health care systems, the county would be the most useful and appropriate scale to evaluate infant health and mortality outcomes in the US.

The specific aims of this study are as follows:

First, this study will apply the spatial analytical techniques to visualize the geographic variations in the IMR and LBW at the county level in the U.S. As the most fundamental aspect of the spatial analysis, mapping the rates of infant mortality and low weight births will provide clear and useful information regarding to the identification of the geographic locations where not only burden of disease and mortality, but relevant risk factors are highest.

Second, given the notion of the spatial clustering of infant mortality and low birth weight, I will examine the geographic concentration of infant mortality and birth weight outcomes and test whether such clusters are statistically significant. In other words, it will test whether such clustering occurs rather by chance.

Third, this study will identify various area risk factors that could be related to infant health and mortality differential across the U.S. counties beyond the socioeconomic characteristics of the population. Broadly, three dimensions of county characteristics will be emphasized; socioeconomic features, physical environments, and the provision of health care services.

Fourth, I will conduct the spatial regression models to take into account the spatial components of county IMR and LBW rates, if any significant spatial clustering is identified. Many researchers acknowledge that the standard regression models are insensitive to the spatial aspect and process of health and mortality outcomes and in turn, the spatial dependence which naturally occurs in the ecological data will produce the biased estimates of underlying risk factors of outcomes of interest (Anselin 1998, forcoming; Messner and Anselin 1999 forthcoming; Morenoff 2003).

Answering such questions will be important for policy makers to have better idea regarding where the most vulnerable area are and in turn, helps to establish better and adequate social and health program to not only improve overall rate of the U.S. low weight births and infant death, but redress regional disparities. This endeavor becomes increasing necessary especially if we consider the continued localization of the social and public programs, in combination of the extreme high-level of the social and racial segregation by the geographic line in the U.S.

BACKGROUND

The economic growth and medical advances in the U.S. have driven infant mortality down substantially over the years. However, its progress was much less than that for many developed countries. For instance, overall infant mortality has been substantially reduced 45.2%, i.e., from 12.6 to 6.9 death per 1,000 live births between 1980 and 2000 (Iyasu 2002). However, the U.S. international ranking of IMRs has been continuously falling over time (i.e., 19th in 1980, and 29th in 2000). The primary reason for the poor U.S. IMRs has been largely related to the high prevalence of low weight births (Paneth 1995). During the last two decade, rates of LBW have actually increased by 20% (Iyasu 2002).

This troubling position of the U.S. infant health and mortality is thought to reflect the inequitable income distribution, the disparities in the medical care system, and the inadequacy of re-distributional efforts such as welfare and health policies in which do not ensure better health and survival for all infants (Gortmaker and Wise 1997; Wise 1999, 2003). In light of this relationship, many studies have shown that the infant mortality rates vary widely across geographic areas, given the substantial differences in the socioeconomic structures and social and health programs across areas in the U.S.

The most common findings are that areas with poor socioeconomic characteristics of individuals increase the relative risk of the low birth weight and infant death as socioeconomic deprivation, especially poverty, is the most critical determinant of disease and premature death (Morenoff 2003; Stockwell et al. 1995; Wise 1999, 2003).The additional factor which has been consistently found to influence the area disparities in the infant health and death outcomes is the racial segregation (Ellen 2002), especially the black population. Wilson (1987) has emphasized the synergic, negative influences of the combinations of the concentration of poverty and racial residential separations on many aspects of residents' life chances and well-being. Later on, Massey and Denton (1993) argue that residential segregation itself is a primary reason for impoverishing communities and perpetuating black poverty in those areas in the United States. In addition to those factors, the significant impacts of several other measures of socioeconomic characteristics of areas such as income inequalities (Mayer and Sarin 2005; Mellor and Milyo 2001), the unemployment rate (O'Campo et al. 1997; Pearl et al. 2001; Shi et al. 2003), rate of female household (Bird and Bauman 1995; Robert et al. 1997), and median family income (Ellen 2000; Fang et al. 1999), the prevalence of the teen childbearing (Clarke et al. 1994; Geronimus 1987) have been documented.

In relatively recent years, some investigators have explored the impact of the availability and accessibility of health care relevant resources (including primary care centers, neonatal intensive care units, per capita physicians, per capital health care spending and state's eligibility of Medicaid for the pregnant women) on initiation of prenatal care, LBW, preterm births, and infant mortality. For instance, Currie and Gruber (1996) documented that the expanded eligibility has significant impacts on the infant mortality risk. Others have examined the impact of state's spending on medical care, expenditure on Medicaid, or the number of recipient of welfare programs and their relationships to the risk of infant death (Bird and Bauman 1995; Clarke and Coward 1991; Howell 2001; Matterson 1998; Mayer and Sarin. 2004). Larson et al. (1997) have studied the relative risk of diverse birth outcomes between rural and urban areas. They found no significant differences between two types of areas once taking into account the relevant risk factors and interpreted that adequate provisions of health care services help mitigate the disadvantages living in the rural areas. The favorable influence of the local availability of prenatal services and neonatal intensive care units on the birth outcomes has been identified across several studies (Heck et al. 2002; Gould et al. 1999; Matteson et al. 1998; Guagliardo et al. 2004). Further, Maciko et al. (2003) have shown that the negative association between primary care physician supply and infant mortality and LBW.

Although pure locational features of areas have been largely ignored in studies of infant health and mortality outcomes, several researchers, especially among medical geographers, have suggested that physical attributes (i.e., altitude, temperature, humidity, quality of water) and environmental aspects of an area such as levels of air pollution could be an fundamental factor in determining the vulnerability of population at risk (Ballester et al. 2003; Ricketts 1994). At least, it is well-established that infectious disease is more prevalent in the warmer areas and there are seasonal differences in morbidity and mortality outcomes, especially among the elderly and the poor and disadvantaged population. In the case of infant health, an earlier study by Bueken and Wilcox (1993) has reported that infants born at locations with high altitude increase risk of being low weight. Several studies have documented the detrimental impact of air pollution on infant health and mortality outcomes (Chay and Greenstone 1999; Ha et al. 2003; Woodruff et al. 1997).

METHODS

Unit of Analysis

For this project, the county would be a reasonable and meaningful contextual unit. Economic development policy, health care systems and public-funded programs are generally organized at the federal and state level. However, counties are the functional unit to which the government allocates resources. Further, they have the primary responsibility for implementing, delivering, and monitoring health care services, and in turn, making them more effective and accessible. Zopf (1992) states, "the county is the most practical subdivision for pinpointing high and low infant mortality."

Data

This study utilizes the 2002 Area Resource Files (ARF). The ARF is a collection of over 50 primary databases providing county-specific information. It includes more than 6,000 measures related to health facilities, health professions, resource scarcity, health and mortality status, economic activity, health training programs, and socioeconomic and environmental characteristics. Although the 2002 version of the ARF is used for this study, each variable might come from different years. Whenever possible, data for the year 1998 are employed as they are the midpoint of the three-year infant mortality and low birth weight rates, 1997-1999. If not available for this year, data for the closest time point are selected. The analyses are limited to the continental U.S. (exclude Alaska and Hawaii), in which result in a total of 3108 counties among 49 states.

Measures

<u>Dependent Variable</u>

The primary outcomes of interest are the rate of infant mortality and low birth weight at the county level. Infant death indicates the premature death of infants less than one year of age. Low weight birth is defined as infants weighting less than 2500 g at birth. The county LBW rates are calculated as the number of low weight births per 100 live births, while the county IMRs are based on the number of deaths of infants per 1,000 live births. To ensure a stable estimate of the outcome of interest, three-year average rates of IMR and LBW, 1997-1999, are examined. As shown in the table 1, LBW rates have a range of 0.00 – 25.00 and a mean of 7.41 during the study period, while county rates of IMRs range from 0.00 to 55.56 and have a mean of 7.21.

-- Table 1 about here --

Independent Variables

Broadly, three dimensions of the area characteristics are emphasized to explore why spatial disparities in the IMR and LBW rate emerge: physical features, socioeconomic aspects, and health care relevant resources.

Physical features indicate a number of ecological factors such as the average degree of July temperature based on the years 1941-1970, the average percentage of the July humidity based on the years 1941-1970, and elevation feet in 1976. Although such data are several decades old, it is hard to image that there is much change in those measures over time. In addition, potential change, if any, could have occurred across all areas rather than have disproportionately affected for certain sections of regions.

Area level socioeconomic characteristics include the proportion of black populations in 2000, the percentage of female head households in 2000, the percentage of persons aged 0 – 17 years in poverty in 1998, the unemployment rate among 16+ people in 1998, and the southern states (i.e., Texas, Okalahoma, Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Kentucky, Georgia, South Carolina, North Carolina, Florida, Virginia, West Virginia, Maryland, and Delaware).

Four measures are operationalized to capture the area landscape of the health care relevant resources, viz., primary care physicians (in 2000) per 1000 live births (three average number of births [1997-1999]), counties with hospitals providing obstetric care in 2000, counties with the neonatal intensive care units (NICUs) and States' Medicaid Eligibility for the pregnant women. Primary care physicians indicate doctors in areas of family medicine, general practice, internal medicine, and pediatrics.

-- Table 2 about here --

ANALYSIS

To visualize the spatial variation in the IMR and LBW rates, a quantile map for the earlier time period is created using the ArcMap Version 9.0 software. Such visual inspection of outcomes of interest can provide a picture of the IMR and LBW burden at the county levels in the U.S. and also suggest evidence regarding to whether there exists a spatial clustering. As it is limited in its ability to assess how significantly clustered spatial patterns are, however, a spatial autocorrelation test using the global Moran's I statistics is performed. [1] Further, its local version of the Moran's I (Local Indicator of Spatial Association [LISA]) allows for decomposing the four different types of spatial autocorrelations – positive (high-high and low-low) and negative (high-low and low-high). For instance, the positive spatial autocorrelations occur when an above average value at one location is surrounded by above average values of neighboring locations, or when a below average value at one location is adjacent to below average neighboring values. In contrast, the negative autocorrelations suggest that a value at the one location tends to have very different scores at neighboring locations. In general, the LISA is especially useful in assessing the geographic areas with the significantly elevated and lowered risk of IMRs

[1] I utilize global and local Moran's I statistics as they are the most general and popular, and most easily computed method for calculating SAC, although there are many measures available.

and LBW rates (hot [high-high] and cold [low-low] spots, respectively). As Moran's I statistics are achieved by applying the weight matrix, spatial weight matrix is constructed on the basis of the queen case adjacency using the GeoDa software and the significance of Moran's I is tested using 999 Monte Carlo permutations.

The last purpose of this study is to examine the associations between infant morbidity and mortality outcomes and selected area characteristics at the county level. If spatial autocorrelations for outcomes of interest are identified using the Moran's I statistics, Ordinary Least Squares estimates are potentially biased as they leave out spatial components. Therefore, the spatial weighted regression using the Maximum Likelihood Estimation will be conducted to take into account the spatial effect. In general, two spatial weighted models are suggested: the spatial lag and spatial error models. The spatial lag model takes into account the spatial dependence with the spatially lagged dependent variable, while the spatial error model incorporates such dependence into the error term. Whether the spatial lag or error model better serves as an alternative model of the OLS regression is determined by the robust Langrange Multiplier (LM) test for spatial lag dependence and the robust LM test for spatial error dependence. In the case that both tests for the spatial lag and error model are significant, Anselin and Rey (1991) conclude that the model with the larger statistics is a more correct form.

-- Table 2 about here --

RESULTS

Descriptive Results

There is a marked spatial pattern in infant mortality and morbidity status. Figure 1 and 2 displays the geographic distribution of LBW and infant mortality rates using a quantile classification method and 4 classes. What is highlighted in the LBW map is that there is a noticeable clustering of county LBW rates, in that the high LBW rates are clustered in the southeastern and middle northeastern regions of the U.S., while low rates are observed in west and upper middle region. Similar to the LBW rates, the southeastern regions show the high-level of IMR rates. However, the magnitude of the clustered pattern of IMRs in other regions seems less clear than that of LBW rates. Further, it appears that counties with the high-level of LBW rates are less likely to be counties with the high IMRs in the non-southeastern regions compared to southeastern counties.

-- Figure 1 and 2 about here --

Despite visual evidence of a spatial clustering of IMR and LBW rates, the spatial autocorrelation test is in need for confirming whether such clustering actually occurs. Table 2 shows the global Moran's I statistic. The values of 0.38 and 0.09, respectively for LBW rates and IMRs, indicate that the spatial autocorrelations for both measures are highly significant at the significance level of 0.001. However, the spatial autocorrelation is clearer for the county LBW rates than the county IMRs, as the coefficients of Moran's I indicate the extent to which characteristics at one location are similar to those at neighboring locations.

Figure 3 and 4 delivers more detail information regarding to the four different types of the spatial associations using the LISA maps as noted above in the discussion of analysis part. The colored areas in those figures indicate the statistically significant clustering of such combinations at least at the significance level of 0.05. As seen in Figure 3, there exists the apparent and massive clustering of the hot (high-high) and cold (low-low) spots for the county LBW rates. Consistent with the quantile map of the LBW rates, the high LBW rates concentrate in the southeastern regions and the center of the Midwest areas in the U.S., while the cold spots (low-low) appear apparently in the west-coastal and Northern-middle regions. The hot and cold spots of the county IMRs are much less clustered in comparison of those of LBW rates, despite the distinct areas notified. Similar to the case of LBW rates, the persistence of the high burden areas of IMRs is located in the southeastern regions. However, the spatial concentration of the LBW rates observed in the center of the center of the Midwest regions is not identified in the case of the IMRs. Further, the low burden areas for IMRs widely spread out in the middle part of the U.S. which is not consistent with the LBW cold spots identified in the west-coastal and Northern-middle regions.

In general, the spatial persistence of the elevated infant morbidity and mortality rates are notified in the southeastern regions, while the patterns of spatial associations between two outcomes are less likely to match in the non-southeastern parts of the U.S.

Geographically Weighted Regression

The visual inspections and Moran's I statistics of the county IMR and LBWs show that there are the marked geographic disparities in outcomes of interest accompanied with clear evidence of the spatial dependence. Thus, the spatial regression models to take into account such spatial components in conjunction of potential area's characteristics are in need.

For the county LBW rates, there is evidence for the need for a spatial error model for the LBW rates. The robust LM test for spatial error dependence is highly significant. In contrast, the result for the IMRs suggests that no evident spatial dependence remains once controlling potential risk factors. Although the robust LM test for the IMR spatial error model is marginally significant at the significance level of 0.10, it can be concluded that the OLS model could adequately account for the spatial dependence. Table 3 presents the results of the spatial error regression models along that of the OLS estimates for the LBW rates and provides just an OLS model for the IMRs.

With respect to results for the county LBW rates, the sign of the coefficients for area variables based on the spatial error model are generally consistent with those observed in non-spatial analyses. However, the OLS model seems to consistently over-estimate the magnitude of area effects than the spatial error model, especially for two covariates. For instance, the effect of the unemployment rate shows the significant effect on the county LBW rates in the OLS model while it is no longer persistent in the spatial error model. Also, counties in states setting the high-level of Medicaid eligibility for the pregnant women exhibit the significantly negative effects on the LBW rates. Yet, such beneficial impact is not found in the spatial error model. Overall, the socioeconomic structural variables play an important role in determining the county level of LBW rates, while health care relevant factors do not take into account for any spatial difference. And, counties in the southern regions in the U.S. reveal the increased risk of LBW rates than the non-southern counties even net of relevant control variables. Interesting enough, pure locational covariates exert a great effect on the county LBW rates. The overall model fitness is reasonable with the adjusted r-square of .41.

For the IMRs, the OLS model seems adequately account for the spatial dependence, as both robust LM tests for spatial lag and error models are not statistically significant at the 0.05 level. Further, the magnitude and direction of the effects of explanatory variables are consistent between the OLS model and the spatial regression models. Because of those reasons, table 3 just presents the coefficients estimated with the OLS regression. Of the measure of area characteristics, socioeconomic factors, except the unemployed rate, are by far more important. Different from the county LBW rates, states' Medicaid eligibility and per capital physician supply are a statistically significant predictor of lower IMRs. Further, the average July humidity increases the county-level of IMRs, while the association between other physical features and IMRs does not persist in this model. The overall model fitness for the county IMRs is relatively poor (adjusted r-square = .12).

CONCLUSION

This study examines the spatial patterning and social processes underlying the spatial disparities in the infant health and mortality conditions across U.S. counties. In general, the results of this study have confirmed the prior ecological studies. First, LBW rates and IMRs vary substantially across the U.S. counties. Second, the high LBW and infant mortality rates are distinctively clustered in the southeastern regions of the U.S. Third, the aggregate socioeconomic aspects of areas play an important role in determining the area-level of the infant health and mortality conditions.

This study, however, reveals several important additional points and improves the existent studies in several ways. First, the spatial clustering of the LBW rates is clearer than that of the IMRs. Second, OLS estimates are potentially biased in the case of studying the aggregate level of the LBW rates, while it is not true of the infant mortality case. Although the spatial autocorrelation is found in the county-level IMRs, the OLS model seems adequately account for the spatial dependence and there are no discrepancies of estimates between the OLS and spatial regression models. Third, of the measure of area characteristics, explanatory variables which are important for predicting infant health and mortality outcomes in the county level are not exactly consistent between two outcomes of interest. For instance, pure physical features such as humidity, temperature, and elevation exert far greater role in determining the county-level of the LBW rates. However, no apparent impact except the humidity measure is identified in the case of the IMRs. In contrast, health care relevant resources appear to have substantial influences on the county IMRs, while the county LBW rates are not affected by those area characteristics.

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Table 1. Low Weight Birth and Infant Mortality Rates

	Mean	St. Dev.	Min	Max
LBW Rate	7.41	2.25	0.00	25.00
IMR	7.21	4.60	0.00	55.56

Table 2. Descriptive Statistics of Risk Factors of IMRs and LBW Rates

	Mean	Std. Dev.	Min.	Max.
Ave. July Hum. Percentage	55.76	14.73	14.00	80.00
Ave. July Temp. Degree	75.81	5.34	55.50	93.70
Elevation Feet	1243.00	1452.39	0.00	10158.00
% of Black Population	8.85	14.57	0.00	86.50
% of Fem. Head Households	14.93	5.84	2.20	44.60
% of child poverty Level (0-17)	20.22	7.45	2.50	49.50
% of Unemployed Pop.	5.26	2.78	1.00	30.50
Physicians per 1000 Live Births	0.24	0.98	0.00	28.57
County with Obst. Hosp.	0.57	0.50	0.00	1.00
County with NICUs	0.12	0.33	0.00	1.00
Medicaid Eligibility	181.90	51.97	133	400

Table 3. Global Moran's I Statistics: IMR and LBW rates (999 Random Permutations)

	I Statistic	P-Value
LBW Rate	0.3829	0.001
IMR	0.0860	0.001

Table 4. OLS and Spatial Regression Analyses of County Infant Low weight and Mortality Rates, United States, 1997-1999

	LBW Rates		**IMR**
	OLS	**Spatial Error**	**OLS**
Ave. July Hum.	0.020***	0.015***	0.024***
Ave. July Temp.	0.037***	0.026**	-.0.020
Elevation	0.0004***	0.0004***	0.000
% of Black Pops.	0.044***	0.050***	0.029***
% of Fem. Head	0.096***	0.077***	0.109***
% of Child Pov.	-0.009	0.006	0.085***
% of Unemployed Pop.	0.040***	0.024	-0.036
South States	0.651***	0.655***	0.280
NICU	0.022	0.08	-0.104
Obst. Hosp.	-0.123	-0.086	0.352*
Per Capita Physicians	-0.001	-0.0004	-0.006*
States' Medicaid Eligibility	-0.001**	-0.001	-0.004***
Lamda		0.0284***	
Intercept	1.138	2.252**	4.517**
Adj. R-Squared.	0.381	0.405	0.115
Spatial Lag Dep.	N.S.		N.S.
Spatial Error Dep.	p <0.001	p <0.001	p<0.10

Figure 1. LBW Rates, United States, 1997-1999

First Quartile (0-7) Second Quartile (7)
Third Quartile (8-9) Fourth Quartile (10-25)

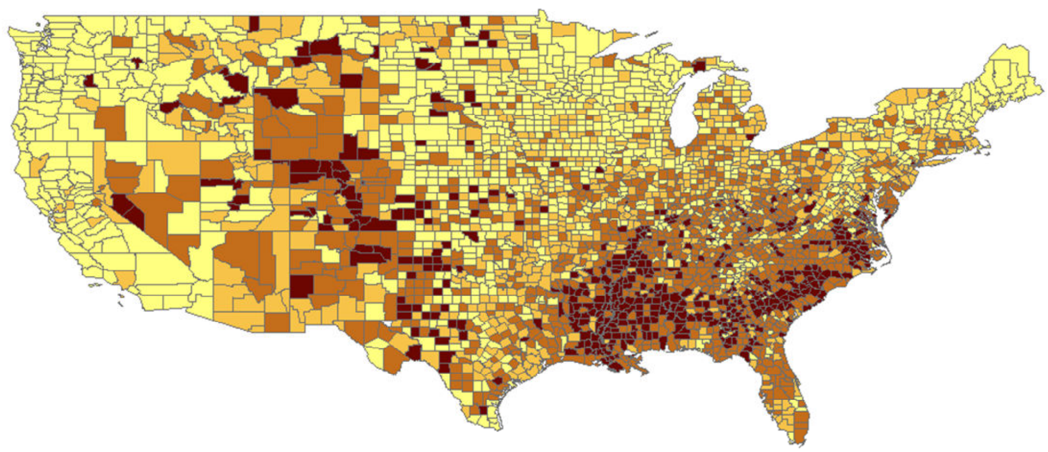


Figure 2. IMRs, United States, 1997-1999

First Quartile (0-5) Second Quartile (6-7)
Third Quartile (8-10) Fourth Quartile (11-56)

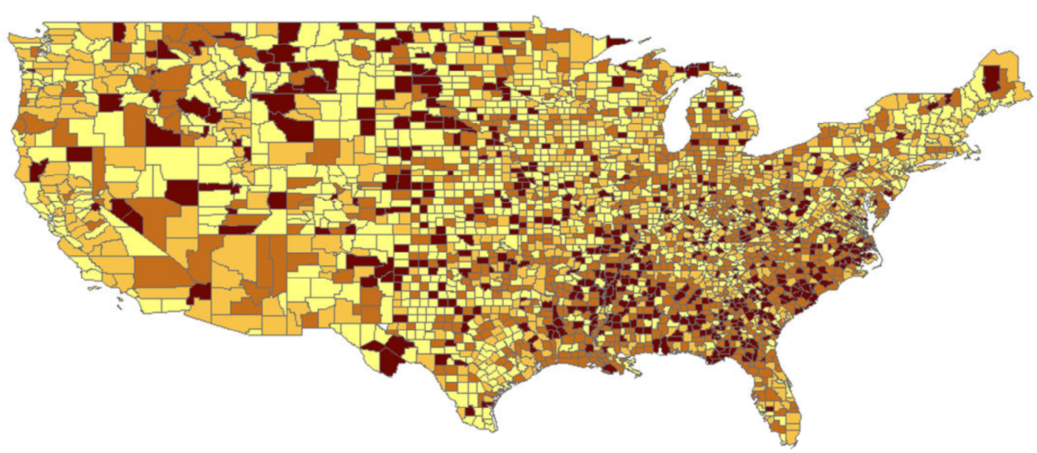
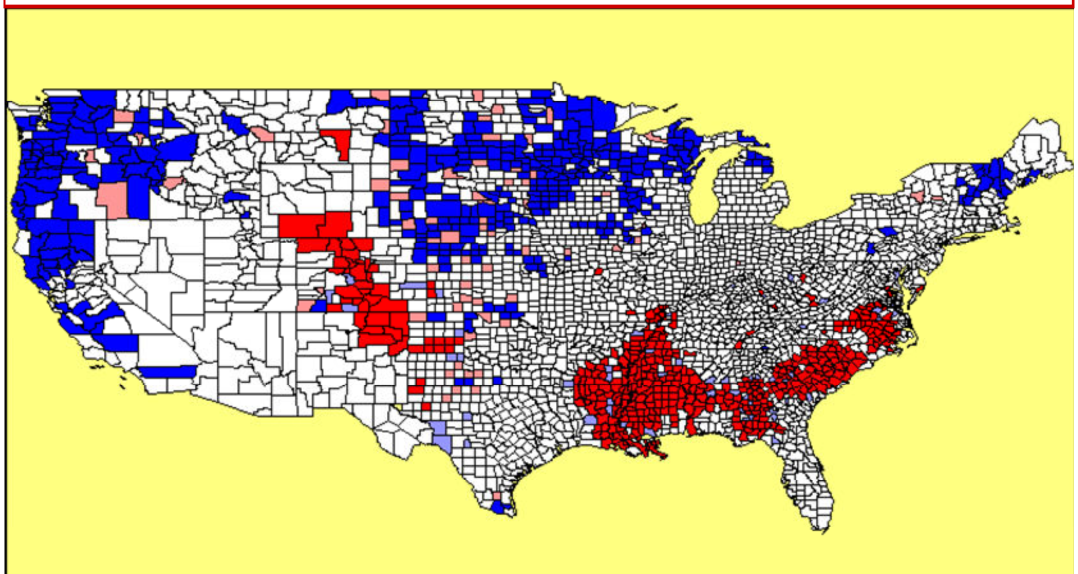
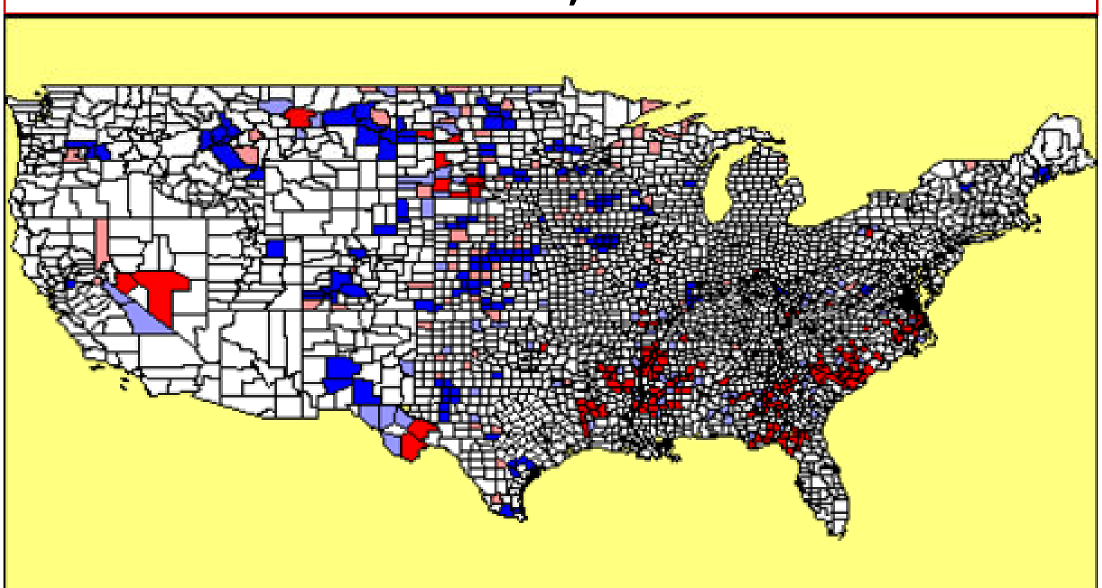


Figure 2. LISA Map: LBW Rates
United States, 1997-1999



■ High-High ■ Low-Low ■ Low-High ■ High-Low

Figure 4. LISA Map: IMRs
United States, 1997-1999



■ High-High ■ Low-Low ■ Low-High ■ High-Low