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ORIGINAL ARTICLE

State- and county-level income inequality and infant mortality in the USA in 2010: a cohort study

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Abstract

Objectives We examined the relationship between income inequality and the risk for infant/neonatal mortality at the state and county level and tested possible mediators of this relationship.

Methods We first linked state and county Gini coefficients to US Vital Statistics 2010 Cohort Linked Birth and Infant Death records (n = 3,954,325). We then fit multilevel models to test whether income inequality was associated with infant/neonatal mortality. County-level factors were tested as potential mediators.

Results Adjusted analyses indicated that income inequality at the county level—but not at the state level—was associated with increased odds of infant mortality (OR 1.14, 95% CI 1.10, 1.18) and neonatal death (OR 1.17, 95% CI 1.12, 1.23). Our mediators explained most of this variation. Bivariate analyses revealed associations between 3 county-level measures—patient-to-physician ratio, the violent crime rate, and sexually transmitted infection rate—and infant and neonatal mortality. Proportion of college-educated adults was associated with decreased odds for neonatal mortality.

Conclusions Local variations in access to care, the rate of sexually transmitted disease, and crime are associated with infant mortality, while variations in college education in addition to these mediators explain neonatal mortality. To reduce infant and neonatal mortality, experiments are needed to examine the effectiveness of policies targeted at reducing income inequality and improving healthcare access, policing, and educational opportunities.

Keywords Income inequality · Infant mortality · Neonatal mortality · Multilevel · Mediation · Disparities · Social determinants

Introduction

Infant mortality rates (IMRs) in the USA far exceed those of other Organisation for Economic Co-operation and Development (OECD) nations (OECD 2013). In 2011, the national average for IMR—defined as number of deaths per 1000 live births within the first year of life—was 6.1, placing the USA ahead of only Turkey and Mexico among OECD nations (OECD 2013). Stark differences in infant and neonatal mortality rates (death within the first 28 days of life) also exist *within* US states and counties. For 2010, the IMR by state ranged from a low of 3.6 in Alaska to a high of 9.6 in Mississippi (Mathews and MacDorman 2013). Dramatic disparities in infant mortality by race have been observed since at least the nineteenth century (DuBois 1903). Of non-Hispanic black babies born in 2010, 11.5 per 1000 died before their first birthday, compared with 5.2 per 1000 non-Hispanic whites (Mathews and MacDorman 2013). These disparities persist after controlling for gestational age, birthweight, multiple gestation, and sex (Anderson et al. 2018), suggesting that social, economic, and political factors play a role in generating these inequities. Immediate causes of infant and neonatal death include preterm birth, low birthweight, and maternal complications in pregnancy (Hoyert and Xu 2012). More distal risk factors range from individual-level socioeconomic factors to

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contextual influences to which an expectant mother is exposed not only during pregnancy, but across the life-course. For example, low income (Blair et al. 2006; Larson 2007; Yang et al. 2008) and residence in economically deprived areas (Gilbert et al. 2013; Kane et al. 2017; Meng et al. 2013) have been linked to preterm birth, low birth-weight, and maternal complications in pregnancy.

Attempts to explain variability in infant mortality risk—and to pinpoint underlying mechanisms—have more recently explored possible contextual effects. One plausible contextual risk factor is income inequality—the gap between rich and poor within a residential area. As income inequality has grown, so has attention to its possible impact on health, including adverse birth outcomes (Olson et al. 2010). The widening gap between those at either end of the income spectrum has been hypothesized to be detrimental to the health of all members of society, regardless of individual income level (Pickett and Wilkinson 2009). This theory posits that when income inequality is high, more psychosocial problems (e.g., depression, anxiety) arise for all people residing in that particular area.

Studies of the association between income inequality and both preterm birth and low birthweight have primarily been conducted using ecological or aggregated data (Olson et al. 2010; Siddiqi et al. 2015, 2016). To improve upon the findings of these ecological studies, multilevel studies exploiting individual-level data have investigated the possibility of a relationship between inequality and adverse birth outcomes. A study in Japan revealed an increased risk of babies born small for gestational age to women from middle- or higher-inequality (Gini) prefectures compared with their peers living in lower-inequality areas (Fujiwara et al. 2013). Within the USA, analyses of linked birth data from the 1980s and 1990s found an association between higher state-level income inequality and neonatal mortality after adjustment for state-level covariates, maternal race, and age (Mayer and Sarin 2005). Wallace et al. (2016) traced changes in income inequality within eleven US states and Washington, D.C. and concluded that preterm birth rates increased in regions where income inequality grew over time. Similarly, increases in state-level income inequality were related with a small but significant increase in infant mortality risk (Pabayo et al. 2019). In another study, income inequality was associated with increased probability of babies being born small for gestational age, but only when both structural racism and income inequality were high (Wallace et al. 2017). Results from a separate US-based study showed an association between county-level inequality and odds of preterm birth and post-neonatal mortality (Huynh et al. 2005). Despite these investigations, the combined influence of inequality at the county and state levels remains understudied, and little is known about the mechanisms through which inequality might lead to increased risk for infant mortality.

State- and county-level income inequality can be viewed as upstream factors influencing the trajectory of social and political changes, while also being itself influenced by such forces. Inequality can be created by policy decisions or allowed to develop in the absence of interventions. Income inequality in turn affects infant mortality risk (Mayer and Sarin 2005). Since data capturing mediators at the individual level were not available, and county-level factors are seen as falling between state factors and individual-level outcomes, we chose to focus on potential county-level mediators. Hypothesized mechanisms linking higher income inequality to poorer health include the erosion of social capital and cohesion, which can lead to the deterioration or loss of public goods (Kawachi and Kennedy 1999). Societies that do not value helping others may have decreased access to high-quality healthcare, and lower investments in education (Stiglitz 2012). Also, limited access to general and reproductive healthcare has been strongly linked to adverse birth outcomes (Shi et al. 2004; Mayer and Sarin 2005).

Another possible mechanism could involve education. High income inequality can lead to limited funding for education, which in turn leads to decreased access (Muller 2002). Also, highly unequal states contain greater numbers of people living in low-income households, who therefore cannot afford to achieve higher levels of learning. Education attainment among mothers has shown to be associated with healthy maternal and infant outcomes (Ko et al. 2014; Pappas et al. 1993; Singh and Yu 1995).

Psychosocial pathways might also explain a link between inequality and health, as social comparisons and feelings of relative deprivation could lead to elevated stress and other adverse, health-damaging psychological states (Pickett and Wilkinson 2009). Evidence indicates that decreased social cohesion is related to a higher likelihood for exposure to violence (Pabayo et al. 2014; Kennedy et al. 1998). Each of these relationships represent potential pathways through which income inequality might indirectly harm women's mental and physical health.

In our study, we first aimed to identify any existing relationship between infant/neonatal death and income inequality at the county and state levels, and to disentangle the possible effect at each level through multilevel analyses. We then test for mediation of this relationship by 7 county-level measures, each of which (based on evidence cited above) could explain any effect of income inequality on general maternal health, and on birth outcomes such as infant and neonatal mortality: Social Capital; patient-to-primary care physician (PCP) ratio; percent uninsured; proportion of population aged 25 years or older with a 4-year college degree or higher; sexually transmitted infection (STI) rate; bad mental health days; and violent crime rate. Our study is novel in its simultaneous incorporation of data from three levels: individuals nested within counties nested within states. We seek to deepen our current understanding by using individual-level data to identify the relationship between income inequality at both county and state level and individual risk of infant/neonatal mortality, and to determine whether county-level factors act as mediators through which inequality might increase risk of infant/neonatal mortality.

Methods

Data sources

Data were extracted from the linked birth and infant death set, which is a valuable tool for monitoring and exploring the complex interrelationships between risk factors present at birth and infant death (cdc.gov/nchs/nvss/linked-birth.htm). We measured income inequality at each infant's birth at the county and state level using Gini coefficients based on household income data taken from the 2010 US Census. Infant and maternal data came from the 2010 United States Vital Statistics Linked Birth and Infant Death (LBID) records from the Centers for Disease Control and Prevention (CDC), which includes information on all births occurring in the USA. We linked county- and state-level measures to the individual-level LBID maternal and birth data via identifying county Federal Information Processing Standards (FIPS) codes. Of the 4,007,105 live births in 2010, we excluded those whose mothers were foreign-born non-residents (7719) and those missing education information (45,061), yielding a sample size of 3,954,325. Infants were followed until their first birthday. Infants who died before their first birthday were identified using the linked death certificate. Ethical approval was obtained from the University of Nevada, Reno, Institutional Review Board.

Measures

Outcomes

Our two outcomes of interest were infant and neonatal mortality, defined as death before first birthday and death within the first 28 days of life, respectively.

Exposures

Our primary exposure was income inequality, as captured by both county-level and state-level Gini coefficient, the calculation of which has been described elsewhere (Kennedy et al. 1996). Briefly, the Gini coefficient ranges from 0 to 1, with 0 indicating perfect income equality within an area, and 1 indicating perfect inequality. We calculated state-level Gini coefficients for each of the 50 states and for the District of Columbia, as well as county-level Gini coefficients for 3146 counties or county equivalents (e.g., parishes) using the 2010 US Census data. Gini coefficients were z-transformed for analysis.

Multilevel covariates

Individual-level covariates from the 2010 LBID records set included: maternal age; marital status (married vs single); race (black, white, Native American, Asian, or other); Hispanic ethnicity; education (< high school, high school graduate, or post-secondary); and number of children to whom the mother had given birth.

County-level covariates were taken from the 2010 Census and included proportion of residents who were non-Hispanic black; proportion of families living below the poverty line; residents' median household income; and population size.

Equivalent state-level covariates captured by the Census were included: proportion of state's residents who were non-Hispanic black; proportion of families living below the poverty line; residents' median income; and population size. We also controlled for US Census region: mid-Atlantic; South Atlantic; East North Central; East South Central; West North Central; East North Central; Mountain; or Pacific.

County-level mediators

Each of our 7 hypothesized mediators were measured at the county level. Social Capital Index was taken from work by Rupasingha and Goetz (2006), who constructed their index using principal component analysis of 4 factors capturing community involvement (political, religious, civic, and recreational). For more detailed information on this index, see Rupasingha and Goetz (2006). The six remaining measures came from the University of Wisconsin's County Health Rankings. Patient-to-physician ratio reflects the ratio of population to primary care physicians based on 2011–2012 Health Resources and Services Administration (HRSA) Area Resource File data. Percent uninsured measures the percent of the population under age 65 without health insurance, based on 2010 Small Area Health Insurance Estimates. Proportion of population aged 25 years or older with a 4-year college degree or higher comes from American Community Survey 5-year estimates for 2007–2011. STI rate was measured by the chlamydia rate per 100,000 population from 2010 data from the National Center for HIV/AIDS, Viral Hepatitis, STD, and TB

Table 1 Characteristics of mothers and their infants born in the USA in 2010 (3,954,325 births)

Individual-level characteristics	*n*	Percentage
Mother's age (years)		
12–19	368,140	9.3
20–29	2,064,408	52.2
30–39	1,409,501	35.6
40–50	122,276	2.8
Mother's race		
White	2,149,280	54.4
Black	584,117	14.8
Native	39,613	1.0
Asian	231,099	5.8
Hispanic	933,514	23.6
Other	16,702	0.4
Education		
Less than high school	747,478	18.9
High school	1,043,478	26.4
Post-secondary	2,163,369	54.7
Marital status		
Single	1,613,474	40.8
Married	2,340,851	59.2
Birth order		
First	1,311,760	33.2
Second	1,105,969	28.0
Third	708,879	17.9
Fourth or more	827,717	20.9
Nativity		
US-born	3,049,765	77.1
Infant death	23,219	0.59
Neonatal death	15,139	0.38

US county-level characteristics	Mean (SD)	Min, Max
Gini 2010	0.43 (0.04)	(0.21, 0.65)
Median income 2010, USD	$44,270 (11,548)	(19,351, 115,574)
Population	26,218 (91,107)	(12, 2,929,277)
African-American (%)	8.1 (13.8)	(0, 81.1)
Families in poverty (%)	11.4 (5.5)	(0, 44.9)

US state-level characteristics	Mean (SD)	Min, Max
Gini 2010	0.45 (0.02)	(0.42, 0.53)
Median income, USD	$51,385 (8376)	(37,838, 70,976)
Population	5,699,069 (6,572,937)	(563,626, 37,300,000)
African-American (%)	12.1 (11.1)	(0.8, 52.2)
Families in poverty (%)	14.8 (3.1)	(8.3, 22.4)

Table 1 (continued)

County-level mediators	Mean (SD)	Min, Max
Social capital index	− 0.0000048 (1.3)	(− 3.9, 17.4)
PCP per 100,000	55.2 (35.0)	(0, 458.9)
Percent uninsured	18.5 (5.6)	(3.6, 41.4)
Proportion with some college Ed	54.2% (12.0)	(0, 100)
STI per 100,000 rate	309.3 (270.9)	(0, 2812.9)
Bad mental health days in the past 30 days	3.4 (0.98)	(.4, 7.5)
Violent crime per 100,000 RATE	270.9 (226.6)	(0, 2061.7)

Prevention. Bad mental health days counts poor mental health days (average number in past 30 days) reported in the Behavioral Risk Factor Surveillance System (BRFSS) 2005–2011. Finally, violent crime rate measures cases of violent crime per 100,000 population, as recorded in the Federal Bureau of Investigation's Uniform Crime Reporting for 2008–2010.

Statistical analysis

The first part of our analyses sought to tease out the possible relationships between income inequality—at both the county and the state levels—and mortality. We used multilevel logistic regression models to test whether inequality (measured using the Gini coefficient) at birth at each of the two area levels was associated with odds of infant or neonatal death for all live births occurring in 2010. For each of the two birth outcomes, we first ran separate null models to explore variation by area level by calculating the intraclass correlation (ICC). Crude models including only the Gini measures and mortality outcomes were then run. A third set of models adjusted for individual-, county-, and state-level covariates. We then added our hypothesized county-level mediators.

To determine whether these 7 county-level measures acted as mediators between county- and state-level income inequality and our mortality outcomes, we applied the Baron and Kenny method to test for mediation (Baron and Kenny 1986). In accordance with their method, we assessed the following associations: (1) each of the two measures of inequality (county- and state-level Gini coefficients) and each of the hypothesized mediators; (2) each measure of income inequality and each of the two mortality outcomes (neonatal and infant death); (3) each of the potential mediators and each of the two mortality outcomes. Finally, we tested the relationship between each measure of income inequality and each mortality outcome, controlling for the possible mediating variables. In the presence of mediation, the association between income inequality and neonatal/infant death would be expected to be attenuated.

Results

Data for 3,954,325/4,007,105 = 98.7% of live births in 2010 were available. Characteristics of our sample are presented in Table 1. Of the live births recorded in 2010, 23,219 (0.59%) ended in death within a year, and 15,139 (0.38%) in death within 28 days. The mean age of women in our sample was 27.7 years old (SD = 6.1). Just over half of the women were non-Hispanic white (54.0%); 14.7% were non-Hispanic black; and nearly a quarter (23.8%) were Hispanic. Eighty percent had at least a high school education, and 40.8% reported being single at the time they gave birth. Three-quarters of the women were US-born (76.8%). For a third of the women (33.2%), the child they had in 2010 was their first born.

The mean Gini coefficients for 2010 across both US states and counties were 0.45 (SD = 0.02) and 0.43 (SD = 0.40), respectively. The range of values for Gini coefficient was larger for counties: 0.21–0.65, compared to the range for states: 0.42–0.53. County- and state-level characteristics can be found in Table 1, along with information on the 7 hypothesized county-level mediators. At the county level, the average ratio of primary care physician to residents was 55.2 per 100,000 residents and ranged from 0 to 459 per 100,000. On average, nearly one-fifth (18.5%) of the population per county lacked health insurance in 2010. Just over half (54.2%) of county residents aged 25 and older had a college degree or higher. County-level mean number of bad mental health days reported in the past 30 days was 3.4 (range 0.4–7.5). The average county violent crime rate was 271 per 100,000, with a range of 0–2062.

Results of intraclass correlation calculations (ICC) from all models for both infant and neonatal mortality across states and counties are found in Tables 2 and 3, respectively. Based on the null models, overall ICC for infant mortality was 0.0111 (1.1% of the variance explained) at the state level (SD 0.003; 95% CI 0.006, 0.02) and 0.054 (5.4% of the variance explained) at the county level (SD 0.004; 95% CI 0.047, 0.064) (Table 2). The overall ICC for neonatal mortality was 0.009 (0.9% of the variance explained) at the state level (SD 0.003; 95% CI 0.004, 0.018) and 0.075 (7.5% of the variance explained) at the county level (SD 0.006; 95% CI 0.064, 0.087) (Table 3).

Each of the four models tested the crude association between county and state income inequality and infant and (Table 2) neonatal mortality (Table 3). When models included both county and state Gini coefficients simultaneously, only county-level Gini coefficient remained significant for infant (OR 1.20; 95% CI 1.16, 1.24) and neonatal (OR 1.23; 95% CI 1.18, 1.29) death.

Results from models identifying the relationship between state and county income inequality and infant and neonatal mortality adjusting for covariates at the individual, county, and state levels are presented in Tables 2 and 3, respectively. Results show that the association persisted between county-level—but not state-level—income inequality and infant mortality (Table 2) and neonatal mortality (Table 3) after adjustment for covariates. An increase in standard deviation of Gini coefficient at the county level was associated with increased odds of both infant death (OR 1.14; 95% CI 1.10, 1.18) and neonatal death (OR 1.17; 95% CI 1.12, 1.23). The addition of mediators resulted in an attenuation and loss of significance for the estimate for county-level Gini coefficient for both infant death (OR 1.04; 95% CI 0.99, 1.09) and neonatal death (OR 1.04; 95% CI 0.98, 1.10). Three of the four county-level mediators were significantly associated with infant mortality risk, as seen in an increase of one standard deviation for the following: physician-to-patient ratio: OR 0.90 (95% CI 0.87, 0.93); STI rate: OR 1.04 (95% CI 1.01, 1.08); and violent crime rate: OR 1.07 (95% CI 1.04, 1.11) (Table 2). An increase in standard deviation for these same three variables was also significantly associated with neonatal death: OR 0.88 (95% CI 0.84, 0.92); OR 1.06 (95% CI 1.02, 1.11); and OR 1.10 (95% CI 1.06, 1.15), respectively (Table 3).

Table 4 presents results from mediation analyses examining bivariate associations between each of the seven proposed mediators. In models controlling for both county-level and state-level income inequality, three of the seven county-level measures were significantly associated with infant death, and four of the seven were significantly associated with neonatal death. An increase in standard deviation of patient-to-physician ratio (OR 0.94; 95% CI 0.91, 0.97) was associated with decreased odds of infant death. An increase in standard deviation for violent crime rate (OR 1.15; 95% CI 1.12, 1.18) and for STI rate (OR 1.14; 95% CI 1.12, 1.17) was associated with increased odds in infant death. Similar findings were observed when odds for neonatal death was the outcome. However, a standard deviation increase in proportion of adults aged 25 years and older with a college degree or higher (OR 0.95; 95% CI 0.91, 0.98) was associated with decreased odds of death.

Table 2 Multi-level analyses investigating the relationship between county- and state-level income inequality and the odds for infant mortality for US births in 2010

	Odds for infant mortality			
	Null model	Crude Model 1 OR (95% CI)	Adjusted Model 2 OR (95% CI)	Mediators Model 3 OR (95% CI)
ICC, SE (95% CI)				
State-level Gini	0.011, 0.003 (0.006, 0.020)	0.0067, 0.002 (0.004, 0.013)	0.0006, 0.0007 (0.0001, 0.005)	0.0014, 0.0008 (0.0004, 0.004)
County-level Gini	0.054, 0.004 (0. 047, 0.064)	0.04, 0.003 (0.037, 0.05)	0.03, 0.003 (0.026, 0.036)	0.023, 0.002 (0.019, 0.028)
State-level characteristics (2010)				
Gini 2010 (*z*-score, cont.)		1.12 (1.04, 1.20)	1.01 (0.93, 1.09)	1.01 (0.93, 1.09)
Proportion black			0.96 (0.88, 1.03)	1.08 (0.99, 1.18)
Proportion in poverty			0.90 (0.78, 1.03)	0.91 (0.79, 1.06)
Median income			0.88 (0.78, 0.98)	0.93 (0.82, 1.04)
Population size			1.01 (0.97, 1.05)	1.00 (0.96, 1.05)
Census division				
New England (ref)			1.00	
Mid-Atlantic			1.17 (0.97, 1.42)	1.07 (0.88, 1.29)
South Atlantic			1.16 (0.94, 1.43)	1.03 (0.83, 1.28)
East North Central			1.21 (0.99, 1.48)	1.01 (0.81, 1.25)
East South Central			1.22 (0.96, 1.54)	1.04 (0.81, 1.33)
West North Central			1.11 (0.92, 1.36)	0.93 (0.76, 1.14)
West South Central			1.17 (0.93, 1.46)	1.00 (0.79, 1.26)
Mountain			1.18 (0.95, 1.47)	1.08 (0.86, 1.34)
Pacific			1.08 (0.86, 1.36)	1.03 (0.81, 1.32)
County-level characteristics (2010)				
Gini 2010 (*z*-score, cont.)		1.20 (1.16, 1.24)	1.14 (1.10, 1.18)	1.04 (0.99, 1.09)
Population size			1.02 (1.01, 1.04)	1.00 (0.96, 1.05)
Percent of families in poverty			0.91 (0.86, 0.97)	0.93 (0.82, 1.04)
Median income 2010			0.95 (0.90, 0.99)	0.93 (0.82, 1.04)
Percent black			1.10 (1.06, 1.15)	1.08 (0.99, 1.18)
Mediators				
Social capital				0.97 (0.93, 1.02)
Physician-to-patient ratio				0.90 (0.87, 0.93)
Percent uninsured				0.98 (0.94, 1.01)
Percent college degree				0.99 (0.94, 1.03)
STI rate				1.04 (1.01, 1.08)
Bad mental health days				1.00 (0.96, 1.03)
Violent crime				1.07 (1.04, 1.11)
Individual-level characteristics				
Mother's age (years)				
12–19 (ref)			1.00	
20–29			0.90 (0.86, 0.94)	0.90 (0.86, 0.94)
30–39			0.86 (0.81, 0.91)	0.86 (0.81, 0.91)
40–50			1.25 (1.15, 1.36)	1.25 (1.15, 1.36)
Marital status				
Married (ref)			1.00	
Unmarried			1.33 (1.28, 1.37)	1.33 (1.29, 1.37)

Table 2 (continued)

	Odds for infant mortality			
	Null model	Crude Model 1 OR (95% CI)	Adjusted Model 2 OR (95% CI)	Mediators Model 3 OR (95% CI)
Mother's race				
Non-Hispanic White (ref)			1.00	
Non-Hispanic Black			1.63 (1.57, 1.69)	1.63 (1.57, 1.69)
Native American			1.39 (1.23, 1.57)	1.43 (1.27, 1.61)
Asian			1.07 (0.99, 1.16)	1.07 (0.99, 1.16)
Hispanic			0.94 (0.90, 0.98)	0.94 (0.90, 0.98)
Other			1.31 (1.08, 1.58)	1.28 (1.06, 1.56)
Mother's education				
Less than high school (ref)			1.00	
High school education			0.92 (0.89, 0.96)	0.92 (0.89, 0.96)
More than high school			0.69 (0.67, 0.72)	0.69 (0.67, 0.72)
Nativity				
Foreign-born (ref)			1.00	
US-born			1.27 (1.22, 1.33)	1.27 (1.22, 1.32)
Birth rank				
First (ref)			1.00	
Second			1.05 (1.01, 1.08)	1.05 (1.01, 1.09)
Third			1.13 (1.09, 1.18)	1.13 (1.09, 1.18)
Fourth or higher			1.41 (1.36, 1.47)	1.41 (1.36, 1.47)

STI sexually transmitted infections

Discussion

The objectives of our study were twofold: to attempt to disentangle the independent influences of income inequality at the county and state levels, and to identify possible variables mediating any such relationship. Our multilevel analysis of US births in 2010 exploits individual-level data to move us beyond the ecological, and suggests that, for our sample, income inequality at the (less macro) county level was a stronger risk factor for infant and neonatal mortality than was inequality at the state level. We found evidence that three of seven county-level measures partially mediated the relationship between county-level income inequality and risk for infant mortality, and that four of the seven measures mediated the association between income inequality and risk for neonatal mortality.

This study is one of the first to investigate the possible impact of income inequality at both state and county levels simultaneously. Our results suggest that county-level inequality is the more powerful risk factor for infant and neonatal mortality risk. Counties tend to determine funding for social goods such as public transportation, health, and education. The results of this investigation are consistent with previous studies identifying income inequality at the county level as an important risk factor for adverse health outcomes in general, and for infant/neonatal death in particular (Huynh et al. 2005). One possible explanation for the more potent role of county-level income inequality in comparison to state-level inequality could lie in the counties' smaller size, and income inequality consequently exerting a more proximal and immediate effect on individuals and their families. This argument seems plausible, though specific to the proposed mechanism. For example, states (rather than counties) have more of an influence on policies affecting access to healthcare and insurance status, physician-to-patient ratio, and access to education. In terms of those health-related mechanisms, therefore, state-level characteristics might play a more influential role. This hypothesis is supported by Shi et al. (2004), who observed an ameliorating effect of higher state-level primary care density on infant mortality and low birthweight.

The results of our mediation analysis underscore the potential power of more locally focused interventions to lessen the damaging influence of income inequality on

Table 3 Multi-level analyses investigating the relationship between county- and state-level income inequality and neonatal mortality for US births in 2010

	Odds for neonatal mortality			
	Null model	Crude Model 1 OR (95% CI)	Adjusted Model 2 OR (95% CI)	Mediators Model 3 OR (95% CI)
ICC, SE (95% CI)				
State-level Gini	0.009, 0.03 (0.004, 0.018)	0.0062, 0.002 (0.003, 0.013)	0.003, 0.0014 (0.0008, 0.0077)	0.0041, 0.0018 (0.0018, 0.005)
County-level Gini	0.075, 0.006 (0.064, 0.087)	0.062, 0.0048 (0.05, 0.07)	0.049, 0.004 (0.042, 0.058)	0.038, 0.0037 (0.031, 0.046)
State-level characteristics (2010)				
Gini 2010 (*z*-score, cont.)		1.14 (1.06, 1.23)	1.03 (0.93, 1.15)	1.03 (0.92, 1.16)
Proportion black			0.95 (0.85, 1.06)	1.13 (0.99, 1.29)
Proportion in poverty			0.90 (0.74, 1.09)	0.92 (0.75, 1.13)
Median income			0.87 (0.74, 1.02)	0.93 (0.78, 1.10)
Population size			1.03 (0.98, 1.09)	1.02 (0.96, 1.08)
Census division				
New England (ref)			1.00	
Mid-Atlantic			1.19 (0.91, 1.54)	1.03 (0.79, 1.36)
South Atlantic			1.08 (0.81, 1.45)	0.92 (0.68, 1.26)
East North Central			1.17 (0.88, 1.56)	0.94 (0.69, 1.27)
East South Central			1.02 (0.72, 1.42)	0.81 (0.57, 1.17)
West North Central			1.12 (0.86, 1.47)	0.91 (0.69, 1.21)
West South Central			0.95 (0.69, 1.30)	0.77 (0.54, 1.08)
Mountain			1.18 (0.88, 1.60)	1.06 (0.77, 1.44)
Pacific			1.06 (0.77, 1.47)	1.03 (1.00, 1.03)
County-level characteristics (2010)				
Gini 2010 (*z*-score, cont.)		1.23 (1.18, 1.29)	1.17 (1.12, 1.23)	1.04 (0.98, 1.10)
Population size			1.03 (1.01, 1.05)	1.01 (1.10, 1.03)
Percent of families in poverty			0.87 (0.80, 0.94)	0.88 (0.80, 0.96)
Median income 2010			0.95 (0.90, 1.01)	0.91 (0.85, 0.96)
Percent black			1.18 (1.11, 1.24)	1.01 (0.95, 1.08)
Mediators				
Social capital				0.95 (0.89, 1.00)
Physician-to-patient ratio				0.88 (0.84, 0.92)
Percent uninsured				0.98 (0.93, 1.02)
Percent college degree				0.98 (0.92, 1.04)
STI rate				1.06(1.02,1.11)
Bad mental health days				0.98 (0.94, 1.03)
Violent crime				1.10 (1.06, 1.15)
Individual-level characteristics				
Mother's age (years)				
12–19 (ref)			1.00	
20–29			0.91 (0.86, 0.97)	0.91 (0.86, 0.97)
30–39			1.01 (0.94, 1.08)	1.01 (0.94, 1.08)
40–50			1.48 (1.34, 1.65)	1.48 (1.34, 1.64)
Marital status				
Married (ref)			1.00	

Table 3 (continued)

	Odds for neonatal mortality			
	Null model	Crude Model 1 OR (95% CI)	Adjusted Model 2 OR (95% CI)	Mediators Model 3 OR (95% CI)
Unmarried			1.22 (1.17, 1.27)	1.22 (1.17, 1.27)
Mother's race				
Non-Hispanic White (ref)			1.00	
Non-Hispanic Black			1.71 (1.63, 1.79)	1.70 (1.63, 1.78)
Native American			1.29 (1.10, 1.52)	1.33 (1.13, 1.57)
Asian			1.07 (0.98, 1.187	1.06 (0.97, 1.16)
Hispanic			1.05 (1.00, 1.11)	1.05 (1.00, 1.11)
Other			1.27 (0.99, 1.63)	1.25 (0.97, 1.60)
Mother's education				
Less than high school (ref)			1.00	
High school education			0.99 (0.94, 1.04)	0.99 (0.94, 1.03)
More than high school			0.77 (0.73, 0.81)	0.77 (0.73, 0.81)
Nativity				
Foreign-born (ref)			1.00	
US-born			1.19 (1.13, 1.25)	1.19 (1.13, 1.25)
Birth rank				
First (ref)			1.00	
Second			0.93 (0.89, 0.97)	0.93 (0.89, 0.97)
Third			0.97 (0.92, 1.02)	0.97 (0.92, 1.02)
Fourth or higher			1.21 (1.15, 1.27)	1.21 (1.16, 1.27)

STI sexually transmitted infections

infant and neonatal mortality—particularly in the realm of women's reproductive healthcare. Our findings suggest an influential mediating role of healthcare access, which is consistent with previous findings showing that increases in state spending on healthcare are associated with lower infant mortality rates (Mayer and Sarin 2005). They could also hint at the detrimental impact on birth outcomes via maternal exposure to violent crime, and its resulting psychosocial stress.

Our findings indicate that STI rate and access to physicians within counties act as potential mediators between income inequality and infant mortality. Kawachi and Kennedy (1999) and Smith (1996) theorized that jurisdictions with high income inequality underinvest in social goods such as healthcare. Thus, counties with high income inequality are less likely to invest in women's health, via, e.g., sexual and reproductive clinics (Harling et al. 2014). A previous study indicated a link between income inequality within countries and access to health services, particularly maternal health and adolescent fertility services (Gonzales et al. 2015). One consequence of this lack of investment in social goods is that not only women's health is adversely affected, but infant health as well. Our results highlight the inseparable nature of maternal health and infant health. These findings are timely, given the rise in calls to defund reproductive health clinics such as those run by Planned Parenthood. Our results suggest that access to sexual and reproductive health is critical not only for the health of women; it can be a matter of life or death for their infants.

In addition, we found that violent crime rate might act as a mediator between income inequality and infant mortality. Previous work has indicated that income inequality is related to aggression, and is therefore tied to violent crime (Pabayo et al. 2014; Kennedy et al. 1998). Exposure to crime is a known predictor of stress, anxiety, and depression (Falsetti et al. 1995; Kilpatrick and Acierno 2003; Thompson et al. 1998). Exposure to crime and violence can have a detrimental effect on mothers' mental health and general well-being, resulting in an increased risk for infant mortality for their newborn children.

Table 4 Bivariate analysis of the relationships between potential county-level mediators and income inequality and infant/neonatal mortality for births in the USA in 2010

β (95% CI)	PCP rate	Percent uninsured	Percent college degree	Social capital	Crime rate	STI rate	Bad mental health days	Neonatal mortality OR (95% CI)	Infant mortality
Both county and state Gini									
County Gini	− 0.50 (− 0.61, − 0.40)	0.38 (0.12, 0.64)	− 0.23 (− 0.38, − 0.08)	0.16 (0.02, 0.31)	0.69 (0.54, 0.84)	0.64 (0.48, 0.80)	0.01 (− 0.07, 0.09)	1.23 (1.18, 1.29)	1.20 (1.16, 1.24)
State Gini	0.22 (0.08, 0.35)	0.13 (− 0.09, 0.36)	0.16 (0.04, 0.28)	− 0.35 (− 0.58, − 0.13)	− 0.45 (− 0.69, − 0.21)	− 0.47 (− 0.69, − 0.25)	− 0.04 (− 0.13, 0.04)	1.03 (0.96, 1.11)	1.03 (0.96, 1.10)
Possible mediators (county-level)									
Social capital								1.00 (0.95, 1.05)	0.99 (0.96, 1.04)
PCP rate								0.90 (0.86, 0.94)	0.94 (0.91, 0.97)
Percent uninsured								0.97 (0.94, 1.01)	1.00 (0.97, 1.02)
Percent college degree								0.95 (0.91, 0.98)	1.00 (0.97, 1.03)
Crime rate								1.19 (1.15, 1.22)	1.15 (1.12, 1.18)
Bad mental health days								1.00 (0.95, 1.04)	1.04 (1.00, 1.07)
STI rate								1.18 (1.14, 1.21)	1.14 (1.12, 1.17)

PCP patient-to-primary care physician, *STI* sexually transmitted infections

Access to education, another social good, is also a plausible mediator between income inequality and infant mortality (Kawachi and Kennedy 1999; Smith 996; Gonzales et al. 2015). Limited access to education could have serious health consequences not just for mothers, but for their infants as well. According to UNESCO, education is the first step in allowing women to realize their full potential, and is a critical means of empowering women with the knowledge, skills, and self-confidence necessary to participate fully in the development process (Medel-Anonuevo and Bochynek 1993). Universal access to pre-kindergarten programs has been tested using randomized trials, which show that they are both effective at improving adult health and longevity (Muennig 2015). Education, over income and occupation, might have a more beneficial and longer-lasting impact on the health of women and their children. Therefore, investment in education, and ensuring access to education among women, is an essential part of a public health intervention to decrease infant mortality risk.

Our study is first limited by residual confounding. Ideally, our data would include a measure for individual-level maternal or family income. Family income could act as a potential confounder between income inequality and infant mortality risk. While educational attainment is a strong measure of socioeconomic status, inclusion of income information would strengthen the analysis. Another limitation is the lack of panel data, or repeated measures. As a result, we could not include time-varying covariates. Future analyses should include time-varying covariates in order to further test possible mechanisms. Also, since the data for this investigation were not originally intended for research purposes, the quality of the data might not be accurate, and therefore might lead to misclassification. Nevertheless, the validity of the mortality data is very high. Finally, data analyzed for this study were collected from infants born in 2010. This was the most recent data available at the time we applied for access from the CDC. The CDC does not release data immediately because it takes several years for the data to be prepared, de-identified, and made available for public use. Also, since we applied to use data linked to geographical county and state place of residence, there is a good deal of additional paperwork, which lengthened the time for us to gain access to the data. Nonetheless, since we linked county-level data, which are based on the 2010 US Census data, the 2010 LBID is the most temporally appropriate data to be utilized for this investigation.

Conclusions

Our study suggests that states and counties should begin to test policies that redistribute wealth, increase access to primary care physicians and high-quality sexual and reproductive healthcare, improve educational attainment among women, and reduce crime. By doing so, researchers may be able to examine whether these policies can reduce infant and neonatal mortality risk and improve overall maternal and child health.

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Compliance with ethical standards

Conflict of interest Amy Ehntholt declares that she has no conflict of interest. Daniel Cook declares that he has no conflict of interest. Natalie Rosenquist declares she has no conflict of interest. Peter Muennig declares he has no conflict of interest. Roman Pabayo declares he has no conflict of interest.

Ethical standards Ethical approval was obtained from the University of Nevada, Reno, Institutional Review Board.

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