Int. J. Epidemiol. Advance Access published March 15, 2007

Published by Oxford University Press on behalf of the International Epidemiological Association
International Journal of Epidemiology

doi:10.1093/ije/dym012

Income inequality and mortality: a multilevel prospective study of 521 248 individuals in 50 US states†

Eric Backlund,[1]* Geoff Rowe,[2] John Lynch,[3] Michael C Wolfson,[2] George A Kaplan[4] and Paul D Sorlie[5]

Accepted 25 January 2007

Background Some of the most consistent evidence in favour of an association between income inequality and health has been among US states. However, in multilevel studies of mortality, only two out of five studies have reported a positive relationship with income inequality after adjustment for the compositional characteristics of the state's inhabitants. In this study, we attempt to clarify these mixed results by analysing the relationship within age–sex groups and by applying a previously unused analytical method to a database that contains more deaths than any multilevel study to date.

Methods The US National Longitudinal Mortality Study (NLMS) was used to model the relationship between income inequality in US states and mortality using both a novel and previously used methodologies that fall into the general framework of multilevel regression. We adjust age–sex specific models for nine socio-economic and demographic variables at the individual level and percentage black and region at the state level.

Results The preponderance of evidence from this study suggests that 1990 state-level income inequality is associated with a 40% differential in state level mortality rates (95% CI = 26–56%) for men 25–64 years and a 14% (95% CI = 3–27%) differential for women 25–64 years after adjustment for compositional factors. No such relationship was found for men or women over 65.

Conlcusions The relationship between income inequality and mortality is only robust to adjustment for compositional factors in men and women under 65. This explains why income inequality is not a major driver of mortality trends in the United States because most deaths occur at ages 65 and over. This analysis does suggest, however, the certain causes of death that occur primarily in the population under 65 may be associated with income inequality. Comparison of analytical techniques also suggests coefficients for income inequality in

[1] US Bureau of the Census, Washington, DC 20233, USA.

[2] Statistics Canada, Ottawa, ON K1A OT6, Canada.

[3] Department of Epidemiology, Biostatistics, and Occupational Health, McGill University, Montreal QC H3A 1A2, Canada.

[4] Department of Epidemiology and Center for Social Epidemiology and Population Health, School of Public Health, University of Michigan, Ann Arbor MI, 48109-2029, USA.

[5] National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, MD, USA.

† The views expressed in this manuscript are attributable to the authors and do not necessarily reflect those of the US Bureau of the Census.

* Corresponding author. Eric Backlund, 6H020, Data Integration Division, US Bureau of the Census, Washington, DC 20233, USA.
E-mail: eric.lars.backlund@census.gov

previous multilevel mortality studies may be biased, but further research is needed to provide a definitive answer.

Keywords income distribution, differential mortality, socioeconomic factors, multilevel models

Introduction

Evidence suggesting that greater income inequality is associated with poorer health has received abundant research and policy interest[1–3] and has been invoked in many influential policy documents and writings.[4,5] Nonetheless, the totality of research evidence raises mixed opinions about the strength of the association[6–8] even though the relationship has been observed in a large number of international data sets,[8] especially for certain outcomes such as homicide.[9] Some of the most robust evidence in favour of this association has come from multilevel studies of US states where self-rated heath status shows a clear inverse relationship with income inequality after adjustment for the compositional characteristics of individuals within states.[10,11] For mortality, however, it is less clear whether the positive association between income inequality and mortality rates, observed in ecological studies,[12–14] is robust to adjustment for compositional factors. Of five studies that examined the relationship between mortality rates and income inequality in US states and adjusted for compositional factors, three showed no relationship[15–17] while two showed a positive relationship between income inequality and mortality.[18,19]

Two methodological differences among multilevel studies of income inequality on mortality may, in part, explain their disparate results. Firstly, most recent multilevel studies have analysed the relationship between income inequality and mortality within a single age range and the exact age range has varied from study to study.[15–19] However, ecological studies have shown the strength of the ecological relationship between income inequality and mortality to vary greatly across age ranges.[20,21]

A second source of inconsistent results for analyses linking state-level income inequality to mortality may be the failure to consider possible bias in estimating state mortality differentials. Most multilevel mortality studies derive state level mortality rates internally from longitudinal cohort data. Estimated mortality rates from longitudinal studies that ascertain mortality by linking different data sources, of which the source for this study the National Longitudinal Mortality Study (NLMS) is but one example, are biased downward due to imperfections in the linking process that cause some deaths to be missed. Unfortunately, there is no guarantee that the effect of missed deaths is similar across states, so differentials among internally derived mortality rates for states may also be biased.[22,23] Fortunately, one study suggests an approach that may help eliminate this bias by supplementing state level mortality rates calculated from the study cohort with external information from state level rates obtained from US vital statistics.[19]

In this study, we employ multilevel analysis, which is being used in a growing number of studies to examine the relationship between income inequality and health, because it allows proper separation of compositional and contextual effects.[24] The sex-specific relationship between income inequality and mortality is examined, after adjustment at the individual level for race, Hispanic origin, urbanization level, the log of family income, household size, education, employment status and marital status, within the age groups of over 65 and 25–64. The age of 65 is chosen as a cutoff point, because it is often used as a dividing point to separate premature mortality from older age mortality and because in the United States, it is the standard age for retirement and qualification for Medicare. The effect of adjusting for two state level variables, region and the percentage of state residents that are black, is also examined because two studies have asserted that these state-level variables explain a large portion of the relationship between state-level income distribution and health or mortality,[15,25] while two others provide evidence that the relationship for health is robust to adjustment for percentage black at the state level.[26,27]

We also use a novel method to formulate estimates of state-level mortality rates, adjusted for compositional variables at the individual level, by supplementing internal estimates from the NLMS with external information from state rates obtained from US Vital Statistics. The results obtained from these two methods are compared in order to ascertain if differential bias in estimates of state-level mortality rates in the NLMS affects the estimated relationship between income inequality and mortality.

Materials and methods

Data were taken from the NLMS—a large prospective mortality study that matches individual records from the Current Population Survey (CPS)[28] to the National Death Index (NDI).[29] Details of the NLMS are published elsewhere.[22,23] The CPS is the major non-Census survey used by the US government to collect economic data. The individual records were taken from nine CPS files dating from 1979–1985. Follow-up for mortality was terminated at the end of 1989 and ranged from 4.75 to 10.75 years with a mean time of 8.4 years. In the population aged 25–64, 11 616 deaths occurred among 202 606 men and 7433 deaths occurred among 222 215 women. In the population aged over 65, 16 982 deaths occurred among the 40 146 men and 16 892 deaths occurred among the 56 281 women.

State income inequality was measured as the percentage of the total state income received by state residents with incomes below the median. This inequality measure was strongly associated with mortality in previous studies in the United States and is highly correlated with other indicators of income inequality.[14,30] Income inequality was calculated using both 1980 and 1990 census data, which represent the beginning and end of the observational period. Income inequality in 1990 was included even though it was measured after the follow-up period, because the person-years of observation are heavily weighted toward the years of follow-up after 1985. Thus, whether the 1980 or 1990 income distribution better represents the income distribution during the follow-up period is unclear.

Data on family income, household size, race (white, black and other), Hispanic ancestry, urbanization level (central city, metropolitan but not central city, non-metropolitan), marital status (married, widowed, divorced, separated, never married), education (grammar school, high school but no diploma, high school diploma, some college, college diploma, beyond college) and employment status (employed, unemployed in the labour force, unable to work, housework, other not in the labour force) was obtained from the individual records of the CPS.

Statistical analysis

Regression analysis of prospective individual mortality records suggests the use of the Cox proportional hazards model while the use of explanatory variables at both the individual and state level suggests a multilevel approach. While multilevel Cox regression models have been developed, they are often quite cumbersome and computationally intensive.[31] Therefore, almost all studies of income inequality and mortality across US states with data sets similar to NLMS have utilized the more tractable marginal method.

As opposed to multilevel estimation of individual and state level coefficients and error terms for each individual, the marginal approach simply estimates Cox regression coefficients using traditional estimation methods. Since standard errors obtained by traditional estimation methods are biased downward due to the geographic clustering of individuals, the marginal method adjusts the variance of these coefficients using a sandwich estimator in order to obtain unbiased estimates of the standard errors and *P*-values for the model coefficients.[32,33] (For details see supplementary data)

In order to examine the NLMS for differential matching bias among states, which may result in biased estimates of relative mortality differentials among US states, state-level mortality rates from the NLMS were compared.[22,23] This analysis showed several states to have estimated mortality rates, relative to the US average, >2 SDs away from those obtained from US vital statistics. Mortality rates estimated from the NLMS for the state of New York appear particularly troublesome because its mortality is much lower relative to the US average in the NLMS than in US Vital Statistics and because New York is a populous state that represents an outlier with regard to income distribution.

A graphical approach employed by Wolfson *et al*.[19] raises the possibility of using auxiliary information from state-level mortality rates from U.S. Vital Statistics to reduce the bias in relative state-level estimates. In this article, we expand this graphic approach into a formal multilevel regression model, which we will term the ratio estimation method. The starting point of ratio estimation is to adjust state level mortality rates from US Vital Statistics for individual level predictors using their internally estimated regression coefficients as obtained from the NLMS. These internally adjusted US Vital Statistics rates are then regressed against state-level income distribution. The NLMS-adjusted state level estimates of mortality rates correspond to the widely used ratio estimate in sample surveys that is used to reduce the variance as well as the bias of a sample estimate of an unknown population value by relating it to a known population value.[34]

Estimates of individual level regression coefficients are obtained using the discrete time piecewise exponential formulation of the Cox model that has been used by Goldstein to estimate multilevel Cox models.[31] In order to make estimation more tractable, we have slightly modified Goldstein's model so that the independent variable representing event time represents all deaths within single calendar years rather than single deaths. The regression coefficients for individual level predictors estimated from such a model using the NLMS are very close numerically to those obtained from the standard Cox proportional hazards model. Ratio estimation involves some minimal assumptions all of which appear to be met for the analyses presented in this study. (For a discussion of these assumptions, as well as a more rigorous explanation of the marginal and ratio estimation methods, consult the supplementary data.)

The marginal and ratio estimation methods are used to estimate regression coefficients for the effect of income distribution on mortality after adjustment for the log of family income, household size, race, Hispanic ancestry, urbanization, marital status, education and employment status at the individual level. The ratio method is also used to additionally adjust for the state level variables of region and percentage black. All regression coefficients presented in this article are scaled to represent the relative risk of mortality in a hypothetical state, with income inequality equal to the highest in the United States, relative to another hypothetical state with income inequality equal to the lowest in the United States. All models are specific to the broad age groups (25–64 and over 65) and sex. For the ratio estimation method, an interaction model, with both sexes and both age groups combined, is used to test the hypothesis of whether the effect of income distribution on mortality differs by age group and sex.

Results

Table 1 displays regression coefficients for the effect of state-level income distribution on state-level mortality rates, after adjustment for all compositional variables, using both the marginal and ratio estimation methods. For example, using the

Table 1 Comparison of relative risks of mortality (with 95% CIs) as estimated by the marginal and ratio methods

Income distribution data	1980	1990
Men 25–64		
Marginal method	1.16 (1.03, 1.31)	1.21 (1.05, 1.41)
Ratio method	1.36 (1.18, 1.56)	1.40 (1.26, 1.56)
Women 25–64		
Marginal method	0.97 (0.86, 1.10)	0.97 (0.89, 1.06)
Ratio estimation method	1.15 (1.02, 1.30)	1.14 (1.03, 1.27)
Men over age 65		
Marginal method	0.92 (0.81, 1.05)	0.93 (0.78, 1.09)
Ratio method	1.00 (0.92, 1.10)	1.03 (0.92, 1.16)
Women over age 65		
Marginal method	0.90 (0.83, 0.97)	0.94 (0.87, 1.03)
Ratio method	0.97 (0.90, 1.04)	0.99 (0.92, 1.09)

The relative risks represent mortality for individuals living in a state with the highest observed income inequality relative to a state with the lowest observed income inequality. All models are adjusted for the log of family income, household size, marital status, education, Hispanic origin, urbanization level, race and employment status at the individual level.

Table 2 Relative risk of mortality for people aged 25–64 living in a state with the highest observed income inequality relative to those living in a state with the lowest inequality as predicted by the ratio estimation method (with 95% CIs) with four different sets state level adjustors

	1980	1990
Men 25–64		
Income inequality	1.36	1.40
Adjusted for compositional variables only	(1.18, 1.56)	(1.26, 1.56)
Income inequality	1.30	1.33
Adjusted for region and compositional variables	(1.05, 1.45)	(1.19, 1.50)
Income inequality	1.15	1.22
Adjusted for % Black and compositional variables	(1.04, 1.28)	(1.10, 1.37)
% Black	1.25	1.22
Adjusted for income distribution and compositional variables	(1.13, 1.40)	(1.10, 1.35)
Women 25–64		
Income Distribution	1.15	1.14
Adjusted for compositional variables only	(1.02, 1.30)	(1.03, 1.27)
Income Distribution	1.15	1.15
Adjusted for region and compositional variables	(1.00, 1.33)	(1.02, 1.30)
Income distribution	1.01	1.05
Adjusted for % Black and compositional variables	(0.88, 1.17)	(0.94, 1.18)
% Black	1.16	1.14
Adjusted for income distribution and compositional variables	(1.04, 1.31)	(1.01, 1.28)

The table also shows the relative risk of living in the state with the highest percentage black residents, relative to the lowest percentage black residents after adjustment for state level income inequality. All models are adjusted for age, the log family income, household size, race, Hispanic origin, education, urbanization, marital status, employment status at the individual level.

1990 income distribution, the ratio method predicts men aged 25–64 living in a hypothetical state with the highest income inequality have a 40% (95% CI = 26–56%) higher mortality risk than men living in a hypothetical state with the lowest (Table 1). Women age 25–64 living in a hypothetical state with the highest 1990 income inequality would be expected to have morality rates that are 14% (95% CI = 3–27%) higher than women living in a state with the lowest (Table 1). The interaction model between income distribution and gender is significant ($P = 0.0021$) in the 25–64 age group showing the effect of income inequality is significantly higher in males.

Between the ages of 25–64, ratio estimation moves all coefficients for income inequality toward a more positive relationship with mortality in comparison to the marginal method (Table 1). In men, the marginal method predicts an increase in mortality risk between the most and least egalitarian states of only 21% as opposed to 40% for the ratio method. In contradiction to the ratio method, there is no significant relationship between income inequality and mortality for women between 25 and 64 when the marginal method is used. Thus, the marginal method might produce biased estimates of the effect of state-level income distribution on state-level mortality due to bias in the estimates of state-level mortality obtained internally from the NLMS. In particular, the correction of the apparent downwardly biased estimate of mortality for New York State from the NLMS has a strong influence on the slope of the regression line because of the state's high inequality and high mortality rate.

In the over-65 age group, no significant effects between income distribution and mortality are observed for either men or women using the ratio method (Table 1). The interaction model shows the effect of income distribution on mortality to be smaller in the older age group for both men ($P < 0.0001$) and women ($P = 0.045$). The marginal method, but not the ratio method shows 1980 income inequality to be positively related to mortality in older women, which is in the opposite direction of what is expected.

Tables 2 and 3 show the effect of adjusting for percentage black and region at the state level, in addition to compositional variables, using ratio estimation. The relationship between income inequality and mortality is not greatly affected by adjustment for region in either the working-age population or the older population (compare the first and second models in Tables 2 and 3, respectively). The positive relationship between income inequality and mortality also remains significant in working-age men after adjustment for percentage black (Table 2). However, the income inequality/mortality relationship is non-significant for working-age women after adjustment for percent black at the state level (Table 2). In older women, higher income inequality is significantly associated with lower mortality after adjustment for percentage black (Table 3). A higher percentage of black residents in each state (Tables 2 and 3) is associated with increased state-level mortality after adjustment for income distribution in all age–sex groups except older men.

Discussion

The NLMS shows significantly different associations between income inequality and mortality among age–gender groups after adjustment for compositional factors. One possible interpretation of these differences may stem from the different specific causes of mortality, which afflict each subgroup. In 1998, among those older than 65, the contribution of deaths due to heart disease, stroke and cancer was about 64%, while in those aged 25–64 it was approximately 57%. However, the composition of the remaining causes of death in these two age groups differs markedly in regard to unintentional injury, suicide, homicide and HIV. These causes account for <4% of mortality at ages 65 and over and they account for almost 18% in those aged 25–64.[35] Additionally, all of these causes of death have higher rates in males. Thus, our finding, that direct effects of income inequality are evident only for ages 25–64, and much stronger for males, may be partially explained by the age–sex distribution of the causes of death. Interestingly, an analysis of self-rated health status, which unlike mortality, is not affected by cause mix, did not show any age–sex interactions.[36]

The modification of the relationship between income inequality and mortality due to age may also explain some of the contradictory results obtained in previous studies. Because of the interaction between income inequality and age, results from studies that analyse a single age range will be sensitive

Table 3 Relative risk of mortality for people over age 65, living in states with the highest observed income inequality relative to those living in states with the lowest income inequality as predicted by the ratio estimation method (with 95% CIs) with four different sets of state level adjustors

	1980	1990
Men over 65		
Income inequality	1.00	1.03
Adjusted for compositional variables only	(0.92, 1.10)	(0.92, 1.16)
Income inequality	1.04	1.05
Adjusted for region and compositional variables	(0.93, 1.13)	(0.95, 1.16)
Income inequality	0.96	0.99
Adjusted for % Black and compositional variables	(0.86, 1.05)	(0.90, 1.11)
% Black	1.07	1.07
Adjusted for income distribution and compositional variables	(0.97, 1.17)	(0.97, 1.16)
Women over 65		
Income distribution	0.97	0.99
Adjusted for compositional variables only	(0.90, 1.04)	(0.92, 1.09)
Income distribution	0.95	0.98
Adjusted for region and compositional variables	(0.87, 1.04)	(0.91, 1.05)
Income distribution	0.87	0.92
Adjusted for % Black and compositional variables	(0.79, 0.95)	(0.84, 1.00)
% Black	1.19	1.17
Adjusted for Income Distribution and compositional variables	(1.11, 1.32)	(1.08, 1.27)

The table also shows the relative risk of living in the state with the highest percentage black residents, relative to the lowest after adjustment for state level income inequality. All models are adjusted for age, the log family income, household size, race, Hispanic origin, education, urbanization, marital status, employment status at the individual level.

to the points where the age range is truncated. Indeed, studies reporting a positive association between income inequality and mortality have truncated out the upper age range[18,19] while studies reporting no relationship have included the entire age range.[15] Two studies that utilized a truncated age range and did not find a relationship between income inequality and mortality probably suffered from inadequate statistical power since they had far fewer deaths than the other studies.[16,17]

The difference in the estimated coefficients using the marginal and ratio methods, as well as the discordant significant tests for women aged 25–64, suggests estimates obtained using the marginal method may be biased. Whether this bias exists in all longitudinal databases derived from multiple sources or is merely an artefact of the NLMS, requires further research. Also, it is worth emphasizing again that the possibility of such bias only occurs in longitudinal studies where numerator and denominator counts are obtained from different data sources.

Deaton and Lubotsky[15] have previously asserted that state-level income distribution does not affect mortality in the NLMS, especially after adjustment for percentage black. While this may be true in the general population, this analysis shows age to be an important mediator of the relationship between income inequality and mortality. Consequently, the NLMS does suggest that a relationship between income inequality and mortality exists in the NLMS for both men and women aged 25–64 after adjustment for compositional factors and that this relationship is robust to adjustment for percentage black in males of this age group. Furthermore, Deaton and Lubotsky's study does not consider the supplementation of estimated state-level mortality rates with data from US vital statistics.

Models presented in this manuscript show percentage black to be significantly related to mortality in all age–sex groups except older males, while income distribution is significant only in younger males and may be negatively related to mortality in older women, when the two contextual variables are considered jointly. However, this result does not seem to invalidate the two most prominent mechanisms proposed to explain the income inequality/health relationship. Larger percentages of black residents in states are associated with a larger gap between the average black and average white incomes within that state.[15] Thus, both percentage black and income distribution appear to serve as a marker of a state's commitment to some sort of social equity in the form of racial equity for the former and economic equity for the later.

The neo-materialist hypothesis, asserts that income distribution is a social marker, which in turn, serves as a marker for investment in health enhancing infrastructure.[3] In the neo-materialist hypothesis, income distribution is only one possible marker for social equity, which is in turn linked with investment in health-enhancing infrastructure. Under the neo-materialist hypothesis, these linkages may vary—over population, subgroups and over time.[37–40] The relative income hypothesis proposes detrimental physiology and psychological effects of excessive social ranking as the driving mechanism for the relationship between income inequality and health, especially through constructs of social capital.[1,3,4,41] Clearly, racial inequality, especially within its unique historical context in the United States could be just as indicative of excessive social ranking as economic inequality and allow fewer opportunities for the formation of social capital.[8] Thus, in regard to either the neo-materialist or the relative income hypothesis some ambiguity might be expected in the joint relationship of income distribution and percentage black to mortality.

The most salient weakness of this study is the failure to account for contextual indicators, observed at the state level, other than income distribution and percentage black. However, the joint consideration of percentage black and income distribution clearly suggests that there is a large degree of overlap between contextual social indicators and their linkages to health. Thus, studies that have shown the coefficient for income distribution is reduced to non-significance after adjustment for a particular set of state-level indicators[25,41] do not provide a strong argument either for or against any specific casual mechanism. Because a large degree of overlap exists among contextual markers, many alternative sets of contextual indicators might be found that would reduce the coefficient for income distribution to non-significance.[7,8]

The degree to which individual level predictors should be regarded as confounders rather than mediators has also been called into question. If individual level education or income reflects relative class differentials or can be partially attributed to social and political factors that are related to income distribution, it could be argued that these factors should at least partially be regarded as intermediate factors rather than true confounders.[8] Omitting income and education from the model as individual level confounders raises the ratio estimate for the 1990 income distribution from 1.40 to 1.44 for men 25–64 and from 1.14 to 1.19 for women 25–64. The changes are smaller in the 65 and over group. Higher income levels are associated with less income inequality and adding income to the model attenuates the relationship between state income distribution and mortality. However, after adjustment for income and other individual level predictors, more favourable education levels are associated with greater inequality and adding education slightly increases the size of the inequality/mortality relationship. Thus, in light of the preceding discussion, adding additional contextual indicators or individual level predictors to the models presented in this study, without careful consideration of a causal pathway, would seem to have an ambiguous interpretation at best.

Conflicts of interest: None declared.

Supplementary data

Supplementary data are available at *IJE* online.

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