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Do people die from income inequality of a decade ago?

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ABSTRACT

The long-term impact of income inequality on health has not been fully explored in the current literature. Until now, 4 studies have examined the lagged effect on population/group mortality rate at the aggregate level, and 7 studies have investigated the effect of income inequality on subsequent individual mortality risk within a restricted time period. These 11 studies suffer from the same limitation: they do not simultaneously control for a series of preceding income inequalities. The results of these studies are also mixed. Using the U.S. National Health Interview Survey data 1986–2004 with mortality follow-up data 1986–2006 ($n = 701{,}179$), this study investigates the lagged effects of national-level income inequality on individual mortality risk. These effects are tested by using a discrete-time hazard model where contemporaneous and preceding income inequalities are treated as time-varying person-specific covariates, which then track a series of income inequalities that a respondent faces from the survey year until s/he dies or is censored. Findings suggest that income inequality did not have an instantaneous detrimental effect on individual mortality risk, but began exerting its influence 5 years later. This effect peaked at 7 years, and then diminished after 12 years. This pattern generally held for three measures of income inequality: the Gini coefficient, the Atkinson index, and the Theil entropy index. The findings suggest that income inequality has a long-term detrimental impact on individual mortality risk. This study also explains discrepancies in the existant literature.

Introduction

The impact of income inequality on population health has become a contentious topic in the field of social epidemiology and public health in the past two decades. Despite a large body of research, current literature has provided mixed findings. It is reasonable to suggest that many scholars now are skeptical of the adverse impact of income inequality on health, while others believe the initial theoretical arguments and maintain that the effects may still exist in certain situations. This uncertainty has high stakes as most developed and developing countries have experienced dramatic increases in income inequality in the past several decades; if income inequality adversely affects health, then even a small effect may have considerable consequences on the population as a whole (Kondo et al., 2009).

Some research has tried to investigate the causes for these mixed findings by using systematic literature review (e.g., Lynch, Davey Smith, Harper, Hillemeier, Ross, et al., 2004; Wilkinson & Pickett, 2006) or meta-analysis (e.g., Kondo et al., 2009, 2011). Their analyses suggest that the mixed findings may result from the countries and time periods studied, units of analysis employed, and levels of income inequality investigated (Subramanian & Kawachi, 2004; Wilkinson & Pickett, 2006; Zheng, 2009). For example, the threshold of income inequality may exist beyond the point at which its detrimental impact starts emerging (e.g., Kondo et al., 2009).

It is informative to review the possible mechanisms linking income inequality to health. Income inequality may erode social cohesion and social capital (e.g., Wilkinson, 1996), reduce investment in human capital and public goods (e.g., Kaplan, Pamuk, Lynch, Cohen, & Balfour, 1996), amplify relative deprivation and subsequent harmful psychosocial stress (e.g., Kawachi, Kennedy, Lochner, & Prothrow-Stith, 1997), and transfer some stress from the deprived to the better off (e.g., Kondo et al., 2009), leading to poorer health across the population.

This study focuses on one outcome—mortality—and systematically reviews 79 studies published in peer review journals up to 2008 concerning the effect of income inequality on mortality and the possible causes for mixed findings. We argue that the timing of effects may be a crucial factor for the discrepancies in outcomes, a factor that has not received much attention in the past. Timing concerns the lags between income inequality and the health outcomes. We attempt to capture the timing of effects by using

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a previously unused data structure and statistical model, which estimate, relatively accurately, the instantaneous and lagged effects of income inequality on individual mortality risk. In this study, we examine the long-term effect of national-level income inequality on individual mortality risk in the United States from 1986 through 2006.

Background

Mixed results and their possible causes

We reviewed all the papers cited by four systematic reviews or meta-analyses of this field, i.e., Lynch, Davey Smith, Harper, Hillemeier, Ross, et al., 2004; Subramanian & Kawachi, 2004; Wilkinson & Pickett, 2006; Kondo et al., 2009. We selected papers with mortality as the outcome variable (either aggregate mortality rate or individual mortality risk). Up to 2008, 79 studies have examined the impact of income inequality on mortality. Among these, 21 use between-country designs (e.g., Jen, Jones, & Johnston, 2009; Leigh & Jencks, 2007), 21 use U.S. states as the units of analysis (e.g., Backlund et al., 2007; Mayer & Sarin, 2005; Mellor & Milyo, 2003), 4 examine states or provinces in other countries (e.g., Blomgren, Martikainen, Makela, & Valkonen, 2004; Shmueli, 2004), 11 examine metropolitan areas and cities (e.g., Ronzio, Pamuk, & Squires, 2004; Sanmartin, Ross, Tremblay, Wolfson, & Lynch, 2003), and 22 examine smaller within-country geo-political units (e.g., Kravdal, 2008; Sohler, Arno, Chang, Fang, & Schechter, 2003). These studies examined all-cause mortality (e.g., Backlund et al., 2007; Dahl, Elstad, Hofoss, & Martin-Mollard, 2006), disease-specific mortality (e.g., Kim, Kawachi, Hoorn, & Ezzati, 2008; Massing et al., 2004), and infant mortality (e.g., Beckfield, 2004; Pampel & Pillai, 1986; Ram, 2006).

Table 1 classifies these 79 studies based on the criteria used by Wilkinson and Pickett (2006). "Supportive studies" only find a significant and positive effect of income inequality on mortality. "Mixed studies" find some significant positive effect but also find null effect. "Unsupportive studies" find a non-significant effect of income inequality on mortality. Overall, the likelihood of detecting significant income inequality effect on mortality declines from international studies, to state or metropolitan area studies, and further to small units (e.g., neighborhoods) studies. This finding is consistent with existent literature (e.g., Wilkinson & Pickett, 2006; Zheng, 2009).

Table 2 lists all studies by their research design (aggregate-level or multilevel studies) and effects of income inequality (instantaneous or lagged effects). Sixty-three of these 79 studies focus on the effect of income inequality on population mortality rate based on aggregate-level data. Among these 63 studies, the effect of income inequality was significant and positive in 29, and non-significant in 14 studies. Twenty studies found mixed results. These findings lean toward the income inequality hypothesis, however these studies are not independent because of overlapping data bases. In addition, aggregate studies suffer from theoretical ambiguity as aggregate association may result from the simple accumulation of individual-level nonlinear associations between health and income (Gravelle, 1998), whereby "the redistribution of income from higher income groups to lower income groups (i.e., decreases in income inequality) will produce improvements in overall population health" (McLeod, Nonnemaker, & Call, 2004). In this case, income inequality only has a compositional effect (i.e., effects that result from an accumulation of individual-level associations) rather than a contextual effect (i.e., effects that result from the independent effect of social context). A multilevel design that controls for confounding individual-level characteristics (e.g., income, education) is needed in order to detect the independent contextual effect of income inequality (Kondo et al., 2009; Subramanian & Kawachi, 2004).

Table 1
79 Studies on the effect of income inequality on mortality by units of analysis.

	Supportive studies (only significant positive findings)	Mixed studies (some significant positive and some null)	Unsupportive studies (No significant positive findings)
International studies (21)	11 (52%)	5 (24%)	5 (24%)
State or metropolitan area studies (36)	17 (47%)	10 (28%)	9 (25%)
Small units studies (22)	4 (18%)	10 (46%)	8 (36%)

Among the 16 studies that use multilevel design and investigate the impact of income inequality on individual mortality risk (e.g., Franzini & Spears, 2003; Lochner, Pamuk, Makuc, Kennedy, & Kawachi, 2001), 3 find positive effects, 5 get mixed results, and 8 report non-significant effects, including 6 small-area studies, which are criticized by Wilkinson and Pickett (2006) because "people's health is not affected by small-area income inequality and relative deprivation within their neighborhoods, but rather by societal levels of income inequality and relative deprivation" (Zheng, 2009). However, even if the 6 small-area studies are removed, we still get mixed and uncertain findings concerning the impact of income inequality on individual mortality risk.

Issues of timing

Besides the unit of analysis and research design, another issue one needs to take into account is whether income inequality has instantaneous or lagged effects on mortality, which have not been fully explored in the current literature. The timing issue concerns the lag between changes in income inequality and their health effects. There are at least two reasons to speculate a lagged effect. First, income inequality affects health by intensifying relative deprivation and psychosocial stresses, underinvesting in public goods, and eroding social capital (e.g., Kawachi & Kennedy, 1999; Wilkinson, 1992). These mediating mechanisms of action may not be instantaneous (Blakely, Kennedy, Glass, & Kawachi, 2000; Kondo et al., 2011). Second, it usually takes years before exposure to risk factors are observed to predict chronic illness, e.g., cardiovascular diseases, cancer, stroke, diabetes (Yusuf, Reddy, Ounpuu, & Anand, 2001). The notion of time indicates that chronic conditions have a long latency period and that there are the lags between the accumulation of risk factors (e.g., income inequality) and the onset of diseases and subsequent mortality risk (Lynch & Davey Smith, 2005). The appropriate intervals between changes in income inequality and health may differ across health outcomes. If the health outcome is chronic illness, life expectancy, or mortality, statistical models should incorporate significant lag times between changes in income inequality and their health effects. For other health outcomes, such as self-rated health and psychological distress, lag times may be much smaller or nearly instantaneous.

Among the 63 aggregate-level studies, 4 studies have examined the lagged effect by linking preceding income inequality to subsequent mortality rate. Only one study finds significant 10-year lag effects (Kim et al., 2008), while the other three studies report non-significant (e.g., Mellor & Milyo, 2003; Shi, Macinko, Starfield, Xu, & Politzer, 2003) or mixed results (e.g., Shi et al., 2004). These studies, however, suffer from aggregate study limitations. Therefore, as noted above, a multilevel design with controls for both income inequality and individual covariates is needed to test the contextual

Table 2
79 Studies on the effect of income inequality on mortality by research designs.

		Supportive studies	Mixed studies	Unsupportive studies
Aggregate-level studies (63)	Instantaneous effects (59)	Duleep, 1995; Flegg, 1982; Hales, Howden-Chapman, Salmond, Woodward, & Mackenbach, 1999; Legrand, 1987; Macinko, Shi, & Starfield, 2004; McIsaac & Wilkinson, 1997; Rodgers, 2002; Waldmann, 1992; Wennemo, 1993; Ram, 2006; Kaplan et al., 1996; Kawachi & Kennedy, 1997; Kawachi et al., 1997; Kennedy, Kawachi, & Prothrow-Stith, 1996; Ross et al., 2000; Shi, 1999; Wilkinson, Kawachi, & Kennedy, 1998; Wolfson, Kaplan, Lynch, Ross, & Backlund, 1999; Cooper et al., 2001; Lynch et al., 1998; Ronzio, 2003; Ronzio et al., 2004; Sanmartin et al., 2003; Shi & Starfield, 2001; Chiang, 1999; Massing et al., 2004; Shi et al., 2005; Stanistreet, Scott-Samuel, & Bellis, 1999	Lobmayer & Wilkinson, 2000; Lynch et al., 2001; Pampel & Pillai, 1986; Ross et al., 2005; Weatherby, Nam, & Isaac, 1983; Laporte, 2002; Lynch, Davey Smith, Harper, & Hillemeier, 2004; Mayer & Sarin, 2005; Mellor & Milyo, 2001; Shmueli, 2004; Lobmayer & Wilkinson, 2002; Sanmartin et al., 2003; Brodish, Massing, & Tyroler, 2000; Franzini, Ribble, & Spears, 2001; McLaughlin & Stokes, 2002; McLaughlin, Stokes, & Nonyama, 2001; Sohler et al., 2003; Szwarcwald, Andrade, & Bastos, 2002; Veenstra, 2002a	Beckfield, 2004; Mellor & Milyo, 2001; Wildman, Gravelle, & Sutton, 2003; Leigh & Jencks, 2007; Deaton & Lubotsky, 2003; McLeod et al., 2004; Muller, 2002; Laporte & Ferguson, 2003; Ross et al., 2000; Deaton & Lubotsky, 2003; Lorant, Thomas, Deliege, & Tonglet, 2001; Veenstra, 2002b
	Lagged effects (4)	Kim et al., 2008	Shi et al., 2004	Shi et al., 2003; Mellor & Milyo, 2003
Multilevel studies (16)	Instantaneous effects (9)	Galea et al., 2003	Backlund et al., 2007; Kravdal, 2008; Henriksson, Allebeck, Weitoft, & Thelle, 2006	Jen et al., 2009; Blomgren et al., 2004; Franzini & Spears, 2003; Gerdtham & Johannesson, 2004; Jones, Duncan, & Twigg, 2004
	Lagged effects (7)	Lochner et al., 2001; Dahl et al., 2006	Daly et al., 1998; Osler et al., 2003	Fiscella & Franks, 1997; Blakely et al., 2003; Osler et al., 2002

lag effect of income inequality on individual mortality risk. Moreover, these studies only test the lag effect of income inequality at a certain year and do not simultaneously control for a series of previous and contemporaneous income inequalities. This approach generates inaccurate estimates of the lag effects because current mortality rates are the result of income inequalities within a period of time rather than a certain point of income inequality in preceding years.

Among the 16 multilevel studies, 7 use survey data with follow-up mortality data and the Cox proportional hazards model (e.g., Fiscella & Franks, 1997; Osler et al., 2002, 2003) or logistics regression (e.g., Daly, Duncan, Kaplan, & Lynch, 1998) to examine the effect of income inequality on individual mortality risk within a restricted time period, e.g., 3 years in Blakely, Atkinson, and O'Dea (2003), 6 years in Dahl et al. (2006), and 8 years in Lochner et al. (2001). Among these 7 studies, 2 support the income inequality hypothesis, 2 find mixed results, and 3 report non-significant findings. Strictly, these studies did not examine the lagged effect because they did not examine whether the mortality risk in a certain year was affected by contemporaneous and preceding income inequalities. Instead, they studied whether income inequality at the survey year affected mortality risk, which can occur contemporaneously or subsequently in any year within the follow-up period; so we are not able to tell the exact order of lag effects. In addition, the mortality risk is not only affected by the income inequality at the year of survey but also by subsequent income inequalities. However, these studies assumed that income inequality remained the same in subsequent years because it was treated as a time-invariant variable in the Cox proportional hazards model or logistics regression model. The limitations of this model specification prevent the long-term effects of income inequality on individual mortality risk from being captured accurately. The effects may be underestimated due to the restrictive follow-up time if income inequality still has an impact beyond this period or they may be overestimated due to the ignorance of subsequent income inequalities if their effects increase.

In all, there is no systematic study examining the possible long-term effect or lagged effect of income inequality on individual mortality risk, hence the objective of this study. We use the U.S. National Health Interview Survey (NHIS) 1986–2004 with mortality follow-up data 1986–2006. By using a discrete-time hazard model, we examine whether national-level income inequality has long-term or lagged effects on individual mortality risk. Both macro-level income inequality and individual covariates including income are controlled, which facilitates testing whether income inequality has a contextual effect on mortality. Each individual's mortality risk is an outcome of a series of income inequalities, which overcomes the limitations of the 11 studies previously mentioned and clearly captures the lag effect of income inequality.

Methods

Data and variables

Data are drawn from the U.S. National Health Interview Survey (NHIS) 1986–2004 with mortality follow-up data 1986–2006. The NHIS is a multistage probability sample survey of the civilian, non-institutionalized U.S. population conducted annually by the National Center for Health Statistics. Respondents interviewed between 1986 and 2004 are linked to the death records in the National Death Index (NDI) 1986–2006 through probabilistic record matching methods based on 12 criteria to ascertain the vital status of each respondent. We limit the analysis to respondents aged 30 and older, as a high proportion of young adults have not completed their educations prior to age 30. We replicated the analysis starting at ages 18 and 25 and findings were very similar. Only non-Hispanic White and non-Hispanic Black subjects are included in the analysis. Hispanics, who are a small proportion of the sample in earlier waves of survey, are omitted because they may have already been subjected to income inequality outside the country. Including them could skew the results. The final sample includes 701,179 respondents and 125,391 deaths.

The original data were organized in a person-level format. In order to use a discrete-time hazard model, we expanded the data into a person-period format based on the exposure duration. That is, if a respondent was interviewed in 1986 (exposure time 1) and then died in 1997 (exposure time 12), s/he was observed for 12 years. Therefore, a respondent may have several observations until s/he dies or is censored. The maximum number of exposures is 21 if a person was interviewed in 1986 and died or was still alive in 2006. Each observation records age, race, gender, education, family income, work status, marital status, and vital status.

The most commonly used measure of income inequality, the Gini coefficient, comes from the U.S. Census Bureau. It ranges in value from 0 indicating complete equality to 1 indicating maximum inequality. Because individuals participate in the NHIS survey in different years, they face different national-level income inequalities since their exposure to the survey. Therefore, we use person-specific income inequality, which is treated as a time-dependent covariate. For example, a person participating in the survey in 1986 faced a Gini of 0.392 in 1986 (exposure time 1), 0.393 in 1987 (exposure time 2), …, until s/he died or was censored. Another person participating in the survey in 1987 faced a Gini of 0.393 in 1987 (exposure time 1), 0.395 in 1988 (exposure time 2), …, until s/he died or was censored. The lag-1 Gini for the first person is 0.389 in 1986 (exposure time 1), 0.392 in 1987 (exposure time 2), 0.393 in 1988 (exposure time 3), … The lag-1 Gini for the second person is 0.392 in 1987 (exposure time 1), 0.393 in 1988 (exposure time 2), 0.395 in 1989 (exposure time 3), … The same logic applies to other lags of the Gini coefficient. As a one-unit increase in the Gini coefficient is not possible—it would mean a country changes from complete equality (0) to complete inequality (1)—we multiply Gini by 100. The estimated coefficient from the model can then be interpreted as how a 0.01-unit increase in Gini may affect individual mortality risk.

We also control for several variables that are established correlates of mortality: survey year, age in years, age squared, sex (1 = male, 0 = female), race (1 = non-Hispanic White, 0 = non-Hispanic Black), marital status (a set of dummy variables: never married, separated, divorced, and widowed with married as a reference group), years of formal education, work status (1 = full/part-time job, 0 = not employed), and family income adjusted for inflation. Family income squared is also included to test whether the effect of income inequality may result from the nonlinear correlation between individual income and health outcome. We also control for GDP per capita, an indicator for *mean* level of *individual* economic achievement, which is suggested for aggregate-level studies but not for multilevel studies where individual-level income is already controlled.

Statistical methods

We use a discrete-time hazard model to estimate the effect of national-level income inequality on individual mortality risk (Singer & Willett, 2003). The discrete-time hazard model is more straightforward and computationally efficient than the Cox proportional hazard model when there are time-dependent covariates (Allison, 1995). The discrete-time hazard model can be specified as

$$\begin{aligned}\text{logit } h(t_{ij}) = {} & [\alpha_1 D_1 + \ldots + \alpha_k D_k + \ldots + \alpha_{21} D_{21}] + \beta \text{survey year}_i \\ & + \lambda_1 \text{age}_{ij} + \lambda_2 \text{age}_{ij}^2 + \sum \kappa_p x_{pi} + \gamma_0 \text{gini}_{ij} + \gamma_1 \text{lag1gini}_{ij} \\ & + \gamma_2 \text{lag2gini}_{ij} + \gamma_3 \text{lag3gini}_{ij} + \ldots + \gamma_{14} \text{lag14gini}_{ij},\end{aligned} \tag{1}$$

where $h(t_{ij})$ is the conditional probability that individual i dies in time period j. D_1 to D_{21} are a set of time dummies, which captures the shape of the baseline logit hazard function (or log odds function). Survey year is controlled because individuals' entry times are different. Age is a time-dependent covariate with j in the subscript. x_p represents a set of time-invariant covariates, including race, gender, education, family income, employment status, and marital status. Each covariate except race and gender is supposed to be time-varying, but because NHIS does not follow up the respondents' education, family income, work status, and marital status, these four variables are treated as time-invariant and can be interpreted as the effects of the original status of these variables on mortality risk. The Gini coefficient is a time-varying covariate. Lags of the Gini coefficient are also time-varying covariates. In sum, we examined contemporaneous and 14-year lags of the Gini coefficient.

The model specification might pose three potential problems. First, including time-varying predictors may cause state dependence and rate dependence problems, i.e., the value of a time-varying predictor at time j may be affected by the individual's *state* (event occurrence status) or individual's value of *hazard* (the "rate") at time j (Singer & Willett, 2003). In the context of this study, *individual* vital status or mortality risk might affect *macro* income inequality, although this is relatively unlikely. A general practice to ease these two dependence problems is to "use lagged predictors to link prior predictor status with current outcome status" (Singer & Willett, 2003: 441) as employed in our model specification. Second, a discrete-time hazard model uses a person-period data format as panel data (i.e., multiple observations for a single individual). There may exist a temporal dependence within each individual, which will then bias the standard error estimates, inflate test statistics, and lead to optimistic inferences. This problem, however, is not a concern of the discrete-time hazard model. In this method, the conditional probability of an event for an individual i at time j can be treated as if "it came from a distinct, independent observation" (Allison, 1995: 223), which follows directly from the likelihood function of this method. The lack of dependence among observations within each individual holds only when no individual has more than one event, which is the key feature of discrete-time survival analysis. In contrast, in the normal setting of panel data with a binary dependent variable, each individual may experience the event multiple times, where the dependence among observations becomes a real concern. Some scholars suggest limiting the analysis to the initial event and using a similar approach as a discrete-time hazard model to deal with the temporal dependence problem in time-series-cross-section data or panel data (e.g., Beck, Katz, & Tucker, 1998). Third, including multiple lags of Gini coefficients may yield multicollinearity problem. This problem may be especially salient for single time series, but it can be "reduced or avoided by use of the cross-sectional differences in individual characteristics" (Hsiao, 2003: 269). Furthermore, panel data significantly increase the sample size that can mitigate the collinearity problem as a large sample size can produce relatively consistent and unbiased standard error estimates even for highly correlated covariates. This study includes 8,282,008 person years, therefore the bias in the estimates and statistical inference caused by the collinearity problem is small if not trivial.

After presenting empirical results from the above model specification, we will describe various tests of robustness of the findings. First, time dummies are replaced with cubic function of time exposures to capture the baseline logit hazard function. BIC statistics indicate cubic function of time exposures fits the data better than linear or quadratic function. The model can be specified as

$$\begin{aligned}\text{logit } h(t_{ij}) = {} & \left[\alpha_1 T + \alpha_2 T^2 + \alpha_3 T^3\right] + \beta \text{survey year}_i + \lambda_1 \text{age}_{ij} \\ & + \lambda_2 \text{age}_{ij}^2 + \sum \kappa_p x_{pi} + \gamma_0 \text{gini}_{ij} + \gamma_1 \text{lag1gini}_{ij} \\ & + \gamma_2 \text{lag2gini}_{ij} + \gamma_3 \text{lag3gini}_{ij} + \ldots \gamma_{14} \text{lag14gini}_{ij} \quad (2)\end{aligned}$$

T is exposure time, ranging from 1 to 21 years. We use PROC LOGISTIC program in SAS software (SAS Institute Inc, Cary, NC) to conduct the analyses using both time dummies and cubic function of time exposures. Second, a series of Cox proportional hazard models are used to capture the changes in the effects of Gini coefficient on individual mortality risk across the length of exposure time. We use PROC PHREG program in SAS software to conduct the analyses. Third, two other measures of income inequality are used to test for robustness: the Atkinson index and the Theil entropy index.

Results

Table 3 reports the unstandardized odds ratio for the discrete-time hazard model of mortality risk on contemporaneous and preceding income inequalities and other predictors with duration dummies included to capture the baseline log odds function. Model 1 tested the contemporaneous effect of income inequality. The Survey year was significantly associated with 1% lower odds, which means people interviewed at a later period had a smaller mortality risk. Age had a positive quadratic relationship with individual mortality risk. In other words, the mortality risks increased with age at a faster rate as age increased. The odds of death were 79% higher for men than for women. Regarding race, being Non-Hispanic White decreased the odds of death by 8%. Being employed decreased the odds of death by 37%. Compared to the married, the never married, separated, divorced, and the widowed had higher mortality risks. Each year of additional education was associated with a statistically significant 3% decrease in the odds of death. Every $10,000 of family income reduced the odds of death by 16%, but this beneficial effect increased at a slower rate when income increased. With regard to the contemporaneous effect of the Gini coefficient, we found no significant effect.

Model 2 includes GDP per capita, which is a time-varying predictor as Gini coefficient. This variable had no significant effect, which may be due to the inclusion of individual-level income and income squared. Due to a concern about the collinearity between the Gini coefficient and GDP per capita ($r = 0.88$), we tried to remove the Gini from the model but GDP per capita was still not significant (table available upon request).

Model 3 adds the 14 lags of the Gini coefficient with GDP per capita removed as it was not significant. The Gini coefficient did not exert an effect until 5 years later and the effects peaked at 7 years and diminished after 12 years. For example, every 0.01-unit increase in the Gini coefficient increased the odds of death by 11% 7 years later. A clear pattern of lagged effects reduces the concern

Table 3
Unstandardized odds ratios for discrete-time hazard model of mortality risk on contemporaneous and preceding income inequalities and other predictors.

	Model 1		Model 2		Model 3	
	Odds ratio [95% CI]	*P*	Odds ratio [95% CI]	*P*	Odds ratio [95% CI]	*P*
Duration dummies	*included*		*included*		*included*	
Survey year	0.99 [0.99, 1.00]	0.000	0.98 [0.97, 1.00]	0.008	0.75 [0.60, 0.92]	0.007
Age	1.08 [1.07, 1.08]	<0.0001	1.08 [1.07, 1.08]	<0.0001	1.08 [1.07, 1.08]	<0.0001
Age^2	1.00 [1.00, 1.00]	0.028	1.00 [1.00, 1.00]	0.028	1.00 [1.00, 1.00]	0.029
Male	1.79 [1.77, 1.81]	<0.0001	1.79 [1.77, 1.81]	<0.0001	1.79 [1.77, 1.81]	<0.0001
Non-Hispanic White	0.92 [0.90, 0.94]	<0.0001	0.92 [0.90, 0.94]	<0.0001	0.92 [0.90, 0.94]	<0.0001
Employed	0.63 [0.62, 0.64]	<0.0001	0.63 [0.62, 0.64]	<0.0001	0.63 [0.62, 0.64]	<0.0001
Never married	1.33 [1.30, 1.37]	<0.0001	1.33 [1.30, 1.37]	<0.0001	1.33 [1.30, 1.37]	<0.0001
Separated	1.36 [1.30, 1.41]	<0.0001	1.36 [1.30, 1.41]	<0.0001	1.36 [1.30, 1.41]	<0.0001
Divorced	1.35 [1.32, 1.37]	<0.0001	1.35 [1.32, 1.37]	<0.0001	1.35 [1.32, 1.37]	<0.0001
Widowed	1.17 [1.15, 1.19]	<0.0001	1.17 [1.15, 1.19]	<0.0001	1.17 [1.15, 1.19]	<0.0001
Education	0.97 [0.97, 0.98]	<0.0001	0.97 [0.97, 0.98]	<0.0001	0.97 [0.97, 0.98]	<0.0001
Income[a]	0.84 [0.82, 0.86]	<0.0001	0.84 [0.82, 0.86]	<0.0001	0.84 [0.82, 0.86]	<0.0001
Income^2	1.01 [1.00, 1.01]	0.000	1.01 [1.00, 1.01]	0.000	1.01 [1.00, 1.01]	0.000
Gini[b]	0.99 [0.98, 1.00]	0.229	1.03 [1.01, 1.05]	0.068	1.00 [0.99, 1.01]	0.235
GDP per capita			1.45 [0.98, 2.13]	0.061		
Lag1gini					1.01 [0.99, 1.04]	0.356
Lag2gini					1.01 [1.00, 1.03]	0.150
Lag3gini					1.05 [1.00, 1.10]	0.068
Lag4gini					1.07 [0.99, 1.15]	0.070
Lag5gini					1.08 [1.02, 1.14]	0.007
Lag6gini					1.08 [1.02, 1.15]	0.010
Lag7gini					1.11 [1.02, 1.20]	0.010
Lag8gini					1.08 [1.01, 1.16]	0.021
Lag9gini					1.10 [1.04, 1.17]	0.002
Lag10gini					1.10 [1.01, 1.19]	0.032
Lag11gini					1.07 [1.00, 1.15]	0.036
Lag12gini					1.07 [1.02, 1.13]	0.004
Lag13gini					1.07 [0.99, 1.15]	0.073
Lag14gini					1.00 [0.94, 1.07]	0.918

[a] In the analysis, income is divided by 10,000 to reduce its scale, then the odds ratios represent how $10,000 increase in family income may affect individual mortality risk.
[b] In the analysis, the Gini and the lags of the Gini are multiplied by 100 to increase their scale, then the odds ratios represent how a 0.01-unit increase in them may affect individual mortality risk.

about biased estimates caused by collinearity among the lagged coefficients, because if the multicollinearity problem was severe, we should have observed non-significant lagged coefficients but very high R^2.

Based on this model, Fig. 1 plots the impact of a 0.01-unit increase in the Gini coefficient on individual mortality risk over time. The top graph shows the marginal effect at each year. Marginal odds of death indicate the instantaneous or lagged effects of income inequality *at* a time point. The dotted line is the smoothed marginal effect after a 3-point moving average. It is clear from this figure that a 0.01-unit increase in the Gini coefficient increased the odds of death, as all the odds were above 1, and the impact peaked at 7 years. The detrimental impact began to decline after 7 years but was significant until year 12. In other words, the Gini coefficient had up to 12 years lagged adverse effect with a peak at 7 years later.

The bottom graph shows the cumulative impact of income inequality on subsequent mortality risk and demonstrates how a 0.01-unit increase in the Gini coefficient affects subsequent odds of death within a time period ranging from 0 year to 12 years. Cumulative odds of death at a certain time point include all the deaths *at* and *before* this time point; this is similar to the previous 7 multilevel studies examining how income inequality affects subsequent mortality risk within a specific time frame. This figure indicates that the cumulative adverse impact of income inequality increased over time and peaked at 12 years when the cumulative odds of death were 2.22 (=1*1.01*1.01*1.05*1.07*1.08*1.08*1.11*1.08*1.10*1.10*1.07*1.07).

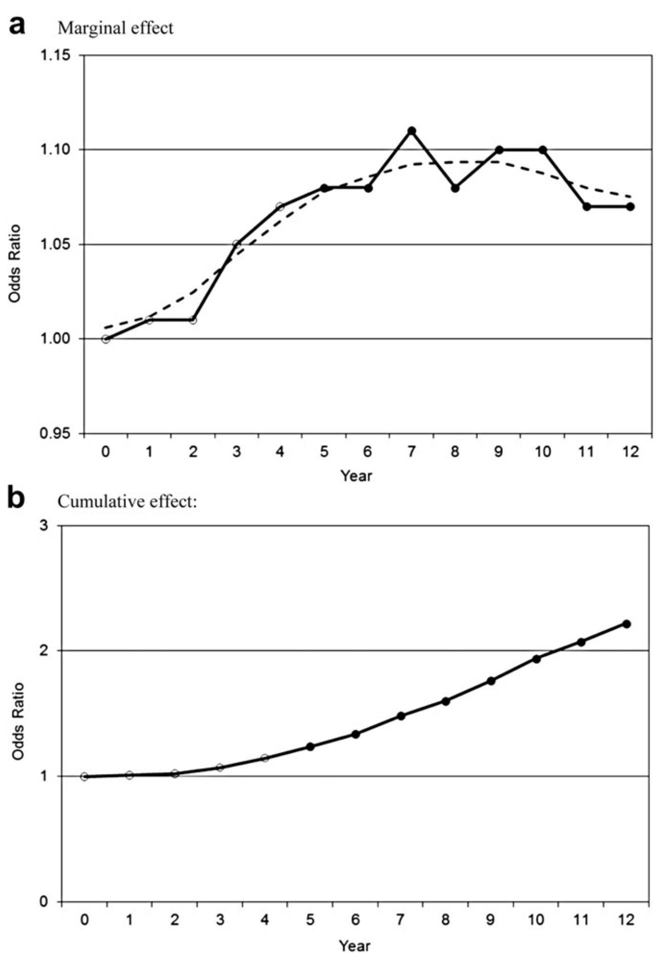

Fig. 1. Response pattern from a 0.01-unit increase in Gini coefficient based on Model 3 in Table 3. Note: Hollow markers indicate non-significant effects.

Robustness analyses

As noted earlier, we did several tests of robustness of the findings to the model specification and measures of income inequality.

Cubic function of exposure time

Table 3 uses duration dummies to represent the baseline logit hazard function. We can also use polynomial function of exposure duration to serve this purpose. Compared with models using linear or quadratic functions of exposure time T (tables available upon request), the model using cubic function of exposure time T gets the smallest BIC, which indicates that this polynomial order is a better fit. Findings are reported in Table 4, which are generally consistent with those reported in Table 3. The general trend and magnitude of lagged effects of Gini coefficient are similar, that is the detrimental effect peaked 7 years later and diminished after 12 years. A small difference is that Gini coefficient started exerting an effect three years later instead of five years later. It is hard to theoretically justify the timing of just when income inequality starts having impact on individual mortality risk; methodologically, the model using time dummies fits better as it has smaller BIC statistics.

Cox proportional hazard model

Like some prior studies, we also used the Cox proportional hazard model to test the effects of the Gini coefficient on subsequent mortality risk. In order to use this model, we employed data in personal-level format and used quarters instead of years as the time unit because the Cox model assumes exposure time to be continuous rather than discrete. The advantage of this model is that it does not need to control for a series of lagged Gini coefficients, which avoids the potential multicollinearity problem. The disadvantage of the Cox model is that it is inefficient for computing the effects of time-varying factors and it is not able to tell the exact trend of lag effects, as the model estimates whether income inequality affects subsequent mortality risk, which can occur contemporaneously or subsequently in any year within the follow-up period. Unlike from the prior studies, we tested the changes in the effects of Gini across the length of exposure time (from 4 to 84 quarters) by running 21 Cox regressions with different lengths of exposure time used. This approach gave us a sense of how long the effect of the Gini would last: if the estimated coefficient of Gini declined, it meant that the Gini had stopped functioning as it did not add more deaths as exposure time increased.

Fig. 2 portrays the changes in the hazard ratios of Gini on individual mortality risk across 4 to 84 quarters based on 21 Cox regressions. The hollow markers indicate non-significant effects. As can be seen, the Gini did not significantly increase subsequent mortality risk until 16 quarters later (i.e., 4 years later). The hazard ratio increased across the length of exposure time, declined after 48 quarters (i.e., 12 years) and stabilized after 68 quarters (i.e., 17 years). Fig. 2 basically shows the cumulative impact of Gini within different lengths of subsequent years, which is very similar to the bottom figure in Fig. 1. The coefficients are definitely different as they are derived from completely different models, a hazard model and a logit model. The odds ratios are usually larger than hazard ratios (Allison, 1995: 136). The declining hazard ratios after 48 quarters meant that the Gini coefficient stopped adding more deaths afterwards. Although the hazard ratio was still significant after 48 quarters, this was mainly due to the increased number of deaths in longer periods. One limitation of this series of Cox regressions is that we cannot tell the exact trend (or relative size) of the marginal lagged effects.

Different measures of income inequality

Although the Gini is the most commonly used measure of income inequality, we also used another two measures, i.e., the

Table 4
Unstandardized odds ratios for discrete-time hazard model of mortality risk on contemporaneous and preceding income inequalities and other predictors.

	Model 1		Model 2		Model 3	
	Odds ratio [95% CI]	*P*	Odds ratio [95% CI]	*P*	Odds ratio [95% CI]	*P*
T	1.25 [1.23, 1.26]	<0.0001	1.24 [1.22, 1.26]	<0.0001	0.95 [0.77, 1.17]	0.636
T2	0.98 [0.98, 0.98]	<0.0001	0.98 [0.98, 0.98]	<0.0001	0.98 [0.98, 0.98]	<0.0001
T3	1.00 [1.00, 1.00]	<0.0001	1.00 [1.00, 1.00]	<0.0001	1.00 [1.00, 1.00]	<0.0001
Survey year	1.00 [1.00, 1.00]	0.219	0.99 [0.98, 1.01]	0.321	0.76 [0.62, 0.94]	0.011
Age	1.08 [1.07, 1.08]	<0.0001	1.08 [1.07, 1.08]	<0.0001	1.08 [1.07, 1.08]	<0.0001
Age^2	1.00 [1.00, 1.00]	0.030	1.00 [1.00, 1.00]	0.030	1.00 [1.00, 1.00]	0.031
Male	1.79 [1.77, 1.81]	<0.0001	1.79 [1.77, 1.81]	<0.0001	1.79 [1.77, 1.81]	<0.0001
Non-Hispanic White	0.92 [0.90, 0.94]	<0.0001	0.92 [0.90, 0.94]	<0.0001	0.92 [0.90, 0.94]	<0.0001
Employed	0.63 [0.62, 0.64]	<0.0001	0.63 [0.62, 0.64]	<0.0001	0.63 [0.62, 0.64]	<0.0001
Never married	1.33 [1.30, 1.37]	<0.0001	1.33 [1.30, 1.37]	<0.0001	1.33 [1.30, 1.37]	<0.0001
Separated	1.36 [1.30, 1.41]	<0.0001	1.36 [1.30, 1.41]	<0.0001	1.36 [1.30, 1.41]	<0.0001
Divorced	1.35 [1.32, 1.38]	<0.0001	1.35 [1.32, 1.38]	<0.0001	1.35 [1.32, 1.38]	<0.0001
Widowed	1.17 [1.15, 1.19]	<0.0001	1.17 [1.15, 1.19]	<0.0001	1.17 [1.15, 1.19]	<0.0001
Education	0.97 [0.97, 0.98]	<0.0001	0.97 [0.97, 0.98]	<0.0001	0.97 [0.97, 0.98]	<0.0001
Income[a]	0.84 [0.82, 0.86]	<0.0001	0.84 [0.82, 0.86]	<0.0001	0.84 [0.82, 0.86]	<0.0001
Income^2	1.01 [1.00, 1.01]	0.000	1.01 [1.00, 1.01]	0.000	1.01 [1.00, 1.01]	0.000
Gini[b]	0.99 [0.98, 1.00]	0.214	0.99 [0.98, 1.01]	0.379	1.00 [0.98, 1.02]	0.771
GDP per capita			1.16 [0.79, 1.69]	0.459		
Lag1gini					1.02 [0.99, 1.04]	0.177
Lag2gini					1.00 [0.99, 1.02]	0.668
Lag3gini					1.07 [1.02, 1.12]	0.008
Lag4gini					1.11 [1.04, 1.19]	0.003
Lag5gini					1.10 [1.04, 1.16]	0.001
Lag6gini					1.09 [1.03, 1.16]	0.004
Lag7gini					1.13 [1.05, 1.22]	0.001
Lag8gini					1.09 [1.02, 1.17]	0.010
Lag9gini					1.10 [1.03, 1.17]	0.003
Lag10gini					1.11 [1.02, 1.21]	0.015
Lag11gini					1.07 [1.00, 1.14]	0.037
Lag12gini					1.05 [1.00, 1.10]	0.046
Lag13gini					1.07 [1.00, 1.15]	0.067
Lag14gini					0.95 [0.89, 1.01]	0.097

[a] In the analysis, income is divided by 10,000 to reduce its scale, then the odds ratios represent how $10,000 increase in family income may affect individual mortality risk.
[b] In the analysis, the Gini and the lags of Gini are multiplied by 100 to increase their scale, then the odds ratios represent how a 0.01-unit increase in them may affect individual mortality risk.

Atkinson index and the Theil index, to test the robustness of the findings. Although the effect size of these two indices in Fig. 3 were different from each other and different from the Gini coefficient due to the differences in metric, both predicted the quadratic lagged effects of income inequality which peaked 7 years later. There were two small differences from the findings based on the Gini: first, the Theil and Atkinson indexes started affecting individual mortality risk 3 years later instead of 5 years later; second, they stopped working 11 years later instead of 13 years later. It is hard to theoretically justify when income inequality should start and stop affecting individual mortality risk, but the general patterns are similar across these three measures of income inequality. As the Gini coefficient may capture the trend of income inequality more accurately and the changes in the effects of Gini on mortality risk are smoother and less fluctuating, we may lean a little toward the findings based on Gini.

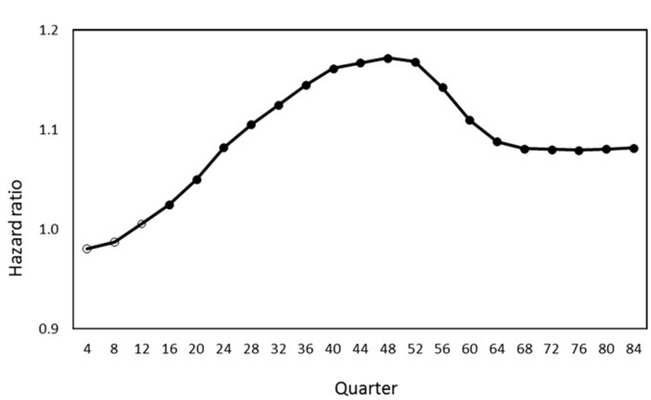

Fig. 2. The effects of a 0.01-unit increase in Gini coefficient on subsequent mortality risk within 4–84 quarters based on 21 Cox proportional hazard models. Note: Hollow markers indicate non-significant effects.

Discussion

The long-term impact of income inequality on population health has not been fully explored in the current literature. Until now, 4 studies have examined the lagged effect on population/group

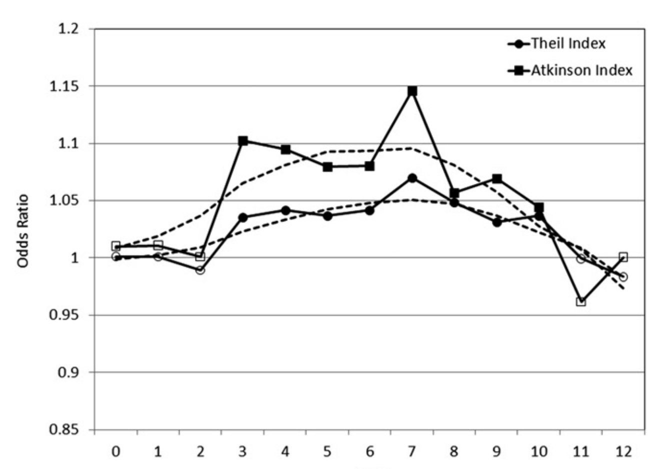

Fig. 3. Response pattern from a 0.01-unit increase in the Theil index or Atkinson index. Note: Hollow markers indicate non-significant effects.

mortality rate at the aggregate level and 7 studies have investigated the effect of income inequality on subsequent individual mortality risk within a restricted time period. These 11 studies, however, all suffer from the same limitation: they do not simultaneously control for a series of preceding income inequalities. This results in an inaccurate estimation of the long-term impact of income inequality. Moreover, we cannot tell from the aggregate studies whether income inequality has an independent contextual impact on health outcome, which goes beyond the simple accumulation of individual-level nonlinear correlation between income and health. Also, by examining the impact of income inequality at the survey year on subsequent individual mortality risks we cannot tell the exact order of lag effects as they can occur in any year within the follow-up period.

This paper overcomes these limitations by using a discrete-time hazard model where income inequality is treated as a time-varying, person-specific variable. The model then tracks a series of income inequalities that a respondent faces from the survey year until s/he dies or is censored. The lags of income inequality are easily adapted from U.S. Census Bureau statistics, which are then treated as time-varying, person-specific variables. Micro-level data including individual vital status and sociodemographic status come from National Health Interview Survey data 1986–2004 with mortality follow-up data 1986–2006. Based on this 21-year longitudinal data ($n = 701{,}179$, or 8,282,008 person years), we find that the Gini coefficient does not have an instantaneous adverse effect on individual mortality risk, but starts exerting its effect 5 years later. This effect peaks at 7 years, then diminishes after 12 years. Including individual-level income and income squared does not change the effects of income inequality, which demonstrates its contextual effect beyond the level of individuals. Robustness analyses generally support the quadratic trend of lagged effects, which peaks 7 years later and diminishes after 12 years, although the starting year of the effect may be different: 3 years for discrete-time hazard model with cubic baseline logit hazard, 4 years for the Cox proportional hazard model, and 3 years for the Theil index and Atkinson index.

The lagged effects may be due to both the time requirement from income inequality to the pathways to its health effects (Kondo et al., 2011) and the latency period between exposure to risk factors and diseases initiation, deterioration, and subsequent mortality (Lynch & Davey Smith, 2005). It is hard to theoretically justify the exact order of lagged effects, i.e., why the effects start at 5 years later, peak at 7 years later, and then diminish 12 years later. It is possible that these numbers may change in different health outcomes, components of mortality, countries, time periods, units of analyses, and levels of income inequality. But we think a general quadratic lagged effects pattern will be similar across the studies.

The findings in this study partially explain the discrepancies in results reported in the 16 multilevel studies. First, they suggest that we are very likely to get a non-significant instantaneous effect of income inequality on individual mortality risk, which is why only one study (i.e., Galea et al., 2003) found a positive effect in the nine studies investigating the instantaneous impact. Second, our findings suggest that we are likely to get non-significant lag effects of income inequality on individual mortality risk if the lag order is smaller than 5 or larger than 12. Non-significant effects or mixed results are reported in Daly et al. (1998), Blakely et al. (2003), Fiscella and Franks (1997), and Osler et al. (2002, 2003), which follow the mortality status for up to 2, 3, 16, and 28 years, respectively. But significant effects are reported in Dahl et al. (2006) and Lochner et al. (2001), which follow the mortality status for up to 6 and 8 years, respectively. These studies are likely to miss the effect if the follow-up period is too short for income inequality to exert its impact or too long for income inequality to maintain its influence.

One more caveat for studies using the Cox proportional model: it is likely to show significant impact of income inequality in a long subsequent period, which may be due to the increased number of deaths in a longer period rather than a lingering income inequality effect. In order to tell the exact order of lagged effects, we need to estimate a series of Cox regressions across the length of exposure time. Income inequality stops working if its estimated coefficient decreases at some time point because it means income inequality does not add more deaths at this point. But these regressions cannot tell us the curve or relative size of the lagged effects.

To our knowledge, there have been eight studies that have examined the lagged effect of income inequality on individual self-rated health at the U.S. state or metropolitan level (e.g., Blakely & Kawachi, 2001; Blakely et al., 2000, 2002; Kahn, Wise, Kennedy, & Kawachi, 2000; Kennedy, Kawachi, Glass, & Prothrow-Smith, 1998; Mellor & Milyo, 2003; Subramanian & Kawachi, 2003, 2004). These studies except Mellor and Milyo (2003) found a significant effect, and Blakely et al. (2000) and Subramanian and Kawachi (2004) suggested that income inequality might have the strongest effect on health up to 15 years later. These eight studies, however, only tested a certain lag of income inequality and did not fully control for a series of lags simultaneously; the same limitation seen in studies of the lagged effects of income inequality on mortality. Therefore, the 15-year lag effect may be overestimated due to the lack of control for preceding income inequalities, although it is possible that self-rated health may endure a longer harmful impact from income inequality. Future studies can further investigate how the long-term impact of income inequality may differ by health outcomes.

In this study we did not control for macro-economic development (e.g., GDP per capita) in the model examining lagged effects of Gini coefficient for several reasons. First, it was not significant even before including the lags of Gini coefficient. Although the Gini and GDP per capita are highly correlated, the non-significant effect of GDP per capita is not due to including the Gini as removing the Gini does not change its non-significant effect. Second, we used a multilevel data design with many individual-level covariates controlled, including income, education, work status, age, gender, race and marital status. GDP per capita, as an indicator of *mean* level of *individual* economic achievement, should be included in aggregate-level research design to get the net effect of income inequality. But in multilevel data design, we already controlled for individual-level income, education and work status, which not only accounted for the mean level of individual socioeconomic achievement, but also for heterogeneity among individuals, which is exactly the advantage of multilevel design compared to aggregate-level studies (Zheng, 2009). Third, theoretically, GDP per capita and other macro socioeconomic development should promote individual health and reduce mortality risk. If income inequality carried the unobserved effect of macro socioeconomic development, it should then either reduce individual mortality risk or be *underestimated* as it is positively correlated with macro socioeconomic development. Fourth, we controlled for survey year and time dummies to capture the general trend of socioeconomic development over time to some extent.

This is probably the first study to control for a series of preceding income inequalities and clearly capture the curve of long-term effect of income inequality on health. Although this study may not completely solve the discrepancies in the 16 multilevel studies of income inequality on individual mortality risk, it does provide a reasonable and clear explanation. As noted above, the robustness of these findings can be further tested by using data in other formats, countries, time periods, unit of analyses, and other health outcomes. For example, this study examines the contextual effect of income inequality at the national level. It is not clear whether country is the best level for understanding the contextual effects of income inequality although several scholars have demonstrated that national income inequality and social hierarchies matter more to people than local social inequality structure (e.g., Kondo et al., 2011; Wilkinson & Pickett, 2006). Further research can investigate the long-term impact of income inequality at the state level on individual mortality risk over time, which may further reduce the collinearity problem among the lags of income inequality.

This study demonstrates that income inequality has long-term effects on individual mortality risk from 5 years later to 12 years. A 0.01-unit increase in the Gini coefficient increases the cumulative odds of death by 122% throughout the 12 years. This finding is striking and supports the argument that income inequality is a public health concern. The death rate for U.S. adults 18 years and older continues declining from 978.6 deaths per 100,000 in 1986 to 776.5 deaths per 100,000 in 2006, and life expectancy at birth continues increasing from 74.7 years in 1986 to 77.7 years in 2006 (Center for Disease Control and Prevention Health Data Interactive, 2011), thanks to substantial socioeconomic development, medical advances and the public health movement. But increasing income inequality in the past three decades suppresses the overall improving health trend. We might have seen an even higher extent of improvement on health if income inequality had remained at a relatively low level.

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