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Economic growth, income inequality and life expectancy in China☆

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ABSTRACT

China had made dramatic health gains before its economic reform that began in 1978 produced rapid economic growth in the ensuing years. Since the economic reform, China's income inequality has substantially increased, and health gains have stagnated. This article investigates the extent to which China's health stagnation may be attributable to the rise in income inequality in China. By simulating the improvement in life expectancy that could have resulted if, *ceteris paribus*, income inequality had stayed constant at the lowest level after the founding of the People's Republic of China in 1949, we find that the sharply increasing income inequality in China has contributed to life loss in China's population, about 0.6 years for men and 0.4 years for women. These findings suggest that redistribution of income from rich to poor may be one of the most important policy levers for improving population health in China.

1. Introduction

Since the late 1970s, market-oriented economic reforms have led to unprecedented and continuous economic growth in China. From 1978 to 2012, China's per-capita gross domestic product (GDP) increased from 381 yuan to 6628 inflation-adjusted yuan, averaging an annual growth rate of 8.76% (State Statistics Bureau of China, 2013). Has China's rapid economic growth brought about equally remarkable survival gains? The answer seems to be "no," according to observers (Lindelow and Wagstaff, 2005; Tang et al., 2008; World Bank, 2005). For example, by plotting life expectancy at birth against the GDP per head for selected countries in 1970-74 and 1995-99 respectively, Tang et al. (2008) pointed out that China's expectation of life at birth was no longer better than that of other countries at similar levels of economic development in the world in 1995–99, whereas it stood out as a superior health achiever in 1970–74. Even in terms of reductions in under-five mortality, China shifted from being an over-performer (its rate of reduction exceeded its expected rate) in the 1960s and 1970s to being an under-performer in the 1980s and 1990s (Lindelow and Wagstaff, 2005).

Why did China perform well in national health when it was relatively poor but experience health stagnation during a period of rapidly rising income? While there is good evidence that earlier gains in life expectancy were associated with improvements in general education and public health campaigns (Babiarz et al., 2015), scholars disagree as to what accounts for the recent stagnation. Some researchers have attributed this to overall weaknesses in China's health system (World Bank, 2005; Tang et al., 2008). Others have blamed it on the rising air pollution that has been a byproduct of economic development (Ebenstein et al., 2015). While there are undoubtedly multiple competing explanations for this phenomenon, we maintain that the rise of income inequality in recent decades in China has also been a contributing factor. It is well documented that China's rapid economic growth has been accompanied by a sharply rising trend of income inequality. Between 1978 and 2012, the Gini coefficient, a measure of income inequality, nearly doubled, from 0.279 to 0.557 (Xie and Zhou, 2014). As Wilkinson (1992, 1996) argued, income inequality is negatively associated with population health. As such, rising inequality is important for understanding the mechanisms by which China's performance in health improvement has deteriorated relative to expectations.

The potential detrimental effect of income inequality has been noted in previous research. Using either cross-sectional or longitudinal data, previous studies have examined the contextual effect of income inequality (Bakkeli, 2016; Feng et al., 2012; Li and Zhu, 2006; Pei and Rodriguez, 2006; Qi, 2006; Zhou and Qi, 2012). Although these studies have helped to underscore the hypothesis that rising income inequality might contribute to the stagnation of life-expectancy gains in China, they do not constitute direct evidence in support of the conjecture. To

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date, no study has directly tested this hypothesis, due to methodological challenges or data limitations. In this paper, we fill the gap by analyzing how rising income inequality contributes to China's recent stagnation in health improvement. We quantify the loss of life from the rise in income inequality over recent decades in China.

The remainder of this article is organized as follows. As background, we begin by reviewing the theoretical basis and empirical evidence for a connection between income inequality and health. We then provide a description of our data and methodological approach. Next, we report the trend in China's life expectancy, paying special attention to its variance from what would be dictated by China's overall rising income levels. Although some piecemeal evidence shows that China lost its achiever position, we report its dynamic of life expectancy spanning a longer period. More importantly, we examine whether China's deteriorating health performance–relative to expectations–has coincided with its changes in income inequality. We follow this with a simulation analysis, yielding an estimate of the increase in life expectancy that could result if, *ceteris paribus*, income inequality had not increased. Finally, we summarize our results and discuss the social and political implications of our findings.

2. Theoretical background

It has been well over three decades since Rodgers (1979) published his seminal work, in which he reported associations, at the population level, between health outcomes, such as life expectancy and infant mortality, and income inequality. His work, together with Wilkinson's (1992; 1996), sparked extensive research interest in the relationship between inequality and health (for review, see Pickett and Wilkinson, 2015; Truesdale and Jencks, 2016; Wilkinson and Pickett, 2006). With few exceptions, the bulk of the literature indicates the existence of an ecological negative association – i.e., people living in more egalitarian societies enjoy better health and longevity (Wilkinson and Pickett, 2006; Pickett and Wilkinson, 2015). However, the issue of whether inequality has real causal effects on population health remains controversial.

Two primary hypotheses have been advanced to explain the ecological association between income inequality and population health: the absolute income hypothesis and the contextual inequality hypothesis, also called the "Wilkinson hypothesis." The absolute income hypothesis asserts that the unequal distribution of income does not directly affect individual health. Instead, it is argued that the observed association between income inequality and population health is solely a result of a curvilinear relation between income and health at the individual level, i.e., a diminishing health return to income (Deaton, 2003; Gravelle, 1998). This argument is illustrated in Fig. 1, where the y-axis represents health, and the x-axis represents income. Suppose that

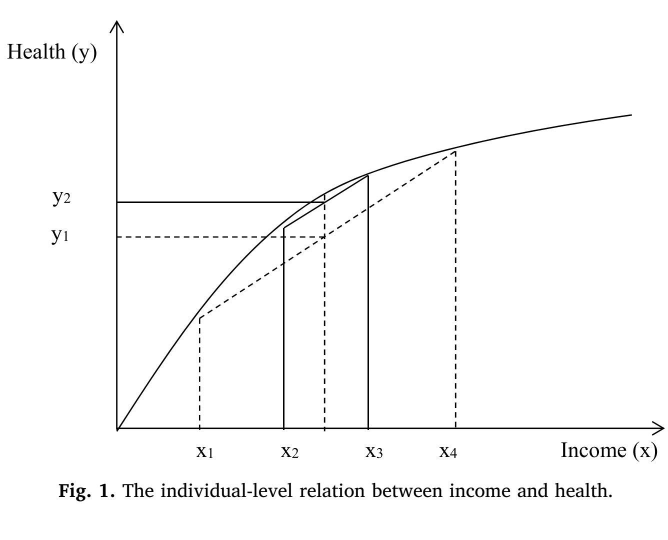

Fig. 1. The individual-level relation between income and health.

health is a nonlinear concave function of income, so that increases in income produce diminishing returns of health. For the sake of simplicity, let a hypothetical society consist of only two, equal-sized groups of people, the rich (with income x_4) and the poor (with income x_1). Correspondingly, the population health is y_1 (the average health between the rich and the poor). If we take a given amount of money $(x_4 - x_3)$ away from the rich and give it to the poor, the rich's health will fall and the poor's health will rise. Because of the diminishing returns to income in the production of health, the poor will have gained more health than the rich have lost. Hence, the population health increases to y_2 from y_1, as the inequality of income decreases, though the average income in the society remains unchanged.

Although researchers are keenly aware of the potential reverse causality in the opposite direction, from good health to higher income (Smith, 1999), both longitudinal and cross-sectional empirical studies have found consistent evidence in support of individual income as a powerful determinant of individual health (Kawachi et al., 2010; Lindahl, 2005). Moreover, most of the evidence points to a nonlinear relationship between individual income and health status (Backlund et al., 1996; Mackenbach et al., 2005; Wolfson et al., 1999). For this reason, the concave relation between income and health at the individual level has been proposed as an explanation for the negative association between population health and income inequality (Mayrhofer and Schmitz, 2014)—the absolute income hypothesis. Of course, the key assumption of the explanation lies in the nonlinearity between income and health at the individual level.

In contrast, the contextual inequality hypothesis, or the Wilkinson hypothesis, postulates a direct, contextual, and causal impact of income inequality in a society on the health of individuals living in that society, over and above underlying individual-level socioeconomic determinants of health, including individual's income (Wilkinson, 1992, 1996, 2000). It is believed that inequitable income distribution adversely influences health outcome primarily through two pathways: psychosocial factors and neo-material conditions (Layte, 2012; Lynch et al., 2000; Pickett and Wilkinson, 2015; Wilkinson, 1996).

As causal mechanisms, psychosocial factors have been proposed. For example, they include the deleterious effects of relative deprivation and the erosion of social cohesion/capital. For example, a large gap between rich and poor intensifies an individual's sense of relative deprivation. Given overall improvement in material conditions and reduction of mortality due to infectious diseases in modern societies, scholars have speculated that relative income/position, rather than absolute material standard, may play an important role in determining individual health, particularly in developed countries (Wilkinson, 1994, 1997; Undurraga et al., 2016). Relative deprivation translates into poorer population health (Adjaye-Gbewonyo and Kawachi, 2012; Jones and Wildman, 2008; Kondo et al., 2008; Mishra and Carleton, 2015), as it results in frustration, shame, anxiety, and stress, as well as health-compromising behaviors, such as smoking and alcohol consumption (De Botton, 2004; Eibner and Evans, 2005; Wilkinson, 2000).

In addition, a widening of income distribution may negatively affect individual health through lowered social cohesion and trust, or reduction of social capital (Aida et al., 2011; Elgar, 2010; Kawachi et al., 1997; Kawachi and Kennedy, 1997; Wilkinson, 1996, 1999). There is some evidence for this reasoning. For example, comparing 33 countries in income inequality, interpersonal trust, healthy life expectancy, and adult mortality, Elgar (2010) found that income inequality was strongly associated with interpersonal trust (measured by respondents' level of agreement with the statement "There are only a few people I can trust completely"), and that lower levels of interpersonal trust were associated with shorter life expectancy, as well as higher adult mortality.

There can be material pathways through which contextual inequality impacts health. Societies that tolerate high levels of income inequality tend to underinvest in a wide range of human, physical, health and social infrastructures that promote population health (Smith, 1996; Detollenaere et al., 2018; Kaplan et al., 1996; Pearce and

Smith, 2003; Rostila et al., 2012). In the analysis of the relationship between income inequality and mortality across the 50 states in the U.S., for example, Kaplan et al. (1996) found that the states with more equitable income distribution allocated a larger proportion of total spending to education, had a lower proportion of people without medical insurance, had more library books per-capita, and had a lower rate of violent crimes, even after adjusting for state-level median income. Why does higher income inequality cause lower social spending? One reason is that income inequality heightens the divergence in interest between rich and poor (Deaton, 2003; Krugman, 1996). The rich pay proportionally more local taxes than their corresponding share of the public goods that the tax money provides. The greater the income gap, the larger the divergence in interest, with the rich being less willing to contribute to social services within a community. This neo-materialist pathway is concerned with macro-level conditions, while the psychosocial one emphasizes the micro mechanism.

Since the ecological association between income inequality and health could be an artifact of the curvilinear relationship between individual income and health (Gravelle, 1998; Wolfson et al., 1999), aggregate data cannot be used to adjudicate between the absolute income hypothesis and the contextual income inequality hypothesis. Recently, many researchers, though largely basing their studies on data from the US and other developed countries, have turned to the multilevel design–examining the effect of an area-level income inequality measure (e.g., community income inequality) on an individual-level health outcome, with individual-level socioeconomic predictors (e.g., individual income) controlled. Among these studies, some found evidence in support of the contextual income inequality hypothesis, whereas others found no significant effect of contextual inequality (for reviews, see Avendano and Hessel, 2015; Kondo et al., 2009; Pickett and Wilkinson, 2015; Qi, 2012; Subramanian and Kawachi, 2004; Wagstaff and Van Doorslaer, 2000).

For China, a few studies have focused on the relationship between individual income, income inequality, and individual-level health outcomes in the multilevel framework. Confirming the contextual income inequality hypothesis, several studies indeed have reported that self-rated health is strongly and negatively associated with area-level income inequality (Feng et al., 2012; Pei and Rodriguez, 2006; Zhou and Qi, 2012). For example, using data from the 2005 Chinese General Social Survey and county-level social statistics, Zhou and Qi (2012) showed a higher risk of reporting fair or poor health among people living in counties with greater income inequality (measured as ratio of rural to urban per-capita income). However, other studies have concluded that the relation between individual health and income inequality is inverse-U shaped. After pooling data from the 1991, 1993, 1997, and 2000 waves of the China Health and Nutrition Survey (CHNS), Li and Zhu (2006) found that self-rated health increased with inequality when community Gini was less than 0.42 and decreased with inequality for larger Gini. Using data from the same survey, Feng and Yu (2007) and Qi (2006) obtained similar findings. Still, some research has founded no association between income inequality and individual health. By using eight waves of the CHNS dataset from 1991 to 2011, Bakkeli (2016) found that income inequality did not have a significant impact on individuals' risks of having health problems in China.

In this article, we do not intend to enter the debate concerning whether income inequality has a true, contextual effect on health. Rather, we assume that there was no direct impact of income distribution on individual health. When we empirically evaluated the assumption of no direct effect of income inequality with a multilevel model, we find that local inequality at the county level is positively associated with mortality. However, the main research objective is not to test the direct effect of income inequality but to assess the consequence of income inequality increase through nonlinear impact of income. Thus, even after we remove the direct impact of income inequality in our main analysis, we ask how income inequality may still have contributed to health stagnation at the population level in China in the most recent period. In other words, we provide a conservative estimation of the loss of life from income inequality.

3. Data sources and analytical strategy

3.1. Data

Our study is based on analysis of the following data that we assembled for this study: (1) Dataset 1: a merged sample of cross-national time series data comprising annual data for over 200 countries/regions; (2) Dataset 2: a series of annual data on income and income inequality in China from 1967 onward; (3) Dataset 3: abridged life tables for China (various years); and (4) Dataset 4: individual-level longitudinal data from the China Family Panel Studies (CFPS).

Dataset 1 consists of life expectancy at birth, GDP per-capita, and the Gini coefficient across different countries and over time. We draw data on life expectancy from World Bank Indicators (World Bank, 2014) and data on real GDP per-capita from the Penn World Table (Heston et al., 2012). The Penn World Table provides data in purchasing power parity-adjusted constant terms, i.e., internationally comparable after adjustments for inflation and currency exchange. Income inequality data come from Solt (2016), who used the Luxembourg Income Study to improve estimates released by the United Nations University's World Income Inequality Database (WIID, UNU-WIDER, 2008). This data series has been used in previous studies (e.g., Baldwin and Huber, 2010; Bergh and Nilsson, 2010; Knight and Rose, 2011; Matsubayashi and Ueda, 2011). We exclude invalid or incomplete observations. The resulting data form a balanced panel, where 221 countries contribute 4103 observations for the period 1960–2010.

One source of Dataset 2 is the *China Statistical Yearbook* (State Statistics Bureau of China, 2013). It does not provide household per-capita income at the country level directly, but it includes information on per-capita disposable annual income of urban households and per-capita net annual income of rural households. We calculated household per-capita income for China as a whole by using these income data and the share of rural/urban population in China, then adjusted household per-capita income by consumer price index. We drew trend data on the Gini index of income inequality in China from the World Income Inequality Database (WIID, UNU-WIDER, 2008) and the article by Xie and Zhou (2014). The former provides Gini coefficients between 1968 and 2005; the latter updates WIID and gives Gini coefficient estimates between 2006 and 2012 based on survey data and interpolations.

Dataset 3 consists of abridged life tables for China. The Chinese government does not release these. As an alternative, we compiled abridged life tables for China for several years, i.e., 1981, 1990, 2000, and 2011. They come from the Institution of Population Research at Renmin University (1987), Lu and Wei (1992), Cai (2005), and the World Health Organization (2013), respectively. We restrict attention to these four years, partly because except for the year 2011, in the three earlier years, a population census was conducted, thus making life tables available. More importantly, these four years cover the important period when China experienced unprecedented economic growth and a sharp rise in income inequality.

For Dataset 4, we use the individual-level data from the China Family Panel Survey (CFPS), a large-scale, almost nationally representative longitudinal survey project conducted by the Institute of Social Science Survey of Peking University. Xie and Hu (2014) provide a description of the survey, with additional resources available online (http://www.isss.edu.cn/cfps/EN/). The CFPS employs a multistage probability sampling procedure to randomly select households from the 25 provinces of China, representing about 95% of the Chinese population. The survey completed interviews with the sampled households and all individuals living in these households. The CFPS data contain detailed information on household and individual characteristics, such as sociodemographic variables and household incomes from each category source, as well as health-related information, such as the date of death, if the individual died. As of this writing, CFPS respondents have been tracked through four rounds of longitudinal data collection: 2010, 2012, 2014 and 2016. We treated 36,964 eligible family members in the contacted 9751 households in the 2010 wave as our baseline study population. Of the 36,964 respondents in the 2010 wave, 29,570 (80 percent) were re-interviewed in the 2016 wave; 1253 (3.4 percent) died before the 2016 follow-up; and 6141 (16.6 percent) were lost to follow-up.

3.2. Analytical strategy

Our analysis consists of two primary stages. At the first stage, we document the trend in life expectancy at birth over recent decades in China. We provide not only the observed trend, but also the predicted trend based on China's income levels. In so doing, we provide evidence for our earlier statement that China's population health has not kept pace with its economic growth in recent years. For this purpose, we estimate the impact of GDP per-capita on life expectancy using the cross-national datasets (excluding China). Specifically, we use the following equation:

$$Y_{it} = \beta_0 + \beta_1 \ln\mathrm{GDP}_{it} + \beta_2 year_{it} + \varepsilon_{it}, \tag{1}$$

where Y_{it} denotes life expectancy for country i at time t; GDP_{it}, the main explanatory variable, is per-capita income in country i at time t. We also include a linear term for *year* of observation in the regression model. This year variable accomplishes several objectives: (1) it provides consistency with previous research; (2) it controls for gradual health improvement that accrues to development not captured by changes in real GDP; (3) it separates out the influence of GDP from its overall trend over time. We compute the robust standard errors, clustered at the country level, to deal with the problems of heteroscedasticity and autocorrelation, relaxing the assumption of independent and identically distributed disturbance terms within countries over time. Given our interest in the health effect of income inequality, we add to equation (1) $Gini_{it}$ – Gini for county i at time t – an income inequality measure, to obtain equation (2):

$$Y_{it} = \beta_0 + \beta_1 \ln\mathrm{GDP}_{it} + \beta_2 Gini_{it} + \beta_3 year_{it} + \varepsilon_{it}. \tag{2}$$

We then apply estimated coefficients from equation (1) to derive life expectancy at birth for China's population that would have been predicted given the country's level of economic development. This exercise would tell us China's life expectancy given its level of economic development if it were at the international average. To maintain consistency, we use China's GDP per-capita income provided by the Penn World Table (Heston et al., 2012).

At the second stage, we measure "life loss" from income inequality in China. We accomplish this objective by first estimating a generic, individual-level relationship between income and mortality risk. We then apply this relationship to a counterfactual Chinese society if China's income inequality had stayed at the lowest level during the period 1968–2012. To calculate the counterfactual life expectancy, we calculate expected relative risks of mortality by detailed income category, change the currently observed income inequality to a much lower one in China's past, and then aggregate mortality rates up to the national level. We summarize the results with life expectancy at birth using standard life table methods. With the two assumptions that (1) absolute income affects health; and (2) the income effects are concave, this procedure necessarily yields the result that the overall life expectancy is higher when income inequality is higher, as shown in Fig. 1. The question is a matter of the degree to which a rise in income inequality has a deleterious overall effect. We quantify this effect by the difference in observed life expectancy and the counterfactual life expectancy, and we call this quantity "life loss" due to increases in income inequality.

To derive the individual-level relationship between income and risk of mortality, we use longitudinal data from the China Family Panel Survey (CFPS). We estimate the effect of household per-capita income on mortality using a Cox proportional hazards model. As a semi-parameter method, the Cox regression makes no distributional assumption concerning how the baseline hazard varies with time. Besides time dependency, the hazard rate also depends on individual-level characteristics such as household income. Specifically, we specify the hazard rate at time t for individual i in the form of:

$$h_i(t) = h_0(t) exp(\beta_1 income_i + \beta_2 age_i + \beta_3 age_i^2), \tag{3}$$

where h_0 is the unknown baseline hazard rate at time t; *income* is the household per-capita income at the start of an episode. In the regression, we also control for age and age-squared. We measure survival time as the number of months of observation from the start of the 2010 baseline survey until death or censoring, with those surviving considered censored at the time of the 2016 follow-up. While no assumptions are made about the functional form of the baseline hazard, the Cox model assumes a proportional relationship between the baseline hazard and the effects of covariates. That is, the relative risk, the ratio in hazards between two individuals (or groups), is always a constant, unchanging with t.

In order to find the optimal functional relationship between household per-capita income and mortality rate, following earlier studies (Gerdtham and Johannesson, 2000, 2004), we carry out a Box–Cox transformation (Box and Cox, 1964), as a flexible method transforming a skewly distributed continuous variable to a normal shape. Specifically, the Box-Cox transformation parameter λ is defined by the operator:

$$income\ (\lambda) = (income^{\lambda} - 1)/\lambda \ \text{ for } \lambda \neq 0 \ \text{ or } \ln income \ \text{ for } \lambda = 0, \tag{4}$$

where *income* is household per-capita income. We determine the maximum likelihood point estimate for λ through a one-dimensional grid search over the interval from -1 to 1 at 0.01 increments.

In the next step in the analysis, we apply this individual-level relationship between income and risk of mortality to different income groups, then aggregate life expectancy by income groups to the population level under two very different assumptions of income inequality: using the observed level of inequality versus holding inequality to the lowest level during the period 1968–2012. This exercise allows us to assess the impact of income inequality increases on life expectancy in China. Specifically, we divide both the actual and hypothetical societies into income deciles, assuming, for simplicity, homogeneity in both income and mortality risk within income decile groups. We can also divide the society into a number of other income groups, but the substantive results would remain unchanged. We further assume that household per-capita income follows a two-parameter lognormal distribution. That is, $y = \log income$ is normally distributed with mean μ and variance σ^2. Under the lognormal distribution assumption, the mean of y, μ, can be derived from the mean of *income*, θ, through the following equation:

$$\mu = ln\theta - \sigma^2/2. \tag{5}$$

Under the lognormal distribution assumption, there is a monotonic relationship between Gini and variance of y, σ^2, through the following equation (Allison, 1978):

$$Gini = 2\Phi[\sigma/(2^{1/2})] - 1, \tag{6}$$

where $\Phi(\cdot)$ is the cumulative distribution function for a standard normal variable. We obtain the average of household per-capita income from a government source (State Statistics Bureau of China, 2013) and Gini estimate from Xie and Zhou (2014). Through equations (5) and (6), we obtain μ and σ. This further allows us to compute the average of household income per-capita for each decile by Monte Carlo experimentation.

In the final analysis, we consider mortality risk by income by constructing separate life tables for different income deciles to evaluate the impact of a rise in inequality on the overall life expectancy. We do this

Table 1
Unstandardized coefficients from OLS regressions of life expectancy at birth on real GDP and income inequality (excluding China).
Source: World Bank, Penn World Table 7.1, and Standardized World Income Inequality Database V4.0

	Model 1	Model 2
Logged Real GDP per-capita	6.911***	6.604***
	(0.293)	(0.347)
Income Inequality (Gini × 100)		−0.073+
		(0.038)
Year	0.128***	0.130***
	(0.018)	(0.017)
Constant	−248.727***	−246.420***
	(35.105)	(33.890)
R^2	0.747	0.751
N	4103	4103

Note: Robust standard errors in parentheses. ***p < 0.001, **p < 0.01, *p < 0.05, + p < 0.1.

for both the observed (high-inequality) society and the hypothetical (low-inequality) society. We use the following relationship between mortality rates in abridged life table and hazard rates:

$$ {}_nh_x = 2 * {}_nq_x/(2\,n - {}_nq_x * n), \quad (7)$$

where n denotes age interval; ${}_nh_x$ denotes the mortality hazard of the individual at the age between x and x + n; ${}_nq_x$ denote the probability that an individual alive at the beginning of the age interval (x) will die before reaching the end of the interval ($x + n$). We use estimated coefficient for income in the Cox model to modify hazards, and thus deriving age-specific mortality rates specific to each income groups and then life tables by income groups. After aggregation across income groups, we then compare the average life expectancy for the actual society with that for the hypothetical society. The result is the life loss resulting from the difference in income inequality.

4. Results

4.1. Trends in Income Inequality and life expectancy in China

Table 1 reports coefficient estimates on the basis of equations (1) and (2), labelled respectively as Models 1 and 2. Alternative specification of these two models, including those containing higher order terms of period effects, yield substantially similar results so that we chose to present the most parsimonious model. Model 1 displays the relationship between life expectancy and GDP per-capita. As expected, GDP per-capita is positively and strongly associated with life expectancy. The coefficient 6.911 for logged real per-capita GDP suggests that a 1 percent increase in per-capita GDP leads to an increase in life expectancy by 0.069 years, and a doubling of per-capita GDP would increase life expectancy by 6.9 years. Both the direction and size of the GDP coefficient are comparable to those reported in previous cross-national studies (Beckfield, 2004; Torre and Myrskylä, 2014). Model 2 reveals the ecological association between life expectancy and income inequality, net of per-capita GDP and shared time trends. Consistent with many other studies (for review, see Wilkinson and Pickett, 2006), we find the coefficient of Gini to have a negative sign and to be statistically significant at the 0.1 level, suggesting that income inequality is associated with lower life expectancy. The estimated coefficient of −0.073 implies that life expectancy decreases by 0.073 years for every additional 0.01 of the Gini coefficient. Although the direction of the income-inequality coefficient is consistent with the inequality-health hypothesis, the size of the coefficient seems a little smaller than that previously reported in cross-national work (Beckfield, 2004).

In Fig. 2, we graphically display observed and predicted trends in life expectancy over recent decades in China. The predicted life expectancy is based on regression results (equation (1)) excluding China, with China's actual per-capita GDP. For consistency, we use data on observed life expectancy from the World Bank (2014) and data on per-capita GDP from the Penn World Table (Heston et al., 2012). For the 1970s and 1980s, the divergence between observed and predicted trends was large, showing China's outstanding performance relative to its peers in population health during the early period. That divergence, however, began to decline afterwards and is no longer statistically significant. That is, from an international perspective, China's national health achievements seem to have shifted from being a positive outlier (better health than expected from the level of economic development) in the 1970s to being at the world average by the 2000s. Specifically, from 1960 to 1980, life expectancy at birth in China grew from 43 years to 67 years, an average gain of 1.2 year of life per annum. Life expectancy in China continued to increase throughout the late 1960s and 1970s, despite the large-scale social and economic disruptions of the Cultural Revolution. During the same period, other countries at similar levels of economic development only enjoyed an average gain of 0.28 year per annum in expectation of life at birth. From 1981 to 2010, the average life expectancy in China continued to rise, but the pace of health gains slowed down dramatically. Life expectancy at birth in China increased only by 6.3 years, in spite of the fifteen-fold increase in average income during these three decades. Compared to other countries at similar levels of economic development, China's advantage in population health waned.

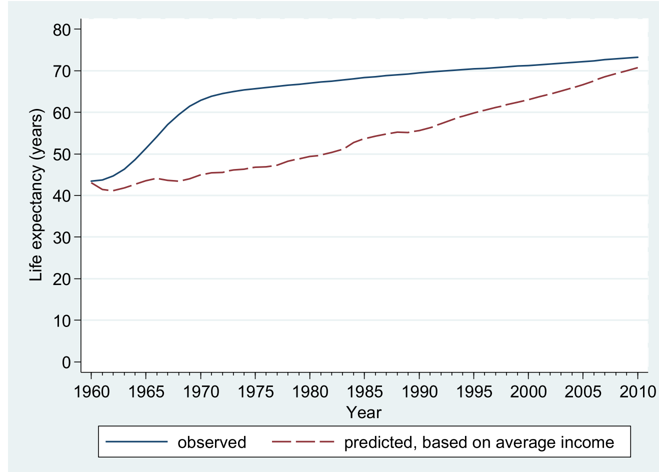

Fig. 2. Observed and expected life expectancy, given China's level of economic development, 1960–2010.
Source: Heston et al., (2012); World Bank (2014).

One possible explanation for the slowdown in health gains of the Chinese population is that life expectancy in China was already high so that room for improvement was limited. This explanation, however, is untenable. Take China's neighboring countries, such as Japan and South Korea, as examples. In 1980, life expectancy at birth in Japan was 76.09 years old, much higher than that (66.99 years old) in China, while life expectancy at birth in South Korea was 65.80 years old, lower than that in China (World Bank, 2014). However, during the period since 1980, health gains grew faster in both these countries, whose economic growth was less than half that of China (World Bank, 2014). Specifically, between 1980 and 2010, life expectancy at birth in Japan and South Korea increased at an average pace of 0.23 and 0.49 year per annum respectively, whereas this figure in China was 0.21 year per annum during the same period (World Bank, 2014).

In Fig. 3, we plot the trend in income inequality in China along with the gap in expectation of life at birth between China and other countries at similar economic development levels (labelled as “life expectancy premium”). We note that the decline of the life expectancy premium in China coincided with the rise of income inequality since the late 1970s.

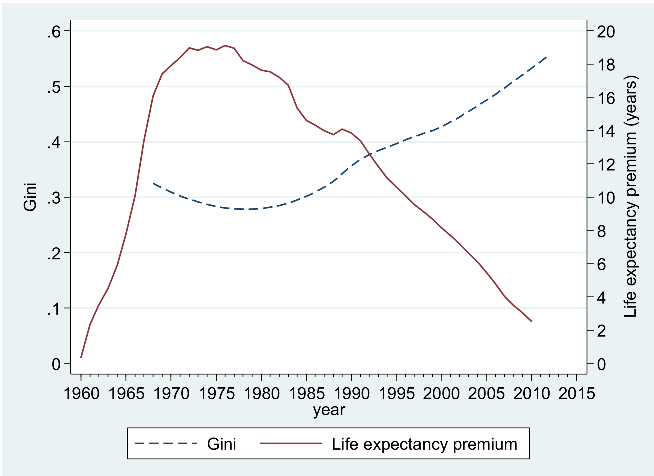

Fig. 3. Trends in income inequality and the life expectancy premium in China.[1]
Note: [1] Life expectancy premium refers to the gap in life expectancy at birth between China and other countries at similar economic development levels.
Source: Heston et al., (2012); Xie and Zhou (2014); World Bank (2014).

Income inequality in China first decreased and then went up, whereas the life expectancy premium in China first increased and then went down. We will next systematically examine whether the narrowing gap between observed and predicted trends in life expectancy in China could be partly attributable to the sharp rise in China's income inequality.

4.2. Measuring life loss from income inequality in China

How can we measure life loss from increases in income inequality in China? To illustrate, we detail the procedure of calculating life loss from income inequality in 2011. As mentioned earlier, we first derive the generic relation between income and risk of mortality for the Chinese population, using the Cox proportional hazards model, using data from the 2010, 2012, 2014 and 2016 CFPS. The log-likelihood function is maximized with a Box-Cox transformation parameter for household per-capita income of 0.20 ($\lambda = 0.20$) among males and 0.43 ($\lambda = 0.43$) among females. In Table 2, we show the estimated hazard function where λ is set at 0.20 for males and 0.43 for females. Tests for the proportionality of hazards failed to reject the proportionality assumption for both males and females (not shown). The estimated relation between household income per-capita and the relative risk of mortality is highly significant, both statistically and substantively, and is clearly consistent with the expectation that the income effect on mortality risk follows a pattern of diminishing return at the individual level. Further, consistent with other studies in developed countries (Deaton, 2003), the convex-curved relationship between household per-capita income and mortality for males appears more curved than that for females.

The estimated relationship between household per-capita income and individual mortality risk is used to modify mortality hazard rates for ten income deciles under two different assumptions about income inequality: (1) actual inequality level in 2011, and (2) the lowest income inequality level during the period 1968–2012. As mentioned above, we assume that household per-capita income follows a two-parameter lognormal distribution. We obtained the average of household per-capita income in 2011 from a government source (State Statistics Bureau of China, 2013) at 13,367 RMB yuan, which is adjusted by consumer price index and deflated to the 2010 purchasing value. Using 2011 *Gini* estimate from Xie and Zhou (2014), i.e., 0.544, as well as equation (6), we calculate the variance of logged household per-capita income to be 1.055. According to equation (5), we further calculate the mean of logged household per-capita income to be 8.944. For the actual inequality, $\sigma = 1.055$. Combining the above information, we calculate the ratio in mortality risk between an income decile group and the lowest income decile in the actual society, shown in Table 3. For males, the relative risk of mortality of the highest income decile to the lowest income decile is 0.571. For females, this corresponding ratio is 0.565.

Suppose a hypothetical scenario in which the 2011 inequality level was reduced to 0.279, the lowest level during the period 1968–2012 (Xie and Zhou, 2014), but the average of household per-capita income stays unchanged. Following the same procedures in Table 3, we obtain the ratio of mortality risk for each decile in the hypothetical society to the lowest income decile in the actual society. The results are displayed in Table 4. For convenience, we still use the lowest income decile group under the actual inequality level (first category of Table 3) as a reference. Relative to this group, the relative risk of mortality of the highest income decile under the hypothetical scenario is 0.648 for males and 0.669 for females.

We now calculate life loss from the rise in income inequality. An important step is to construct separate life tables for ten income decile groups. The basic idea is to modify the overall life table for China (World Health Organization, 2013) by income. As with the Cox model, we assume that differences in mortality hazards are proportional across income groups, regardless of age. Given this assumption, we convert death rates in the abridged life table to hazard rates, modify them by income groups with results in Tables 3 and 4, and then construct group-specific life tables, using the relationship ${}_nh_x = 2^* {}_nq_x/(2n-{}_nq_x{}^*n)$. From

Table 2
Cox proportional hazards regression coefficients predicting mortality in the Chinese population, 2010–2016.
Source: China Family Panel Studies (2010, 2012, 2014 and 2016)

	Male	Female
Boxinc (λ = 0.20/0.43)[a]	−0.024***	−0.003**
	(0.006)	(0.001)
Age	0.026*	0.042**
	(0.010)	(0.013)
Age^2	0.001***	0.000***
	(0.000)	(0.000)
No. of deaths	744	509
No. of observations	15,780	15,043

Note: standard errors in parentheses. ***p < 0.001, **p < 0.01, *p < 0.05, + p < 0.1.
[a] Boxinc = (household income per-capita$^{0.20}$-1)/0.20 for males, and = (household income per-capita$^{0.43}$-1)/0.43 for females, respectively.

Table 3
Average income by decile and the relative mortality hazard, when Gini Coefficient = 0.544, household income Per-capita = 13,367 in 2011.

Decile Number	Average Income	Mortality hazard relative to persons within the lowest income decile	
		Male	Female
1	1299.789	1	1
2	2565.771	0.929	0.953
3	3764.917	0.888	0.921
4	5110.781	0.854	0.892
5	6725.13	0.822	0.864
6	8774.036	0.792	0.834
7	11556.12	0.759	0.800
8	15727.72	0.723	0.760
9	23277.18	0.675	0.704
10	54867.72	0.571	0.565
	Mean = 13,367		

Note: The household income per-capita was adjusted by consumer price index and was deflated to its 2010 purchasing value.

Table 4
Average income by decile and the relative mortality hazard when Gini coefficient decreases to 0.279 and household income Per-capita = 13,367 in 2011.

Decile Number	Average Income	Mortality hazard relative to persons within the lowest income decile, when Gini = 0.544	
		Male	Female
1	4956.657	0.857	0.895
2	6966.869	0.818	0.860
3	8375.914	0.797	0.839
4	9695.393	0.780	0.822
5	11054.88	0.764	0.806
6	12552.26	0.749	0.790
7	14315.55	0.734	0.773
8	16580.82	0.716	0.753
9	19974.27	0.694	0.727
10	29196.32	0.648	0.669
	Mean = 13,367		

Note: The household income per-capita was adjusted by consumer price index and was deflated to its 2010 purchasing value.

Table 5
Life expectancy at birth for males and females in different income decile in 2011.

Decile Number	Males		Females	
	When Gini = 0.544	When Gini = 0.279	When Gini = 0.544	When Gini = 0.279
1	71.54	73.27	75.21	76.37
2	72.37	73.77	75.72	76.77
3	72.88	74.05	76.08	77.01
4	73.31	74.28	76.40	77.22
5	73.72	74.49	76.73	77.41
6	74.13	74.70	77.08	77.60
7	74.57	74.92	77.47	77.81
8	75.08	75.17	77.97	78.06
9	75.76	75.49	78.68	78.39
10	77.38	76.18	80.56	79.13
All	**74.07**	**74.63**	**77.19**	**77.58**

separate life tables, it is straightforward to calculate life expectancy for the ten income decile groups. We present group-specific life expectancies in Table 5.

Recall in Fig. 1, we presented our core argument that a rise in inequality results in an overall decline in population health due to concavity in the relationship between income and health. We now illustrate this point with our life expectancy results in Table 5. A shift of high Gini to low Gini would result in a reduction of males' life expectancy from 75.76 to 75.49, a 0.27 difference, for the ninth income decile. However, for the second decile, males' life expectancy would increase from 72.37 to 73.77, a large 1.40 difference! The overall life expectancy at the population level, given in the last row of Table 5, summarizes the main findings of our study. We observe that a hypothetical shift from a comparatively high degree of income inequality (Gini = 0.544) to a relatively equal distribution of income among individuals (Gini = 0.279) would increase life expectancy at birth by 0.56 years for males; the corresponding figure for females is 0.39 years.

We repeated the same procedure and calculated the observed and counterfactual expectation of life at birth for some other years (i.e., 1981, 1990, and 2000). The results are presented in Table 6. Two findings emerge from an examination of Table 6. First, as the extent of income inequality in China rose over time, the life loss also increased. For example, life loss for males was only 0.14 in 1990, grew to 0.27 in 2000, and finally reached 0.56 in 2011. Another persistent finding is that males suffer more from inequitable income distribution than females throughout the period.

5. Conclusion

Why did China experience stagnation in health gains during the reform decades of rapidly rising income? In this article, we advanced the thesis that rising income inequality over recent decades is partly responsible for the relative deterioration of China's health performance. We evaluated this hypothesis by simulating the increase in life expectancy at birth that would result if, *ceteris paribus*, income inequality were kept constant at the lowest level during the period 1968–2012.

Our analysis indicates that inequitable distribution of income harms population health. Accompanying the sharply increasing income inequality in China has been a cost in the life loss of China's population. In 1981, life loss from income inequality was negligible. Thirty years later, however, for males' life expectancy, about 0.56 years might be lost due to the rise in income inequality; for females' life expectancy, this figure is about 0.39 years. To aid estimation of the life loss from income distribution, we take the conservative approach and assume that income inequality is not directly detrimental to individual health. This may not be the case. Even though the relation between individual health and income inequality is inversely-U shaped, as suggested by some Chinese scholars (Feng and Yu, 2007; Li and Zhu, 2006; Qi, 2006), with recent estimates of a Gini coefficient of 0.5 (Knight, 2014) or even higher (Xie and Zhou, 2014) in China, we may well underestimate the life loss from income inequality in recent years. Moreover, because the association between income inequality and mortality stronger at younger ages (Torre and Myrskylä, 2014), life loss attributable to income inequality may have impact on population dynamics beyond life expectancy (Arias et al., 2013).

We observe a sex difference in the life loss from inequitable income distribution, as the loss is larger for men than for women. Indeed, data from the US National Longitudinal Mortality Study also reveal that the association between income distribution and mortality is stronger for men than for women (Backlund et al., 2007). Similar differences in favor of women have repeatedly been found in international analyses (Dorling et al., 2007; Torre and Myrskylä, 2014). One plausible explanation for this difference lies in the different gender roles men and women occupy. Typically, men are considered the breadwinners and women the homemakers. Income inequality may expose men more to the stress of maintaining or improving the family's socioeconomic status, intensifying competition among them to be upwardly mobile (Torre and Myrskylä, 2014). Social stress and competition translate into poorer health, as they may increase testosterone levels, thereby resulting in various health-compromising behaviors, such as smoking, driving at excessive speeds, and alcohol abuse (Cockerham, 2010).

In summary, our results show that inequitable income distribution in China leads to life loss and that men suffer more than women from income inequality. Our results thus shed new light on the puzzle of China's pace of health gains slowing down despite its ever-growing economy during the reform decades. We know that China's income inequality is largely driven by regional difference and rural/urban divide (Xie and Zhou, 2014). As a consequence, accompanying the slowdown health gains in China have been increases in health disparities by these two structural dimensions over recent decades (Tang et al., 2008). For example, within China, improvement in life expectancy has been slower in poor provinces than in rich ones. Between 1981 and 2010, life expectancy at birth in Beijing and Shanghai, two of the most developed large cities, went up by 8.2 years (from 72.0 to 80.2) and 7.2 years (from 73.0 to 80.3) respectively (Institution of Population Research at Renmin University, 1987; State Statistics Bureau of China, 2013). In contrast, over the same period there was a smaller improvement in life expectancy in Gansu, one of China's poorest provinces, with a gain of 6.1 years (from 66.1 to 72.2). Our results also suggest that redistribution of income from the rich to the poor would lead not only to a reduction in income inequality but also to improvements in the average life expectancy and reductions in health disparities. Since the early 2000s, new policy levers have begun to be developed, such as state-run

Table 6
Observed and counterfactual life expectancy at birth.

Year	Gini	Income per-capita[a]	Male		Female	
			Observed	Counterfactual[b]	Observed	Counterfactual[b]
1981	0.282	1811	66.40	66.44	69.22	69.26
1990	0.357	3942	67.56	67.70	70.87	70.93
2000	0.427	8559	71.02	71.29	74.81	74.99
2011	0.544	13,367	74.07	74.63	77.19	77.58

Note:
[a] Household income per-capita was adjusted by consumer price index and was inflated (deflated) to its 2010 purchasing value.
[b] For a particular year, its counterfactual life expectancy at birth is obtained by keeping income per-capita unchanged, but changing the distribution of income (i.e., reducing the Gini coefficient to 0.279, the lowest level during the period 1968–2012).

medical insurance programs (i.e. New Rural Co-operative Medical Scheme, Urban Resident Basic Medical Insurance Scheme, and the new unified system of these two schemes—Urban and Rural Residents' Basic Medical Insurance Scheme) and old-age insurance programs (i.e., New Rural Old-age Insurance and Urban Residents Old-age Insurance). These policies have aimed to achieve this very objective. There are some signs that inequality increases in China may have tapered off around 2010 (Xie and Zhou, 2014). Further research is needed to evaluate whether this is indeed the beginning of a new trend that will help to improve China's population health in the future.

CRediT authorship contribution statement

Weixiang Luo: Conceptualization, Formal analysis, Methodology, Writing - original draft. **Yu Xie:** Methodology, Supervision, Writing - review & editing.

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