Social Indicators Research

Heterogeneous influence of socioeconomic inequality on population health: a cross-national study

--Manuscript Draft--

Manuscript Number:	SOCI-D-22-00808R1
Full Title:	Heterogeneous influence of socioeconomic inequality on population health: a cross-national study
Article Type:	Original Research
Keywords:	socioeconomic inequality; life expectancy; healthy life expectancy; quantile regression; heterogeneity
Abstract:	Prior studies have documented that socioeconomic inequality can negatively influence population health, but few literature has discussed the heterogeneous health effect of socioeconomic inequality. This study used the quantile regression model to examine the heterogeneous relationship between socioeconomic inequality (educational inequality, income inequality, and unemployment rate) and population health (life expectancy and healthy life expectancy) based on macro panel data from 160 countries. It is found that, in both rich and poor countries, elevated income inequality and unemployment rate were significantly associated with reduced life expectancy and healthy life expectancy, while the associations between educational inequality and two health outcomes were not statistically significantly. Furthermore, the negative associations between three inequality forms and two health outcomes were mainly observed in countries with lower-level population health rather than those with higher-level population health. Robust results were still yielded when lagged population health outcomes were used. Therefore, nations with poor population health should pay more attention to socioeconomic inequality, state regulations should be actively used to promote equality in income, education and employment for health promotion.

SOCI-D-22-00808 R1 Review report for Reviewer#1

Reviewer #1: The paper concerns the very important problem to examine the heterogeneous effect of socioeconomic inequality on life expectancy and healthy life expectancy. Authors found that elevated income inequality and unemployment rate could significantly reduce life expectancy and healthy life expectancy at the national level, with differences between developed and developing countries. The idea is interesting, both from a statistical and an interpretational viewpoint, however, it may have some drawbacks.

Q1. I suggest taking current interpretations with a grain of salt, you are actually investigating linear relationships using a regression model, be careful to claim the emergence of causal effects.

Reply: Thanks for this reminder. Accordingly, I adjust some words when I describe my statistical results. I avoid the use of "impact" and "influence", and use "relationship/related" or "association/associated" in the results section. Also, in the limitations, I remind readers that the causal effect is not clear because the endogeneity problems such as omitted variable and sample selection biases have not been fully addressed.

Q2. The proposed longevity literature shows serious shortfalls, please reconsider your introduction and the related argument on the basis of the following articles, milestones in the field:

- Oeppen J, Vaupel JW (2002) Broken limits to life expectancy. Science 296(5570):1029-1031

- Oeppen J (2006) Life expectancy convergence among nations since 1820: Separating the effects of technology and income. In: Bengtsson T, Keilman N (eds) Old and new perspectives on mortality forecasting. Demographic research monographs (A series of the Max Planck Institute for demographic research). Springer, Cham, pp 197-219

- Vaupel, J. W., Villavicencio, F., Bergeron-Boucher, M.P.: Demographic perspectives on the rise of longevity. Proceedings of the National Academy of Sciences, 18(9) (2021)

- Preston, Samuel H. (1975). The Changing Relation between Mortality and level of Economic Development. Population Studies, 29(2), 231-248.

- Shkolnikov VM, Andreev EM, Tursun-zade R, Leon D (2019) Patterns in the relationship between life expectancy and gross domestic product in Russia in 2005-15: a cross-sectional analysis. The Lancet Public Health 4(4):181-188

Reply: Thanks for listing the literature above, and I read them and majorly revise the Introduction about longevity based on them.

Q3. Please, consider better and formally defining the measure you are dealing with, life expectancy and healthy life expectancy, at which age?

Reply: I have revised this error and they are life expectancy and healthy life expectancy at birth. See section 3.2.

Q4. Please consider the substantial literature on measuring the spread and behavior of the life expectancy distribution, see, e.g.

- The relationship between longevity and lifespan variation. A Nigri, E Barbi, S Levantesi. Statistical Methods & Applications 31 (3), 481-493

- The relay for human longevity: Country-specific contributions to the increase of the best-practice life expectancy. A Nigri, E Barbi, S Levantesi. Quality & Quantity, 1-13

Reply: Thanks for providing me these two studies, and I use the second one in the Introduction when introducing the life expectancy change in recent years.

Q5. Quantile regression model. Please provide a formal and statistically rigorous description of quantile modeling.

Reply: Based on this comment, I add more contents on why this paper use the quantile regression (what it can do and why it is better). See section 3.3: "The above mixed regression model can only predict the expected mean of population health. However, it is of more value to estimate the prediction of socioeconomic inequality on the global distribution of population health, which can help clarify whether there are differences in the association between socioeconomic inequality and population health across successive health levels. Accordingly, the quantile regression model was used to examine whether the association between socioeconomic inequality and population health would change across successive health levels. The quantile regression model assumes that the quantile of conditional distribution of the dependent variable is a linear function of independent variables, which helps to obtain the influence of independent variables on dependent variable within specific quantiles. This model depicts the conditional distribution of outcome variables at greater length and highlights the local relationship, which can reduce the disturbance of outliers and enhance model's robustness".

Q6. In summary, I would be happy to review the paper once the above comments

and reference suggestions were satisfactorily taken into account.

Reply: Thanks for your positive comment on this work!

SOCI-D-22-00808 R1 Review report for Reviewer#2

Reviewer #2: The authors address a much-debated topic in the literature: the study of the effects of socioeconomic inequalities on health. This study also aims to highlight the differences between developed and underdeveloped countries.

Q1. The topic is interesting, however it is not possible to grasp the authors' original contribution, which could be the use of quantile regression (but should be checked if there are other examples in the literature), the use of panel data (but section 4.3 is not very detailed) or the comparison between developed and underdeveloped countries. In the latter case, the authors should consider that there is a wide literature on the comparison of models estimated on different groups (among many see "Chow, G.C.: Test of equality between sets of coefficients in two linear regressions. Econometrica 28, 591-605 (1960)" and « Lebart, L., Morineau, A., P., F.J.: Traitement des Donnees Statistiques (1979) ». Moreover, in many places the authors should be more detailed and precise.

Reply: Thanks for these good comments. First, in my point of view, the hugest contribution of my paper is using quantile regression and identifying the heterogeneous influence of socioeconomic inequality on population health. Use of panel data is just a method to obtain more accurate and reasonable estimations, and comparison between rich and poor . Second, based on the suggestion, I add the test of group when comparing the regression between rich and poor countries (see Appendixes 2 and 8). The well-known Chow test cannot perform the group test when bootstrap is used, so I use the non-official command “bdiff” developed by Lian et al. (2010) to do the test of group.

Lian, Peng & Su. 2010. Financing constraints and liquidity management behavior. Journal of Financial Research (10), 158-171.

Q2. The authors focus on an analysis at the national level. It is well known that an aggregate analysis can flatten the differences within the nation and mask a possible heterogeneity of the phenomenon. I would suggest adding a few comments on this topic.

Reply: This issue indeed exists when analyzing this topic at the national level. However, this paper cannot overcome it because only the national-level data are available and used. Thus, I decide to add this as a limitation and add a few comments on this issue in the limitations.

Q3. The literature review in section 1.2 shows contradictory results on the effects of socio-economic factors on health. The authors should include some arguments to justify the hypotheses they intend to test in the paper by linking them to the previously described analysis. Maybe an argument could also be the idea of analyzing the effect of all three factors simultaneously.

Reply: Thanks for this instructive comment. I majorly revise the literature review and discuss each hypothesis before it is proposed to make a closer connection between the hypothesis and prior literatures. Certainly, these arguments also explain the differences in existing research results. In addition, it is true that few researches have discussed all of the three inequality factors, but the most important for this paper is still the heterogeneity across successive health levels.

Q4. The following sentence at the end of page 2 and the beginning of page 3 is not clear (it seems contradictory) and it is crucial for understanding the aim of the paper: "Prior studies usually use income, education and occupational status as elements of socioeconomic status (SES). Accordingly, wealth or income inequality is usually considered the most important socioeconomic inequality form, but other forms of socioeconomic inequality, such as inequality in education and employment, are also worthy of attention."

Reply: I revise these unclear statements based on the comment: “One cavtake is that studies over the past several decades have mainly focused on the health effect of income or wealth inequality. While it is true that wealth or income inequality is one of the most important forms of socioeconomic inequality, inequalities in areas such as education and employment are also worth watching. Unfortunately, research on the health consequences of inequality in education and employment has been sparse and inconclusive”.

Q5. Introduction: I suggest giving more details about the aim of the paper, the dataset and the structure of the paper. The section ends quite abruptly with the following sentence "Accordingly, this study tried to answer the above two inquiries based on panel data from 160 countries."

Reply: Thanks for this good suggestion. I revise and add the aim, dataset and structure of the paper at the end of Introduction: “Thus, based on the country-level data published by the World Health Organization (WHO) and the United Nations Development Programme (UNDP), this study used the mixed regression and quantile regression methods to estimate the heterogeneous influence of socioeconomic inequality on population health. The full structure of this study is as follows: Section

2 reviewed the health effect of income, education and employment inequality and proposed research hypotheses; Section 3 introduced the data set, variables and statistical methods used in this study; Section 4 presented the research results; Section 5 discussed the results based on prior studies and proposed potential policy implications; and the last section summarized the research conclusions and limitations".

Q6. Missing data imputation: Considering that the phenomenon analyzed has a strong link to geographical location, an imputation system based on the average of the nearest nations would have been less biasing. Clarify the sentence at the end of page 6 "In the case of the complete absence of data for a certain indicator in a certain country, the paper did not make up for it to avoid bias."

Reply: The spatial autocorrelation may be a useful tool for missing data imputation. However, compared to specific country properties and country development, properties and development of neighbors can explain less variation in socioeconomic development, socioeconomic inequality and population health. Thus, using an imputation system based on the average of the nearest nations may not be better than using an imputation system based on the linear development trend or the short-term development status of the country itself. For example, North Korea is a neighboring country of South Korea, but the two countries differ greatly in numerous areas of social development. Similar cases are countless. I believe using neighbors' data to make the data imputation will make a larger bias. Accordingly, the paper perseveres in using the current missing data imputation, and I add an explanation in the manuscript that "Some missing data were interpolated within specific countries, because a countries' socioeconomic development has a strong temporal correlation (Koeda, 2012), which is stronger than the spatial correlation".

In addition, the sentence "In the case of … to avoid bias" means that if the data are completely missing on one indicator for a country, then I would not make a imputation for it, because in this country no time-series data for this indicator can be used for data imputation. I revise these statements to make it clearer: "Specifically, when the data of a specific indicator were missing only in one period, the missing data would be filled using linear interpolation within specific countries. When the data of a specific indicator were missing in two periods, the subsistent value of the indicator within specific countries was used to impute the missing cells. When the data of a specific indicator were missing in all three periods in a specific country, this country would be excluded in the analysis to avoid bias".

Koeda, J. 2012. How does yield curve predict GDP growth? A macro-finance approach revisited. *Applied Economic Letters* 19(10), 929-933.

Q7 Section Data and methods

Data description: table 1 should be deeply commented. It is not even clear what the values indicate, probably national averages.

Reply: I am sorry for the lack of clarity, and I revised the table title as "Table 1 Descriptive information of variables used, national averages from 2010 to 2019".

Q8. Threshold to identify developed and developing countries: better motivate this choice: is it related to the data analyzed, data driven, or is it the one commonly used in the literature?

Reply: It is more likely to be data driven, but similar tactic has been used previously. Lee (2018) used the median of GDP level to divide his sample (194 countries), and it was declared that this split-sample method could be used to overcome endogeneity problems. Accordingly, I adopt a similar split-sample method based on GDP level. Lee (2018) used the median, while I use a specific GDP level as the cut-off point. Considering that "developed" and "developing" countries are defined by some organizations (e.g., UN and World Bank), I decide to use "rich" and "poor" countries. If I use "developed" and "developing" countries based on existing rules, the number of developed countries is much small and may make the subgroup analysis not robust.

Lee, S. 2018. Social capital and health at the country level. Social Science Journal, 55(1), 37-51.

Q9. I also suggest inserting an appendix with the list of countries

Reply: I have added the list of countries used in the paper as Appendix 1.

Q10. Quantile regression: I suggest adding some references (among many see "Koenker, R., Bassett Jr, G.: Regression quantiles. Econometrica, 33-50 (1978)", "Davino, C., Furno, M., Vistocco, D.: Quantile Regression: Theory and Applications (2013)") and few details (maybe in appendix) about the methodology and the interpretation of the results.

Reply: Based on this comment, I add contents on why this paper use the quantile regression (what it can do and why it is better). See section 3.3: "The above mixed regression model can only predict the expected mean of population health. However, it is of more value to estimate the prediction of socioeconomic inequality on the

global distribution of population health, which can help clarify whether there are differences in the association between socioeconomic inequality and population health across successive health levels. Accordingly, the quantile regression model was used to examine whether the association between socioeconomic inequality and population health would change across successive health levels. The quantile regression model assumes that the quantile of conditional distribution of the dependent variable is a linear function of independent variables, which helps to obtain the influence of independent variables on dependent variable within specific quantiles. This model depicts the conditional distribution of outcome variables at greater length and highlights the local relationship, which can reduce the disturbance of outliers and enhance model's robustness (Koenker & Bassett, 1978, 1982)".

Q11. Section 4.1 Results of the mixed regression

Two different models are commented on in Table 2 and Appendix 1. Clarify this point and the role of control variables.

Reply: There might be some misunderstanding. Covariates were controlled for in both models in Table 2 and Appendix, and control variables were used to reduce the confounding effect.

A12. 4.2 Results of the quantile regression model

Justify the grid of quantiles used. It is well known that an infinite number of models can be estimated in quantile regression. Therefore, the choice of a finite number of quantiles is always arbitrary, but quantiles of easy interpretation (quartiles, deciles) are generally used. A different choice (0.30, 0.7 in this case) must be justified.

Reply: I decide to revise the quartile choice according to this comment. In Table 3, the paper now uses the deciles (0.1, 0.2,…, 0.9) as quantiles. In the following figures, the paper still uses the deciles. Because a larger number of quartiles can help us understand the changing trend of social inequality's health effect.

Q13. In the description of the results, the effects of each regressor on each conditional quantile of the dependent variable are highlighted. In my opinion, it is more interesting to show the trends of the coefficients of each regressor in the various models by highlighting any changes in the size and sign of the coefficients. This interpretation must obviously be supplemented with information on significance.

Reply: I totally agree with this comment. Accordingly, I majorly revise my results

section and focus on the changing trend of relationships between socioeconomic inequality and health across successive quantiles. Also, the group test in specific quantiles is also conducted and reported in Appendix 8, to further help understand the difference in the changing trend between rich and poor countries.

Q14. All figures are not readable, it is not clear to which regressor each figure refers and there are overlapping confidence bands.

Reply: Thanks for your reminder. I redraw all of the figures and the quality has been improved. Each regressor has been marked in each small figure, and 90% CI is reported as dash area. Also, some redundant lines in the original manuscript have been deleted.

Q15. 4.3 Robustness check

The analysis of the results proposed in this section is somewhat superficial. The comparison between Appendix 3 and Table 2 and between Appendix 4 and Table 3 is not so simple and it is not obvious to state that there are no differences. This section could represent the original contribution of the work but is not well detailed

Reply: Thanks for this valuable comment. I revise my description in the robustness check, but I mainly revise it based on the Q13 (highlighting any changes in the size and sign of the coefficients). The reviewer puts that "The comparison between Appendix 3 and Table 2 and between Appendix 4 and Table 3 is not so simple and it is not obvious to state that there are no differences" in this comment. However, I do not think there is any fundamental difference between the results in Appendix 4 and those in Table 2 (also between the results in Appendix 5 and those in Table 3). Although the results between Appendix 4 and Table 2 (also between Appendix 5 and Table 3) seem to be not the same in specific quantiles, they have similar trend across successive quantiles; also, if we compare their trends based on the overlap of 90%CI, it is also supported that the difference is not statistically significant. Thus, I am prone to believe there is no substantial difference between the results in Appendix 4 and those in Table 2 (also between the results in Appendix 5 and those in Table 3).

Q16. Typos and minor remarks:

Check the journal style citations and references

Reply: Thanks for this reminder. According to my experiences in publishing, Social Indicators Research accepts the APA 6th style.

Q17. Page 2, line -4: "cavetake". Please specify what you mean

Reply: “One cavtake is that” means something that should be paid special attention, and this phrase has been used in some prior studies.

Q18. Page 5, line -7: why is "countercyclical mortality" in italics?

Reply: Countercyclical mortality and procyclical mortality are specific social phenomena, so the paper wants to express them using a special word form. In this version, I add quotation marks to them rather than writing them in italics.

Q19. I would suggest changing the title without including the number of analyzed countries

The title has been revised as “Heterogeneous influence of socioeconomic inequality on population health: a cross-national study”.

SOCI-D-22-00808 R1 Review report for Reviewer#3

Reviewer #3: The paper entitled "Heterogeneous influence of socioeconomic inequality on population health: evidence from 160 countries" deals with a very interesting topic. The paper's idea is interesting, and the manuscript has good potential. The work needs some improvement before the potential publication in a high-profile journal such as Social Indicators Research. I suggest some substantial changes:

Q1. In the introduction, the author(s) should better specify the aim of the work and contextualise it within the reference literature. The first part of the work is too fragmented. The research hypotheses, data, and methods used should be explained in the introduction.

Reply: I agree with this comment, and the introduction and literature review sections have been majorly revised. I specify the aim (also the most important contribution) of this paper in the fourth paragraph of introduction (reasons were also briefly declared in the third paragraph). I also specify the data and methods used in the fourth paragraph of introduction section. Hypotheses are proposed in the literature review and research hypotheses section, and I review literatures mainly according to the research context. For example, for the health effect of income inequality, different results are observed between earlier and more recent published studies, and some recent studies also point out and try to explain why this difference appears. For unemployment, studies found distinct results in rich and poor countries; a possible reason prior studies put is that social protection system is weak in poor countries.

Based on this query and the Q5 below, maybe (I suppose) the reviewer wants to see an introduction style that is in line with most economic papers (e.g., first theory basis and then hypothesis based on specific economic theory and formula derivation). However, as a researcher in the area of medical sociology or social medicine, the style presented in current manuscript is more widely accepted in my research area. I try my best to revise the introduction and literature review sections, based on all of the three reviewers' comments. If you think this part still needs more detailed revisions, please list them, and I am willing to revise them in next revision chance.

Q2. The data description should be improved. Please, justify the data using the related literature.

Reply: Thanks for this useful suggestion, and I add citations to justify the data used in the paper and introduce our data and variables more detailedly. More details can be seen in sections 3.1 and 3.2.

Q3. The quality of the Figure should be improved

Reply: Thanks for your reminder. I redraw all of the figures and the quality has been improved. Each regressor has been marked in each small figure, and 90% CI is reported as dash area. Also, some redundant lines in the original manuscript have been deleted.

Q4. The authors should better explain what the limitations of their work are

Reply: Thanks for this good suggestion, and I revise the limitation paragraph, explaining more on the two limitations listed before and adding a new limitation. See the last paragraph of the paper: "There are still some limitations to this study. First, the connotation of socioeconomic inequality may be very broad, while this study only discusses the inequality in education, income and employment, which may ignore other inequality forms, such as the employment discrimination and unequal wage returns caused by sexism, and the inequality in educational opportunities and quality across different groups. Second, this study only focuses on socioeconomic inequality and population health at the national level, and this aggregate data analysis usually flattens potential differences within the nation and masks the possible heterogeneity. Further, the mechanism that socioeconomic inequality influences population health at a lower level may be substantially distinct with that at the national level. Third, although panel data are used in this study, the endogeneity problems such as omitted variable and sample selection biases are not fully examined and conquered, and only the simultaneous bias has been checked in the robustness analysis. Thus, the causal relationship between socioeconomic inequality and population health is not robustly established in this study. These issues need to be discussed in future works."

Q5. The empirical results should be better explained through the economic literature. Estimates are not contextualised in the related literature. No economic explanations are provided.

Reply: Thanks for this good suggestion. The results section (section 4) only displays what the paper find, more interpretations can be seen in the discussion section (section 5), and I add more contents to explain my results.

Q6. The discussion section needs to have substantial improvements. In this section, the authors should explain their empirical findings' implications.

Reply: Thanks for this useful suggestion. I revise the discussion and discuss more on the implications of the findings. I add some implications such as the following: "It

suggests that income inequality may be one of the most important culprits that results in health crisis in countries with high-level economic development and well-developed healthcare systems but low-level population health development. This phenomenon actually follows the law of diminishing marginal benefits, that is, in richer countries, the serious inequality in income distribution will lead to more serious social deprivation, and the low-level population health further magnifies the marginal effect of income inequality, which makes the population health problem falls into a vicious circle", and "…suggesting that poor countries are more likely to fall into the vicious cycle of "unemployment-health deterioration". This is mainly due to the imperfect social security system design and practice, which leads to the unequal distribution of high-quality public goods and health services and finally the reduction in population health".

I also put detailed policy implications, such as policies to improve the equality in education, income and employment, and focusing more on poor countries with low-level population health, based on my paper's findings.

Q7. A conclusion section is required

Reply: A conclusion has been added in the last section: "This study used cross-national panel data to examine the heterogeneous relationship between socioeconomic inequality and population health at the national level. A significant association between higher income inequality and unemployment and lower-level population health was found, while the association between educational inequality and population health was weak. The negative association between socioeconomic inequality and population health was mainly found in countries with lower-level population health, but had no significant association in countries with higher-level population health. Thus, countries with a lower level of health should pay more attention to social equity, improve the equity of national education, income and employment, in order to promote citizens' health."

Q8. Suggested references

Auluck, A., Walker, B. B., Hislop, G., Lear, S. A., Schuurman, N., & Rosin, M. (2016). Socio-economic deprivation: a significant determinant affecting stage of oral cancer diagnosis and survival. BMC cancer, 16(1), 1-10.

Alicandro, G., Sebastiani, G., Bertuccio, P., Zengarini, N., Costa, G., La Vecchia, C., & Frova, L. (2018). The main causes of death contributing to absolute and relative socio-economic inequality in Italy. Public Health, 164, 39-48.

Agovino, M., Cerciello, M., & Musella, G. (2021). Campania and cancer

mortality: An inseparable pair? The role of environmental quality and socio-economic deprivation. Social Science & Medicine, 287, 114328.

Regidor, E., Calle, M. E., Navarro, P., & Domínguez, V. (2003). Trends in the association between average income, poverty and income inequality and life expectancy in Spain. Social science & medicine, 56(5), 961-971.

Smith, D., Thomson, K., Bambra, C., & Todd, A. (2019). The breast cancer paradox: a systematic review of the association between area-level deprivation and breast cancer screening uptake in Europe. Cancer Epidemiology, 60, 77-85.

Reply: Thanks for providing me these references, and I add three of them in the paper (mainly in Introduction and Literature review).

Heterogeneous influence of socioeconomic inequality on population health: a cross-national study

Abstract: Prior studies have documented that socioeconomic inequality can negatively influence population health, but few literature has discussed the heterogeneous health effect of socioeconomic inequality. This study used the quantile regression model to examine the heterogeneous relationship between socioeconomic inequality (educational inequality, income inequality, and unemployment rate) and population health (life expectancy and healthy life expectancy) based on macro panel data from 160 countries. It is found that, in both rich and poor countries, elevated income inequality and unemployment rate were significantly associated with reduced life expectancy and healthy life expectancy, while the associations between educational inequality and two health outcomes were not statistically significantly. Furthermore, the negative associations between three inequality forms and two health outcomes were mainly observed in countries with lower-level population health rather than those with higher-level population health. Robust results were still yielded when lagged population health outcomes were used. Therefore, nations with poor population health should pay more attention to socioeconomic inequality, state regulations should be actively used to promote equality in income, education and employment for health promotion.

Keywords: socioeconomic inequality, life expectancy, healthy life expectancy, quantile regression, heterogeneity

1. Introduction

Longevity and health are eternal pursuits of mankind. With the development of social economy and medicine, as well as people's pursuit of healthy lifestyles, the life expectancy and population health in most nations have shown an continuous growth trend in recent decades (Nigri, Barbi, & Levantesi, 2022; Oeppen & Vaupel, 2002; Vaupel, Villavicencio, & Bergeron-Boucher, 2021). Since Preston (1975) and Sen (1999) and other earlier scholars made profound analyses on the association between

social development and population health several years ago, more studies published in recent years report that socioeconomic development factors have a fundamental impact on population health; higher levels of socioeconomic and cultural development, stable political and organizational systems, and advanced medical system and technologies, are closely associated with reduced mortality (Buckles, Hagemann, Malamud, Morrill, & Wozniak, 2016; Preston, 1975; Schooling, Lau, Tin, & Leung, 2010), elevated life expectancy (Ebenstein et al., 2015; Jiang, Luo, Xu, & Wang, 2018; Vaupel et al., 2021) and higher healthy life expectancy (Islam et al., 2018; J. I. Kim & Kim, 2016). However, influences of socioeconomic inequality at the national level on population health also deserve much attention, especially in the context of COVID-19 pandemic. This ongoing pandemic has exacerbated socioeconomic inequality, leading to rising unemployment and a widening gap in income and education (Donnelly, Zajdel, & Farina, 2022; C.-W. Su, Dai, Ullah, & Andlib, 2022), which has gradually become a major challenge to the sustained promotion of population health.

Actually, the unequal distribution of wealth or income has long been an active issue in the area of public health. As early as the 1970s, Rodgers found that countries with higher Gini coefficient of income had lower life expectancy and higher infant mortality (Rodgers, 1979). However, some scholars believe that the so-called negative health effect of income inequality is actually due to the phenomenon of diminishing health effect of individual income, which is called the absolute income theory (Gravelle, 1998; Subramanian & Kawachi, 2004). By contrast, the income inequality theory holds that the health effect of income inequality is independent of absolute income level, and income inequality can reduce population health by increasing social deprivation, reducing social cohesion and social welfares receipt (Kaplan, Pamuk, Lynch, Cohen, & Balfour, 1996; Kawachi & Kennedy, 1999; Wilkinson, 1996). In recent years, more and more evidence has been observed that income inequality is negatively associated with population health (Curran & Mahutga, 2018; Hill & Jorgenson, 2018; Karlsson, Nilsson, Lyttkens, & Leeson, 2010; K.-t. Kim, 2019; Luo & Xie, 2020; Z. Su & Zhang, 2021). One far-reaching point is that individuals who live in a more unequal society usually have poorer health due to the "pollution effect"

of inequality (Subramanian & Kawachi, 2004).

One cavtake is that studies over the past several decades have mainly focused on the health effect of income or wealth inequality. While it is true that wealth or income inequality is one of the most important forms of socioeconomic inequality, inequalities in areas such as education and employment are also worth watching. Unfortunately, research on the health consequences of inequality in education and employment has been sparse and inconclusive (Alicandro et al., 2018; Ariizumi & Schirle, 2012; Berkman, Kawachi, & Glymour, 2014; Schenkman & Bousquat, 2021). On the other hand, the heterogeneity of socioeconomic inequality affecting population health is rarely involved in prior studies. This heterogeneity is reflected not only in the differences in the health effect of socioeconomic inequality between rich and poor countries, but also in the changes in the health effect of socioeconomic inequality across successive health levels, and the latter is particularly ignored in prior studies.

The main purpose or contribution of this study was to reveal the heterogeneous influence of socioeconomic inequality on population health, especially the heterogeneous influence across successive health levels. Clarifying this heterogeneity is of great significance for countries to formulate suitable health policies. Thus, based on the country-level data published by the World Health Organization (WHO) and the United Nations Development Programme (UNDP), this study used the mixed regression and quantile regression methods to estimate the heterogeneous influence of socioeconomic inequality on population health. The full structure of this study is as follows: Section 2 reviewed the health effect of income, education and employment inequality and proposed research hypotheses; Section 3 introduced the data set, variables and statistical methods used in this study; Section 4 presented the research results; Section 5 discussed the results based on prior studies and proposed potential policy implications; and the last section summarized the research conclusions and limitations.

2. Literature review and research hypotheses

Income inequality is one of the most studied social determinants of population

health, and both absolute income theory and income inequality theory reflect negative health consequences of income inequality. In a review study, Pickett and Wilkinson (2015) reported that there were plenty of empirical studies on the relationship between income inequality and population health, and most of them found a strong association between higher income inequality and higher infant mortality or lower life expectancy, no matter the analysis unit used was country or province/state. However, the influence of income inequality on population health may vary with country's level of economic development. Although earlier studies put that income inequality has a detrimental effect on life expectancy in developed countries (Deaton, 2003; Regidor, Calle, Navarro, & Domínguez, 2003; Wilkinson, 1992), evidence from subsequent studies is inconsistent. For example, Babones found that income inequality had a negative effect on life expectancy and positive effect on infant mortality in developing countries, but its associations with these two health indicators were not significant in developed countries (Babones, 2008). Herzer and Nunnenkamp found that income inequality showed a negative impact on life expectancy in developing countries, but it strangely presented a positive health effect in developed countries (Herzer & Nunnenkamp, 2015). This phenomenon may reflect the positive spillover effect of health system that can mitigate the negative health effect of income inequality in richer nations. In addition, evidence from low- and middle-income countries in Latin America and Asia suggests that the negative effect of income inequality on life expectancy is awfully strong (Biggs, King, Basu, & Stuckler, 2013; Chang & Gao, 2021; Luo & Xie, 2020). However, Hill and Jorgenson found that even in developed countries such as the United States, the negative effect of income inequality on life expectancy was still significant (Hill & Jorgenson, 2018). The non-significant results in prior studies may be due to the different income inequality indicators that used, because Hill and Jorgenson (2018) found that income inequality represented by Gini coefficient had no significant association with life expectancy, but significant negative associations were observed when income inequality was measured by the proportion of rich households' income in the total household income. The heterogeneous influence of income inequality on health between developed and developing countries suggests the logic

that socioeconomic inequality influences population health may be distinct among countries with different levels of economic development.

Why income inequality leads to a negative health consequence in most cases? Earlier studies suggest that income inequality increases social deprivation, reduces social cohesion and the equity of access to public resources, thus bringing about negative health outcomes (Kaplan et al., 1996; Kawachi & Kennedy, 1999; Wilkinson, 1996). More recent empirical studies provide more comprehensive support for these views. A wealth of empirical evidence suggests that an important consequence of income inequality is socioeconomic deprivation, and socioeconomic deprivation is proved to be an important factor that increases mortality and impairs individual health (Agovino, Cerciello, & Musella, 2021; Hastings, 2019; Mishra & Carleton, 2015; Z. Su & Zhang, 2021). Other empirical studies have found that income inequality is not conducive to the promotion of social capital and social cohesion (Elgar, 2010; Paarlberg, Hoyman, & McCall, 2018), and it also impedes the improvement of public services quality and equity of access to public services (Bhattacharya, Saha, & Banerjee, 2016; Detollenaere, Desmarest, Boeckxstaens, & Willems, 2018), which eventually leading to poor health outcomes.

Another concern is the spatial scale or level when operating income inequality. Pickett and Wilkinson admonished that when discussing the health effect of income inequality, the inequality should be measured in a large-scale geographical unit, such as country or state/province level, to minimize the confounding of other factors (e.g., social deprivation and residential isolation) caused by small geographic units (e.g., community or town) (Pickett & Wilkinson, 2015; Wilkinson & Pickett, 2006). This strategy is not only applicable to the operationalization of income inequality, but can be used when measuring educational and employment inequality.

Few prior studies have discussed the health effect of educational inequality at the national or regional level. Schenkman and Bousquat (2021) put that prior research focused too much on the negative health consequences of income inequality, neglecting other social inequality forms. They believed the health effect of income inequality was minuscule compared with social inequality, which was richer in

content and form. Logically, educational inequality is related to population health. Educational inequality is a driving factor of income inequality, as education determines income in most situations. If there is little social mobility, educational inequality will gradually evolve into income inequality (Chen, Wang, & Wei, 2004; Liu & Ma, 2017) and damage health. At present, both individual education attainment and regional or national education development have been documented to have a strong health promotion effect (Hu, 2014; J. I. Kim & Kim, 2016), and a small amount of evidence shows that educational inequality can increase mortality (Alicandro et al., 2018) and widening health inequality (Ni & Zhao, 2014), but the robust link between educational inequality and population health has not been built.

Unemployment is a key reflection of employment inequality, because workers being older and with few human capitals are more likely to get the hook during the recession, while workers with more economic and human capitals usually own higher occupational status and are less likely to lose jobs (Berkman et al., 2014). The impact of unemployment on life expectancy and mortality at the national or regional level has been documented in numerous studies. For example, the economic depression and rising unemployment rate caused by the collapse of the Soviet Union significantly increased male mortality and reduced life expectancy in Russia (Shkolnikov, Andreev, Tursun-zade, & Leon, 2019; Stuckler, King, & McKee, 2009), and some global evidence also shows that elevated unemployment can reduce life expectancy (Schenkman & Bousquat, 2021). However, evidence of "countercyclical mortality" is observed in the United States and Canada; that is, mortality increases when the economy expands, and it declines when the economy contracts and unemployment rate increases (Ariizumi & Schirle, 2012; Berkman et al., 2014; Ruhm, 2000). This can be partly attributed to the decline in smoking and excessive drinking, as well as the increase in leisure-time physical activity, during recessions (Berkman et al., 2014; Ruhm, 2005). However, evidence from Europe shows no health effect of economic cycles or no evidence of "countercyclical mortality" (Berkman et al., 2014; Ruhm, 2005). This inconsistent evidence may be caused by the moderating effect of macrosocial context (Berkman et al., 2014; Ruhm, 2015).

The above evidence suggests that the negative influence of socioeconomic inequality, especially income inequality, on population health seems to be preliminarily established, but the heterogeneity in this association is less-frequently discussed. Significant differences in the health effects of income inequality and unemployment across countries have been clearly found, but it is unclear whether there are national disparities in the health effects of education inequality. According to prior studies, the health of residents' in poorer countries appears to be more negatively affected by income inequality and unemployment than those in richer countries (Berkman et al., 2014; Herzer & Nunnenkamp, 2015; Shkolnikov et al., 2019), which may be partly attributed to the former's relatively complete social security system (Renahy et al., 2018). Accordingly, the pattern of inter-country heterogeneous associations between educational inequality and population health may be similar, but further tests are needed.

Furthermore, previous studies lay too much stress on the unequal health effect moderated by economic levels, but ignore the unequal health effect of socioeconomic inequality across successive health levels. The latter heterogeneity is possible because socioeconomic inequality may have different effects on population health at different stages of national development. Due to the high prevalence and mortality rates of older adults, the life expectancy is usually hard to continuously and rapidly rise after it reaches a certain high value, and in that case there may even be long-term stagnation and temporary decline in population health in specific periods and countries (Heuveline, 2022; Venkataramani, O'Brien, & Tsai, 2021), which may lead to a phenomenon that the same amount of economic put or inequality produces varying marginal health changes at different health levels. However, from a global perspective, it is still unclear what the pattern of the above heterogeneity is, and further empirical evidence is needed. Based on the evidence above, the following research hypotheses were proposed:

H1: Socioeconomic inequality has a negative effect on population health.

H2: Socioeconomic inequality has a stronger negative effect on population health in poor countries than in rich countries.

H3: The influence of socioeconomic inequality on population health varies across successive health levels.

3. Data and methods

3.1 Data source

The panel data of 183 countries for the years of 2010, 2015 and 2019 were obtained from the official websites of the World Health Organization (WHO) and the United Nations Development Programme (UNDP)[1]. The data have been widely used and proven to be accurate and reliable in prior studies (Messerli et al., 2021; Vogli, Mistry, Gnesotto, & Cornia, 2005). Some missing data were interpolated within specific countries, because a countries' socioeconomic development has a strong temporal correlation (Koeda, 2012), which is stronger than the spatial correlation. Specifically, when the data of a specific indicator were missing only in one period, the missing data would be filled using linear interpolation within specific countries. When the data of a specific indicator were missing in two periods, the subsistent value of the indicator within specific countries was used to impute the missing cells. When the data of a specific indicator were missing in all three periods in a specific country, this country would be excluded in the analysis to avoid bias. Finally, a total of 160 countries were used in the following analysis (List of countries can be seen in Appendix 1).

3.2 Variables selection and descriptive information

This study would examine the relationships between socioeconomic inequality and population health, educational inequality, income inequality and unemployment rate were thus used as measures of socioeconomic inequality at the national level. Life expectancy and healthy life expectancy at birth were used as measures of population health at the national level. Life expectancy was calculated using the life table method,

[1] The outcome variables, including life expectancy and healthy life expectancy, were obtained from the official website of the WHO (WHO, 2022). Other variables were obtained from the official website of the UNDP (UNDP, 2022).

while healthy life expectancy was calculated using the Sullivan method (Sullivan, 1971). Compared to life expectancy, healthy life expectancy takes both mortality and disability into account (Fouweather et al., 2015; Hay et al., 2017) and is more in line with the connotation of health.

In addition, urbanization rate (proportion of urban population), GDP per capita (purchasing power parity in 2017), average years of schooling, and proportion of governmental health expenditure to total GDP were used as control variables[2]; these indicators cover economic, educational and healthcare development states, which are the most important influencing factors of population health in specific countries. More details can be seen in Table 1.

Table 1 is here

In addition, in order to examine the national disparity in the effect of socioeconomic inequality on population health, countries were divided into rich and poor countries based on their levels of GDP per capita, therein countries with GDP per capita (averages of GDP per capita in 2010, 2015 and 2019) less than 15 thousand dollars were treated poor countries and others were considered rich countries[3]. Considering potential endogeneity problems, differences in estimates between these two groups should be unbiased, since potential biases for each group should be the same (Hoshi, Kashyap, & Scharfstein, 1991; Lee, 2018).

3.3 Statistical methods

Based on the short panel data between 2010 and 2019, a mixed regression model was used to control for temporal changes in population health. The model was specified as follows.

[2] Life expectancy and healthy life expectancy are not related to age structure of the population in terms of operationalization (Souza & Rêgo, 2018), so age structure index is not used as a control variable in the analysis.

[3] The average GDP per capita of three periods was not used as the cut-off point, because this strategy would make the number of developed countries very small, which might make the standard error larger and mislead us about the significance of estimations.

$$LE_i = \beta_0 + \beta_1 SI_i + \beta_2 period_t + \beta_3 covariate_i + \mu_i$$

In the above equation, LE_i denoted the life expectancy or healthy life expectancy of country i; SI_i denoted three socioeconomic inequality indicators (educational inequality, income inequality and unemployment rate); $period_t$ denoted two period dummy variables; $covariate_i$ denoted a series of control variables (urbanization rate, GDP per capita, average schooling years, and proportion of governmental health expenditure to total GDP); β meant the estimated coefficients of independent variables, and μ_i meant the random disturbance term.

The above mixed regression model can only predict the expected mean of population health. However, it is of more value to estimate the prediction of socioeconomic inequality on the global distribution of population health, which can help clarify whether there are differences in the association between socioeconomic inequality and population health across successive health levels. Accordingly, the quantile regression model was used to examine whether the association between socioeconomic inequality and population health would change across successive health levels. The quantile regression model assumes that the quantile of conditional distribution of the dependent variable is a linear function of independent variables, which helps to obtain the influence of independent variables on dependent variable within specific quantiles. This model depicts the conditional distribution of outcome variables at greater length and highlights the local relationship, which can reduce the disturbance of outliers and enhance model's robustness (Koenker & Bassett, 1978, 1982). The model was specified as follows.

$$Quant(LE_i|X_i) = \beta^{\theta} X_i$$

The left side of the above equation represented the conditional quantile of life expectancy or healthy life expectancy corresponding to the quantile θ in condition of a given X; X_i represented all of the independent variables in the model, including socioeconomic inequality indicators and other covariates; the coefficient vector β^{θ} corresponding to the quantile θ was achieved by minimizing the absolute deviation. Ten quantiles of health outcomes were used to estimate potential heterogeneities, and the bootstrap method (seed number = 19950111, time of repeated sampling = 200)

was used to re-estimated the standard error of coefficients in the quantile method.

Based on the above model specifications, Stata version 12.0 (StataCorp, College Station, TX, USA) was used to perform the above models. The Stata syntax "bdiff" developed by Lian and his colleagues was used to test whether the differences in the association between socioeconomic inequality and population health between rich and poor countries were statistically significant (Lian, Peng, & Su, 2010), and the bootstrap method (seed number = 19950111, time of repeated sampling = 200) was again used to re-estimated the standard errors. Considering the small sample size (n=160) if using country as the basic analytical unit, $p<0.1$ was used as the criterion of statistical significance in this study.

4. Results

4.1 Results of the mixed regression

Table 2 shows that, with other variables controlled for, socioeconomic inequality was negatively associated with population health averagely. Educational inequality seemed to have a weak association with life expectancy (β=-0.065, $p<0.1$), but it had no significant association with healthy life expectancy. The negative relationships between income inequality and unemployment rate and two health outcomes were significant and strong. Every additional unit of income inequality decreased life expectancy by 0.063 years ($p<0.01$) and healthy life expectancy by 0.100 years ($p<0.001$). Every additional unit of unemployment rate decreased life expectancy by 0.160 years ($p<0.01$) and healthy life expectancy by 0.224 years ($p<0.001$).

Table 2 is here

Appendix 2 shows the health effect of socioeconomic inequality varied across countries. The association between educational inequality and population health seemed to be statistically nonsignificant in both rich and poor countries. The negative association between income inequality and population health was significant in both rich and poor countries, but this negative association seemed to be stronger in rich

countries (for healthy life expectancy, difference=0.086, $p<0.05$). By contrast, the negative association between unemployment rate and population health was significant, but this negative association was stronger in poor countries than in rich countries (for life expectancy, difference=-0.243, $p<0.05$).

4.2 Results of the quantile regression model

Accordingly to Table 3, it is observed that the negative association between socioeconomic inequality and population health was stronger in countries with lower-level population health. In the 1st decile of life expectancy, elevated educational inequality, income inequality and unemployment rate were all related to reduced life expectancy (β=-0.233, $p<0.05$; β=-0.117, $p<0.05$; β=-0.268, $p<0.01$; respectively). However, with the increase in life expectancy quantile, the relationship between socioeconomic inequality and life expectancy gradually reduced. In the 4th decile of life expectancy or above, all three socioeconomic inequality indicators were not significantly related to life expectancy.

Similar results can be yielded when it comes to healthy life expectancy. In the 1st decile of healthy life expectancy, elevated income inequality and unemployment rate were both related to reduced healthy life expectancy (β=-0.131, $p<0.01$; β=-0.451, $p<0.001$; respectively). While the relationship between socioeconomic inequality and healthy life expectancy gradually reduced with the increase in healthy life expectancy quantile. In the 5th decile of healthy life expectancy or above, both income inequality and unemployment rate were not significantly related to healthy life expectancy. One cavtake is that, the association between educational inequality and healthy life expectancy was nonsignificant across all quantiles.

Table 3 is here

Figures 1 and 2, in the form of line chart, present the estimates for each quantile in rich and poor countries, and Appendix 3 reports the group test results between rich and poor countries. Averagely, in both rich and poor countries, the negative

association between socioeconomic inequality and population health reduced with the promotion of health, and it was not statistically significant when the quantile was high. However, some differences in the above association can be observed between rich and poor countries.

The association between educational inequality and population health did not appear to differ between rich and poor countries at each quantile, as the 90% confidence intervals of the curves in rich and poor countries overlapped at all quantiles in Figure 1. However, the estimates in rich countries suggest a positive association between educational inequality and health at higher quantiles, and the estimates in poor countries show a significant negative association between educational inequality and health at the lowest quantile. The group test in Appendix 3 reports similar country differences in the association between educational inequality and population health at some quantiles.

The association between income inequality and life expectancy was not statistically different between rich and poor countries at all quantiles. However, the association between income and healthy life expectancy in rich countries showed a significant U-shaped change at lower quantiles. In the 1st decile, the association was not significant in rich countries but was significantly negative in poor countries. In the 3rd and 4th deciles, this negative association was stronger in rich countries than in poor countries.

The association between unemployment rate and population health differed significantly between rich and poor countries. The association between unemployment rate and life expectancy in rich countries was weak and varied little across successive life expectancy quantiles. By contrast, the negative association between unemployment rate and life expectancy in poor countries was stronger at lower quantiles and declined with the increase in life expectancy quantile, and it was not significant at higher quantiles. The negative association between unemployment rate and healthy life expectancy in poor countries was stronger than that in rich countries, but this mainly occurred at the middle quantiles.

Figures 1 and 2 are here

4.3 Robustness check

In this study, the lagged terms of life expectancy and healthy life expectancy were included in the mixed and quantile regression models to overcome the simultaneity bias (or called bidirectional causality). Appendix 4 shows that the results of mixed lag-term regression were highly similar to those of mixed regression in Table 2, suggesting the robustness of aforementioned estimations.

Appendix 5 displays the results of quantile regression that used lagged terms of life expectancy and healthy life expectancy as outcomes, which were highly similar to those in Table 3, suggesting the robustness of foregoing estimations. Specifically, the lagged health effect of educational inequality was still not significant, and it also hardly varied across successive health levels. The negative associations between income inequality and unemployment rate and lagged health outcomes were statistically significant at lower quantiles, and the strength of these associations reduced with the increase in population health, showing nonsignificant associations at higher quantiles.

Appendixes 3, 6 and 7 present the comparative results between rich and poor countries, and it is observed that the results were highly similar to those in Figures 1 and 2, suggesting the robustness of foregoing estimations. Specifically, the association between educational inequality and lagged population health in rich countries showed little change across successive quantiles, but a positive association was observed at higher quantiles. By contrast, educational inequality was slightly and negatively related to lagged population health at lower quantiles in poor countries. Although the negative association between income inequality and lagged population health in both rich and poor countries was gradually weakened with the increase in health and was not significant at higher quantiles, there was a significant difference between rich and poor countries at lower quantiles; the negative association in rich countries was significantly stronger than that in poor countries at lower quantiles. The association between unemployment rate and lagged life expectancy in rich countries was not

significant, but it was significantly negative in poor countries at lower quantiles, and there were significant differences between the two at almost all quantiles. Similarly, the negative association between unemployment rate and lagged healthy life expectancy in both rich and poor countries gradually weakened with the increase in the outcome, but this negative association was stronger in poor countries than in rich countries at middle quantiles.

5. Discussion

Modernization is always accompanied by various forms of socioeconomic inequality, which have fundamental influences on population health. Based on a cross-national panel dataset between 2010 and 2019, the present study re-examined the effect of socioeconomic inequality (covering education, income and employment) on population health at the national level, using the quantile regression model. It is suggested that socioeconomic inequality, especially the inequality in income and employment, is more likely to be negatively associated with population health in countries with lower-level population health; in countries with higher-level population health, socioeconomic inequality is hard to directly relate to population health. Furthermore, differences in the above association between rich and poor countries were also observed.

In line with most prior studies, this study also found that income inequality had a strong, negative and long-lasting impact on population health (Chang & Gao, 2021; Pickett & Wilkinson, 2015). Further, this study found this negative health effect was stronger in rich countries, which is in line with Deaton's (2003) findings but is not in line with some other studies (Babones, 2008; Herzer & Nunnenkamp, 2015). This study holds that most rich or developed countries are suffering from some structural crises recently, income inequality in some developed capitalist countries is becoming increasingly serious (Hertz & Silva, 2020; Shi, Paul, & Paramati, 2020), and this unbalance of income distribution is gradually evolving into a health crisis among lower and middle class citizens. In addition, income inequality seemed to have a stronger negative association with population health in rich countries with lower-level

population health. It suggests that income inequality may be one of the most important culprits that results in health crisis in countries with high-level economic development and well-developed healthcare systems but low-level population health development. This phenomenon actually follows the law of diminishing marginal benefits, that is, in richer countries, the serious inequality in income distribution will lead to more serious social deprivation, and the low-level population health further magnifies the marginal effect of income inequality, which makes the population health problem falls into a vicious circle.

The negative health effect of educational inequality seems to be not worth mention, and it occurs to be significant in neither rich nor poor countries. However, it does not mean educational inequality is not important for population health. Compared to income, education is a more upstream influencing factor of health. At the micro level, education can promote individual health by increasing people's income, health awareness and health behaviors (Cheng, Zhang, & Shen, 2015; Hu, 2014). At the macro level, educational development serves, first and foremost, national economic and technological development, and consequently produces considerable health benefits over a long period of time. Educational inequality is more likely to evolve into income inequality, employment inequality and inequality in access to health services (Yang, Lai, & Qiu, 2015), which finally leads to the deterioration of population health. According to the quantile regression results, educational inequality still had a weak but negative association with population health in poor countries with low-level health, suggesting that countries facing disadvantages in both economy and population health should consider alleviating educational inequality as one of the priorities to promote population health.

The overall impact of unemployment on population health is significantly negative, supporting the evidence of "procyclical mortality" (Schenkman & Bousquat, 2021). However, the present study found the increase in unemployment rate had a stronger negative association with population health in poor countries, which is mainly due to the immaturity in the construction and practice of unemployment security system. By contrast, most rich or developed countries have established

excellent unemployment security system, which can help to mitigate the adverse health effect of economic depression and unemployment (Renahy et al., 2018). On the other hand, the adverse effect of unemployment on population health is stronger in countries with poor population health, which is similar to that of income inequality. One difference is that, unemployment shows a stronger negative association with population health in poor countries with low-level health, suggesting that poor countries are more likely to fall into the vicious cycle of "unemployment-health deterioration". This is mainly due to the imperfect social security system design and practice, which leads to the unequal distribution of high-quality public goods and health services and finally the reduction in population health (Bhattacharya et al., 2016; Detollenaere et al., 2018).

The present study provides some new insights for socioeconomic inequality and population health, which have some important policy implications. First, socioeconomic inequality is one of the major barriers to improving national health. The allocation of social resources deserves more attention when a country is in a phase of rapid socioeconomic development, because the spontaneous distribution in the context of market economy can hardly achieve a consequence of fair distribution or re-distribution. It is necessary to strengthen and give full play to the role of governmental macro-control to keep the basic socioeconomic equality and improve population health, such as promoting the equal distribution of basic education resources and guaranteeing the right to education of all citizens, refining the income distribution system to narrow the income gap, and promoting social security legislation to provide basic living conditions for the underemployed. Second, countries with low-level population health, especially those with low-level economic development, deserve more attention. As unequal access to public goods and services is an important channel for the negative health effect of income inequality, poor countries with less health resources are more likely to fall into a vicious cycle of "economic depression - health deterioration". Evidence from this study suggest that promoting the reform of distribution system in these countries and reducing the inequality in education, income and employment will bring more health benefits,

which is an important opportunity for the promotion of health human capital and economic boom for them.

6. Conclusions and Limitations

This study used cross-national panel data to examine the heterogeneous relationship between socioeconomic inequality and population health at the national level. A significant association between higher income inequality and unemployment and lower-level population health was found, while the association between educational inequality and population health was weak. The negative association between socioeconomic inequality and population health was mainly found in countries with lower-level population health, but had no significant association in countries with higher-level population health. Thus, countries with a lower level of health should pay more attention to social equity, improve the equity of national education, income and employment, in order to promote citizens' health.

There are still some limitations to this study. First, the connotation of socioeconomic inequality may be very broad, while this study only discusses the inequality in education, income and employment, which may ignore other inequality forms, such as the employment discrimination and unequal wage returns caused by sexism, and the inequality in educational opportunities and quality across different groups. Second, this study only focuses on socioeconomic inequality and population health at the national level, and this aggregate data analysis usually flattens potential differences within the nation and masks the possible heterogeneity. Further, the mechanism that socioeconomic inequality influences population health at a lower level may be substantially distinct with that at the national level (Bakkeli, 2016; Luo & Xie, 2020). Third, although panel data are used in this study, the endogeneity problems such as omitted variable and sample selection biases are not fully examined and conquered, and only the simultaneous bias has been checked in the robustness analysis. Thus, the causal relationship between socioeconomic inequality and population health is not robustly established in this study. These issues need to be discussed in future works.

Appendixes 1 to 7 are here.

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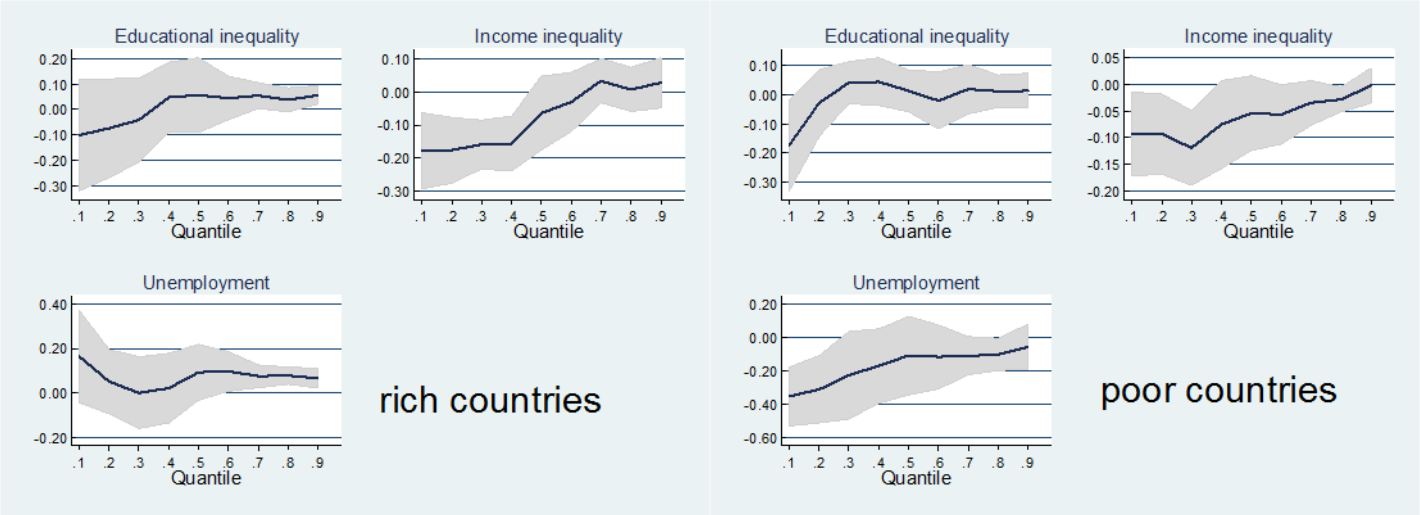


Figure 1 Heterogeneous association between socioeconomic inequality and life expectancy, 90% confidence interval in dash area

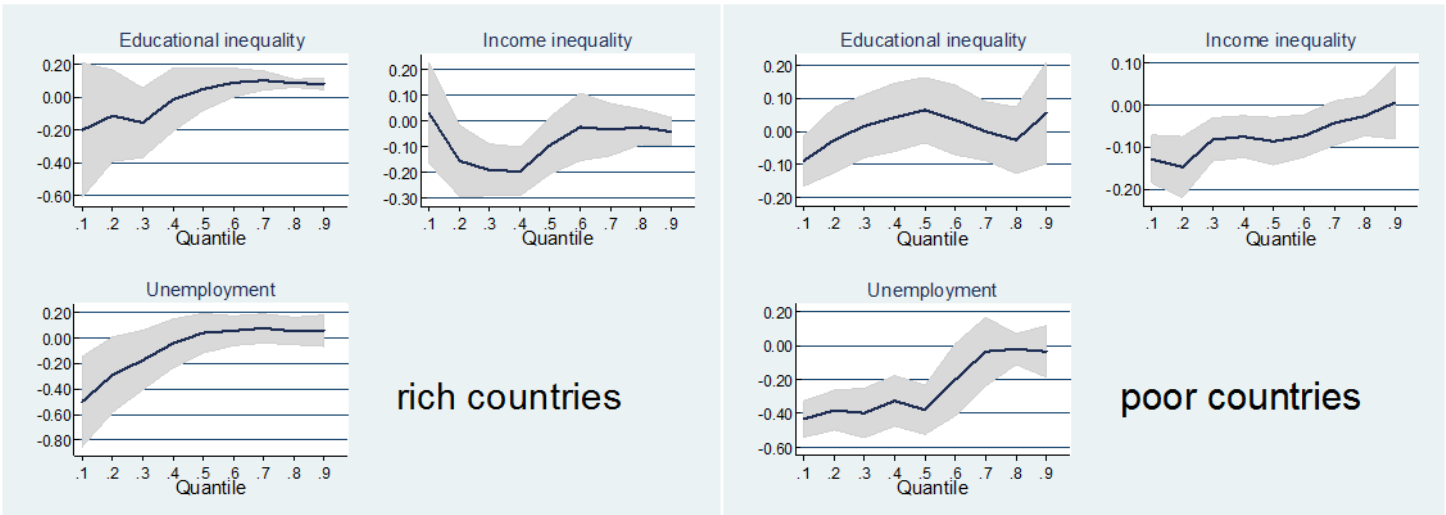
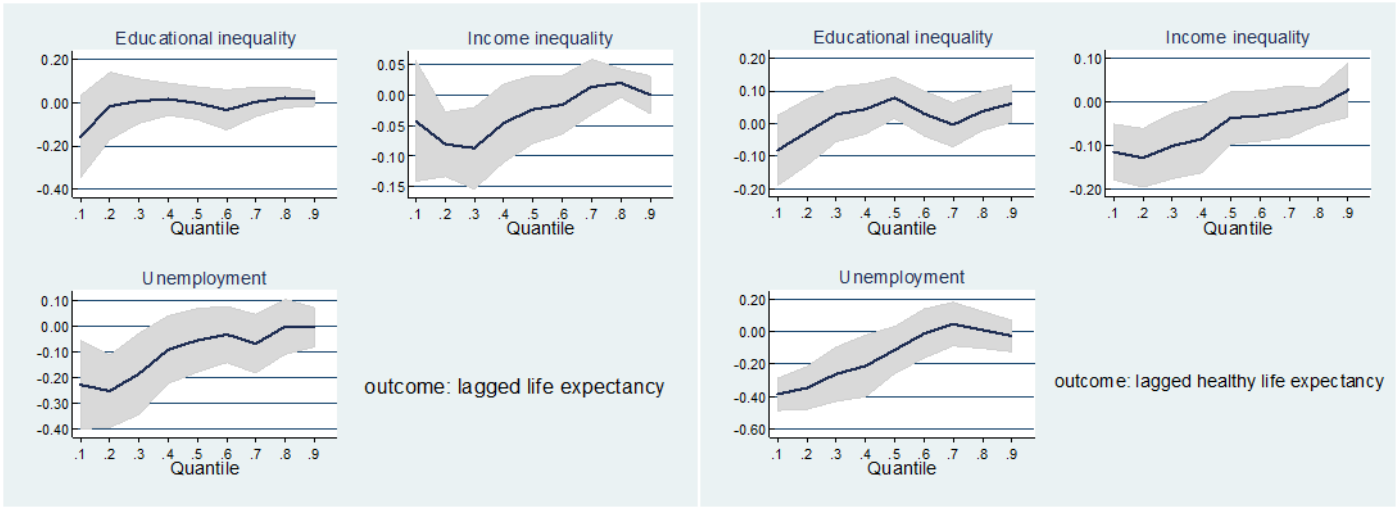
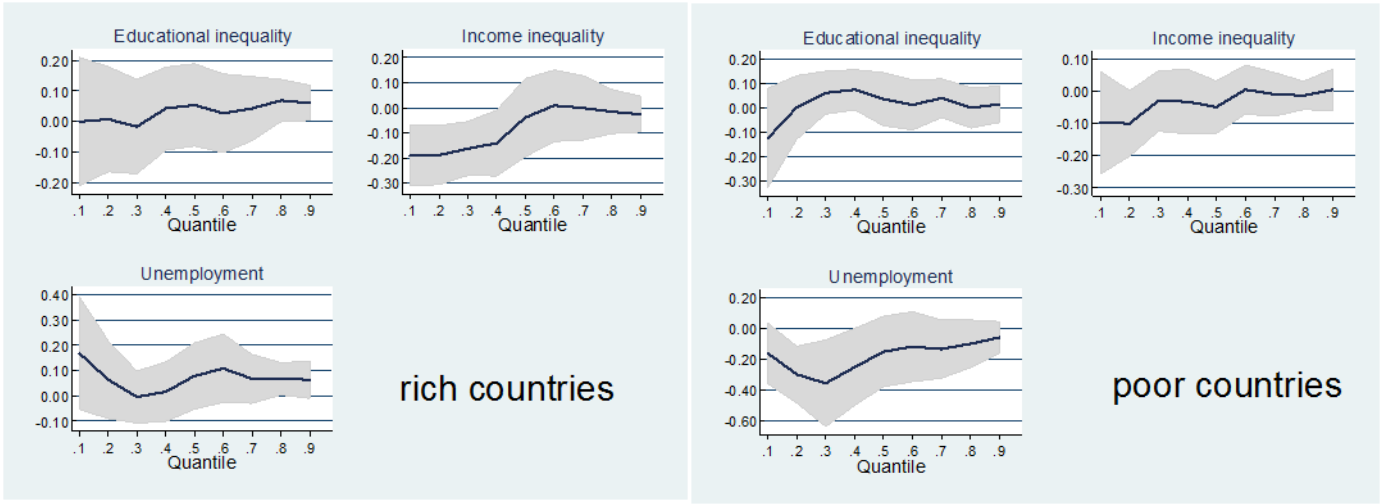


Figure 2 Heterogeneous association between socioeconomic inequality and healthy life expectancy, 90% confidence interval in dash area

Appendix 5 Heterogeneous association between socioeconomic inequality and population health, 90% confidence interval in dash area



Appendix 6 Heterogeneous association between socioeconomic inequality and lagged life expectancy, 90% confidence interval in dash area



Appendix 7 Heterogeneous association between socioeconomic inequality and lagged healthy life expectancy, 90% confidence interval in dash area

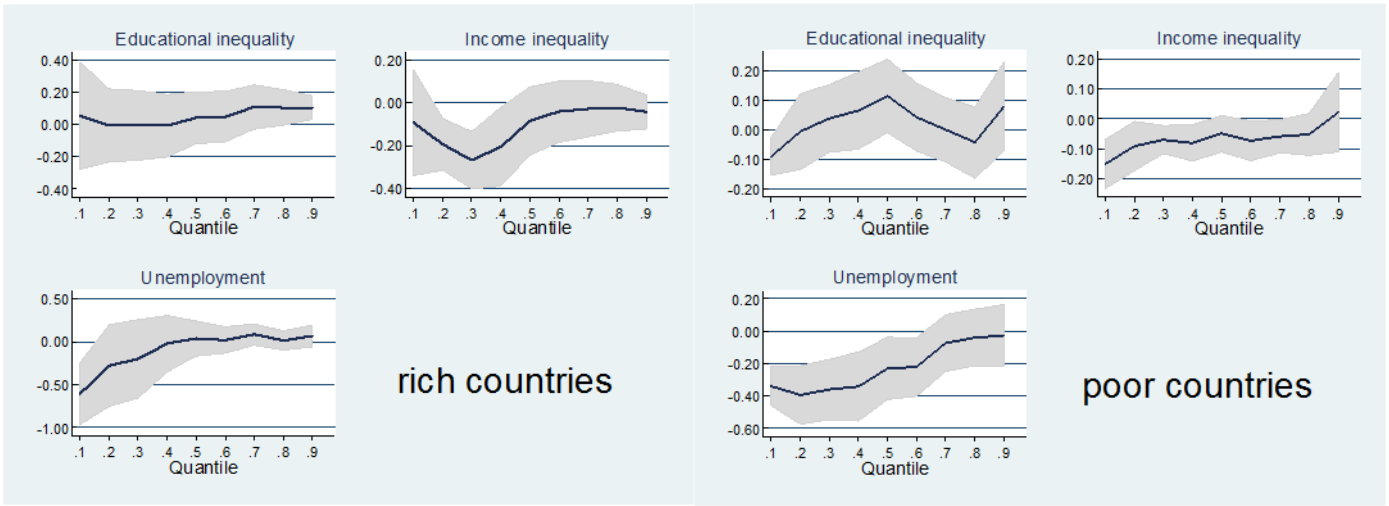


Table 1 Descriptive information of variables used, national averages from 2010 to 2019

Indicators	Unit	2010	2015	2019
Educational inequality	%	21.486	20.124	19.249
Income inequality	%	24.294	24.229	23.614
Unemployment rate	%	8.165	7.832	6.972
Urbanization rate	%	54.929	56.606	57.961
GDP per capita	1000 $	16.480	17.861	19.256
Schooling year per capita	year	7.886	8.366	8.628
Health input rate	%	6.564	6.721	6.628
Life expectancy	year	69.536	71.394	72.414
Healthy life expectancy	year	60.995	62.321	63.206

Table 2 Socioeconomic inequality and population health, mixed regression

	Model 1: LE		Model 2: HLE	
	β	R_SE	β	R_SE
Educational inequality	-0.065^	0.036	-0.012	0.033
Income inequality	-0.063**	0.021	-0.100***	0.022
Unemployment	-0.160**	0.054	-0.224***	0.058
Urbanization	0.019	0.014	0.010	0.015
Ln_ per GDP	5.080***	0.352	3.373***	0.439
Schooling year	0.001	0.181	0.228	0.194
Health input rate	0.142^	0.077	0.124	0.079
Period (=2015)	1.128*	0.501	0.730	0.554
Period (=2019)	1.557**	0.480	1.060*	0.536
Intercept	25.520***	3.139	31.591***	3.670
R_squared	0.749		0.575	
n	480		480	

Note: ^p<0.1, *p<0.05, **p<0.01, ***p<0.001. LE meant life expectancy, HLE meant healthy life expectancy, Ln_ per GDP meant the log transformation of GDP per capita, R_SE meant robust standard error, and the year 2010 was used as the reference for period variable.

Table 3 Socioeconomic inequality and population health, quantile regression

Panel A: LE	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
Educational inequality	-0.233*	-0.061	-0.038	-0.012	-0.017	-0.088^	-0.017	0.013	0.006
	(0.116)	(0.088)	(0.064)	(0.059)	(0.051)	(0.046)	(0.037)	(0.026)	(0.022)
Income inequality	-0.117*	-0.094**	-0.102**	-0.048	-0.033	-0.027	-0.004	0.009	0.018
	(0.058)	(0.033)	(0.033)	(0.041)	(0.030)	(0.025)	(0.024)	(0.019)	(0.019)
Unemployment	-0.268**	-0.236*	-0.166^	-0.087	0.003	-0.015	-0.007	0.041	0.023
	(0.102)	(0.101)	(0.097)	(0.088)	(0.065)	(0.064)	(0.050)	(0.040)	(0.028)
Intercept	-509.4*	-302.7	-224.5	-250.1*	-252.7*	-217.5^	-238.5*	-316.5**	-187.0*
	(217.5)	(194.1)	(137.2)	(124.3)	(123.8)	(129.0)	(115.2)	(108.9)	(86.9)
Pseudo R_squared	0.516	0.532	0.540	0.536	0.529	0.520	0.523	0.528	0.513
Panel B: HLE	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
Educational inequality	-0.068	-0.032	-0.022	0.014	0.031	0.020	0.004	0.037	0.031
	(0.054)	(0.053)	(0.060)	(0.047)	(0.044)	(0.045)	(0.033)	(0.029)	(0.028)
Income inequality	-0.131**	-0.147***	-0.112**	-0.082*	-0.040	-0.036	-0.031	0.008	0.010
	(0.039)	(0.026)	(0.032)	(0.035)	(0.039)	(0.033)	(0.022)	(0.025)	(0.034)
Unemployment	-0.451***	-0.361***	-0.298**	-0.170	-0.131	0.025	0.047	0.044	-0.013
	(0.073)	(0.061)	(0.099)	(0.107)	(0.088)	(0.078)	(0.061)	(0.048)	(0.052)
Intercept	-476.9*	-250.6	-176.7	-152.4	-97.2	-122.6	-102.6	-107.6	-99.9
	(193.0)	(158.5)	(146.7)	(122.4)	(115.8)	(124.2)	(128.4)	(110.3)	(98.4)
Pseudo R_squared	0.403	0.439	0.448	0.437	0.417	0.395	0.378	0.364	0.308

Note: ^p<0.1, *p<0.05, **p<0.01, ***p<0.001. LE meant life expectancy, HLE meant healthy life expectancy. Bootstrap standard error in parentheses, all other covariates were controlled for in the models. The analysis of variance across quantiles in Panel A shows that: F=1.16, p=0.327 for educational inequality; F=3.11, p=0.015 for income inequality; F=2.54, p=0.040 for unemployment rate. The analysis of variance across quantiles in Panel B shows that: F=1.29, p=0.273 for educational inequality; F=2.47, p=0.044 for income inequality; F=9.72, p<0.001 for unemployment rate.

Appendix 1 List of countries used in the paper

Rich countries	Argentina, Australia, Austria, Bahamas, Barbados, Belarus,Belgium, Botswana, Bulgaria, Canada, Chile, Costa Rica, Croatia, Cyprus, Czechia, Denmark, Dominican Republic, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Kazakhstan, Latvia, Lebanon, Lithuania, Luxembourg, Malaysia, Maldives, Malta, Mauritius, Mexico, Montenegro, Netherlands, New Zealand, Norway, Oman, Panama, Poland, Portugal, Republic of Korea, Romania, Russian Federation, Serbia, Singapore, Slovakia, Slovenia, Spain, Suriname, Sweden, Switzerland, Thailand, Trinidad and Tobago, Turkey, United

	Kingdom of Great Britain and Northern Ireland, United States of America, Uruguay
Poor countries	Afghanistan, Albania, Algeria, Angola, Armenia, Azerbaijan, Bangladesh, Belize, Benin, Bhutan, Bolivia (Plurinational State of), Bosnia and Herzegovina, Brazil, Burkina Faso, Burundi, Cabo Verde, Cambodia, Cameroon, Central African Republic, Chad, China, Coate d'Ivoire, Colombia, Comoros, Congo, Democratic Republic of the Congo, Djibouti, Ecuador, Egypt, El Salvador, Eswatini, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iran (Islamic Republic of), Iraq, Jamaica, Jordan, Kenya, Kiribati, Kyrgyzstan, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mongolia, Morocco, Mozambique, Namibia, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Papua New Guinea, Paraguay, Peru, Philippines, Republic of Moldova, Rwanda, Saint Lucia, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, South Africa, South Sudan, Sri Lanka, Sudan, Tajikistan, Timor-Leste, Togo, Tunisia, Turkmenistan, Uganda, Ukraine, United Republic of Tanzania, Uzbekistan, Vanuatu, Viet Nam, Yemen, Zambia, Zimbabwe

Appendix 2 Socioeconomic inequality and healthy life expectancy, mixed regression, international comparison

Panel A: LE	Model 1: rich		Model 2: poor		Difference
	β	R_SE	β	R_SE	
Educational inequality	-0.026	0.054	-0.034	0.048	-0.009
Income inequality	-0.108**	0.040	-0.072**	0.025	0.036
Unemployment	-0.003	0.054	-0.245**	0.071	-0.243*
Intercept	25.127***	6.519	22.021***	4.235	-3.106
R_squared	0.579		0.554		
n	189		291		
Panel B: HLE	Model 3: rich		Model 4: poor		Difference
	β	R_SE	β	R_SE	
Educational inequality	-0.024	0.061	0.004	0.041	0.028
Income inequality	-0.181**	0.054	-0.095***	0.024	0.086*
Unemployment	-0.229*	0.108	-0.315***	0.071	-0.085
Intercept	63.650***	14.629	20.410***	4.070	-43.241***
R_squared	0.258		0.469		
n	189		291		

Note: ^p<0.1, *p<0.05, **p<0.01, ***p<0.001. LE meant life expectancy, HLE meant healthy life expectancy. All other covariates were controlled for in the models. Time of bootstrap was 200 when performing the test of group.

Appendix 3 Socioeconomic inequality and population health, quantile regression, international comparison

Panel A: LE	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
Educational inequality	-0.071	0.046	0.084	-0.003	-0.044	-0.065	-0.036	-0.026	-0.043
Income inequality	0.085	0.084	0.040	0.082	0.010	-0.026	-0.069*	-0.036	-0.030
Unemployment	-0.519*	-0.363*	-0.228	-0.193	-0.202*	-0.214*	-0.185*	-0.180***	-0.123*
Panel B: HLE	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
Educational inequality	0.112^	0.086	0.171*	0.057	0.014	-0.056	-0.102^	-0.113*	-0.027
Income inequality	-0.159**	0.008	0.110*	0.122*	0.010	-0.050	-0.008	-0.003	0.047
Unemployment	0.066	-0.095	-0.223	-0.283*	-0.415***	-0.253*	-0.108	-0.072	-0.088
Panel C: lagged LE	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
Educational inequality	-0.125	-0.007	0.077	0.031	-0.019	-0.016	-0.004	-0.069	-0.048
Income inequality	0.092	0.088	0.132^	0.108^	-0.011	-0.004	-0.010	0.002	0.030
Unemployment	-0.331*	-0.362*	-0.350^	-0.265^	-0.228^	-0.226^	-0.200^	-0.166^	-0.123
Panel D: lagged HLE	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
Educational inequality	-0.146*	-0.000	0.044	0.071	0.072	-0.006	-0.111	-0.148*	-0.027
Income inequality	-0.056	0.105*	0.200**	0.126*	0.037	-0.031	-0.029	-0.028	0.066
Unemployment	0.268*	-0.114	-0.158	-0.317*	-0.266*	-0.238^	-0.157	-0.051	-0.094

Note: ^p<0.1, *p<0.05, **p<0.01, ***p<0.001. LE meant life expectancy, HLE meant healthy life expectancy. Estimated differences between rich and poor countries were reported. All other covariates were controlled for in the models.

Appendix 4 Results of mixed lag-term regression

	Model 1: lagged LE		Model 2: lagged HLE	
	β	R_SE	β	R_SE
Educational inequality	-0.040	0.037	0.007	0.035
Income inequality	-0.045*	0.022	-0.085***	0.023
Unemployment	-0.151**	0.056	-0.221**	0.066
Urbanization	0.010	0.016	0.006	0.017
Ln_ per GDP	4.889***	0.386	3.230***	0.451
Schooling year	0.142	0.184	0.311	0.205
Health input rate	0.179*	0.089	0.214*	0.087
Period	0.287	0.444	0.286	0.489
Intercept	27.179***	3.370	32.433***	3.782
R_squared	0.753		0.578	
n	320		320	

Note: ^p<0.1, *p<0.05, **p<0.01, ***p<0.001. LE meant life expectancy, HLE meant healthy life expectancy, Ln_ per GDP meant the log transformation of GDP per capita, R_SE meant robust standard error.