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ORIGINAL PAPER

Historical trends in suicide risk for the residents of mainland China: APC modeling of the archived national suicide mortality rates during 1987–2012

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Abstract

Purpose Distinctive and dramatic changes in the history of China with a rapid suicide decline in recent years present an opportunity to investigate the risk of suicide. In this study, we investigated suicide risk with a historical perspective with archived data to inform suicide research and prevention policies and strategies.

Method Documented age-specific suicide mortality rates in 1987–2012 were decomposed into age, period, and cohort effect using APC-modeling method and intrinsic estimator (IE) technique. The estimated effects were further analyzed by numerical differentiation.

Results The data satisfactorily fit the constructed APC models. Cohort effect indicated that suicide risk in China fluctuated at very high levels during 1903–1967, followed by a sharp decline during 1968–1977, and reached the lowest level in 1983–1987 before increased again. Period effect confirmed the declining trend since 1987. Three sunny cohorts with reduced suicide risk and four cloudy cohorts with increased risk were, respectively, associated with significant cultural, social, political, and economic events in China since the 1900s.

Conclusions The mega trends in the suicide risk at the population level are closely related to significant historical events in China. Suicide is anticipated to increase because of the growing risk for the young cohorts (particularly young females) as the country further develops. Study findings suggest the significance of national strategies for suicide prevention and control, including maintenance of social harmony and stability, provision of more opportunities for development, enhancement of social integration, and restriction of suicide facilitating factors.

Keywords Suicide research · Social determinants · Historical epidemiology · China · Age–period–cohort modeling

Introduction

Suicide has been a puzzle since the recorded history and remains a challenge in modern society [1–4]. Why a person deliberately ends his or her own life against the instinct desire for survival? Persons who have committed suicide may have the true answers, but it is rather hard if not impossible to collect the data. Alternatively, levels of and time trends in suicide mortality of a population may provide useful evidence at the macro-level. Suicide is multi-faceted, being affected by many factors, particularly cultural, psychosocial [4, 5], and biogenetic factors [6, 7]. Risk of suicide by age provides evidence regarding the impact of factors related to development and maturation across the lifespan [8]; molecular studies add evidence regarding the biogenetics factors [7, 9]. More studies are needed to understand historical, cultural, social, and economic factors to inform

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evidence-based suicide prevention policies and strategies [4].

Opportunities to advance suicide research with data from China

China is traditionally a country characterized with collectivism and high levels of social integration [10, 11]. Since the 1900s, China has experienced a record number of cultural, social, political and economic changes [10] that might be related to suicide. Typical examples include revolutions (e.g., Xin Hai Revolution in 1911) replacing the 2000-year-old feudalism with a bourgeois democratic system [12], and the establishment of the People's Republic of China in 1949; foreign invasions (e.g., Anti-Japanese War, 1931–1945) and civil wars (e.g., Civil War I, 1924–1927; Civil War II, 1927–1937; and Civil War III, 1945–1949); natural disasters and domestic chaos after 1949 (e.g., the 1959–1961 Three-year disasters, and the 1966–1976 Cultural Revolution) [10]; the 1979–2016 One-Child Policy [13]; the initiation of Economic Reform since 1978 [14, 15]; official restriction and ban of various pesticides since the 1990s after using in agriculture for more than two decades [16].

Historical data are needed to examine the relationship between historical events and suicide risk in China, but such data are extremely limited. No national data were collected for over many decades prior to the 1980s when the country was devastated by wars, political movements, social conflicts, and natural disasters. Suicide data reported in the literature are primarily vital statistics which had not been released until 1987 [17–24]. Study findings using the released data indicate that in contrast to Durkheim's modernization–social disintegration theory [25]: (1) suicide risk in China was among the highest in the world prior to the 1990s when the country was economically backward [26–28]; (2) it declined rapidly thereafter, bringing China into the countries with low-suicide rates, along with the well-known rapid industrialization and urbanization [19, 29–31]; and (3) more vulnerable population subgroups selectively experienced greater reductions in suicide, such as women and rural residents [18, 20, 22, 27] probably due to some suicide prevention efforts. A typical example was the restrictions and bans of pesticides, a means most commonly used by rural residents, particularly women for suicide [16]. Another example is the mental health services within the well-known Three-Tier Network of Health Care and Prevention in China with social and educational programs for suicide prevention among rural residents [32].

Despite much information, findings from the studies described above provide evidence on suicide risk only since the 1990s in China. Little is known regarding suicide risk during the 1900–1990 when many cultural, social, political and economic events had occurred but not even one single set of national data were collected for research. Understanding the levels of and time trends in suicide risk during the whole period is likely to provide new evidence, useful to advance suicide research and evidence-based policies and strategies for suicide prevention. One immediate and possibly promising approach to fill in the data gap would be to conduct a historical epidemiologic study to investigate whether and how suicide in China is associated with its significant historical events.

Age–period–cohort modeling and cohort effect on suicide risk

The classic age–period–cohort (APC) modeling [33–36] provides a useful approach to conduct a historical epidemiology study on suicide risk. According to APC-modeling analysis, information for past suicide risk may be in fact contained in more recent age-specific suicide mortality rate data. For example, the suicide mortality rate for a group of people aged 80 years in 1980 may contain the information to assess suicide risk in 1900 when they were born.

In APC-modeling analysis, difference in suicide risk for people who were born in different years is referred to as cohort effect [33–36]. It is this cohort effect that enables researchers to gain insight into the past on suicide risk using more recent data. In this regard, age-specific vital statistics data in more recent times are eventually digital fossils containing the evidence of suicide risk in the past [18, 24]. One primary purpose of APC-modeling analysis is to extract the cohort effect from these digital fossils.

APC modeling and the period and age effect on suicide risk

Despite great potentials to investigate suicide risk historically using more recent data, the birth-cohort effect described above is closely entangled with other two important time-related factors: chronological age and time period. Fortunately, APC-modeling method (detailed in the "Materials and methods" section later) provide an approach to analytically separate the cohort effect from the effect of chronological age (age effect) and time period (period effect) [34, 35, 37–40]. The estimated age, period and cohort effects are also statistically mutually independent and can easily be interpreted, because they can be expressed either as log linear regression coefficient or odds ratio.

In addition to cohort effect, period effect provides a net measure of suicide risk over time, after controlling for age and cohort effect. Therefore, period effect provides an unbiased measure better than annual suicide rates to assess time trends, because period effect is not biased by age and birth cohort [24, 41–43]. China has experienced huge changes in population composition due to the One-Child Policy since the 1970s [13] and the rapid economic growth and quick industrialization and urbanization in the past decades [44]. Age-standardized rates are used in studying suicide mortality in China [17, 45]; however, standardized rates remain biased by another time-related factor: birth cohort. People in different ages in a year were born in different years, their suicide risk are affected by the time when they were born.

APC-modeling analysis also provides data on age effect for suicide. Like period and cohort, age effect derived from APC modeling is a net measure of changes in suicide risk along with chronological age with multiple waves of data after controlling for period and cohort effects. Therefore, age effect estimated through APC modeling is statistically unbiased and robust to describe age patterns of suicide risk, better than age-specific rates [24, 41–43].

Previous APC modeling of national suicide mortality in China

A thorough review of the literature in both English and Chinese, we have located only one APC-model-based suicide study using the vital rates in China by Wang and colleagues [17]. Wang and his colleagues handled the non-identifiability issue of an APC model by further decomposing the effects of chronological age, time period and birth cohort each into a linear and a nonlinear component [34]. This approach permitted the authors to obtain the age, period and cohort effects while avoiding the non-identifiability issue.

Despite the methodological innovation, the focus of Wang's study was not on the impact of histological events on suicide risk; therefore, the study provided no data regarding the relationship between significant historical events and suicide risk in China. Furthermore, the authors pointed out that the age effect from their study might not be valid, because the suicide risk was substantially higher for people aged 15–39 years than for those aged 50 and older [34], while a reverse was true by the observed age-specific suicide rates used in the study and reported results by others in many countries [46–48]. Finally, although some of the findings from that study were consistent with the literature, such as a declining period and cohort effects, and significant rural–urban and male–female differences in suicide risk [18, 20]; the estimated effects are either linear or curve liner with a very smooth pattern. More rigorous methods are needed to advance the analysis.

A new method for solving an APC model

Most published suicide studies simply present suicide rates over time, overall and by subpopulation groups and geographic areas [19–23, 28, 31, 45, 49], few used APC-modeling analysis. A significant barrier to APC modeling is the non-identifiability problem inherited from the complete collinearity among the three predictors (i.e., age = period − cohort) [33, 36]. Even for many published studies on suicide risk in other countries [39, 50–53], the validity of the findings remains an issue as many authors often admitted, including the only APC-modeling study of suicide mortality rates in China [17].

A new method named intrinsic estimator (IE) provides an alternative to deal with the collinearity problem in APC-modeling analysis [33, 36]. There is no additional assumption for IE method; the restriction for solving model parameters is a minimum; and the estimated effects with the method can be interpreted like in a logistic or log-linear regression [34, 54]. With the IE-based APC-modeling approach, more studies are reported now in investigating suicide risk with a historical perspective in the United States and other countries [24, 41–43].

Purpose of this study

The purpose of this study is to fill the data gaps regarding suicide risk in China, to advance our understanding of suicide risk from a historical epidemiological angle, and to provide evidence at the macro-level supporting policies and strategies for suicide prevention. In addition to the overall population, analysis for significant subgroups was emphasized, including male and female gender, urban and rural residence, and the four combinations of the two.

Materials and methods

Data sources and processing

Age-specific mortality rates during 1987–2012 were derived from the *China Health Statistical Yearbook*. Suicide deaths were collected from the Vital Registration System and the Health and Family Planning Commission of China and population data were from China National Census and random sample surveys. The ICD-10 (the 10th version of the International Statistical Classification of Diseases and Related Health Problems) has been utilized in China to determine the causes of death [55] and a death was coded as suicide if it met any of the following ICD-10 codes: X60–X84 (intentional self-harm, including hanging, drowning, jumping, poisoning, burning, cutting, shooting), Y10–Y19 (self-poisoning with undetermined intent), Y20–Y34 (other events of undetermined intent), and Y87.0 (later effects of self-harm).

Suicide rates (1/100,000) were computed as the number of suicide death over the population, overall and by 5-year age group. We limited the age-group range from 10–14 years to 80–84 years with a total of 15 age groups. The last age group 85+ was excluded, because APC model cannot handle open-ended age group [33, 34]. With data for participants aged 80–84 in 1987, we can assess suicide risk as early as 1903–1907 (1987–84 = 1903 and 1987–80 = 1907). In addition to the total population, rates by sex (male and female), residence (urban and rural) and four combinations of the two were included.

In conventional APC-modeling analysis, 5-year average rates are used [34, 35, 42], including suicide studies [17, 56–58]. A limitation to this approach is that persons in a 5-year age group within 5-year period were born in a 10-year range as show in Supplementary Appendix Fig. F1a. Therefore, this approach will reduce the time precision to describe suicide risk as seen in previous study [17]. To overcome this limitation we used single-year data, 5-year apart in 1987, 1992, 1997, 2002, 2007, and 2012. As shown in Supplementary Appendix Fig. F1b, persons in a 5-year age group in 1 year were all born within 5 years, exactly matching the cohort period but the time precision was doubled [24].

APC-modeling analysis

Let r_{ijk} be the documented suicide rate for a person in age group i, period j and cohort k. By definition, $r_{ijk} = \frac{d_{ijk}}{n_{ijk}}$, where d_{ijk} and n_{ijk} were the number of suicide deaths and the at-risk population, respectively. Assuming that suicide in a population is a rare event, the Poisson log-linear model was used:

$$\log\left(\frac{d_{ijk}}{n_{ijk}}\right) = \mu + \alpha_i + \beta_j + \gamma_k,$$

where μ denotes the intercept; α_i denotes effect of age group i (i = 10–14, 15–19, …, 80–84); β_j denotes the effect of time period j (j = 1987, 1992, …, 2012); and γ_k denotes the effect of birth cohort k (k = 1903–1907, 1908–1912, …, 1998–2002).

With this model specification, a total of 42 parameters were estimated (a grant mean μ, 15 a effects, 6 β effects, and 20 γ effects) using the IE method [33, 36, 42]. The data-model fit was evaluated using the fit deviance, AIC and BIC. The modeling analysis was conducted using the STATA-based software package apc_ie assuming a Poisson distribution.

Numerical differentiations in estimated effect

To visually describe changes in suicide risk efficiently along with age, period and cohort, numerical differentiation was performed over the estimated log-linear effects [24]. In plotting the data, y-axis was reversed such that an upward trend indicates a Sunny age group-time period-birth Cohort with a declining suicide risk and a downward trend indicates a Cloudy Cohort with growing suicide risk.

Results

The age-specific suicide mortality rates data satisfactorily fit all constructed APC models. The fit statistics and the estimated effects for age, period and cohort were included in the Supplementary Appendix Table T1.

Trend of suicide mortality

Results in Fig. 1 indicate that during 1987–2012, suicide mortality rate for the total population (square-dotted line) declined from 23.3 to 7.4 with more reductions for rural residents (27.7–8.6) than for urban residents (9.8–4.8), and more for females (27.5–9.8) than for males (19.4–7.9). It is worth noting that the annual rates were biased if used for describing time trends.

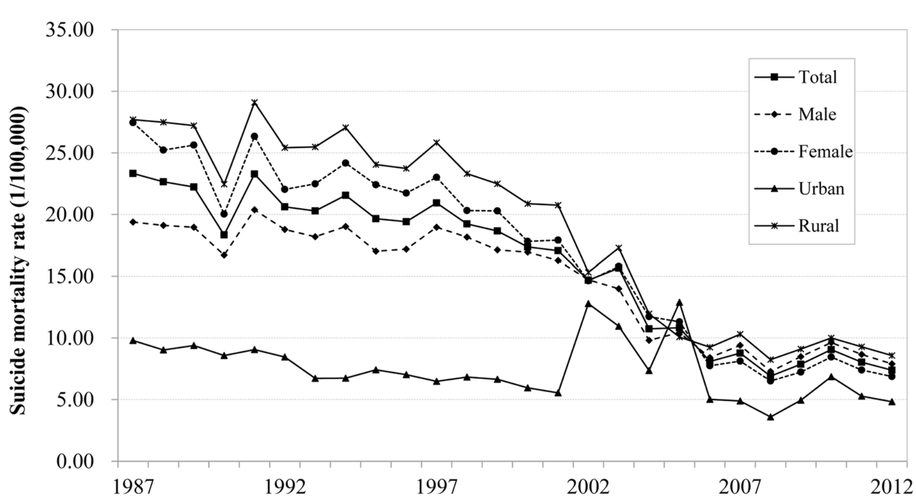

Fig. 1 Suicide mortality rate (1/100,000) among Chinese residents aged 10–84, overall and by sex (male and female) and residence (urban and rural), 1987–2012, PR China. Data source: Prepared with data from China Statistical Yearbook

Cohort effect of suicide risk

Figure 2 presents the cohort effect by birth-year starting from 1903–07 to 1998–2002, including the effect level (the solid line) and speed of change (the dashed line). Overall the cohort effect can be divided into four segments: (a) a growing segment during 1903–1927; (b) a flat segment with fluctuations during 1927–1967; (c) a rapid declining segment during 1968–1987; and (d) ended with an upward trend since 1988.

Changes in the cohort effect (dashed line in Fig. 2, vertical axes on right) indicate roughly three segments with accelerated reduction (upward) in suicide risk. They were (1) the 1928–1932 Civil War II Cohort; (2) the 1953–1962 Early China Cohort; and (3) the 1968–1977 Cultural Revolution Cohort. We termed them as Sunny Cohorts. Likewise, by ignoring some small fluctuations, four segments with accelerated increase (downward) in suicide risks were: (1) the 1913–1917 Post-Xin Hai Revolution Cohort; (2) the 1933–1952 Mixed Cohort (covering the Anti-Japanese War, Civil War III and establishment of New China); (3) the 1963–1967 Prior-Cultural Revolution Cohort; and (4) the 1978–2002 Economic Reform Cohort. We termed them as Cloudy Cohorts.

The cohort effect differed by gender and residence (Fig. 3a). There were two cross-overs in the cohort effect by gender, one during 1933–1937 and another during 1983–1987. The suicide risk was greater for males (square-dotted line) than for females (round-dotted line) before the first crossover and after the second crossover, while a reversed pattern was true in between during 1937–1983. Interestingly, the cohort effect for rural residents (triangle-dotted line) matched well with that of the total population (dashed line), although higher than that of urban residents for most cohorts except for those younger than 1923 and older than 1978.

Figure 3b indicates some gender differences in cohort effect for both urban and rural residents. Rural females (triangle-dotted line) started with the lowest suicide risk, passed urban females in 1918–1922, reached highest level in 1963–1967, and dropped to lowest level during 1993–1997. Gender differences among urban residents were relatively smaller with higher risk for males (diamond-dotted line) than for females (round-dotted line). Surprisingly, there was a sudden increase in suicide risk for the 1998–02 cohort, particularly for urban females.

Period effect of suicide risk

Figure 4 shows that the period effect (solid line) showed a two-phase reduction with a slow phase before 1997 and quick phase thereafter. Changes in the period effect (dashed line) depict the sharp accelerated reduction in suicide risk during 1997–2007. Figure 4b indicates a zig-zag pattern for urban residents (diamond-dotted line); and the effect for rural residents (triangle-dotted line) was close to national average (dashed line). A crossover in the period effect between males (square-dotted line) and females (circle-dotted line) with higher risk for females before 1997 and the relationship was reversed after 1997. The same urban–rural difference by gender is also presented in Fig. 4.

Age effect of suicide risk

Figure 5a shows that the estimated suicide risk (solid line) increased before age 25, declined after 25 to the lowest at around age group 40–44, followed by a progressively increase. Accordingly, changes in age effect (dashed line) indicates that age 15–19 were cloudy with the quickest

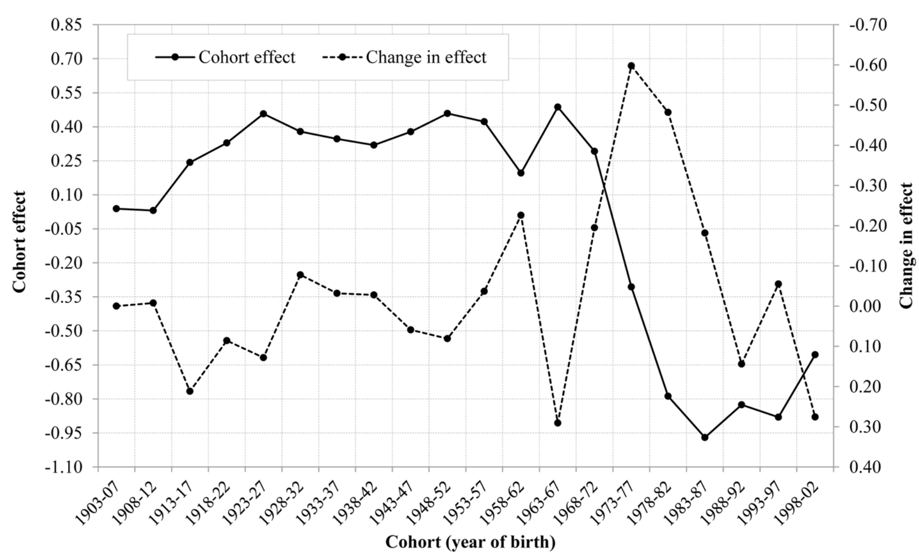

Fig. 2 Cohort effect of suicide risk for Chinese born during 1903–2002, results from APC-modeling analysis of 1987–2012 data. Cohort effect refers to the estimated log-linear coefficients for cohort; change in effect refers to the relative change of cohort effect over time

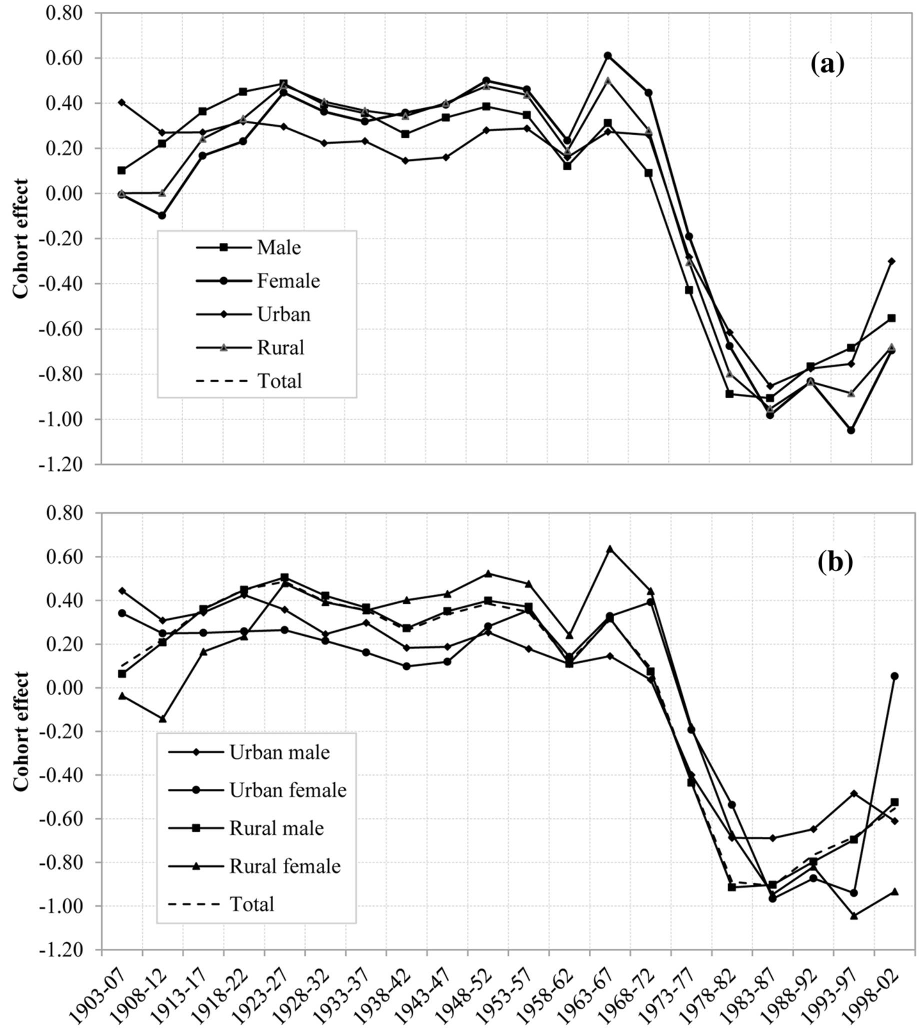

Fig. 3 Differences in cohort effect of suicide risk by male and female and urban and rural as well as urban male, urban female, rural male and rural female. Cohort effect refers to the estimated log-linear coefficients for cohort

increase in suicide risk; age 25–29 were sunny with the quickest reduction in suicide risk; the rest ages thereafter were cloudy.

Figure 5b, c shows that the age pattern of suicide risk was similar between males and females, urban and rural residents with some appreciate differences at age range 15–34.

Discussion

In this study, we investigated the risk of suicide mortality of the Mainland Chinese dating back by birth cohort to 1903, with archived mortality rates during 1987–2012. In addition to the overall population, results by gender, residence and combinations of the two are generated. APC-modeling analysis was conducted with multiple 1-year data 5-year apart with enhanced time precision for cohort effect. Non-identifiability problem was handled with the state-of-the-art IE technique to ensure the validity of the estimated parameters.

Megatrends in suicide mortality risk in China since 1903

Findings of this study provided systematic data regarding the suicide risk over a period of 110 years during 1903–2012, of which 25 years (1987–2012) were based on data collected during 1987–2012, and 100 years (1903–2002) were based estimated effects (with a 15-year overlap for 1987–2002). Supportive to several other studies [17, 19, 22, 23, 31, 58], the estimated cohort and period effects of this study suggest that changes in the suicide risk in China during 1903–2012 can be divided into three phases: (a) high-risk phase before 1949; (b) transition phase during 1949–1977; and (c) low-risk phase since 1978.

The high-risk phase lasted for half a century, corresponding to a chaotic and suffering time by foreign invasion, civil wars, and other natural, cultural and political disturbances. For Chinese who were bounded by collective cultures, these events would have radically dissolved the social integration, proving Durkheim's suicide theory of social disintegration

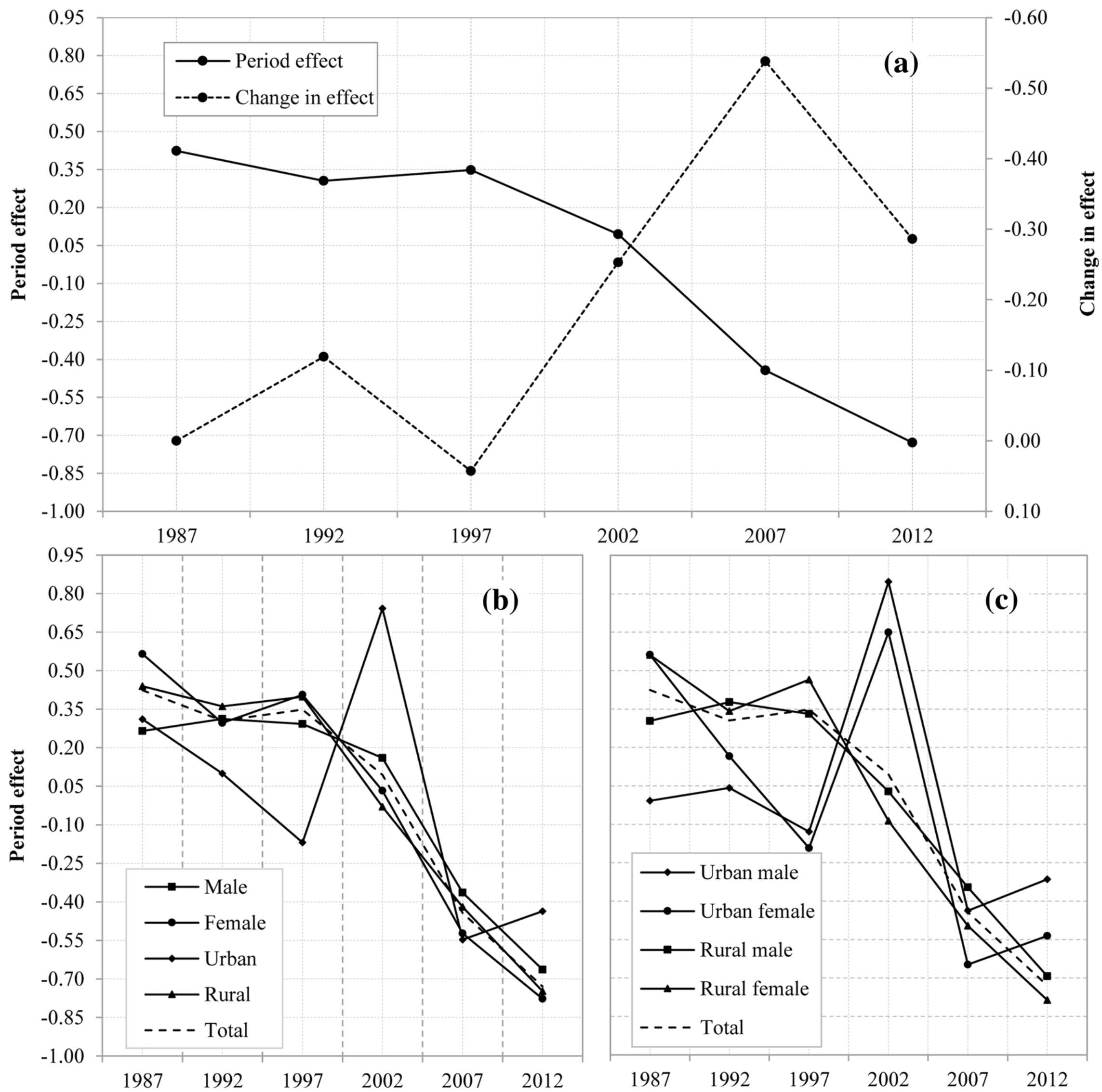

Fig. 4 Period effect of and changes in the suicide risk during 1987–2012 among Chinese population aged 10–84 and difference by gender and residence. Period effect refers to the estimated log-linear coefficients for period; change in period refers to the relative change of estimated log-linear coefficients for period

[25] from the other way—not due to development but catastrophic and destructive cultural, social, political and economic events. This high suicide risk period is also in line with the strain theory proposed by Zhang and colleagues, which posits that suicide risk is related to various strains, including recourse for survival, value conflict, and personal freedom [59, 60].

The transition phase (1949–1977) lasted for 28 years with the suicide risk fluctuated at a very high level up to 1967 before it plunged down. This was the period when China rebuilt its country while dealing with international, domestic and natural disasters during the first two-thirds, followed by the 10-year cultural revolution. The overall declining trend in suicide risk during this period can be explained by both Zhang's strains theory [59, 60] and Stack's opportunity theory [58, 61, 62]. This is the period when China gained its independence and the country returned to peace. People all over the nation returned home to rebuild the war-torn families, communities and society with increased resilience against stress, reduced strains for suicide, increasing opportunities for survival [25].

In addition, common people were valued highly spiritually during this period. Despite the poor economy, people hold the greatest hope about their future [11]. Although intellectuals, governmental officers and business leaders were suffered, the impact did not show up in our data probably because these people only counted a small proportion of total Chinese population. A similar result was also

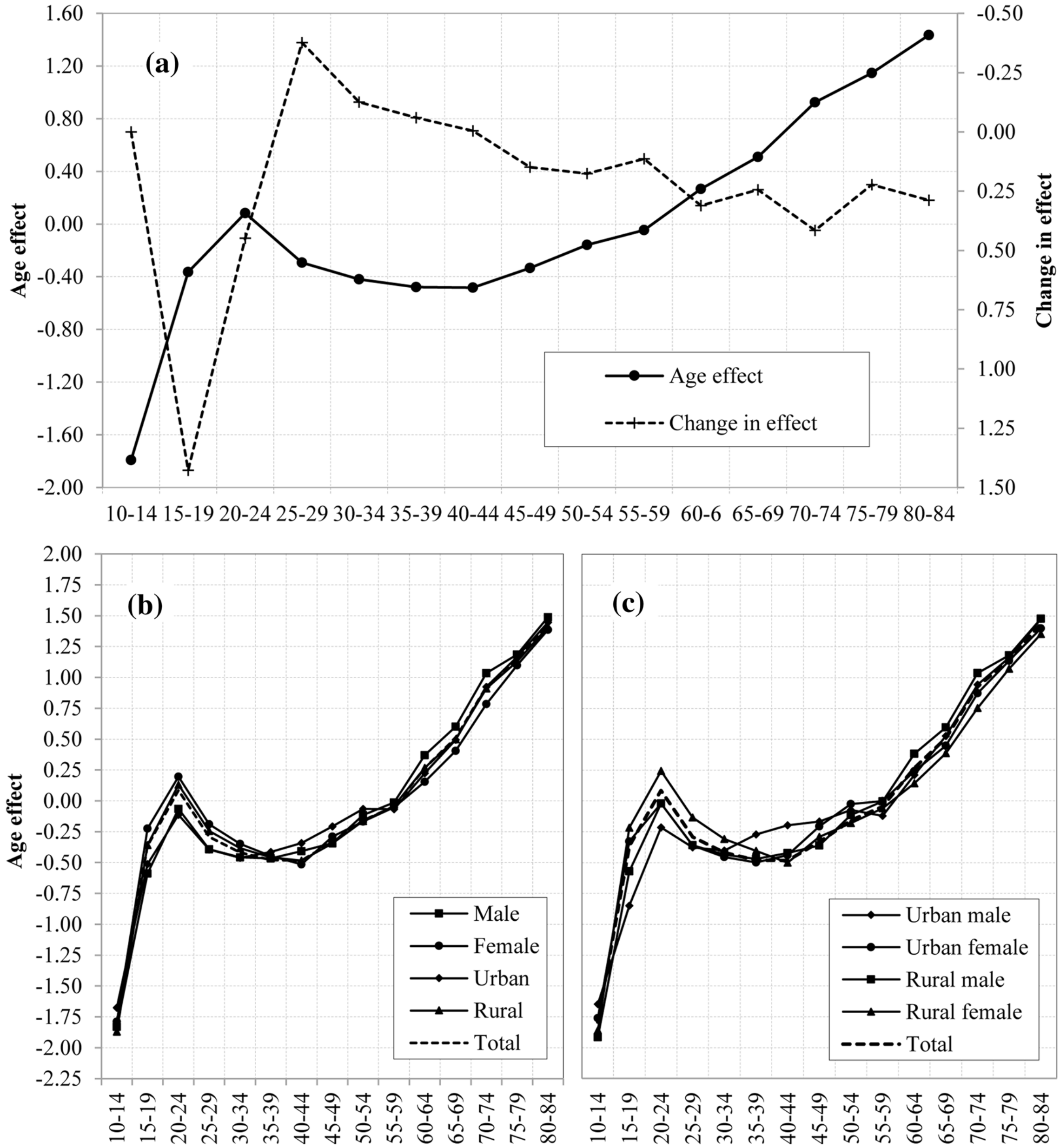

Fig. 5 Age effect of and changes in the suicide risk during 1987–2012 (**a**), and difference age effect by gender and residence (**b**) and the combination of gender by residence (**c**). Age effect refers to the estimated log-linear coefficients for age; change in effect refers to the relative change of estimated log-linear coefficients for age

observed in another study to analyzing risks for the total mortality in China [24].

A last but not the least explanation of the rapid suicide risk decline could be attributed to the Free Healthcare System for urban residents and the Primary Healthcare Systems backed by barefoot doctors for rural residents [24]. Although the services were really primary, these systems might have greatly enhanced opportunities for survival and reduced risk of mortality, including suicide death.

The low-risk period (1978 and later) was corresponding to the ongoing *Economic Reform* initiated in 1978, followed by a rapid growth in industrialization, economy and urbanization [14, 15, 63]. Opposite to Durkheim's theory, findings of our study support Stark's opportunity theory [58, 61, 62] and Zhang's strain theory [59, 60]. The lower suicide risk could be due to great improvement in quality of life due to sustained economy growth, rapid industrialization and urbanization, minimizing the risks for suicide

[22, 59] and maximizing the opportunity for survival [58, 61]. Our findings are also in consistence with Rubenstein's dynamic diathesis–stress theory [64]. The lower suicide risk during this period could be related to the collective and integrative culture in favor of fostering resilience and skill for people to cope with stressors [64–66], reducing suicide risk.

Linkage of significant historical events with the Sunny and Cloudy cohorts

In addition to the mega trends, one important finding is the discovery of three Sunny Cohorts and four Cloudy Cohorts. There three Sunny cohorts are (1) the 1928–1932 Civil War II Cohort associated with domestic wars; (2) the 1953–1962 Early China Cohort associated with the period after China gained independence; and (3) the 1968–1977 Cultural Revolution Cohort associated with domestic political movement; the four Cloudy Cohorts were (1) the 1913–1917 Post-Xin Hai Revolution Cohort associated with wars and political movement to remove the 1000-year-old feudal system; (2) the 1933–1952 Mixed Cohort associated with the Anti-Japanese War, Civil War III, and early years of New China; (3) the 1963–1967 Prior-Cultural Revolution Cohort associated domestic and international social and natural disasters; and (4) the 1978–2002 Economic Reform Cohort associated with the rapid growth and development after the open policy and economic reform.

Although linking these cohorts to more specific historical events can deepen our understanding of the influential factors on suicide risk, caution is needed when interpreting these cohort effects tracing back in time. Cohort effect provides a measure of suicidal risk associated with birth-years based on information stored in the corresponding birth cohort. Findings of this and previous studies support this interpretation [24].

Finally, we cannot ignore the cloudy Economic Reform Cohort—those Chinese who were born after 1987, particularly the females in urban areas. Different from the low-suicide risk for the total population, suicide for this cohort increased during this period given the economic growth and development. Consistent with theories regarding cohort effect [67–69], this cohort was more vulnerable to suicide because of extra parental care, highly self-centered personality, and limited opportunities for developing resilience [70, 71]. It was harder for them than their parents to make significant achievements despite better education and more opportunities. Starting with a high living standard also made them less likely to feel satisfied than their parents. This cohort is the hidden risk for suicide to increase in China in the future [72].

The estimated period effect for the recent reduction in suicide risk

As being discussed in detail in the Introduction and the Methods section, time trends based on the period effect is more valid than annual rates to describe time trends, because annual rates are confounded by age and cohort effect. In contrast to the finding of a smooth decline in suicide risk by others [17], the estimated period effect in the current study indicates a quicker reduction in suicide risk before 1997 and slower reduction after 1997, consistent with the scaled-up economic growth in China after 1997 as well as the suicide prevention efforts for pesticides regulations and ban [16].

The period effect for rural residents was similar to the national total, while the same effect for urban residents showed a large peak during 1997–2007, corresponding to the large-scale marketization of state-run firms and labor market reform beginning in 1997 with millions of urban workers becoming jobless [14, 63]. This period effect supports Stack's opportunity theory [58, 61, 62]. Finally, the suicide prevention programs targeting rural women by restricting and banning pesticides (the major source of self-poisoning particularly for rural women) since the 1990s [16] may also contributed to more reduction in suicide risk among rural females.

The estimated age effect for measuring suicide risk by chronological age

Opposite to the age pattern reported by another study in China [17], the age effect observed in this study reflects the age pattern of suicide risk as seen by the age-specific mortality as well as the estimated effect in many other countries in Europe [51, 73], North America [39], Australia [53], and Asia [40, 47]. From age 10, the risk increased rapidly and peaked at age 20–24, followed by a progressive decline, reaching the lowest level at age 40–44, and followed by a progressive increase. The age pattern for Chinese was also observed among Brazilians [52], while the suicide risk in other countries declined further after age 40–44 [39, 40, 51, 73].

The progressive increase in suicide risk after ages 40–45 can be explained by most theories regarding suicide. According to the Zhang's theory of strains [59, 60] and Stack's theory of opportunity [58, 61, 62], when a person gets older, his ability to live and work will deteriorate, he/she may feel more strains and less opportunity in life. Following Durkheim's social integration theory [25], after retirement, a person has cut of a major connection with the society, increasing suicide risk. According to Rubinstein's dynamic diathesis–stress theory [64], when people get older, they become more pessimistic and less resilient, thus more likely to commit suicide after exposure to internal (e.g., sick, disabled) or external strains (e.g., being stigmatized).

Limitations and conclusions

There was a lack of archived suicide data by single-year of age, preventing this study from investigating the cohort effect in more detail and more associate with historical events with more accurate points in time. More importantly, APC modeling of aggregated data cannot replace studies using individual data to test various study hypotheses. However, findings from such analysis, if conducting correctly, provide useful data supporting in-depth research with individual participant-level data. Despite the limitations, this study examined suicide mortality rates in China with APC-modeling method with IE technique to handle the identifiability problem, capitalizing on rapid social changes since the 1900s in China and the archived data since the 1990s. Study findings are supported by many well-known theories and consistent with the mega historical events in China. In addition to deepening our understanding of the suicide epidemiology, findings of this study provide evidence supporting policies and strategies at the macro-level for suicide prevention and control.

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Author contributions XC initiated the idea and worked with the team to establish the framework, guided data analysis, write most of the manuscript. YS participated in framing the research, collected data and participated in data analysis, results interpretation and manuscript development. ZL participated in later-stage in reframing the research topic, collected part of the data, and conducted most of the analysis, contributed much for manuscript preparation. BY and GG assisted in literature search, data analysis, results tabulation and graphing, manuscript writing and reviewing. PW participated in results interpretation and manuscript development.

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Compliance with ethical standards

Conflict of interest None of the authors has a conflict of interest associated with the reported research.

Availability of data and material The data sets generated and/or analyzed during the current study are available in the NHFPC (National Health and Family Planning Commission of the People's Republic of China) repository, http://www.nhfpc.gov.cn/zwgk/tjnj1/ejlist.shtml, and published on Annual *China Health Statistical Yearbook*, which renamed as *China Health and Family Planning Statistics Yearbook* from year 2014.

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