Use of the average age ratio method in analyzing age heaping in censuses: The case of China

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ABSTRACT: Based on the methods of the average period age ratio and the average cohort age ratio, this study systematically assesses age heaping or digit preference in all population censuses of China. Our study finds that the overall age heaping was relatively low in the Chinese censuses; however, there was a notable preference for ages ending with zero after age 50 in the first two censuses, despite a weakening trend over time. Our study further shows that age heaping in China’s censuses is likely associated with age-related policies such as those on late marriage and retirement. As shown in the study, the average age ratio method can be an alternative of the Whipple’s Index and be improved if the size of birth cohort was taken into account when the number of births is generally reliable.

Keywords: Age concentration index; Age heaping; age ratio; Age reporting; Average age ratio; Average period age ratio; Average cohort age ratio; China; Census; Digit preference; Digit avoidance; Whipple’s index; Myer’s blended index

1. Introduction

Censuses are foundational data sources for population studies, the accuracy of which determines the validity and reliability of demographic research (Moultrie, Dorrington, Hill et al., 2013; United Nations, 1983, 2008). Throughout the procedure of census, errors may occur on many occasions such as age reporting and recording. Age reporting may suffer from two types of errors, intentional and unintentional misreporting. Unintentional misreporting mainly refers to the situation where the interviewee does not know or could not remember the exact birth date. By contrast, intentional misreporting occurs when the interviewee, though knowing the exact birth date, chooses to “avoid” or “prefer” certain digits in reporting of his/her age (commonly known as digit preference), due to personal, cultural, and social considerations (Moultrie, Dorrington, Hill et al., 2013; United Nations, 1983). For example, in a society where vital registration is underdeveloped, a young person who has not reached the minimum legal age for marriage may report an older age in applications to join the military, and some older adults may exaggerate their ages for the legitimacy of retirement welfare. Unintentional misreporting is mainly random, and thus, it will not cause a severe bias in results. However, intentional misreporting would lead to “age heaping,” a situation in which the population at a certain age or an age ended with certain digit significantly outnumber populations at adjacent ages or ages ended with other digits (Moultrie, Dorrington, Hill et al., 2013; Spoorenberg, 2007). This would introduce inaccuracy in the age statistics of population studies. Although the data quality...
of age reporting is also affected by census enumerators and the household registration management and archiving, these errors are often systematical biases and thus may not generate “age heaping” in practice.

1.1. Common Methods for Checking Age Heaping

Some common methods to examine the data quality of age reporting in census include the Whipple’s Index (Whipple, 1919), the Myers’ Blended Index (Myers, 1940), the Bachi’s Index (Bachi, 1954), the Carrer’s Index (Carrier, 1959), the Ramchandran’s Index (Ramachandran, 1965; Shryock and Siege, 1973), and the UN Age-sex Accuracy Index (United Nations, 1952). The Whipple’s and Myers’ Blended indexes are among the most commonly used methods to check digit preferences or age heaping (Spoorenberg, 2007). The conventional Whipple’s Index checks digit preferences for ages ending with digits of 0 and 5, and the modified Whipple’s Index could check digit preferences for ages ending digits other than 0 and 5 (Spoorenberg, 2007). The Myers’ Blended Index also can be used to check digit preferences. The UN age-sex Accuracy Index is designed to assess the overall quality check of age reporting, not particularly for checking age heaping (United Nations, 1983). The details of these methods and their applications can be found in common demographic textbooks and above literature, and thus, they are not repeated herein.

In the existing literature, the age ratio method is only used in checking a segment of age ranges such as the adjacent five ages, instead of the whole age range at adulthood ages, such as the Whipple’s Index, and thus it has not commonly been used to check digit preferences in age-reporting. In this study, we argue that age ratio method may be a good alternative for checking the digit preference or age heaping in age reporting from population censuses, vital registration, and/or sample surveys with large-scale and high representativeness.

1.2. Literature on Age Heaping Studies in China

Age heaping in China’s censuses has been frequently considered as one major research theme among Chinese demographers, with a vast majority of studies using the Whipple’s Index (Guo and Che, 2008; Li, 2012; Ma, 1984; Qiao, 1993; Qiao and Li, 1993; Li, Qiang and Yang, 1993; Wang, 2012; Wu and Gan, 2013; Yang, 1988; Zha and Qiao, 1993; Zhai, 1987). Most of these studies revealed that the overall age heaping was minor in Chinese censuses, with a few exceptions in the ethnic minorities. Enlightened by Keyfitz’s “demographic discontinuity” theory (Keyfitz, 1987), Huang (1993, 2009), and Huang and Xiao (2009) investigated the digit preference through calculating the frequency of distribution of signs (+/-) on each digit based on the age-specific first- or second-order difference in its proportional share of population. The first-order difference in the population proportion for age \( x \) is the difference in population between age \( x \) and \( x+1 \). One limitation of this method is that a negative sign of a given age \( x \) can be due to underreports at age \( x \), or due to overreports at age \( x+1 \), or due to both. The second-order difference is the difference between age \( x \), age \( x+1 \), and age \( x+2 \), which also suffers from the limitation above. Nevertheless, all these previous studies have contributed to our understanding of age heaping and the accuracy of aging reporting in censuses of China.

Except for the Huang’s method of differential signs, all methods assume that the changes of the study population are in a stable and smooth manner. For example, both the conventional and modified Whipple’s Indexes assume that the population change linearly (Spoorenberg, 2007). If the population changes were not smooth, both the conventional and modified Whipple’s Indexes would produce somewhat biased results. However, affected by natural disasters, extreme weathers, and birth planning policies since the 1950s, the population of China witnessed irregular changes in annual births and deaths. Such irregular population changes will bring forward errors in the application of the routine methods and undermine the research validity in demographic analyses. Another limitation of these methods is the lack of validation across multiple censuses. A more effective method is thus needed to investigate digit preferences for populations with irregular changes, and for age heaping in general as well as at some specific ages. This paper proposes an extended age ratio method to fill this gap and uses the census data of China for an empirical illustration and validation.

2. Data and Method

We used an extended age ratio method, consisting of the average period age ratio (APAR) and the average cohort age ratio (ACAR), to examine age heaping for Chinese censuses in the years of 1953, 1964, 1982, 1990, 2000, and 2010. The data of single year of age by sex in these six censuses were obtained from the National Statistical Bureau of China (1983, 1992, 2002, 2012).

2.1. Average Period Age Ratio (APAR)

- Step 1: Calculate the period age ratio
  
  For a given census, we calculate age ratio for a certain age based on the five consecutive single years of age (three, seven, or nine ages are also applicable):
\[ AR(x,t) = \frac{5*P(x,t)}{P(x-2,t) + P(x-1,t) + P(x,t) + P(x+1,t) + P(x+2,t)}, \]  
\[ C(x) = \frac{5*B(t-x)*L(x)}{B(t-x+2)*L(x-2) + B(t-x+1)*L(x-1) + B(t-x)*L(x) + B(t-x-1)*L(x+1) + B(t-x-2)*L(x+2)}, \]

where \( t \) is the census year, \( P(x,t) \) is the enumerated number of population at the age \( x \) in the census year \( t \), and \( AR(x,t) \) is the age ratio at the age \( x \) in the census year \( t \), also called as the age concentration index. If numbers of births in these five cohorts are similar (or change in a stable manner) and the following changes are even, the age ratio should be equal or close to 1. If the age ratio is larger than one to a significant degree, the population at the age \( x \) should exceed populations at the other adjacent four ages (concentration); if the age ratio is smaller than 1 to a significant degree, the population at age \( x \) should be smaller than populations at the other adjacent four ages.

However, it is possible in reality that the population at a certain age may vary greatly in size as compared to populations of neighboring ages (e.g. in the baby boom and baby bust periods). That means that the value of the age ratio may deviate from one, even though there is no age misreporting. On the other hand, when age misreporting presents, it is yet possible that the age ratio is close to one at certain ages, because populations at these ages might be lower (or higher) at birth in contrast to other ages. Therefore, in the cases when the number of births varies greatly by cohort and when these data are available, it is better to further adjust the age ratio by the number of births and/or survival rates of the neighboring cohorts:

\[ AR'(x,t) = \frac{5*P(x,t)}{P(x-2,t) + P(x-1,t) + P(x,t) + P(x+1,t) + P(x+2,t)} / C(x), \]  

where

\[ C(x) = \frac{5*B(t-x)*L(x)}{B(t-x+2)*L(x-2) + B(t-x+1)*L(x-1) + B(t-x)*L(x) + B(t-x-1)*L(x+1) + B(t-x-2)*L(x+2)}, \]

\( B(t-x) \) is the number of births in year \((t-x)\), and \( L(x) \) is the number of survivors relative to 100,000 (or survival ratio from birth to age \( x \)) for the cohort born \( x \) years ago. When there are no epidemics or wars, it is acceptable to assume that survival ratios are the same or very close to each other for neighboring cohorts. If this is the case, \( C(x) \) would be fully depending on the size of neighboring birth cohorts; and when the size of birth cohorts is stable or changes smoothly, \( AR'(x,t) \) would be very close to \( AR(x,t) \). Of course, numbers of births of these cohorts need to be accurate or have the same pattern of under- or over-estimation. As the vital registration system in most developing countries is usually underdeveloped or incomplete, the availability of the number of births may be a challenge. In such cases, the value of such an adjustment would be depreciated. However, this method is still useful as it would not produce substantial biases as long as the coverage of vital registration is stable (or improved gradually) and the quality of data is generally acceptable over time.

If population changes are not even by age (e.g., large scale migration due to epidemics or wars for some specific periods), we may consider further adjustments through adding the parameters of population changes \( Z(x) \) of each cohort in \( C(x) \). Unfortunately, in most cases, such parameters are hard to obtain, particularly in developing societies. Thus, when the number of births at adjacent years is roughly close to each other, and the subsequent population changes did not suffer from a substantial fluctuation, the age ratios without adjustment for births may be considered as acceptable.

- **Step 2: Calculate the APAR**

For the age range to be studied, we could add up all age ratios of the same ending digit of ages, and calculate APAR for each ending digit:

\[ APAR(i) = \frac{PAR(i)}{PAR(i)} = \frac{AR(x,i) + AR(x+10,i) + \ldots + AR(x+n*10,i)}{n+1}, \]

where \( i \) is an ending digit of age, \( APAR(i) \) or \( PAR(i) \) is the APAR for the ending digit \( i \), \((n+1)\) is the number of age ratios with the same ending digit. When numbers of births vary greatly by cohort, we could further adjust the age ratio by the birth size for a more accurate estimation (Equation 1a). Based on our preliminary investigation (see Appendix Figure A), we recommend using the following criteria for assessment of digit preferences or age heaping: A ratio ranging from 0.97 to 1.03 indicates almost no ending digit preference/avoidance of age, a ratio of 0.95-0.97 or 1.03-1.05 indicates a mild digit preference/avoidance, a ratio lower than 0.95 or higher than 1.05 indicates a moderate digit preference/avoidance, and a ratio lower than 0.90 or higher than 1.10 indicates a severe digit preference/avoidance. For a ratio lower than 0.85 or higher than 1.15, it is necessary to adjust and correct the raw data.

For a given census, we could also sum all APARs for a general description of age heaping across all ending digits, namely, the Total Period Age Concentration Index (ToPACI):

\[ ToPACI = 100 \times \sum_{i=0}^{9} \sqrt{(APAR(i) - 1)^2}. \]
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If $ToPACi$ is $< 25$, age heaping at ending digit could be considered minimal; if $ToPACi$ is between 25 and 50, age heaping could be considered mild, between 50 and 100, moderate, between 100 and 200, substantial; and above 200, the aging heaping could be considered severe, calling for an adjustment and a correction on the raw data.

In use of APAR, without information on the number of births by cohort, cautions are needed to assess age heaping in that the irregular births across cohorts may occur due to specific historical events such as wars, natural disasters, fertility policy, and migration. In addition, APAR could only be used for investigating age heaping in a single census. When the data of two and more censuses are available, ACAR to be introduced in the following session could be applied, and APAR and ACAR could be jointly used to compare and verify findings of age heaping in censuses.

2.2. Average Cohort Age Ratio (ACAR)

There are three steps to calculate the ACAR. The first step is to calculate the age ratio, which has been previously described. We thus start with Step 2.

- Step 2: Calculate the cohort age ratio

We could calculate the cohort age ratio by comparing age ratios of the same cohort at the two censuses:

$$ CAR(x, t) = \frac{AR(x, t)}{AR(x-k, t-k)} $$

(4)

where $t$ is the current census year, $k$ is the interval of the two censuses under study, $t-k$ is the year of the previous census, $x$ is the age, and $CAR(x, t)$ is the cohort age ratio at the age $x$ and the census year $t$.

Assume $S(x-k)$ is the survival ratio for individuals aged $x-k$ in the previous census to the current census when the same cohort reaches the age $x$. If there are no age misreporting and no population migration, $P(x,t) = P(x-k,t-k)*S(x-k)$, $P(x-k,t-k)$ is the number of population at age $x-k$ in the first census in the year $t-k$, and $P(x,t)$ is the number of population at age $x$ in the second census in the year $t$.

And Equation (4) could be transformed as:

$$ CAR(x, t) = S(x-k, t-k) / \left( \sum_{i=-2}^{2} S(x-k+i,t-k)*P(x-k+i,t-k) \right) / \left( \sum_{i=-2}^{2} P(x-k+i,t-k) \right). $$

(5)

Evidently, if $S(x-k,t-k)$, $S(x-k-1,t-k)$, $S(x-k,t-k)$, and $S(x-k+1,t-k)$ are close to one, or the survival rates of adjacent age groups changes evenly, $CAR(x, t)$ should be equal or close to one. That is, if the digit preference/avoidance does not exist, as long as the survival rates of adjacent age groups change similarly, the cohort age ratio should be close to one, even though the birth numbers of these cohorts may show irregularities. To clarify such issues, it is necessary to examine the age ratio, preferably those adjusted by the cohort size (i.e., number of births).

As long as, the survival rates of adjacent age groups change similarly, $CAR(x, t)$ significantly higher or lower than one would indicate the existence of age misreporting, either age heaping in the current census at the age $x$ or age avoidance in the previous census at the age $x-k$. To clarify which case it is, it is suggested to examine the age ratio adjusted by numbers of births if the number of births is available and reliable or by the APAR as introduced in the previous session.

- Step 3: Calculate the ACAR

For the age range to be studied, we could add all the cohort age ratios of the same ending digit of ages, and calculate an ACAR for each ending digit:

$$ ACAR(i) = ACAR(i) = \frac{CAR(x, i) + CAR(x + 10, i) + \ldots + CAR(x + n*10, i)}{n+1}, $$

(6)

where $i$ is the ending digit of age, $APAR(i)$ or $PAR(i)$ is the ACAR for the ending digit $i$, $(n+1)$ is the number of age ratios with the same ending digit.

As long as, the census interval is not exactly equal to 10 years and the population change over the census interval is even (if not evenly, extra data are needed in analyses), with ACARs for certain ending digit being significantly higher or lower than one, it will be relatively easy to evaluate the presence of digit preferences/avoidances. If the census interval is exactly equal to 10 years and when number of births is not available by cohort or by year, ACAR may be less effective. In this situation, we need to combine the use of the APAR method.
We propose that an ACAR ranging from 0.97 to 1.03 indicates a strong consistency in the digit preference/avoidance at the ending digit, a ratio of 0.95-0.97 or 1.03-1.05 indicates a mild digit preference/avoidance, a ratio lower than 0.95 or higher than 1.05 indicates a moderate digit preference/avoidance, and a ratio lower than 0.90 or higher than 1.10 indicates a severe digit preference/avoidance. For a ratio lower than 0.85 or higher than 1.15, it is necessary to adjust and correct the raw data.

When the number of births of the original cohorts is available, and the quality is good, the ACAR is likely more robust and accurate in identifying age heaping compared with the conventional and modified Whipple’s Indexes and the Myers’ Index that are based on either a single time point of data or one census. Similar to that for APAR, we could also sum the deviation from one for each ending digit for a general description of age heaping across all ending digits, namely, the Total Cohort Age Concentration Index (ToPACI):

$$ToCACI = 100 \sum_{i=0}^{q} \sqrt{(ACAR(i) - 1)^2}. \quad (7)$$

The criterion of ToCACI is the same as that of ToPACI.

3. Empirical Validation

The methodology used for calculating APAR is similar to that used for the (modified) Whipple’s Index. The difference between these two methods is that APAR calculates age ratio first for a specific age from population counts of its neighboring ages and then averages the ratios for ages with the same ending digit, while the modified Whipple’s Index sums population counts first for the same ending digit of ages and then divides by the total population counts of their neighboring ages (for details see Spoorenberg, 2007).

For a stable or a stationary population, mathematically, it can be proved that these two methods produce identical results. In reality, when they are applied to Japan and Sweden, the two countries with the highest data quality of population counts in the world (Thatcher, Kanisto, and Vaupel, 1998), these two methods also produce very close results (Appendix Table A) that compare the APAR method with the modified Whipple’s Index for the preferences over ending digits of age for years from 1980 to 2015. These data are obtained from the Human Mortality Database (HMD), which are mainly from censuses and vital registration of these countries (Wilmoth, Andreev, Jdanov et al., 2017).

Figure 1 compares the APAR method with the modified Whipple Index for ages 21-64 in male populations for Japan and France (France is a country with very good data quality of population counts) for selected years. The very closeness of the two sets of results indicates that the average age ratio is a valid measure for examining age heaping. However, Figure 1 indicates that both the APAR method and the Whipple’s Index misrepresented the true state of age heaping in the Japanese and French male populations in the illustration periods. For example, both indicators suggest that there was a somewhat preference for the ending digit of 1 in Japanese male population in 1980, while there was a digit preference of 7 in 1985. However, this is likely wrong because such fluctuations were mainly due to the post-war baby boomers born in 1948-1949 with the birth numbers of 10% higher than the adjacent ages, who happened to reach the ages of 31 and 32 in 1980, and the ages of 36 and 37 in 1985.

For France, both methods suggest that French population had a preference for ending digits of 5 and 9 in 1950, and then shifted to 4 and 8 in 1959. However, a closer look demonstrates the true reason: After the World War I, in which France was involved from August in 1914 to November 1918, there was a baby boom period in France from 1920 to 1921 with a 20% higher in the number of births than the adjacent years, and these baby boomers reached age 29 in 1950. The sharp decline in births during the war also made the population at age 35 exceeding those of the adjacent ages in 1950 by about 18%. In 1959, those born in 1920-1921 reached the age of 38 while those born in 1914-1915 reached the age of 44. For Japanese male population, the total deviation (*100) was 14.5 and 12.4 for APAR (i.e., ToPACI) and 17.8 and 14.9 for the Whipple’s Index 14-18 in 1980 and 1985, respectively. For French male population, the total deviation (*100) was 29.8 and 32.1 for APAR, and 26.8 and 27.9 for the Whipple’s Index in 1950 and 1959, respectively.

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After adjusting the cohort size and survivorship for APAR [Figure 2] (the results were similar without adjusting survivorship), we found that there was no digit preference of age reporting in Japanese male populations in 1980 and 1985 and French male population in 1950 and 1959. ToAPCI with birth-adjusted APAR for Japanese male population was below 5 for both years, whereas it was around 13 for French males population in 1950 and 1959. The ToCACI was <1 for both countries in study years. A couple of approaches were tested to adjust the Whipple’s Index by birth cohort size, yet given their complexity and uncertainty, no set of adjustment was presented in the present study.
Figure 3 further presents ACAR for Sweden, France, and Japan for ages 20-90, rather than for the classic age range of 23-62 for Whipple Index or the age range of 21-64 for the modified Whipple’s Index. Clearly, between the age of 20 and 80 years, ACAR at each age was very close to 1 (0.99-1.01) for the three countries. After age 80, the ratio at each age declined rapidly due to the high mortality rates. These results indicate that there is no age preference in these three countries and that the age range for calculating APAR and ACAR can go beyond normal adulthood as used for the Whipple’s Index.

4. Results of Examination on the Chinese Censuses

Our examination of age heaping in the Chinese censuses focuses on the age range from 10 to 80 years old, rather than from age 0 to age 89 years. This is because mortality underestimation for young children aged 0-5 years and mortality underestimation for the oldest-old population are different from other ages (Guo, Yin, Wang, et al., 2015). In other words, the age range to be studied in a given census in the present study is from 20 to 80 years, and the age range in its previous census is correspondingly from 10 to 70 years. In addition, when comparing the census data for 2000 versus 1990, we converted the 2000 census data (November 1) to mid-year data by assuming that the population is evenly distributed across months within a given calendar year.

Figure 4 reveals the modified Whipple Index at each ending digit of age calculated based on the age range of 21-64 each census. The results point out that in the recent three censuses, there seemed to exist a preference on the ending digit of 7 and avoidance on 9. However, this conclusion is not correct as there were a larger number of babies born in 1963-1964, resulted from a baby boom after the feminine in 1959-1961., the cohort born in 1963-1964 aged 27, 37, and 47 years in the 1990, 2000, and 2010 censuses, respectively. Hence, the age heaping on the ending digit of 7 should not indicate an age digit preference as proposed by some scholars (Wu and Gan, 2013), but a result of different sizes of birth cohorts.

Figure 5 presents the birth-adjusted APAR for the 2000 and 2010 censuses in comparison to the modified Whipple’s Index. The comparison shows that the preference revealed by the modified Whipple’s Index on digits 2 and 7 found in 2000 and on digits 2, 7, and 8 in 2010 and that the avoidance in digits 1, 8, and 9 in 2000 and 9 in 2010 were indeed due to different size of the original birth cohorts. Figure 6 illustrates ACAR for ending digits of age, clearly suggesting that

![Figure 1](https://www.mortality.org/).

![Figure 2](https://www.mortality.org/).
there was generally no preference on the ending digits of age in the age range of 21-64. No significant age heaping was found in the age ranges 21-64. For earlier censuses, since we do not have the number of births in the 1920s and 1930s in China, we are not able to present birth-adjusted APAR in these censuses.

No preference on an ending digit of age does not mean no preference on some specific ages, which we indeed observed in certain censuses. Figure 7 illustrates age ratios for the age range of 20-80 in multiple censuses, and Figure 8 shows the cohort age ratios at different ages based on a comparison of the same cohorts in these censuses. Altogether, in the 1953 and 1964 censuses, we find out some mild preference on the ages 40, 50, 60, 70, and 80 years old. For example, in Figure 7, the age ratios at ages of 40, 50, 60, 70, and 80 were all above 1.03: These ages hold at least 3% more of population numbers than the adjacent ages. In contrast, age ratios at the adjacent ages were all below 1. Although there were wars and social riots in China from 1870 to 1900, most of them were small-scaled, and thus the cohort born in 1870 to 1900 could be considered as rather stable. At the same time, because the mortality rate was relatively high before 1950 (Lee and Wang, 1999; Seifert, 1935), the difference in the number of births between adjacent cohorts is likely minor and could be ignored after certain ages in adulthood. Therefore, if there was no preference on ages, the age ratios at ages of 50, 60, 70, or 80 are supposed to be very close to one. According to Figure 7, in 1964, the cohort age ratios at 61 and 71 were all <1. This also proves that the first census of China had somewhat age heaping at the ages of 60 and 70.

With social development, the age preference on the ages of 40 and 50 generally disappeared after 1982. In the recent three censuses of 1990, 2000, and 2010, however, the preference on age 60, 70 and particularly 80 was still observable in these ages. For example, in the 2000 census, the age ratios at 70 and 80 were more than 1.05. In the 2010 census,

![Figure 3](image-url). Average cohort age ratio in Sweden, Japan, and France

![Figure 4](image-url). The modified Whipple Index for different ending digits of age in six censuses in China

Note: (1) Data were for ages 21-64 only from National Bureau of Statistics of China.
even though the age ratio at 80 was lower than that of 10 years ago when they were 70 years old, but it was still greater than 1.05. These results demonstrate that older adults in China still have some preference for the ending digit of 0 when reporting their ages.

We consider that the preference for some specific ages was policy associated. For example, there was a preference on the age of 18 in the 1953 census, which was consistent by gender (results available on request). This preference is also confirmed by the analysis on the census 11 years later (i.e. 1964), in which the cohort age ratio at the age 29 was <1. It is likely that this age preference is related to the marriage law that sets 18 years old as the minimum marriage age for women, and the regulation that required men enlisted into the army to be at least 18 years old in the 1950s and 1960s. The age ratios in the 1964 and 1982 censuses [Figure 7] as well as the cohort age ratios between both censuses [Figure 8] further demonstrate that there existed age avoidance on ages 20-23 in the 1982 census and the age preference on ages 24 and 25. This could be caused by the fertility decline during the period of natural disasters (1959-1961) and the birth compensation afterward. On the other hand, it may also indicate misreporting to a certain degree in both censuses. This is also revealed by cohort age ratios based on the 1990 and 1982 censuses [Figure 8]. Meanwhile, the underreporting at ages of 21 and 22 in the 1982 census could be affected by the national policy in the early 1980s to promote late marriage and childbirth.

Another observation is that for the 2000 and 2010 censuses, the age ratios had major fluctuations, particularly for the range from 30 to 45 years old [Figures 7 and 8]. Compared with the previous censuses as shown in the two figures, it is highly likely that the data quality of age reporting worsened in the latest two censuses in 2000 and 2010. This may be due to the increasing population mobility, which brings in difficulty for the census enumeration. The worsening data quality in age reporting could lead to the rise of inconsistency across ages between 2000 and 2010, which was particularly significant in the ages below 20 years old [Figure 8].

Figure 5. The modified Whipple Index and the birth-adjusted APAR, ages 21-64, China, 2000 and 2010 censuses
Note: Data were from the National Bureau of Statistics of China

Figure 6. ACAR for different ending digits of age based on the multiple censuses in China for ages 21-64
Note: (1) Data were from the National Bureau of Statistics of China. (2) Average cohort age ratio is unadjusted by birth cohort size.
5. Concluding Remarks

This paper applied APAR (birth-size adjusted and unadjusted) and ACAR to the six population censuses in China since 1950 to analyze age heaping in China. We found that the Chinese population generally had a low preference for ending digits of age; however, there existed preferences for specific ages in certain censuses. These preferences had two main patterns: First, in middle and old ages, the Chinese population had a preference on the ending digit of 0, yet this preference diminished after 1990. This trend may be due to the institutional implementation and improvement of the household registration system and personal the identity card system as well as the increasing demands for accurate age reporting in school application, job hunting, housing purchase, and medical insurance. The current youth almost cannot over-report their ages, as census enumerators could examine their household registration system and identity cards. However, when census numerators visited a household, they typically asked a person in the household (mostly the household head) to fill the census forms without crosschecking with other available data. Consequently, underreports/undercounts or overreports/overcounts of individuals, out-migrants, and deaths in the household are common in many censuses, despite the well-developed household registration system (Guo and Che, 2008; Li and Ma, 1984; Qiao, 1993; Qiao and Yang, 1993; Wu and Gan, 2013; Yang, 1987; Zha and Qiao, 1993; Zhai, 1987). When people begin to acknowledge the necessity of reporting accurate birth date and age, the cultural tradition preferring or avoiding reporting certain ages will gradually fade away. With the improvement of the vital registration and
Average age ratio method and age heaping in Chinese censuses

household registration systems, the age heaping phenomenon in China will eventually diminish. Second, there existed a preference for specific ages in certain periods of time, which was mainly related to the implementation of some age-related policies such as regulation on the minimal legal ages of marriage, childbearing, and retirement. People likely intentionally misreported, typically over-reported, their ages to meet the age thresholds of these policies. Last, we found that, although the preference for ending digit of age declined after 1990, inconsistencies of age reporting across censuses had indeed increased. This suggests that the overall data quality of age reporting in the 2000 and 2010 censuses likely decreased, which may be due to the increased domestic migrations that made it difficult to enumerate accurately in censuses after 1990. More research is clearly warranted for more insights on this theme.

Using data from Japan and Sweden, two countries with the best quality of demographic data, we show that the APAR method has similar properties as the modified Whipple’s Index (Noumbissi, 1992; Spoorenberg, 2007). However, we also acknowledged the limitation of both the Whipple’s Index and the APAR method. When population changes are not smooth (due to significant differences in births, deaths, and migration), it may not accurately reflect age heaping if the direct calculation of the ratio or the index is used (Barrett, 2019). That means, when applying these two methods to identify the age preference/avoidance, it is necessary to consider the historical background of the specific birth cohort or time period in the study population, to clarify whether the observed age heaping is due to misreporting or is due to particular historical events such as wars that caused the major cohort differences. As a result, we suggest taking the birth cohort size into the calculation as an adjusting factor if such data are available and relatively reliable.

However, caution is needed for a few issues on applying the APAR and ACAR methods. First, the calculation of ACAR must be based on two or more censuses, to capture the degree of the age preference/avoidance or age reporting consistency. Since the general preference/avoidance for ending digits of age is mainly driven by the cultural tradition and custom, which are difficult to change, the age preference/avoidance at the same age or same digit is generally comparable between adjacent censuses when the censual interval is relatively short. (e.g., less than 20 years). Second, when the censual interval is exactly 10 years, unless ACAR is adjusted by the size of the birth cohort, the utility of this method could be weakened. However, in this case, the method is yet helpful to examine the consistency of age registration and reporting in multiple censuses. Third, when using the cohort age ratios to identify the preference/avoidance of the ending digits of age, it is ideal to combine with the period age ratios, and if possible, it is also good to adjust the cohort age ratios by the number of births of the cohort if such data are available and relatively reliable (Equation 1a). Otherwise, it may be difficult to clarify whether there really exists digit preferences or digit avoidances in age-reporting. Fourth, the criterion used for assessing the levels of a preference/avoidance in the present study is quite arbitrarily. We suggest using a combination of criteria of different age ratio methods to determine the level of age heaping in the study population(s). A systematic examination using various data sources with the known quality (e.g., data from human mortality database) is also warranted to shed light on this issue. Fifth, the average age ratio is not reliable, especially after age 90, when population numbers vary greatly across ages. Other methods are thus needed for analyzing and detecting age heaping in age-reporting among older and very older people. Sixth, as the preference/avoidance of a certain age may be a response to certain policies and the preference for a certain ending digit of age may mainly come from customs, it is recommended to pay attention to both situations when investigating age heaping. Seventh, the large scale of international migration in some countries may produce a bias in detecting the digit preference in age-reporting in censuses if such migration is not evenly distributed across ages. This makes up a challenge to assess the age heaping in such countries. This is also the case for examining the age heaping in sub-national populations when domestic migration is relatively large.

Our approach presented in this study uses age ratios calculated from five adjacent ages. To test its statistical sensitivity, we also examined the situations of three, seven, and nine adjacent ages. The tests produced similar outcomes and supported the effectiveness and robustness of age ratios based on five adjacent ages. Furthermore, besides the census data as illustrated in the current study, the method can also be applied to data obtained from vital registration or even surveys if its coverage and representativeness are adequate.

In sum, APAR and ACAR are likely good alternative methods to the traditional or the modified Whipple’s Index to study the digit preference/avoidance in age reporting. Both the APAR and ACAR methods can be applied to ages beyond adulthood ages used by the Whipple’s Index as long as the population changes are smooth. If APAR is adjusted by the size of birth cohorts, it would better reflect ending digit preference in age-reporting. ACAR could also be used to test the consistency of age registration/reporting across multiple censuses if the birth registration data quality is reasonably good. However, the limitations of this method abovementioned still suggest a need for new and better methods for examining the age heaping.
Authors’ Contributions
DG designed the study, performed the analysis, drafted, and revised the manuscript. QF revised the manuscript and interpreted the results.

Conflicts of Interest and Funding
None.

Ethics Approval
Not applicable – this study used secondary aggregated data from publicly available census tabulations.

Disclaimer
The views expressed in this paper are solely those of the authors and do not reflect those of the United Nations and the National University of Singapore.

References
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Appendix

Figure A. Distribution of age period average ratio (APAR) by periods for Human Mortality Countries. (A) Two countries with the best demographic data quality (Japan and Sweden), (B) Eleven countries with the very good demographic data quality*, (C) Remaining HMD countries (twenty 25)

Note: *11 countries with good data (excluding Sweden and Japan, two countries with best quality of demographic data) were from Thatcher, Kannisto and Vaupel (1998).
### Table A. Comparison of the average period age ratio (APAR) and the Whipple Index (WI) for ending digits of age among male populations in Sweden and Japan in selected years

<table>
<thead>
<tr>
<th>Ending digits of age</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>100*Total Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden, 1800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APAR</td>
<td>1.031</td>
<td>1.006</td>
<td>0.990</td>
<td>1.001</td>
<td>0.991</td>
<td>0.974</td>
<td>0.997</td>
<td>0.991</td>
<td>0.997</td>
<td>1.012</td>
<td>11.270</td>
</tr>
<tr>
<td>WI</td>
<td>1.034</td>
<td>1.008</td>
<td>0.988</td>
<td>1.003</td>
<td>0.990</td>
<td>0.974</td>
<td>0.998</td>
<td>0.987</td>
<td>0.996</td>
<td>1.014</td>
<td>12.523</td>
</tr>
<tr>
<td>APAR-WI</td>
<td>-0.003</td>
<td>-0.002</td>
<td>0.002</td>
<td>-0.002</td>
<td>0.001</td>
<td>0.000</td>
<td>-0.001</td>
<td>0.004</td>
<td>0.001</td>
<td>-0.002</td>
<td>-1.253</td>
</tr>
<tr>
<td>Sweden, 1900</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APAR</td>
<td>1.016</td>
<td>0.964</td>
<td>0.977</td>
<td>0.996</td>
<td>1.004</td>
<td>1.032</td>
<td>0.999</td>
<td>0.978</td>
<td>0.992</td>
<td>1.021</td>
<td>16.779</td>
</tr>
<tr>
<td>WI</td>
<td>1.017</td>
<td>0.961</td>
<td>0.976</td>
<td>1.001</td>
<td>1.005</td>
<td>1.024</td>
<td>0.999</td>
<td>0.978</td>
<td>0.993</td>
<td>1.018</td>
<td>15.707</td>
</tr>
<tr>
<td>APAR-WI</td>
<td>-0.001</td>
<td>0.003</td>
<td>0.001</td>
<td>-0.005</td>
<td>-0.001</td>
<td>0.008</td>
<td>-0.000</td>
<td>-0.000</td>
<td>-0.001</td>
<td>0.003</td>
<td>1.072</td>
</tr>
<tr>
<td>Sweden, 2010</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APAR</td>
<td>0.994</td>
<td>0.992</td>
<td>1.005</td>
<td>1.006</td>
<td>1.006</td>
<td>1.007</td>
<td>0.999</td>
<td>0.996</td>
<td>0.990</td>
<td>0.997</td>
<td>5.536</td>
</tr>
<tr>
<td>WI</td>
<td>1.017</td>
<td>1.036</td>
<td>1.038</td>
<td>0.965</td>
<td>1.004</td>
<td>1.014</td>
<td>1.007</td>
<td>0.997</td>
<td>0.989</td>
<td>0.996</td>
<td>5.863</td>
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<tr>
<td>APAR-WI</td>
<td>-0.021</td>
<td>-0.044</td>
<td>-0.033</td>
<td>0.041</td>
<td>0.002</td>
<td>-0.007</td>
<td>-0.008</td>
<td>-0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>-0.327</td>
</tr>
<tr>
<td>Japan, 1960</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>APAR</td>
<td>0.983</td>
<td>1.006</td>
<td>1.039</td>
<td>0.973</td>
<td>0.970</td>
<td>1.000</td>
<td>0.996</td>
<td>0.997</td>
<td>1.004</td>
<td>1.014</td>
<td>14.525</td>
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<tr>
<td>WI</td>
<td>0.991</td>
<td>1.022</td>
<td>1.053</td>
<td>0.965</td>
<td>0.962</td>
<td>1.000</td>
<td>1.000</td>
<td>1.002</td>
<td>1.008</td>
<td>1.008</td>
<td>17.751</td>
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<tr>
<td>APAR-WI</td>
<td>-0.008</td>
<td>-0.016</td>
<td>-0.014</td>
<td>0.008</td>
<td>0.008</td>
<td>0.000</td>
<td>-0.004</td>
<td>-0.005</td>
<td>-0.004</td>
<td>0.006</td>
<td>-3.226</td>
</tr>
<tr>
<td>Japan, 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APAR</td>
<td>1.015</td>
<td>1.032</td>
<td>1.034</td>
<td>0.967</td>
<td>1.005</td>
<td>1.014</td>
<td>1.006</td>
<td>0.996</td>
<td>0.988</td>
<td>0.996</td>
<td>15.856</td>
</tr>
<tr>
<td>WI</td>
<td>1.017</td>
<td>1.036</td>
<td>1.038</td>
<td>0.965</td>
<td>1.004</td>
<td>1.014</td>
<td>1.007</td>
<td>0.997</td>
<td>0.989</td>
<td>0.996</td>
<td>16.901</td>
</tr>
<tr>
<td>APAR-WI</td>
<td>-0.002</td>
<td>-0.004</td>
<td>-0.004</td>
<td>0.002</td>
<td>0.001</td>
<td>0.000</td>
<td>-0.001</td>
<td>-0.001</td>
<td>-0.001</td>
<td>0.000</td>
<td>-1.045</td>
</tr>
</tbody>
</table>

Note: (1) Data were from the Human Mortality Database (https://www.mortality.org/). Only populations aged 21-64 were used in calculating these two indicators. (2) Total Deviation is calculated as sum of the absolute difference between each ratio (Index) and 1 over all ending digits, multiplying by 100. In the case of APAR, the total deviation is also called the Total Period Age Concentration Index (ToPACI).