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A Comparison of Mortality Transition in China and India 1950-2022

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Introduction

China and India are the only two billion-plus countries in the world. They accounted for almost 36 per cent of the world population in 2021 (United Nations, 2022). The world demographic prospects, therefore, have always been heavily conditioned by demographic transition in the two countries. The comparative perspective of demography and development in the two countries has always been of interest to both demographers and development experts (Coale, 1983; Adlakha and Banister, 1995; Dummer and Cook, 2008; Singh and Liu, 2012; Golley and Tyres, 2013; Joe et al, 2015; Chaurasia 2017; 2020). Around 1950, the two countries were at a very similar stage of demography and development. The situation has changed radically since then. China is now at a very advanced stage of demographic transition and its population has now started shrinking. India continues to be in the middle of transition, although, it has recently achieved the replacement fertility. The population of India continues to increase, albeit at a slower pace, and its population appears to have now surpassed that of China.

From social, cultural, and political perspectives, China and India are poles apart which has implications to both population and development processes in the two countries. The social, cultural, and political unity of China has always been impeccable. The Han ethnic community constitutes more than 90 per cent of the population of China (Chen et al, 2009). China is also one of the few countries of the world that has never be entirely colonised by the foreign powers so that the society, the culture, and the economy, especially, of the mainland China has largely remained unaffected by colonisation. After becoming Red in 1948, China has adopted the single-party political system which has virtually little scope for democratic diversity and divergent views to government policies and programmes which has implications for both demography and development.

The social, cultural, and political diversity of India, on the other hand, has always been so perplexing that the country is often called as the country of countries. India was ruled by foreign invaders for almost 1000 years so that its society and culture stands deeply distorted and fractured. The prolonged foreign rule has divided the Indian society broadly into two classes – the rulers and the ruled – with a great divide between the two. After independence in 1947, the country adopted multi-party political system leading to the democratic diversity of the extreme order. One implication of the system has been that there has rarely been political unanimity or consensus on issues related to demography and development. The lack of political consensus has influenced demographic transition in the country and has an impact on social and economic development processes.

It is in the above context that this paper analyses mortality transition in China and India through a comparative perspective. Mortality transition signals beginning of demographic transition. Mortality has also been recommended as an indicator of economic success (Sen, 1998). Transition in mortality can throw light on the transition in social and economic development processes in terms of social inequalities, including gender bias and racial disparities (Sen, 1998). Understanding mortality transition, therefore, is the first step towards understanding the demographic transition and in characterising social and economic development processes.

Mortality transition encompasses transition in aggregate mortality level and transition in the age pattern of mortality. The most commonly used measure of analysing transition in mortality level is the life expectancy at birth (e_0) which is independent of population age structure so that it can be compared over time and across different populations at different stages of mortality transition. However, e_0 has some limitations for analysing mortality transition at the aggregate level as it reflects mortality experience of a hypothetical population not of the real population. It is the average of the age distribution of deaths and, therefore, is not unique. Different age distributions of deaths may have the same e_0 (Goerlich Gisbert, 2020). The increase in e_0 is also influenced more by the decrease in the risk of death at older ages (Chaurasia, 2023; Keyfitz, 1977; Vaupel, 1986).

In view of the limitations of e_0 alternative measures of aggregate mortality have been suggested. One alternative is the median age at death ((INE, 1952; 1958). The other is the modal age at death (Canudas-Romo 2008). The geometric mean of age-specific death rates (Schoen, 1972) and geometric mean of age distribution of deaths (Ghislandi et al, 2019) have also been suggested. Goerlich Gisbert (2020) has suggested a distributionally adjusted e_0 that considers not only the level but also the age distribution of deaths. Chaurasia (2023) has used the geometric mean of the age-specific probabilities of death as the measure of aggregate level of mortality to analyse mortality transition in India. The advantage of using the probability of death rather than the death rate is that the probability of death is easy to interpret (King and Soneji, 2011). It always ranges between 0 and 1 and is used for the construction of the life table and calculation of e_0 (de Beer 2012).

The paper is organised as follows. The next section analyses mortality transition in China and India during 1950-2021 in terms of two measures of aggregate mortality – the life expectancy at birth and the geometric mean of the age-specific probabilities of death using joinpoint regression model. We found that mortality transition reflected by the trend in e_0 is different from that reflected by the trend in the geometric mean of the age-specific probabilities of death in the two countries. The third section of the paper analyses how the change in age-specific probabilities of death contributes to the change in the geometric mean of age-specific probabilities of death. The fourth section analyses the transition in age-specific probabilities of death in the two countries by fitting a non-parametric model. The fifth section decomposes the difference in age-specific probabilities of death between the two countries the difference attributed to the difference in average mortality across all years and all ages, the difference in average mortality in different years across all ages, the difference in average mortality in different ages across all years and the difference in the residual component. The last section of the paper summarises the main findings of the analysis to characterise the difference in mortality transition in the two countries since 1950.

The paper is based on the latest annual estimates of the life expectancy at birth and age-specific probabilities of death in the two countries prepared by the Population Division of the United Nations for the period 1950-2021 (United Nations, 2022). The United Nations has been providing estimates of demographic indicators for its member countries as the average of different five-year periods beginning 1950. However, in the latest, 2022 revision, the United Nations has provided annual estimates of demographic indicators for its member countries including the probability of death by single year of age since 1950 which constituted the basic data set for the present analysis. The estimates of mortality indicators prepared by the United Nations for its member countries are based on a common methodology and a standard set of assumptions so that they permit comparison of mortality transition between the two countries over time beginning 1950. The official estimates of age-specific probabilities of death of the two countries have not been used in the present analysis because these estimates are based on different methodologies and are not available on an annual basis for the period 1950-2021. The estimates of estimates age-specific probabilities of death by single years of age prepared by the United Nations for the period 1950-2021 are the only data source that permit comparison of mortality transition between the two countries over time.

Trend in Aggregate Mortality

Estimates prepared by the United Nations suggest that e_0 in China increased from around 43.7 years in 1950 to more than 78 years in 2021 (United Nations, 2022), an increase of more than 34 years between 1950 and 2021 (Figure 1). In India, e_0 increased by around 25 years during this period from 41.7 years in 1950 to 70.9 years in 2019 but then decreased to 67.2 years in 2021 because of the mortality impact of COVID-19 pandemic. Similarly, the geometric mean of age-specific probabilities of death decreased from 0.0234 in 1950 to 0.0048 in 2021 in China whereas in India, it decreased from 0.0286 in 1950 to 0.0086 in 2019 and then increased to 0.0109 in 2021. In China, e_0 increased while geometric mean of age-specific probabilities of death decreased even during the COVID-19 pandemic. In India, however e_0 decreased while the geometric mean of age-specific probabilities of death increased during the pandemic. The geometric mean of age-specific probabilities of death was lower in India than in China during 1950-1961. However, e_0 in China has been higher than that in India, except for the short duration 1959-1961.

Figure 1 suggests that, in both countries, the trend in e_0 and in geometric mean of the age-specific probabilities of death changed many times during between 1950 and 2021. We have, therefore, analysed mortality transition in the two countries using the joinpoint model which identifies the inflexion point(s) in the trend or joinpoint(s) and then estimates the trend in the time-segment between two inflexion points or joinpoints assuming that the trend is linear in the time-segment. If there is no point of inflexion in the trend, the joinpoint model reduces to simple linear model. There are two steps in fitting the joinpoint model. The first is to identify joinpoint(s). The second is to fit the trend in the time-segment between two successive joinpoints assuming that the trend is linear on the Log-scale in the time-segment.

We have used the Joinpoint Regression Analysis software (National Cancer Institute, 2023) for fitting the joinpoint model. The software requires, a priori, minimum, and maximum number of joinpoints. When the number of joinpoints is zero, the software fits a straight line to the data. The software also provides estimates of annual per cent change (APC) in different time-segments of the trend period. The APCs in different time-segments are then combined into average annual per cent change (AAPC) during the trend period as the weighted average of APC in different time-segments with weights equal to the length of the time-segment. The AAPC is argued to be a better reflection of the trend over time compared to the conventional rate of change obtained through the application of the linear regression analysis on a Log scale (Clegg et al, 2009).

Table 1 presents results of the analysis of the trend in e_0 in China and India. In China, the trend changed four times between 1950 and 2021 so that the entire period 1950-2021 can be divided into five time-segments and the trend in e_0 in different time-segments has been different. The e_0 increased, instead decreased, during the period 1957-1960. Combining the APC in different time-segments, the average annual per cent change (AAPC) in e_0 in China is estimated to be 0.849 per cent per year during 1950-2021. The rate of increase in e_0 in the country slowed down considerably after 1981 compared to the rate of increase during the 18 years period between 1963 and 1981.

In India, the trend in e_0 changed five times. During the period 1963-1966, e_0 in the country virtually remained stagnant. The rate of improvement in e_0 in India has been slower than that in China before 1986, but, during 1986-2019, it has been faster than that in China. The gap in e_0 between the two countries, therefore, first increased from around 2 years in 1950 to more than 10.8 years during 1979-1981 and then decreased to 6.8 years in 2017, the lowest since 1965, but increased to 7.1 years in 2019. During the COVID-19 pandemic (2020-2021), e_0 in India decreased very rapidly so that the gap in e_0 between China and India increased very rapidly to reach an all-time high of around 11 years in 2021. The average annual per cent change (AAPC) in e_0 in India during the 70 years period between 1950 and 2021 has also been much slower than that in China.

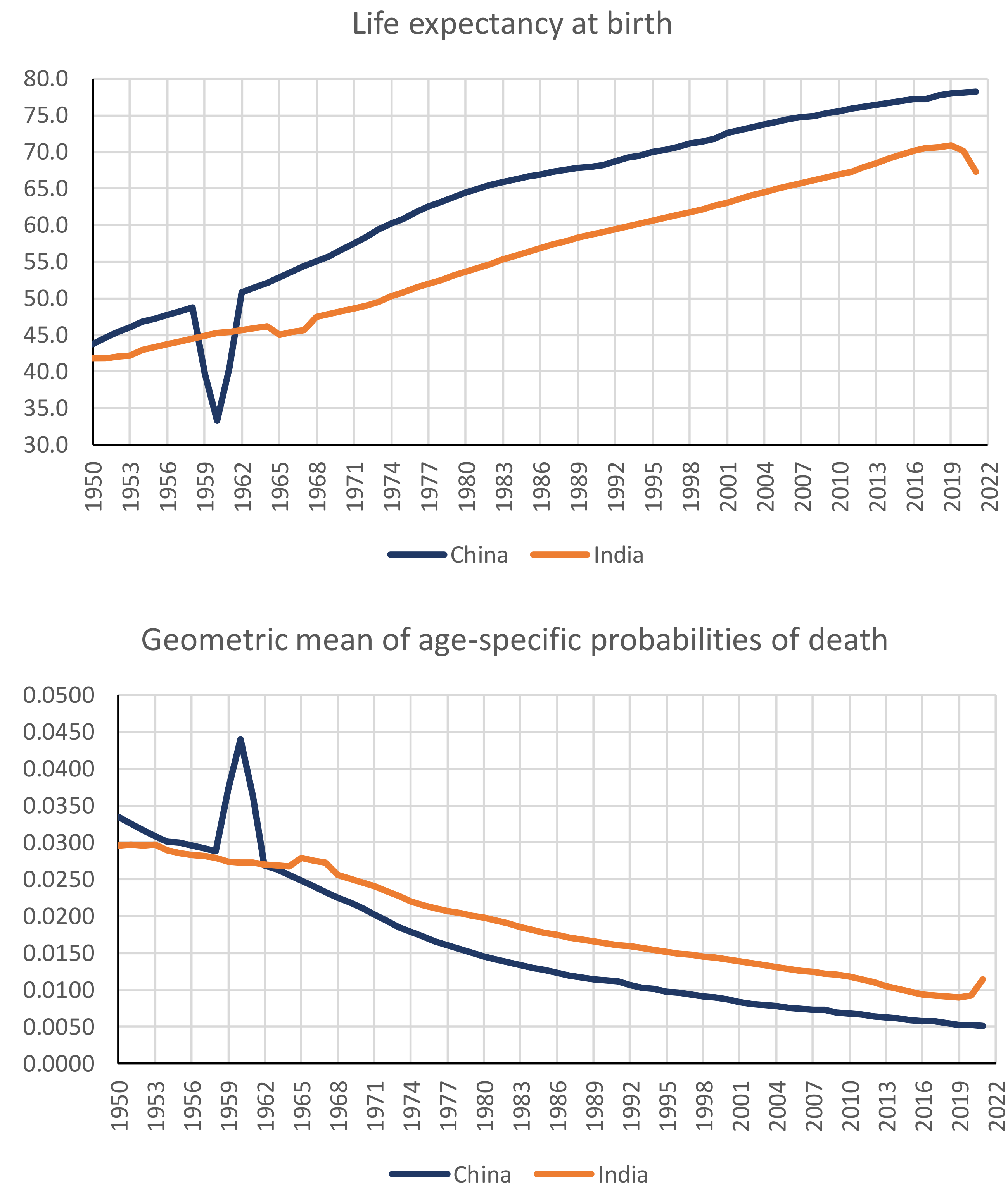

Figure 1: Trend in summary measures of mortality in China and India, 1950-2021.
Source: Author

Table 1: Analysis of the trend in e_0 in China and India, 1950-2021.

Segment	Time-segment		Annual per cent change			Test statistic (t)	Prob > |t|
	Lower	Upper	Estimate	Lower CI	Upper CI		
				China			
1	1950	1957	1.909	1.706	2.112	18.986	< 0.001
2	1957	1960	-10.563	-12.032	-9.069	-13.491	< 0.001
3	1960	1963	13.650	11.783	15.548	15.462	< 0.001
4	1963	1981	1.261	1.209	1.313	49.180	< 0.001
5	1981	2021	0.484	0.470	0.498	69.032	< 0.001
Full Range	1950	2021	0.849	0.748	0.949	16.575	< 0.001
				India			
1	1950	1963	0.827	0.794	0.861	49.811	< 0.001
2	1963	1966	-0.801	-1.573	-0.022	-2.060	0.044
3	1966	1969	1.921	1.127	2.721	4.875	< 0.001
4	1969	1986	1.047	1.023	1.071	86.807	< 0.001
5	1986	2019	0.683	0.674	0.691	162.607	< 0.001
6	2019	2021	-2.639	-3.405	-1.867	-6.786	< 0.001
Full Range	1950	2021	0.690	0.638	0.742	26.203	< 0.001

Source: Author

Table 2: Analysis the trend in the geometric mean of age-specific probabilities of death in China and India, 1950-2021.

Segment	Time-segment		Annual per cent change			Test statistic (t)	Prob > |t|
	Lower	Upper	Estimate	Lower CI	Upper CI		
				China			
1	1950	1957	-2.494	-2.814	-2.172	-15.388	< 0.001
2	1957	1960	14.364	11.010	17.819	9.036	< 0.001
3	1960	1963	-15.646	-18.120	-13.097	-11.455	< 0.001
4	1963	1966	-1.100	-4.000	1.889	-0.744	0.460
5	1966	1979	-3.753	-3.889	-3.618	-54.330	< 0.001
6	1979	2021	-2.516	-2.536	-2.496	-243.490	< 0.001
Full Range	1950	2021	-2.620	-2.832	-2.409	-23.959	< 0.001
				India			
1	1950	1963	-0.873	-1.005	-0.740	-13.161	< 0.001
2	1963	1966	1.035	-1.741	3.890	0.741	0.462
3	1966	1976	-2.741	-2.968	-2.513	-23.807	< 0.001
4	1976	2009	-1.650	-1.683	-1.616	-97.609	< 0.001
5	2009	2019	-3.269	-3.495	-3.043	-28.475	< 0.001
6	2019	2021	12.909	9.802	16.103	8.720	< 0.001
Full Range	1950	2021	-1.398	-1.544	-1.251	-18.578	< 0.001

Source: Author

The trend in the geometric mean of the age-specific probabilities of death has, however, been different from the trend in e_0 in both countries (Table 2). Unlike the trend in e_0, the trend in the geometric mean of the age-specific probabilities of death changed five times in both countries so that the period 1950-2021 can be divided into six time-segments. The points of inflexion in the trend in the geometric mean of age-specific probabilities of death have been the same in both the countries during the period 1950-1963 in China and during the period 1950-1966 in India. However, after 1963 in China, and, after 1966 in India, the points of inflexion in the trend in the geometric mean of the age-specific probabilities of death have been different from the points of inflexions in the trend in e_0. A comparison of tables 1 and 2 suggests that mortality transition reflected by the trend in e_0 is different from the mortality transition reflected by the trend in geometric mean of age-specific probabilities of death in both countries. One reason for this difference is that the trend in e_0 depicts mortality transition in a hypothetical population whereas the trend in geometric mean of age-specific probabilities of death depicts mortality transition in the real population. The annual age-specific probabilities of death permit comparison of period age-specific probabilities of death in 1950 with the age-specific probabilities of death for the cohort born in 1950 for ages 0-71 years and the two set of age-specific probabilities of death are different in both countries. For example, a person born in 1950 in China was 71 years old in 2021 and the probability of death for the person in the 71^{st} year of life was 0.0241 whereas the probability of death in 71 years of age in 1950 was 0.0945. The e_0 for the year 1950 is calculated assuming that a person born in 1950 will be subject to age-specific probabilities of death that prevailed in the year 1950. However, the actual age-specific probabilities of death to which a person born in 1950 was subjected or the 1950 cohort age-specific probabilities of death were substantially lower than the age-specific probabilities that prevailed in 1950. Obviously, the actual age-specific risk of death experienced by a person born in 1950 was different from the age-specific risk of death reflected by the age-specific probabilities of death that prevailed in the country in 1950. In India also, the risk of death experienced by a person born in 1950 in the 71^{st} year of age was different from the probability of death in 71 years of age in the year 1950, although the difference between the cohort and the period age-specific probabilities of death in India is relatively narrower than that in China. The trend in e_0 reflects mortality transition of a hypothetical population only and not mortality transition of the real population. The difference in the trend in *e0* and the trend in the geometric mean of the age-specific probabilities of death suggests that it is more appropriate to use the geometric mean of the age-specific probabilities of death as the summary measure of mortality to analyse mortality transition rather than the life expectancy at birth, e_0.

In the analysis that follows, we have used the geometric mean of the age-specific probabilities of death as the summary measure of mortality to analyse mortality transition in the two countries. There are many advantages of using the geometric mean of the age-specific probabilities of death as the summary measure of mortality. One advantage is that it gives equal weight to the probabilities of death in different ages. This is not the case with e_0. Another advantage of the geometric mean of the age-specific probabilities of death is that the change in any of the age-specific probabilities of death results in a change in the geometric mean of the age-specific probabilities of death which is not the case when the median or the mode of the age-specific probabilities of death is used as a summary measure of mortality. The geometric mean of the age-specific probabilities of death also addresses the problem of perfect substitutability which is associated with the arithmetic mean.

We have also used the age-specific probabilities of death by single years of age instead of the age-specific death rates by single years of age to analyse mortality transition. The reason is that the probability of death in the last, open ended, age interval is always equal to 1 so that the geometric mean of the age-specific probabilities of death is not influenced by the risk or the probability of death in the last, open ended age interval. This is not the case with the death rate in the last, open ended age interval. It is well-known that it is always difficult to estimate the death rate in the last, open-ended age interval. It is also straightforward to decompose the change in the geometric mean of the age-specific probabilities of death to the change in the probability of death in different ages. This decomposition helps in characterising mortality transition in the population and in comparing mortality transition between two populations.

Decomposition of the Change in Geometric Mean

The change in the geometric mean of the age-specific probabilities of death (g) between two points in time, t_1 and t_2 ($t_2>t_1$), ∇g, can be decomposed into the change attributed to the transition or change in the probability of death in different ages following the index decomposition analysis (IDA). The IDA approach was first used in the early 1980s to analyse industrial energy consumption and has been widely applied in energy and emission studies (Ang, 2015). Among different IDA approaches, the Logarithmic mean Divisia index (LMDI) decomposition approach has been a dominating one (Ang, 2005; Ang and Liu, 2001). The popularity of the LMDI approach stems from a number of desirable properties it possesses (Ang, 2004). The approach has been popularly used in analysing the contribution of different factors to the increase in energy consumption and Carbon Dioxide emission (Makutėnienė et al, 2022; Lisaba and Lopez, 2020; He and Myers, 2021; Tu et al, 2019). It has also been used in analysing the contribution of the change in different factors to the change in demographic indicators (Chaurasia, 2023).

The change in g, between t_1 and t_2, ∇g, can be written as:

$$\nabla g = g_2 - g_1 = \frac{g_2 - g_1}{\ln\left(\frac{g_2}{g_1}\right)} \times \ln\left(\frac{g_2}{g_1}\right) = l_{21} \times \ln\left(\frac{g_2}{g_1}\right) \tag{1}$$

where

$$l_{21} = \frac{g_2 - g_1}{\ln\left(\frac{g_2}{g_1}\right)} \tag{2}$$

is the logarithmic mean of g_2 and g_1 (Carlson, 1966; 1972; Bhatia, 2008; Ostle and Terwilliger, 1957; Lin, 1974). If q_i is the probability of death in age i, then.

$$g = \left(\prod_{i=1}^{n} q_i\right)^{\frac{1}{n}} \tag{3}$$

$$\ln\left(\frac{g_2}{g_1}\right) = ln\left(\frac{\left(\prod_{i=1}^{n} q_{2i}\right)^{\frac{1}{n}}}{\left(\prod_{i=1}^{n} q_{1i}\right)^{\frac{1}{n}}}\right) \tag{4}$$

$$\ln\left(\frac{g_2}{g_1}\right) = \frac{1}{n}\sum_{i=1}^{n} ln\left(\frac{q_{2i}}{q_{1i}}\right) \tag{5}$$

Substituting, we get

$$\nabla g = g_2 - g_1 = \frac{l_{21}}{n} \times \sum_{i=1}^{n} ln\left(\frac{q_{2i}}{q_{1i}}\right) \tag{6}$$

Results of the decomposition of the change in g that is attributed to the change in the probability of death in different ages in the two countries are presented in Figure 4 and summarised in table 3. More than 53 per cent of the decrease in g in China during 1950-2021 is attributed to the decrease in the probability of death in population younger than 35 years of age whereas this proportion was almost 70 per cent in India. On the other hand, decrease in the probability of death in population aged 35-90 years accounted for a decrease of almost 45 per cent in g in China but less than 28 per cent in India. The contribution of the decrease in the probability of death in the age group 55-90 years to the decrease in g in India was less than 10 per cent but more than 23 per cent in China. In both countries, the decrease in the probability of death in the age group 1-14 years accounted for most of the decrease in g – around 24 per cent in China but almost 31 per cent in India (Figure 4).

Table 3: Contribution of the change in probability of death in different age-groups to the change in the geometric mean of the age-specific probabilities of death (g) in China and India, 1950-2021.

Age	China						
	Change in g during the period						
	1950-2021	1950-1957	1957-1960	1960-1963	1963-1966	1966-1979	1979-2021
	-0.0127	-0.0042	0.0145	-0.0172	-0.0022	-0.0088	-0.0096
	Contribution of the change in the probability of death in the age group						
0	1.65	1.16	-1.36	1.36	1.05	1.25	1.96
1-4	9.02	7.69	-8.88	8.87	6.71	7.99	9.84
5-9	9.47	9.86	-9.97	9.98	6.94	7.83	10.30
10-14	7.87	10.74	-9.57	9.57	6.34	5.95	8.30
15-19	6.98	9.76	-6.85	7.48	6.92	5.85	6.84
20-24	6.28	8.56	-5.78	6.53	7.57	6.14	5.64
25-29	6.06	8.68	-5.64	6.07	6.96	6.69	5.21
30-34	5.95	9.34	-5.81	6.12	6.07	6.41	5.17
35-39	6.05	8.40	-5.71	6.26	5.95	6.08	5.52
40-44	5.78	6.96	-5.09	5.65	6.87	5.58	5.43
45-49	5.25	5.85	-5.09	5.31	6.49	5.60	4.83
50-54	4.80	5.55	-4.65	4.67	5.55	5.60	4.29
55-59	4.48	5.87	-4.65	4.52	4.85	5.13	4.04
60-64	4.21	4.56	-3.79	3.96	4.38	4.37	4.04
65-69	3.90	3.28	-3.64	3.64	4.92	3.81	3.96
70-74	3.41	1.72	-3.46	3.23	4.12	3.68	3.55
75-79	2.93	1.47	-3.43	2.84	3.37	3.55	3.04
80-94	2.33	-0.33	-2.30	1.87	2.06	3.11	2.56
85-89	1.77	-1.57	-1.85	1.21	2.08	2.34	2.21
90-94	1.17	-3.33	-1.42	0.57	0.86	1.81	1.87
95-99	0.67	-4.22	-1.05	0.32	-0.05	1.22	1.42

	India						
	Change in g during the period						
	1950-2021	1950-1963	1963-1966	1966-1976	1976-2009	2009-2019	2019-2021
	-0.0177	-0.0026	0.0006	-0.0063	-0.0088	-0.0029	0.0023
	Contribution of the change in the probability of death in the age group						
0	2.03	1.77	-0.55	0.70	1.75	1.81	0.38
1-4	12.72	11.45	-8.41	4.33	11.36	11.17	2.13
5-9	11.18	7.02	-30.79	2.14	11.11	11.98	1.99
10-14	10.49	7.31	-16.48	7.41	9.60	7.31	1.00
15-19	8.96	5.45	3.16	6.23	8.27	8.11	-2.95
20-24	8.58	5.45	4.83	6.04	7.63	8.99	-4.02
25-29	8.14	5.47	5.22	7.24	7.50	6.58	-3.93
30-34	7.19	5.77	3.17	8.21	6.28	5.60	-4.66
35-39	6.08	5.77	2.28	8.01	5.80	3.61	-5.28
40-44	4.99	5.51	-0.08	6.49	5.99	1.70	-5.75
45-49	3.96	5.42	-3.82	4.95	4.68	3.56	-6.91
50-54	2.67	5.35	-6.51	3.43	4.81	1.02	-7.31
55-59	1.84	5.21	-7.95	2.18	4.81	-0.54	-7.14
60-64	1.69	4.96	-8.88	1.55	3.74	2.48	-8.03
65-69	1.43	4.58	-9.08	2.17	2.74	3.01	-7.89
70-74	1.26	4.07	-8.75	2.92	1.96	3.16	-7.56
75-79	1.43	3.37	-7.11	3.46	1.96	2.90	-7.03
80-94	1.24	2.58	-4.33	4.44	0.95	4.05	-7.91
85-89	0.99	1.84	-2.97	5.37	0.19	4.55	-8.61
90-94	1.49	1.04	-1.76	6.34	-0.35	4.53	-6.19
95-99	1.64	0.62	-1.20	6.37	-0.76	4.41	-4.33

Source: Author

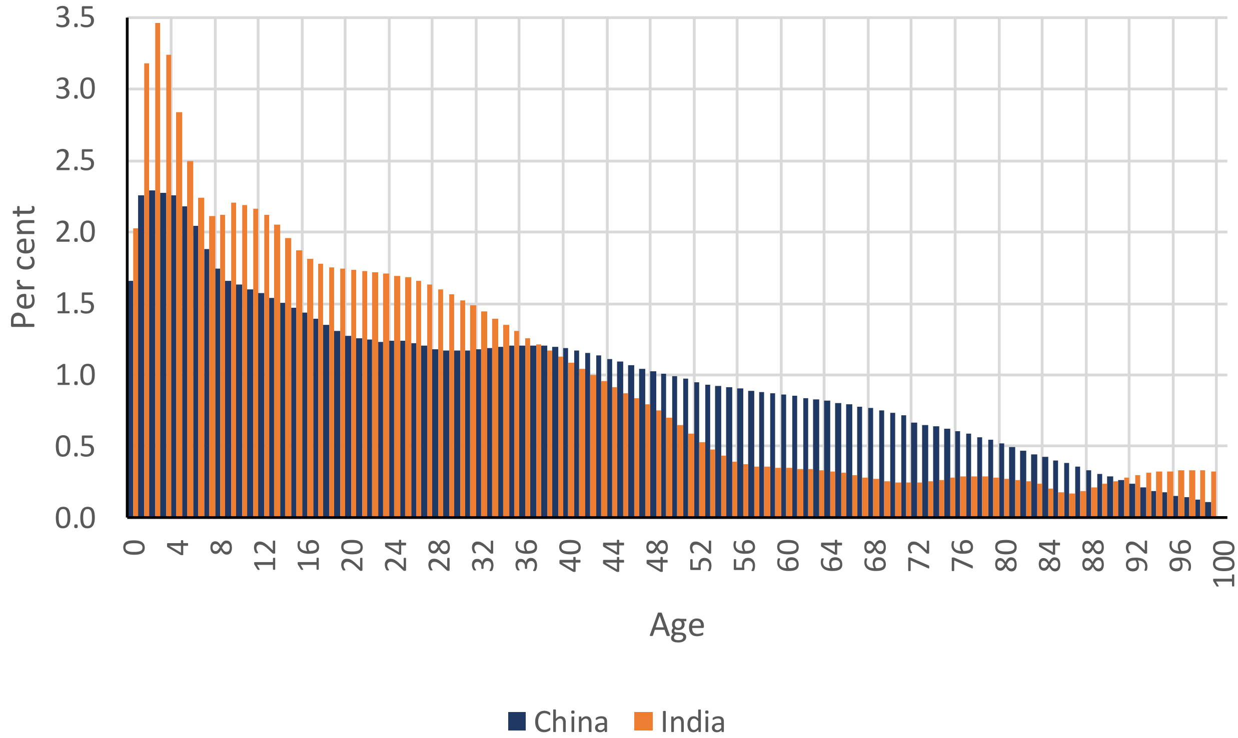

Figure 4: Proportionate contribution of the decrease in the probability of death in different ages to the decrease in *g* in China and India, 1950-2021.
Source: Author

Table 3 also decomposes the decrease in g in both countries in different time-segments in which the trend in g has been different. The proportionate contribution of the decrease in the probability of death in the conventional five-year age groups to the decrease in g in different time-segment has been different in China and India. In China, the probability of death in population aged 80 years and above increased during the period 1950-1957 which contributed to increase, instead decrease, in g. The increase in the probability of death in all ages contributed to the increase in g in China during 1957-1960. After 1960, the decrease in the probability of death in all ages contributed to the decrease in g with the only exception of the population aged 90 years and above during 1963-1966.

In India, on the other hand, the decrease in g during 1950-1963 was due to the decrease in the probability of death in all ages whereas the increase in g during 1963-1966 was due to the increase in the probability of death in ages below 15 years and in ages 40 years and above. During 1966-2019, the decrease in the probability of death in all ages contributed to the decrease in g in the country except during the period 1966-2019. During the COVID-19 pandemic, g increased and this increase was due to the increase in probability of death in ages 15 years and above.

The difference in g between two populations, A and B, at time t_2 depends upon two factors - the difference in g between the two populations at time t_1 and change in g between t_1 and t_2 (Andreev et al, 2002; Jdanov et al, 2017). The difference in g between population A and population B at time t_2 may be written as:

$$\Delta g^2 = g_A^2 - g_B^2 = l_{AB}^2 \times ln\left(\frac{g_A^2}{g_B^2}\right) \quad (7)$$

where,

$$l_{AB}^2 = \frac{g_A^2 - g_B^2}{ln\left(\frac{g_A^2}{g_B^2}\right)} \tag{8}$$

is the logarithmic mean of the g_A and g_B at time t_2. Now

$$ln\left(\frac{g_A^2}{g_B^2}\right) = ln\left(\frac{g_A^1}{g_B^1} \times \frac{g_B^1}{g_A^1} \times \frac{g_A^2}{g_B^2}\right) = ln\left(\frac{g_A^1}{g_B^1}\right) + ln\left(\frac{g_A^2}{g_A^1}\right) - ln\left(\frac{g_B^2}{g_B^1}\right) \tag{9}$$

Substituting in (8), we get

$$\Delta g^2 = g_A^2 - g_B^2 = l_{AB}^2 \times ln\left(\frac{g_A^1}{g_B^1}\right) + l_{AB}^2 \times ln\left(\frac{g_A^2}{g_A^1}\right) - l_{AB}^2 \times ln\left(\frac{g_B^2}{g_B^1}\right) \tag{10}$$

$$\Delta g^2 = g_A^2 - g_B^2 = \frac{l_{AB}^2}{n} \times \sum_{i=1}^{n} ln\left(\frac{q_{1i}^A}{q_{1i}^B}\right) + \frac{l_{AB}^2}{n} \times \sum_{i=1}^{n} ln\left(\frac{q_{2i}^A}{q_{1i}^A}\right) - \frac{l_{AB}^2}{n} \times \sum_{i=1}^{n} ln\left(\frac{q_{2i}^B}{q_{1i}^B}\right) \tag{11}$$

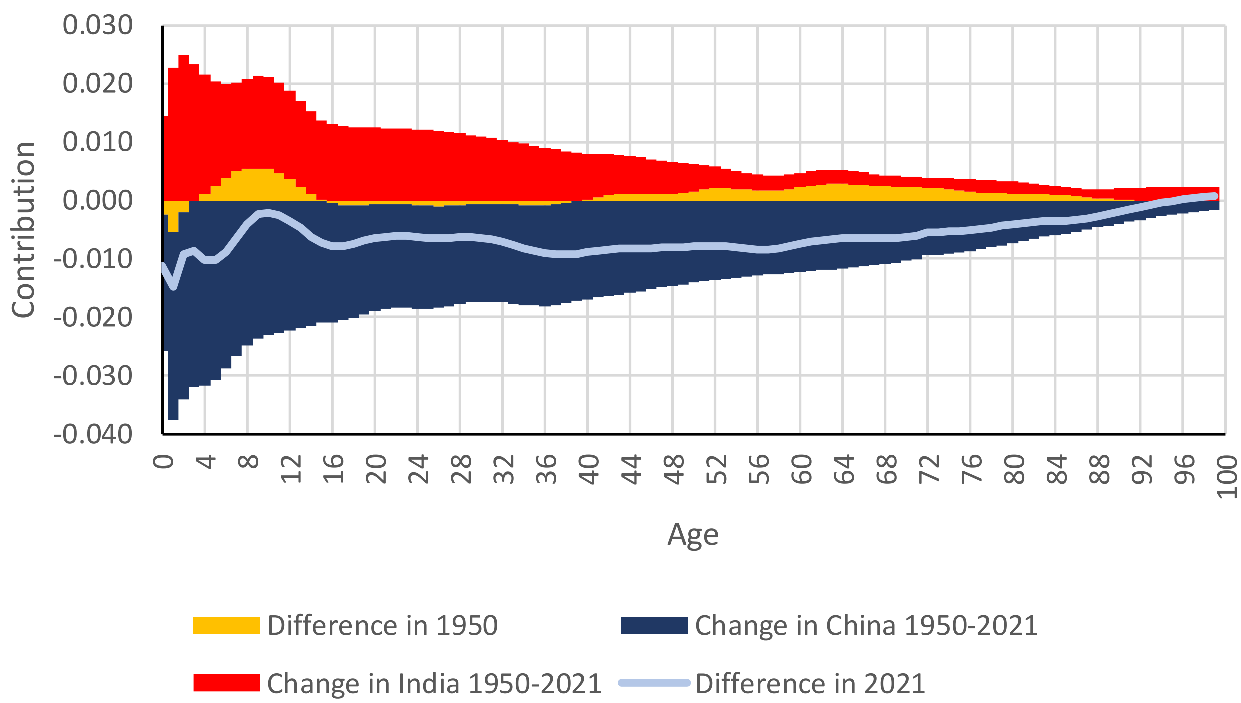

Figure 1: Decomposition of the difference in g in China and India in 2021.
Source: Author

Results of the decomposition of the difference in *g* between China and India are presented in figure 6. In 1950, *g* was higher in China because of higher probability of death in ages 3-15 and 40-91 years. The decrease in the probability of death in ages less than 96 years has been more rapid in China but more rapid in India in ages 96 years and above. The contribution of the decrease in the probability of death in ages 0-37 years and 91 years and above to the decrease in *g* has been higher in India but in ages 38-90 years, it has been higher in China. The lower mortality in China in 2021 has been due to relatively more rapid decrease in the probability of death in ages 0-95 years. However, the decrease in the probability of death in ages 96 years and above has been more rapid in India which has contributed to narrow down the difference in mortality between China and India in 2021.

Modelling Age-specific Probability of Death

The age-specific probability of death in year i and age j, q_{ij} can be decomposed in terms of a common factor ($q_{..}$) across all i and j; a row or year specific factor ($q_{i.}$) which is common to all columns or ages, j, of the row or the year i; a column or age specific factor ($q_{.j}$) which is common to all rows or years, i, of the column or age, j, and a residual factor r_{ij} which is specific to each pair of i and j as follows:

$$q_{ij} = q_{..} \times q_{i.} \times q_{.j} \times \frac{q_{ij}}{q_{..} \times q_{i.} \times q_{.j}} \tag{9}$$

Equation (9) can be written as

$$q_{ij} = q_{..} \times \frac{q_{i.}}{q_{..}} \times \frac{q_{.j}}{q_{..}} \times \frac{q_{ij} \times q_{..} \times q_{..}}{q_{..} \times q_{i.} \times q_{.j}} \tag{10}$$

or

$$q_{ij} = q_{..} \times m_{i.} \times m_{.j} \times m_{ij} \tag{11}$$

where,

$$m_{i.} = \frac{q_{i.}}{q_{..}} \tag{12}$$

$$m_{.j} = \frac{q_{.j}}{q_{..}} \tag{13}$$

$$m_{ij} = \frac{q_{ij} \times q_{..} \times q_{..}}{q_{..} \times q_{i.} \times q_{.j}} = \frac{\left(\frac{q_{ij}}{q_{..}}\right)}{\left(\frac{q_{i.}}{q_{..}} \times \frac{q_{i.}}{q_{..}}\right)} \tag{14}$$

Equation (11) can be fitted by applying the polishing technique, first proposed by Tukey (1977), by choosing an appropriate polishing function. The polishing technique successively sweeps the polishing function out of rows or years (divides row values by the polishing function for the row), then sweeps the polishing function out of columns or ages (divides column values by the polishing function for the column), then rows, then columns, and so on, accumulates them in 'all', 'row', and 'column' registers to obtain values of $q_{..}$, $m_{i.}$, and $m_{.j}$ respectively, and leaves behind the table of residuals (m_{ij}) which are specific to the row or the year i and the column or the age j. When the entire variation in q_{ij} across all i and all j is explained by $q_{..}$, $m_{i.}$, and $m_{.j}$ or, equivalently, by $q_{..}$, $q_{i.}$, and $q_{.j}$, all residuals (m_{ij}) are equal to 1. Otherwise m_{ij} reflects that part of q_{ij} which is not explained by $q_{..}$, $m_{i.}$, and $m_{.j}$.

We have used the geometric mean of the age-specific probabilities of death as the polishing function to fit the model given by equation (11) because the age distribution of the probability of death is not normal but skewed. With the use of the geometric mean of the age-specific probabilities of death as the polishing function, the geometric mean of residual multipliers m_{ij} for all i and j is equal to 1. Similarly, the geometric mean of m_{i}, for all i is equal to 1, and the geometric mean of $m_{.j}$ for all j is also equal to 1. It may also be noticed that multipliers $m_{i.}$, $m_{.j}$, and m_{ij} can be less than or more than 1. A value of the multiplier greater than 1 inflates $q_{..}$ whereas a value less than 1 deflates $q_{..}$. For example, if $m_{i.}>1$, then $q_{i.}$ is higher than $q_{..}$ whereas $q_{i.}$ is lower than $q_{..}$ if $m_{i.}<1$ and $q_{i.}$ is equal to $q_{..}$ if $m_{i.}=1$. Similar interpretation can be made for the multiplier $m_{.j}$. On the other hand, if $m_{ij}>1$ than q_{ij} is higher than that determined by $q_{..}$, $m_{i.}$, and $m_{.j}$. If $m_{ij}<1$ than q_{ij} is lower than that determined by $q_{..}$, $m_{i.}$, and $m_{.j}$ and q_{ij} is the same as determined by $q_{..}$, $m_{i.}$, and $m_{.j}$ when $m_{ij}=1$.

The model (11) is fitted to 7100 q_{ij} values, i ranging from 1 (1950) to 71 (2021) and j ranging from age 0 year to age 99 years for both China and India to estimate values of $q_{..}$, $m_{i.}$, $m_{.j}$, and m_{ij} for the two countries. The $q_{..}$ for China (0.0127) is estimated to be around 25 per cent lower than $q_{..}$ for India (0.0170) which indicates that overall mortality level in India has been higher than that in India during the 70 years period under reference. If the period of COVID-19 pandemic (2020-2021) is excluded, then $q_{..}$ is estimated to be around 32 per cent higher in India (0.0173) than that in China (0.0131) during the period 1950-2019. This implies that the COVID-19 pandemic has resulted in widening of the difference in the overall mortality level of the two countries. This widening of the difference in the overall mortality level between the two countries again confirms that the mortality impact of COVID-19 pandemic has been comparatively higher in India than that in China.

The fitting of the model reveals that the multiplier $m_{i.}$ has decreased in both countries during 1950-2021, although the trend has been different (Figure 7). The joinpoint regression analysis suggests that $m_{i.}$ in China decreased at an average annual rate of decrease of 2.64 per cent per year during 1950-2021 compared to an average annual rate of decrease of 1.41 per cent per year in India indicating that the decrease in average mortality across all ages has been more rapid in China than in India. In China, $m_{i.}$ was greater than 1 up to 1983 but turned less than 1 after 1983. In India, on the other hand, $m_{i.}$ was greater than 1 up to 1985 but turned less than 1 after 1985. The $m_{i.}>1$ implies $q_{i.}>q_{..}$. It may also be noticed from figure 7 that $m_{i.}$ in China was higher than that in India during the period 1950-1978 but, after 1978, it turned higher in India than in China. This means that relative to the overall mortality level, $q_{..}$, $q_{i.}$ was higher in China than that in India during 1950-1978 but, after 1978, relative to $q_{..}$, $q_{i.}$ became higher in India than that in China.

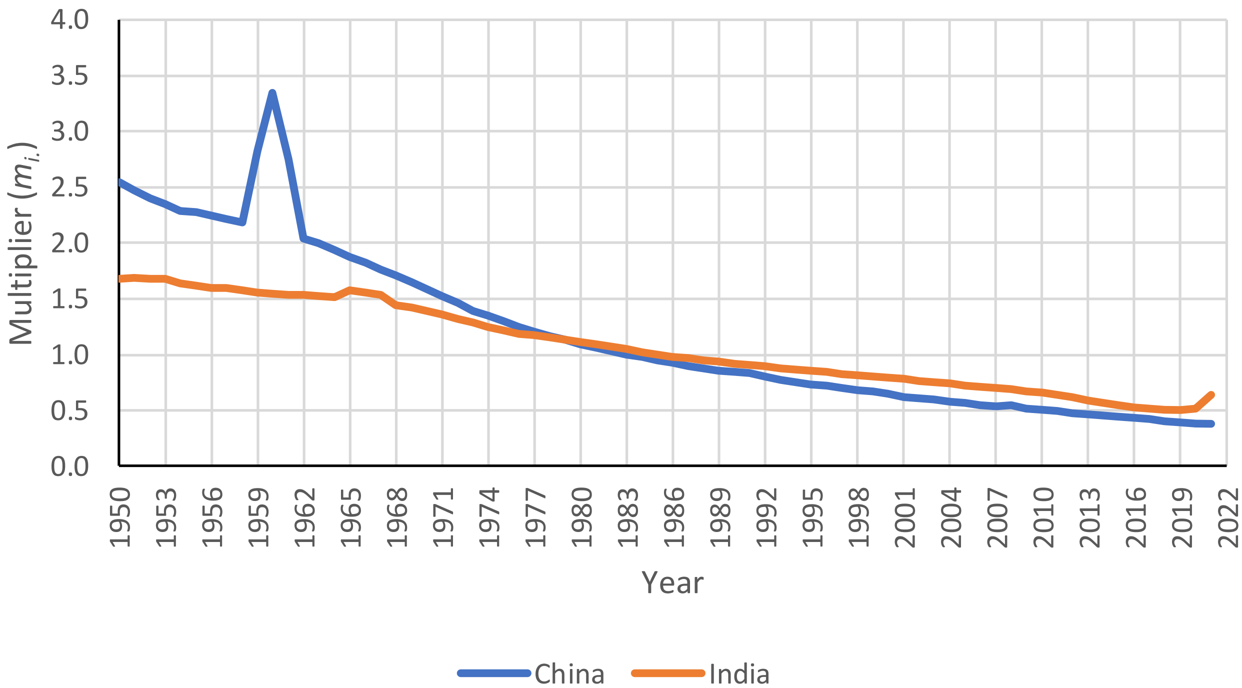

Figure 2: Trend in $m_{i.}$ in China and India, 1950-2021.
Source: Author

The age multiplier $m_{.j}$ or the ratio of $q_{.j}$, to $q_{..}$, has also been different in the two countries (Figure 8). The average probability of death in the first year of life during 1950-2021, $q_{.1}$, was more than 3 times the $q_{..}$ in China but more than 5 times the $q_{..}$ in India. However, in ages 8-13 years, multiplier $m_{.j}$ has been higher in China than in India, suggesting that, relative to $q_{..}$, the probability of death in China was higher than that in India in 8-13 years of age. Similarly, in ages more than 60 years, the multiplier $m_{.j}$ is again higher in China than that in India and the difference increased with age. For example, $q_{.90}$ is more than 19 times the $q_{..}$ in China but only about 13 times the $q_{..}$ in India. In ages 9-60 years, however, $q_{.j}$, relative to $q_{..}$ has been higher in India as compared to $q_{.j}$, relative to $q_{..}$ in China.

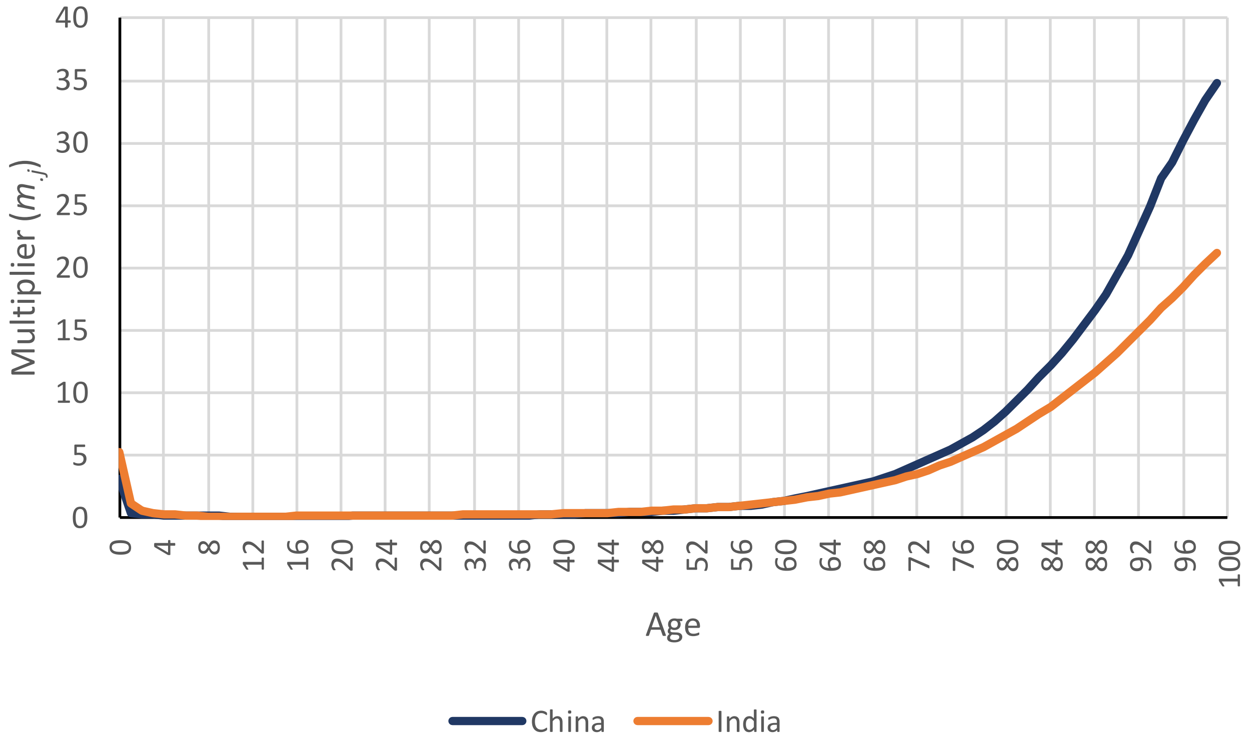

Figure 3: The age multiplier($m_{i.}$) common to the period 1950-2021 in China and India.
Source: Author

The trend in the residual multiplier (m_{ij}) in the two countries is depicted in figure 4. In both countries, m_{ij} decreased markedly with time in the younger ages but increased markedly with time in the older ages whereas as the change in the middle ages of life has not been so marked. An increase in m_{ij} implies an increase in the actual probability of death specific to the year *i* and age *j* which is not explained by $q_{..}$, $q_{i.}$, and $q_{.j}$. and vice versa. For example, the probability of death in the first year of life in China was more than 30 per cent higher than the probability of death determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 1950 but was more than 62 per cent lower than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 2021. It may also be noticed from the figure that the actual probability of death in the first year of life in China remained higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ up to the year 2002 and became lower than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ only after 2002. By contrast, the actual probability of death in the first year of life in India was around 21 per cent higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 1950 but was about 55 per cent lower than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 2021. The actual probability of death in the first year of life in India remained higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ up to the year 1997 and turned lower than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ after the year 1997 only. On the other hand, the actual probability of death in 80 years of age in China was around 24 per cent lower than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 1950 but was more than 59 per cent higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 2021. Similarly, the actual probability of death in 80 years of age in India was around 38 per cent lower than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 1950 but was almost 54 per cent higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in the year 2021. In China, the actual probability of death in the year 1950 was higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ up to 56 years of age but in the year 2021, it was higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in ages 47 years and above. Similarly, in India, the actual probability of death in the year 1950 was higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ up to 47 years of age but in the year 2021, it was higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$ in ages 37 years and above.

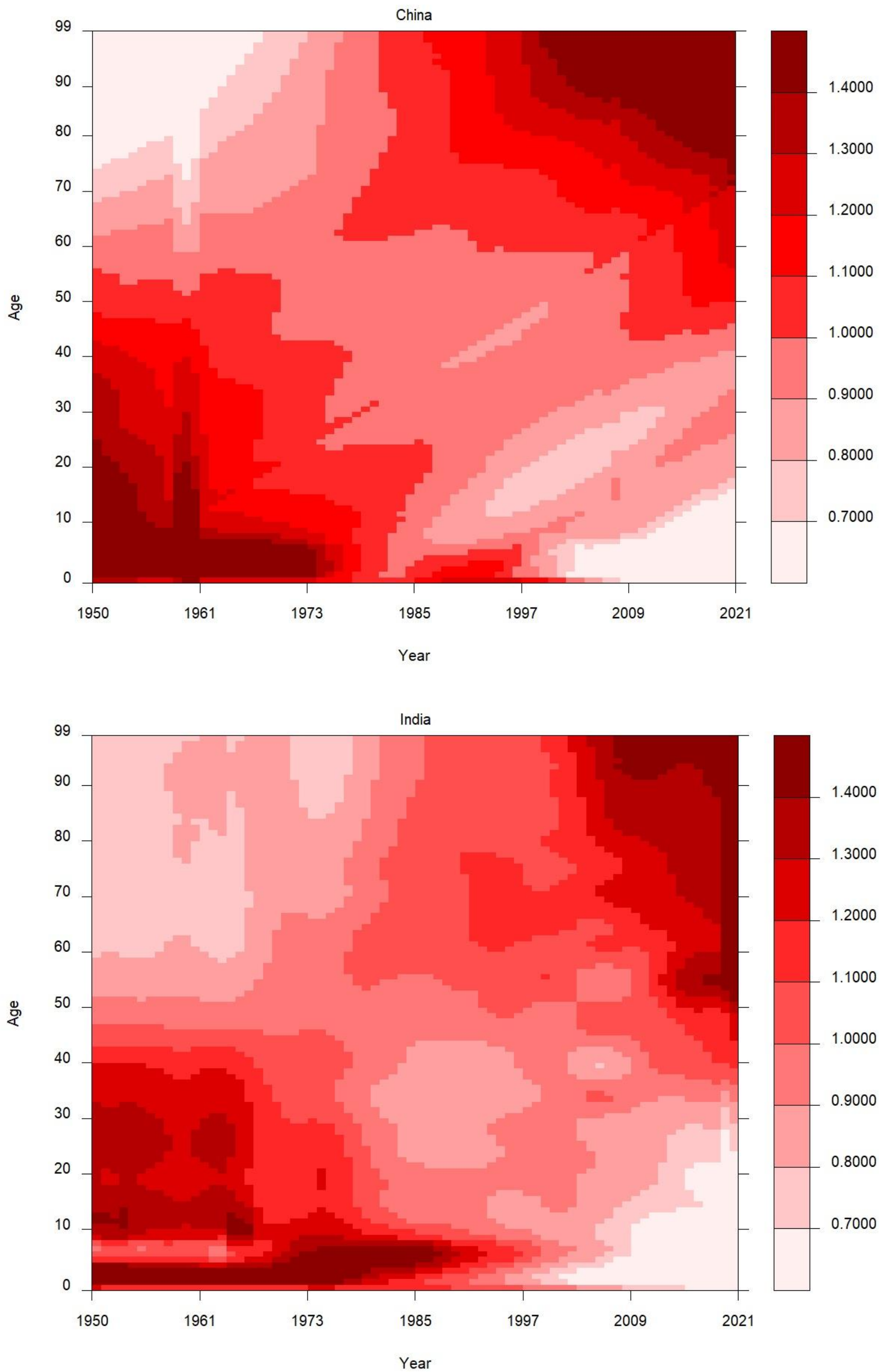

Figure 4: Residual multipliers (m_{ij}) in China and India.
Source: Author

Decomposing the Change in Age-specific Probabilities of Death

Equation (11) suggests that difference in q_{ij} between two populations A and B can be decomposed into four components as follows:

$$\nabla q_{ij} = q_{ij}^{A} - q_{ij}^{B} = \left(q_{..}^{A} \times m_{i.}^{A} \times m_{.j}^{A} \times m_{ij}^{A}\right) - \left(q_{..}^{B} \times m_{i.}^{B} \times m_{.j}^{B} \times m_{ij}^{B}\right) \tag{15}$$

We can write,

$$\nabla q_{ij} = \frac{q_{ij}^{A}-q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right) = \frac{q_{ij}^{A}-q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{..}^{A}\times m_{i.}^{A}\times m_{.j}^{A}\times m_{ij}^{A}}{q_{..}^{B}\times m_{i.}^{B}\times m_{.j}^{B}\times m_{ij}^{B}}\right) \tag{16}$$

$$\nabla q_{ij} = \frac{q_{ij}^{A}-q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times \left(ln\left(\frac{q_{..}^{A}}{q_{..}^{B}}\right) + ln\left(\frac{m_{i.}^{A}}{m_{i.}^{B}}\right) + ln\left(\frac{m_{.j}^{A}}{m_{.j}^{B}}\right) + ln\left(\frac{m_{ij}^{A}}{m_{ij}^{B}}\right)\right) \tag{17}$$

$$\Delta q_{ij} = \left\{\frac{q_{ij}^{A}-q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{..}^{A}}{q_{..}^{B}}\right)\right\} + \left\{\frac{q_{ij}^{A}-q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{m_{i.}^{A}}{m_{i.}^{B}}\right)\right\} + \left\{\frac{q_{ij}^{2}-q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{.j}^{2}}{m_{.j}^{1}}\right)\right\} + \left\{\frac{q_{ij}^{2}-q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{ij}^{2}}{m_{ij}^{1}}\right)\right\}$$

$$\Delta q_{ij} = C_{..} + C_{i.} + C_{.j} + C_{ij} \tag{18}$$

$$C_{..} = \left\{\frac{q_{ij}^{A}-q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{..}^{A}}{q_{..}^{B}}\right)\right\} \tag{19}$$

$$C_{i.} = \left\{\frac{q_{ij}^{A}-q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{m_{i.}^{A}}{m_{i.}^{B}}\right)\right\} \tag{20}$$

$$C_{.j} = \left\{\frac{q_{ij}^{2}-q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{.j}^{2}}{m_{.j}^{1}}\right)\right\} \tag{21}$$

$$C_{ij} = \left\{\frac{q_{ij}^{2}-q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{ij}^{2}}{m_{ij}^{1}}\right)\right\} \tag{22}$$

Equation (18) suggests that the difference in q_{ij} between two populations can be described in terms of the contribution attributed to the difference in the overall level of mortality, $q_{..}$ (Component $C_{..}$), difference in the multiplier for the year i ($m_{i.}$) across all ages (Component $C_{i.}$), difference in the multiplier for age j ($m_{.j}$) across all years (Component $C_{.j}$), and difference in the residual multiplier (m_{ij}) which reflects the probability of death not explained by $q_{..}$, $q_{i.}$, and $q_{.j}$ (Component C_{ij}).

Figure 5 depicts the difference in q_{ij} between China and India for different years of the period 1950 through 2021 and for each age ranging from 0 year to 99 years. A negative value of the difference means that q_{ij} is higher in India as compared to China. On the other hand, a positive value of the difference means that q_{ij} is higher in China as compared to India. It may be seen from the figure that q_{ij} has not always been lower in China as compared to India. Moreover, the magnitude of the difference varies widely across ages and across time. In ages 50-90 years, the probability of death in India has markedly been higher than that in China after 1980 but in ages less than 5 years and in ages 90 years and above, the probability of death in China has been markedly higher than that in India.

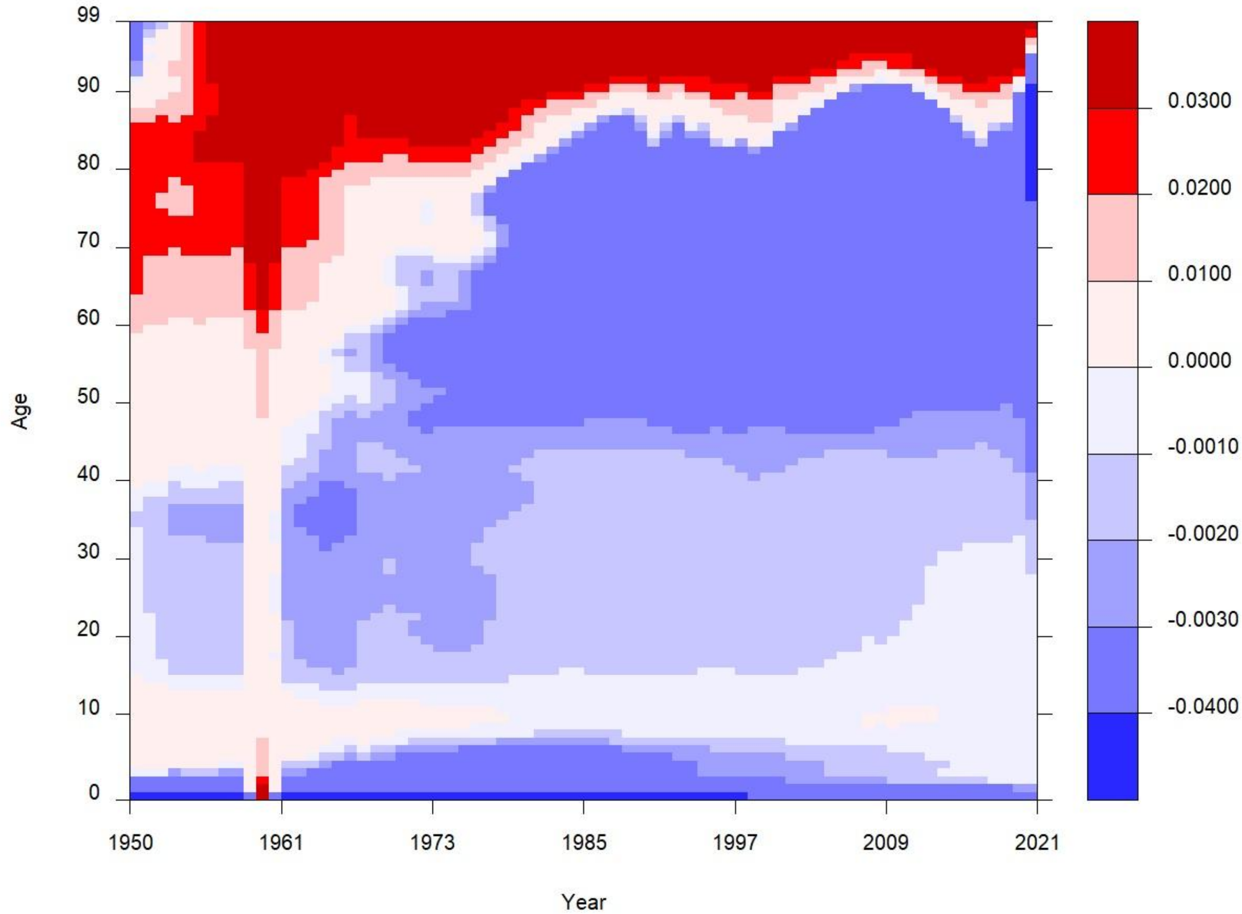

Figure 5: The difference in the age-specific probabilities of death (q_{ij}) between China and India, 1950-2021. Source: Author

Results of the decomposition of the difference in q_{ij} between China and India into its four components in conjunction with equation (18) is summarised in figures 6 through 9. The contribution of the difference in $q_{..}$ between the two countries (Component $C_{..}$) has always been negative as the average probability of death across all ages and all years ($q_{..}$) has always been lower in China as compared to India. The contribution has, however, varied widely from a minimum of -0.1426 to the maximum of -0.0001. Figure 6 suggests that the contribution increases with the increase in age, and, in the older ages, the contribution is the highest. On the other hand, the contribution of the difference in the multiplier $m_{i.}$ and in the multiplier $m_{.j}$ is both negative and positive. The same is the case with the residual multiplier m_{ij}. Moreover, there is a clear pattern in the contribution of the difference in $q_{..}$, $m_{i.}$, and $m_{.j}$, the distribution of the contribution of the difference in m_{ij} appears to be largely random across time and age.

Table 4 which shows how the difference in $q_{..}$, $m_{i.}$, $m_{.j}$, and m_{ij} contribute to the difference in q_{ij} between China and India in the first year, in the 40th year, and in the 80th year in 1950, 1985, and 2021. In the year 1950, the probability of death in age 0 ($q_{1950,0}$) was 0.132 in China but 0.181 in India. This difference was due to higher overall mortality and higher age effect in India than that in China as the year effect and the residual effect were lower in India compared to China which contributed to narrow down the difference in the probability of death in age 0 in 1950. In 1985, on the other hand, $q_{1985,0}$ was 0.041 in China, but 0.102 in India and all the four components contributed to lower the probability of death in China compared to India. Similarly, in 2021, $q_{2021,0}$ was 0.006 in China but 0.026 in India and the contribution of all the four components of the difference contributed to lower the probability of death in the first year of life in China compared to India.

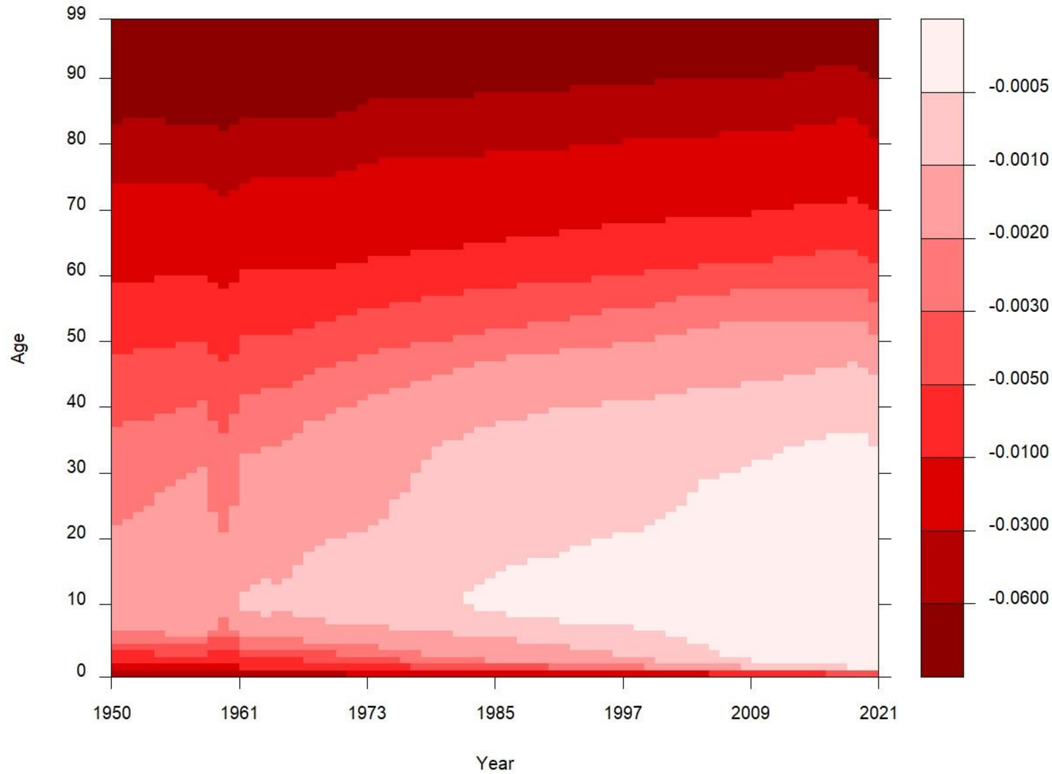

Figure 6: Contribution of the difference in $q_{..}$ to the difference in q_{ij} between China and India.
Source: Author

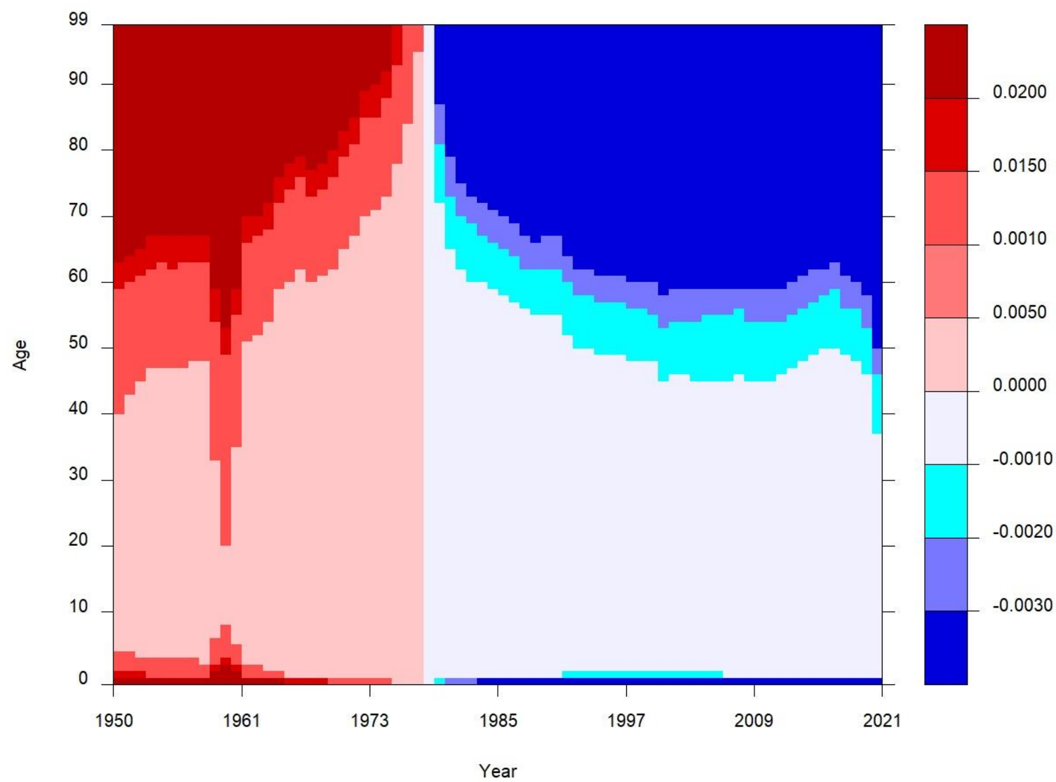

Figure 7: Contribution of the difference in $m_{i.}$ to the difference in q_{ij} between China and India.
Source: Author

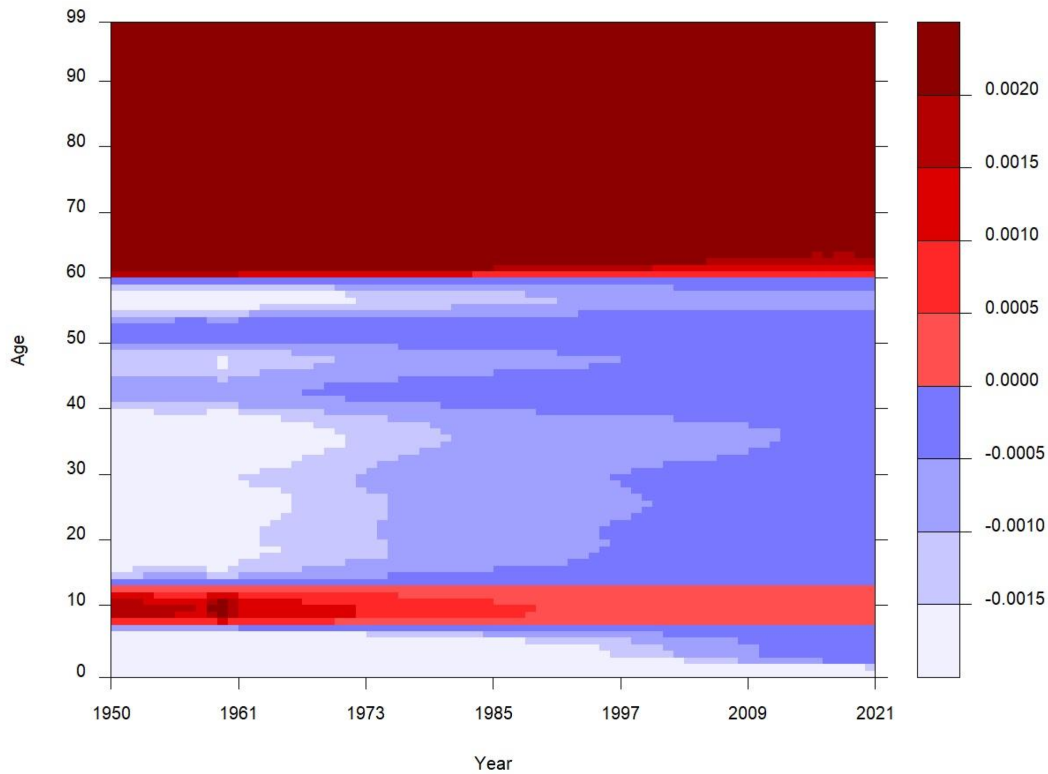

Figure 8: Contribution of the difference in $m_{.j}$ to the difference in q_{ij} between China and India.
Source: Author

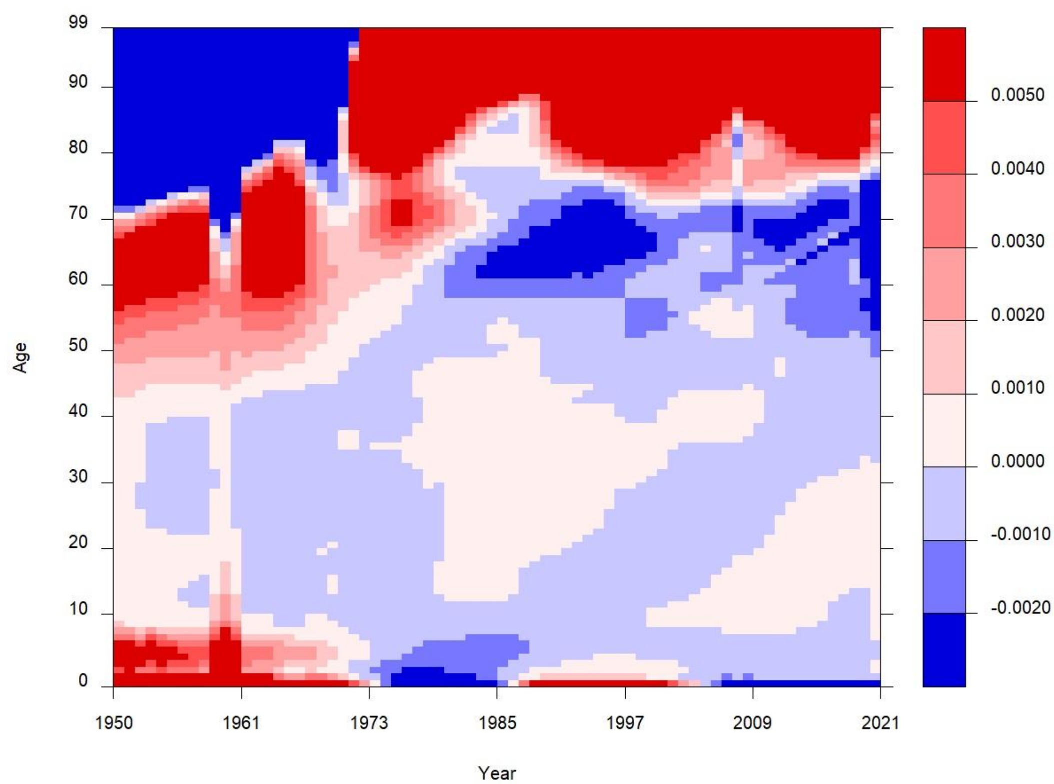

Figure 9: Contribution of the difference in m_{ij} to difference in q_{ij} between China and India.
Source: Author

Table 4: Decomposition of the difference in q_{ij} between China and India.

Measure	1950			1985			2021		
	China	India	Difference/ contribution	China	India	Difference/ contribution	China	India	Difference/ contribution
					Age 0 years				
q_{ij}	0.132	0.187	-0.049	0.041	0.102	-0.060	0.006	0.026	-0.020
$q_{..}$	0.013	0.017	-0.045	0.013	0.017	-0.019	0.013	0.017	-0.004
$m_{i.}$	2.545	1.678	0.065	0.952	1.003	-0.004	0.377	0.638	-0.007
$m_{.j}$	3.119	5.230	-0.080	3.119	5.230	-0.035	3.119	5.230	-0.007
m_{ij}	1.304	1.212	0.011	1.087	1.138	-0.003	0.378	0.448	-0.002
					Age 40 years				
q_{ij}	0.012	0.012	0	0.003	0.005	-0.002	0.001	0.004	-0.003
$q_{..}$	0.013	0.017	-0.003	0.013	0.017	-0.001	0.013	0.017	-0.001
$m_{i.}$	2.545	1.003	0.005	0.952	1.003	0	0.377	0.638	-0.001
$m_{.j}$	3.119	5.230	-0.002	0.248	0.327	-0.001	0.248	0.327	0
m_{ij}	1.087	1.138	0	0.940	0.881	0	0.873	1.114	-0.001
					Age 80 years				
q_{ij}	0.170	0.145	0.026	0.106	0.116	-0.010	0.063	0.111	-0.048
$q_{..}$	0.013	0.017	-0.046	0.013	0.017	-0.032	0.013	0.017	-0.025
$m_{i.}$	2.545	1.678	0.065	0.952	1.006	-0.006	0.377	0.638	-0.045
$m_{.j}$	8.548	6.611	0.039	8.468	6.611	0.027	8.468	6.611	0.021
m_{ij}	0.618	0.764	-0.033	1.033	1.026	0.001	1.560	1.537	0.001

Source: Author

Discussion and Conclusions

This paper has highlighted how mortality transition in China has been different from that in India during 1950-2021. At the aggregate level, mortality transition has been more rapid in China than in India. There are, however, ages in which mortality transition in India has been more rapid than that in China. An important difference between mortality transition in China and India is that mortality transition in China has been spread across all ages up to 90 years of age. This has not been the case in India where mortality transition has largely been confined to younger ages. There has been little transition in mortality in ages 55-90 years of age in the country during the 71 years under reference. Mortality transition in ages below 30 years has been quite impressive in India but the impressive mortality transition in younger ages has been compromised, substantially, by very slow mortality transition in older ages. India has now achieved the replacement fertility which means that an increasing proportion of the population of the country will now be getting older. This means that, to hasten the pace of mortality transition, India must make efforts to accelerate the reduction in the probability of death in older ages, especially in ages 55 years and above. This will require a comprehensive reinvigoration of the health care delivery system of the country which has historically been evolved following the extension approach the delivery of health care services. This approach is primarily aimed at addressing morbidity and mortality from infectious and communicable diseases through the application of the low-cost appropriate technology. It appears to have largely been successful in reducing the risk of death in younger ages in India, especially the risk of death during childhood. However, this approach has its limitations in addressing the health care needs of the older population as non-communicable and degenerative diseases are now the primary causes of morbidity and mortality in older ages. India needs an institution-based approach of meeting the health care needs of the old population to accelerate the decrease in the risk of death in old ages. The present analysis reveals that the difference in mortality transition in China and India, essentially, is located in the difference in mortality transition in older ages between the two countries. India has performed quietly impressively in terms of mortality transition in the younger ages but mortality transition in older ages remains a grey area as regards mortality transition in the country. A reinvigoration in the health care delivery system to meet the health care needs of the old people, therefore, is the need of the time.

The present analysis also suggests that at the aggregate level, mortality transition should not be analysed in terms of the trend in the life expectancy at birth. Rather, mortality transition should be analysed in terms of the geometric mean of the age-specific probabilities of death. The trend in the life expectancy at birth depicts mortality transition in a hypothetical population and not mortality transition in the real population. The present analysis shows that mortality transition depicted by the trend in the life expectancy at birth is slower than that depicted by the trend in the geometric mean of the age-specific probabilities of death.

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