RESEARCH ARTICLE

Changes in total and disability-free life expectancy among older adults in China: Do they portend a compression of morbidity?

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Abstract: The purpose of this research is to determine whether disability-free life expectancy (DFLE) in China has been increasing more rapidly than total life expectancy (TLE). Such a scenario would be consistent with a compression of morbidity, a situation that is especially desirable in a country experiencing rapid population aging and gains in old-age longevity. Using the Chinese Longitudinal Healthy Longevity Study, an exponential survival regression is used to calculate TLE. The Sullivan method is then employed for computing DFLE. Results for a 65 and older sample are compared across data collected during two periods, the first with a 2002 baseline and a 2005 follow-up (N=15,641) and the second with a 2008 baseline and a 2011 follow-up (N=15,622). The first comparison is by age and sex. The second comparison divides the sample further by rural/urban residence and education. The ratio of DFLE/TLE across periods provides evidence of whether older Chinese are living both longer and healthier lives. The findings are favorable for the total population aged 65+, but improvements are only statistically significant for females. Results also suggest heterogeneous compression occurring across residential status with the urban population experiencing more favorable changes than their rural counterparts. Results both portend a compression of morbidity and continuing disadvantage for rural residents who may not be participating in population-wide improvements in health.

Keywords: aging, China, compression of morbidity, disability, life expectancy, longevity, mortality, Sullivan method

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Received: April 9, 2015; **Accepted:** June 1, 2015; **Published Online:** June 7, 2015

Citation: Zimmer Z, Hidajat M, and Saito Y. (2015). Changes in total and disability-free life expectancy among older adults in China: Do they portend a compression of morbidity? *International Journal of Population Studies*, vol.1(1): 4–18. http://dx.doi.org/10.18063/IJPS.2015.01.001.

1 Introduction

1.1 Demographic Change in China and Implications for Disability

This study looks at whether and how total and disability-free life expectancy among older Chinese has been changing, whether the changes suggest a compression of morbidity, and whether changes are consistent across sex, education and rural/urban residence. The topic is important given demographic changes experienced by China over the last few decades. These changes are influencing China's age structure. According to estimates from the United Nations (2013), around 1970 the Total Fertility Rate and Crude Birth Rate measured about 6 children per woman and 40 births per 1,000 persons respectively; rates typical for developing countries. Nonetheless, by about 2000, these figures dropped steeply to about 1.5 and 14 respectively; rates typical of more developed countries. While total mortality also declined, it is mortality among older persons that is consequential for the current study. World Health Organization (2012) estimates indicate life expectancy at 65 was 13.2 for males and 14.5 for females in 1990 and rose to 14.3 for males and 16.4 for females by 2009. Over the same period, the percent chance that a 65 year old survived to 80 increased from about 40% to 47% for males and 48% to 58% for females.

As demographers have long recognized (Goldstein, 2009), precipitous declines in fertility leads to population aging. Thus, China's population is now among the fastest aging population in the world (Chen and Liu, 2009). Ever increasing longevity is resulting in aging amongst the aged since those reaching old age are surviving to more advanced ages. Data from the United Nations (2013) reveals the fastest growing portion of China's population today is its oldest-old. Those 80+ are growing at more than 5% per year, which results in a doubling of the oldest-old population in less than 14 years, while growth rates for other ages remain stable or are negative.

These changes have implications for population-wide prevalence of health problems that tend to increase with age (Kinsella and Phillips, 2005). Disability, defined as the incapacity to accomplish tasks on one's own, that are necessary for daily survival like feeding and bathing (Verbrugge and Jette, 1994), is one of these problems. Still, the precise impact of demographic changes on disability depends on a number of factors. One is how disability rates change as survival increases. There are several scenarios, each of which has implications. One scenario assumes a status quo whereby there are few changes in the tendency to have disability at different ages. An alternate scenario is one where as people live to increasingly advanced ages they are living additional years in good health and thus age-specific disability rates are falling. This is consistent with the notion of a compression of morbidity, initially popularized by James Fries (1980), which predicts that as longevity expands morbid conditions become increasingly compressed only into a short time preceding death. Although a compression of morbidity technically concerns what is happening just before death, if it is occurring then we would expect people to be living both longer lives and a greater proportion of life in a healthy state. A third possible scenario represents a compromise which we term as *heterogeneous compression*, whereby a compression of morbidity occurs among certain subgroups. For instance, the compression may be occurring for more advantaged populations like those with higher education or living in areas where there is uncomplicated access to health care.

Clearly, for a country like China, which of these is taking place has implications for population health. With a scenario resembling a status quo, a greater number of older persons mean more disabled. With a scenario resembling a compression of morbidity, population aging and increasing longevity does not necessarily mean more disability. A heterogeneous compression is suggestive of inequalities in health and aging and might point towards a situation whereby some groups are advantaged more so than others.

1.2 Trends in Disability Prevalence and Disability-free Life Expectancy

A common way of assessing which scenario is occurring has been to examine disability trends. There is a long history of such research in the United States where population aging has been a concern for some time and reliable data exists to monitor changes over the relatively long term. Much of this research has been summarized by Freedman and colleagues (2002 and 2004). The general conclusion is that the 1960's and 1970's saw increases in disability rates (Colvez and Blanchet, 1981). More recently there have been persistent declines (Martin *et al*., 2010; Schoeni *et al*., 2001). Some of the turn-around is a function of population composition. In particular, education tends to be inversely association with disability and there is a rising proportion of more educated in the older population (Freedman and Martin, 1999).

A more direct way of determining whether longer and healthier lives are being lived is to observe changes to healthy or active life expectancy. These are measures that evaluate number of years or proportion of remaining life an individual can expect to live in a healthy state. Disability-free life expectancy (DFLE) is derived from these general measures and focuses on separating total life expectancy (TLE) into years expected to be lived with and without disability (Saito *et al*., 2014). The most pessimistic scenario relates to TLE rising but DFLE remaining stagnant, indicating extra years of life are being lived in states of disability (Crimmins *et al*., 1989) The most optimistic scenario, and one that would comport with a compression of morbidity, would see DFLE rising faster than TLE (Fries, 1980). While there have been a series of DFLE estimates in the United States and in other developed countries, only a few studies have examined trends over time, notably those by Crimmins and colleagues (1997, 2001, 2009). In general, these studies indicate changes in DFLE in the U.S. are, with some variation, paralleling increases in TLE.

Despite rapid demographic changes taking place in China, similar research there has been scarce, partially due to data availability. However, in recent years there have been several attempts to examine disability trends for the total country or sub-regions (Feng *et al*., 2013; Zimmer *et al*., 2014; Gu *et al*., 2009). Liu *et al*. (2009) examined changes in TLE and DFLE and concluded a compression of morbidity was occurring, particularly amongst oldest-old. There have been a scattering of studies on disability prevalence and DFLE trends across other countries in the region (Schoeni *et al*., 2006; Ofstedal *et al*., 2007; Martin *et al*., 2011; Chou *et al*., 2008). These findings have been inconclusive. Trends in disability generally may be seen as improving, however this is not the case everywhere and trends do not necessarily hold when socio-demographic and economic control variables are added.

1.3 Using DFLE to Assess Longer Life Versus Healthier Life

DFLE has been widely used for comparing health across populations and examining how health has been changing over time (Saito *et al*., 2003; Jagger *et al*., 2009; Robine *et al*., 2001). Comparing TLE and DFLE over time allows for an assessment of whether longer life and better health is occurring simultaneously, the scenario consistent with a compression of morbidity. These comparisons can be made in different ways. One comparison is whether net increases in DFLE match increases in TLE. This is an indication of whether, on a population-wide level, extra years of life are being lived without disability. More applicable for the current study is the ratio of DFLE to TLE, or the proportion of remaining life without disability. An increasing ratio speaks of relative gains — again on a population-wide level. It is possible that the net DFLE increase does not match the net TLE increase, but because DFLE is always something less than TLE, the relative increase may match or be greater. While this might mean that not all additional years of life are spent disability free, it implies the proportion of disability-free life is increasing, which is in line with the compression of morbidity scenario.

The current study uses national longitudinal panel data from China to test whether evidence of a status quo, a compression of morbidity, or heterogeneous compression exists among older persons during a period of rapid socio-economic and demographic change. The study first examines this by age and sex. Over a very short period of time China has become more urbanized and more educated, and both of these factors could be influencing disability. Thus, second, the study examines changes across four sub-groups: higher educated urban, lower educated urban, higher educated rural, lower educated rural. The study asks the questions, do recent changes in total and disability-free life expectancy in China suggest that older Chinese are living both longer and healthier lives portending a compression of morbidity and is the result consistent across sexes, rural/urban residence and levels of education?

2 Methods

2.1 Data

Data come from four waves of the China Longitudinal Healthy Longevity Survey (CLHLS), a multi-wave panel study of elderly Chinese. It is conducted in 22 provinces which account for over 85% of China's population. CLHLS baseline data was collected in 1998. Follow-ups were conducted in 2000, 2002, 2005, 2008 and 2011. Follow-ups combined re-interviews with add-in observations to account for both mortality and non-mortality attrition. When the study was launched the age of the sample was 80+. In 2002 the study expanded coverage to those 65 and older. Because of the more extensive age range, the current study begins with the 2002 sample. The sampling strategy involved oversampling oldest-old (age 80+) and as such the study contains a considerable number of octogenarians, nonagenarians, and centenarians. The current analysis involves two separate samples, the first with baseline data collected in 2002 and follow-up in 2005 and the second baseline in 2008 and follow-up in 2011. Sample sizes are 15,641 and 15,622 respectively.

Assessments of data reliability have been conducted (Zeng *et al*., 2001 and 2002; Gu, 2007). There is a volume that reviews fundamental findings of the survey (Zeng *et al*., 2008). Detailed information and assessments of data quality can be found on the study's website (http://centerforaging.duke.edu/chinese-longitudinal-healthy-longevity-survey). The website lists hundreds of peer-reviewed publications in both English and Chinese, Ph.D., M.S. and M.A. theses and other notable publications. A number of studies (Dupre *et al*., 2008; Yi *et al*., 2001 and 2002; Gu, 2009) relate to life expectancy, disability and healthy longevity.

2.2 Measures

The measure of disability is based on survey items originally employed by Katz *et al*. (1963) in their Activities of Daily Living (ADL) scale. Specifically, individuals are asked whether they can conduct the following tasks on their own and without assistive devices: bathing, dressing, toileting, getting up from a bed and chair, and eating. Answers for interviewees that are unable to respond due to cognitive and other health problems are provided by proxy respondents. As in the common conceptualization of the disablement process, the inability to conduct one of these ADL tasks independently is considered to be a disability (Verbrugge and Jette, 1994). Age and sex are recorded for each respondent when they first enter the panel. A rural/urban measure is based on the place of residence variable included in CLHLS data (Zeng, 2001 and 2002). Education is based on a survey question about highest achieved level of education. We create a dichotomous variable for education that makes sense, given the distributions of education among this cohort. The categories are: primary or less, estimated as being 4 or fewer years of schooling; and more than primary, estimated as 5+ years. From this point on we refer to this delineation simply as lower educated and higher educated.

2.3 Analytical Strategy

The Sullivan method is used for computing DFLE (Saito *et al*., 2014; Sullivan, 1971; Jagger *et al*., 2014). The method customarily applies disability prevalence rates from a sample survey to published life tables to compute DFLE. However, this limits comparisons to groups that are identified in published life tables. Since no life tables for China divide the population into rural/urban by education sub-groups, we use a technique employed by Chiu (2013) where both the life table and disability prevalence rates are derived from sample surveys.

TLE is determined from survival models that have an exponential distribution computed with SAS software and its PROC LIFEREG procedure. The equation first estimates the hazard of dying as a function of sex and age. The second estimates the hazards adding covariates education and residence. The second equation can be notated as follows:

$$M_x = e^{\left(-\left[\beta_0+\beta_1 X_{sex}+\beta_2 X_{age}+\beta_3 X_{education}+\beta_4 X_{residence}\right]\right)}$$

M_x in this equation indicates a central death rate for an age interval. It is converted into the probability that an individual at exact age x dies before reaching the next age interval, or life table function q_x. From here, other life table functions (l_x, d_x, p_x, L_x, T_x and e_x) are determined.

Prevalence of disability by age, sex, rural/urban residence and education is calculated as number disabled within a sub-group divided by the survey population size of that sub-group. To determine DFLE, prevalence for those in a given age range, considered as the average prevalence across the baseline and follow-up years, is used to separate the L_x life table column, indicating total person years lived within an age range, into years lived disabled and non-disabled. This is done by multiplying L_x by the proportion disabled. Standard errors and confidence intervals are calculated for each TLE and DFLE using formulae provided in Jagger *et al*. (2014). For calculations of DFLE these formulae are based on standard errors that combine variances of both prevalence and mortality.

To assess whether both longer life and longer disability-free life are occurring, TLE and DFLE by age and sex are calculated for two periods of time. The first uses 2002 as baseline and 2005 as follow-up. The second uses 2008 as baseline and 2011 as follow-up. Comparisons focus on the ratio of DFLE/TLE, or the life proportion expected to be lived without disability. A ratio of 1.00 means all remaining life is disability-free. This is an ideal scenario but never actually exists. If a compression of morbidity is occurring, DFLE will be rising faster than TLE, which would indicate that this ratio gets closer to 1.00.

There are two stages to the analysis. First, computations examine results by age and sex, with age divided into five year intervals. Second, computations further divide the population by rural/urban residence and level of education. Therefore, the second stage analyzes results by age and sex for sub-groups: (i) Rural / Lower educated; (ii) Rural / Higher educated; (iii) Urban / Lower educated; (iv) Urban/ Higher educated.

There is substantial variation in TLE and DFLE from age 100 onwards, which makes estimates at upper ages unstable. In addition, while the CLHLS includes a large sample of centenarians, in reality persons of age 100 and older represent less than 0.05% of the population age 65+. For these reasons, findings are displayed in five-year intervals from 65 to 95. There is further instability for some specific sub-groups due to small numbers of observations. Importantly, small percentages of females are higher educated. Estimates for these sub-groups are cautiously interpreted.

3 Results

3.1 Description of Sample

Table 1 presents sample characteristics at baseline for the two periods. Sample sizes are similar across baseline years, which is the result of re-sampling at each wave to account for attrition. There are slight increases in mean age, likely a result of increased survival. Importantly, a dramatic change in residence and education is noticed. For instance, the percentage of the sample urban population with higher education levels increases from 19.7% to 28.4% for males and 7.6% to 14.2% for females over the six-year interval. At the same time, the percentage of the sample rural population with lower education levels decreases from 43.5% to 32.1% for males and 61.1% to 49.8% for females. Note the very small percentage of higher educated females, especially in rural areas. It is 3.9% in 2002 and 6.0% in 2008.

3.2 Mortality and Disability Rates

To provide an idea of mortality and disability changes over the short term, Table 2 shows rates across periods by age and sex. Mortality rate is defined as the number that died annually between baseline and follow-up expressed for every 1,000 persons in the sample. Disability rate is defined as the average number disabled across baseline and follow-up, also expressed for every 1,000 persons. Net change provides a quick description of whether rates have been increasing, decreasing or remaining stable. Mortality rates declined for males within most age categories. For instance, males between ages of 65 and 69 at baseline had a mortality rate of 29.9 deaths per 1,000 per year between 2002 and 2005 and 21.8 deaths per 1,000 per year between 2008 and 2011, representing a decline of 8.1 points. Mortality rates also declined for females in every age group. Similarly, disability prevalence declined for almost all age and sex groups over time. Only males aged 70 to 74 and females aged 65 to 69 experienced an increase in disability prevalence.

3.3 Changes in TLE and DFLE by Age and Sex

Table 3 presents estimates for individuals at age 80. Age 80 is used as an illustration for heuristic purposes. It is the mid-point of the age range being examined and our analysis suggests that changes seen at age 80 represent main trends for the total elderly population quite well. Life expectancy estimates are in line with those published by the World Health

Table 1. Description of sample at baseline

	Males		Females	
Period	2002–05	2008–11	2002–05	2008–11
N[1]	6,715	6,626	8,926	9,003
Mean age (standard deviation)	71.98 (5.76)	72.79 (5.81)	73.13 (6.47)	73.65 (6.40)
Percent Residence / Education				
% Rural / Lower	43.5	32.1	61.1	49.8
% Rural / Higher	21.0	23.7	3.9	6.0
% Urban / Lower	15.7	15.8	27.4	29.9
% Urban / Higher	19.7	28.4	7.6	14.2
Total	100.0	100.0	100.0	100.0

1 N’s are unweighted.

Table 2. Average annual mortality rate and average disability prevalence rate by age, sex and period[1]

	Period			
	Baseline age	2002-05	2008-11	Net change
Mortality rate				
Males	65–69	29.9	21.8	–8.1
	70–74	39.4	44.4	+5.0
	75–79	66.0	70.0	+4.0
	80–84	118.8	103.3	–15.5
	85–89	184.7	160.3	–24.4
	90–94	261.3	239.7	–21.6
	95–99	339.0	291.2	–47.8
Females	65–69	26.8	11.8	–15.0
	70–74	30.6	28.5	–2.1
	75–79	59.2	50.3	–8.9
	80–84	106.7	80.1	–26.6
	85–89	149.3	130.2	–19.1
	90–94	226.6	210.8	–15.8
	95–99	289.6	283.8	–5.8
Disability prevalence rate				
Males	65–69	43.6	35.1	–8.5
	70–74	51.4	55.6	+4.2
	75–79	95.7	84.9	–10.8
	80–84	162.4	141.6	–20.8
	85–89	227.0	199.7	–27.3
	90–94	314.3	272.0	–42.3
	95–99	404.6	382.5	–22.1
Females	65–69	28.0	33.1	+5.1
	70–74	71.0	65.4	–5.6
	75–79	106.8	89.7	–17.1
	80–84	201.5	132.7	–68.8
	85–89	314.1	240.7	–73.4
	90–94	411.3	344.4	–66.9
	95–99	493.4	426.0	–67.4

[1]Mortality rate defined as deaths per 1,000 population. Prevalence rate defined as number with disability per 1,000 population.

Table 3. Total and disability free life expectancy estimates, 95% confidence intervals, and related statistics at age 80 by sex and period

	Males			Females		
Period	2002–05	2008–11	Net change	2002–05	2008–11	Net change
TLE	6.90	7.28	+0.38	7.61	8.20	+0.59
95% CI	6.69–7.11	7.04–7.53		7.36–7.86	7.89–8.51	
DFLE	5.48	5.94	+0.46	5.51	6.46	+0.95
95% CI	5.37–5.58	5.84–6.05		5.39–5.64	6.35–6.58	
Ratio of DFLE/TLE	0.794	.816	+0.022	0.724	0.788	+0.064
95% CI	0.779–0.809	0.801–0.831		0.708–0.741	0.774–0.803	

Organization (2012), indicating that mortality is reliably measured. In accordance with the mortality and disability rates shown above, TLE and DFLE increased for both males and females. For instance, life expectancy for males aged 80 was 6.90 in the 2002–05 period (95% CI 6.69–7.11) and increased to 7.28 (95% CI 7.04–7.53) by the 2008–11 period, representing a net change of +0.38 years. DFLE rose from 5.48 (95% CI 5.37–5.58) to 5.94 (95% CI 5.84–6.05) over the same period, representing a net change of +0.46 years. The entire increase in life expectancy plus a bit is accounted for by time spent disability-free. Females experienced greater net increases in both TLE and DFLE. TLE rose from 7.61 to 8.20 (95% CI 7.36–7.86 and 7.89–8.51) and DFLE from 5.51 to 6.46 (95% CI 5.39–5.64 and 6.35–6.58).

For males the DFLE/TLE ratio increased from 0.794 to 0.816. This is a positive change and therefore suggestive of a compression of morbidity. However, 95% confidence intervals indicate that the increase is not statistically significant. We draw this conclusion because the 95% intervals, shown in the table, overlap. Therefore, there is not enough change over time to be 95% certain that males aged 80 experienced relatively more years disability-free in the later period. For females however, there is a greater increase in the ratio from 0.724 to 0.788, and the 95% confidence intervals do not overlap, suggesting a statistically significant improvement. Therefore, while females overall spend a lesser proportion of remaining life at age 80 disability-free, the improvement in DFLE is more robust for females.

Figure 1 shows the ratios of DFLE/TLE across ages. The gap in the ratios is an indication of whether and how the ratio has changed. Asterisks next to the age on the *x*-axis indicate whether the gap or change in the ratio is statistically significant. These ratios indicate several things. First, they are generally higher for males than females, indicating that males live disability-free for longer periods of time. Second, they are generally higher in the second period than the first, indicating a compression of morbidity scenario. Third, the gap is larger for females than males, indicating more improvement for females. Fourth, the gap increases with increasing age, indicating more improvement at older ages. Finally, the changes are statistically significant for females but not for males, suggesting confidence in a compression of morbidity among females but not among males.

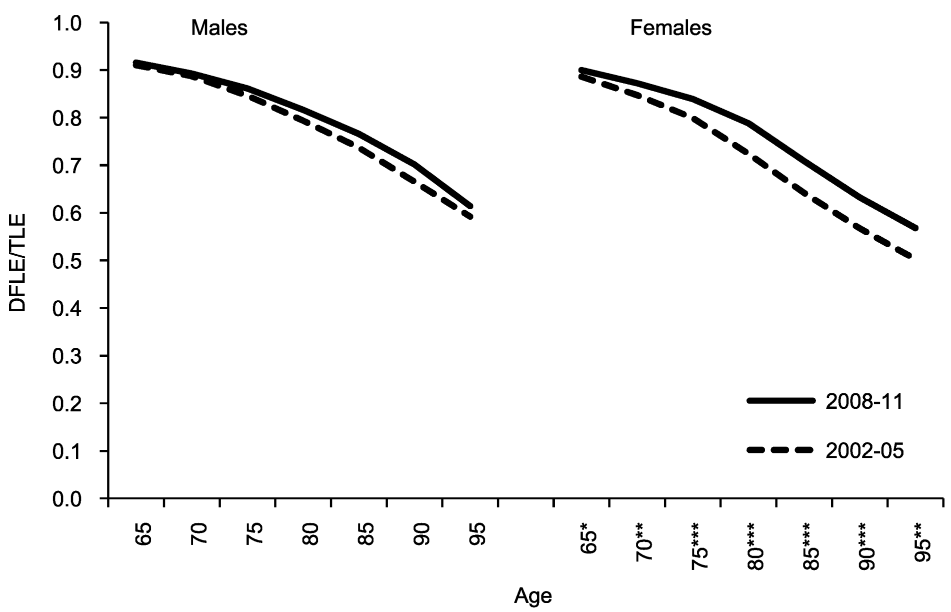

Figure 1. Ratio of DFLE/TLE by age, sex and period.

Note: asterisks next to ages indicate that the difference in DFLE/TLE ratio is statistically significant at: * 0.05 < p < 0.10 ** 0.01 < p < 0.05 *** p < 0.01

3.4 Changes in TLE and DFLE by Rural/urban Residence and Education

Table 4 illustrates changes experienced by males and females aged 80, divided into four sub-groups according to rural/urban residence and lower/higher education. Net changes in TLE and DFLE were positive for all sub-groups except DFLE for rural, higher educated males. For instance, for males living in rural areas with lower education, TLE increased from 6.72 (95% CIs 6.40–7.05) to 6.92 (95% CIs 6.60–7.24), representing a net increase of 0.20 years. DFLE for this group increased from 5.65 (95% CIs 5.72–6.01) to 5.86 (95% CIs 5.72–6.01), a net of 0.21 years. The ratio of DFLE/TLE indicates that relative increases in DFLE kept pace with TLE, increasing slightly from 0.840 for the 2002–05 period to 0.847 for the 2008–11 period.

The results differ across sub-groups. Net TLE and DFLE and ratios increased more for urbanites versus rural residents and more for females versus males. Take, for instance, urban lower-educated females, who at age 80 seem to have benefited quite substantially. For

Table 4. Total and disability free life expectancy statistics at age 80 by sex, rural/urban residence, education and period

	Males			Females		
Period	2002–05	2008–11	Net change	2002–05	2008–11	Net change
i. Rural / Lower educated						
TLE	6.72	6.92	+0.20	7.52	7.93	+0.41
95% CI	6.40–7.05	6.60–7.24		7.16–7.87	7.56–8.31	
DFLE	5.65	5.86	+0.21	5.73	6.38	+0.65
95% CI	5.50–5.80	5.72–6.01		5.55–5.90	6.24–6.53	
Ratio of DFLE/TLE	0.840	0.847	+0.01	0.762	0.805	+0.04
95% CI	0.817–0.863	0.766–0.827		0.739–0.785	0.786–0.823	
ii. Rural / Higher educated						
TLE	7.13	7.33	+0.20	7.96	8.38	+0.42
95% CI	6.53–7.73	6.71–7.95		5.68–10.23	6.19–10.57	
DFLE	5.99	5.99	+0.00	6.06	7.21	+1.15
95% CI	5.73–6.25	5.72–6.26		5.18–6.94	6.50–7.93	
Ratio of DFLE/TLE	0.840	0.816	−0.02	0.762	0.861	+0.10
95% CI	0.803–0.876	0.780–0.853		0.651–0.873	0.776–0.946	
iii. Urban / Lower educated						
TLE	6.89	7.52	+0.63	7.69	8.59	+0.90
95% CI	6.50–7.28	6.96–8.08		7.30–8.08	7.99–9.18	
DFLE	5.11	5.99	+0.88	5.32	6.53	+1.30
95 % CI	4.90–5.31	5.76–6.22		5.13–5.51	6.32–6.75	
Ratio of DFLE/TLE	0.741	0.796	+0.06	0.692	0.761	+0.06
95% CI	0.711–0.771	0.766–0.827		0.667–0.717	0.736–0.786	
iv. Urban / Higher educated						
TLE	7.30	7.96	+0.66	8.14	9.05	+0.91
95% CI	6.77–7.84	7.00–8.91		6.97–9.30	6.51–11.60	
DFLE	5.43	6.05	+0.62	5.11	6.98	+1.87
95% CI	5.17–5.69	5.72–6.26		4.52–5.70	6.40–7.56	
Ratio of DFLE/TLE	0.744	0.760	+0.02	0.628	0.771	+0.14
95% CI	0.708–0.779	0.717–0.803		0.555–0.700	0.707–0.835	

them, net TLE increased by 0.90 years and DFLE by 1.30 years. The ratio of DFLE/TLE rose from 0.692 to 0.761 and this change is statistically significant.

An important caveat is suggested by confidence intervals. Because numbers within sub-groups can be small, some standard errors are large and subsequently confidence intervals are wide. This is particularly the case for higher educated females in rural areas. The point estimate for life expectancy in the 2008–11 period for this group is 8.38, but the 95% confidence interval varies from 6.19 to 10.57. Although the estimate for life expectancy is reasonable, wide confidence intervals suggest instability. More importantly, the 95% confidence interval for the DFLE estimate is wide, and thus despite a relatively large increase in the DFLE/TLE ratio, the finding is not statistically significant.

Figure 2 expands examination to all age groups for ratios of DFLE/TLE. Again, gaps in the lines indicate whether improvements in DFLE were experienced over time by sub-groups. Statistical significance is indicated by asterisks on the *x*-axis. While significant change is not realized among every age, in general, improvement, or a compression of

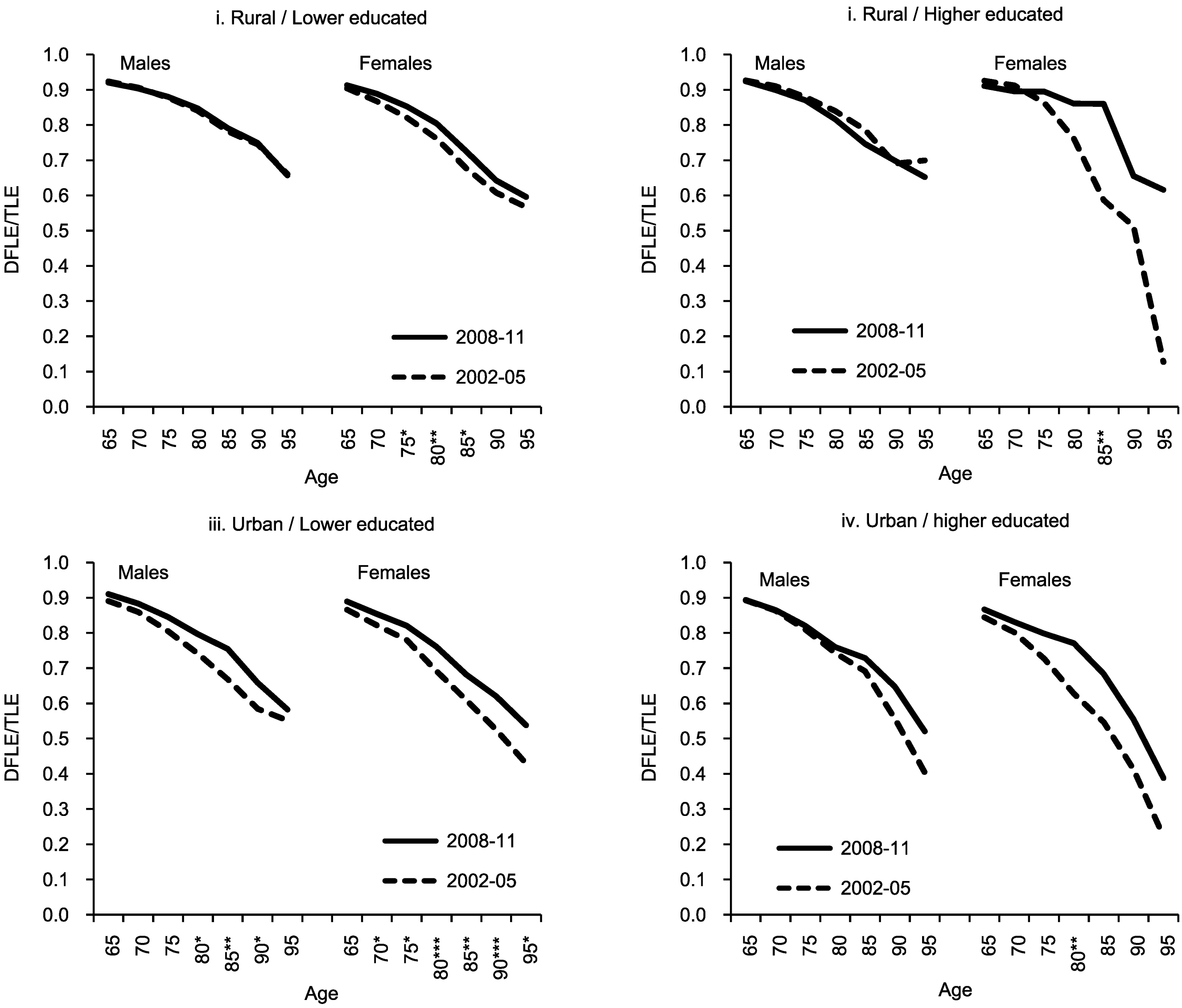

Figure 2. DFLE/TLE by age, sex, rural/urban residence, education and period.
Note: asterisks next to ages indicate that the difference in DFLE/TLE ratio is statistically significant at: * 0.05 < p < 0.10 ** 0.01 < p < 0.05 *** p < 0.01

morbidity, is suggested for the following sub-groups: urban males with lower education, urban females with lower education, and rural females with lower education. No change, either favorable or unfavorable, is detected for the following sub-groups: urban males with higher education, rural males with lower education, and rural males with higher education. Some evidence of improvement is found among urban females with higher education and rural females with higher education, but small sample sizes make these estimates unstable and uncertain. On balance then, favorable changes were experienced more so by females than males and more so in urban than in rural areas. Furthermore, across all sub-groups, changes are most likely to be robust and statistically significant for older-old, around the ages 75 to 90.

4 Conclusions

Like many developing countries around the world, the demographic changes occurring in China mean its population is rapidly getting older and its older population is living to more advanced ages. Given the inextricable link between aging and disability, such changes may ominously signify persistently growing numbers and proportions disabled. However, the extent to which population-wide disability rates are affected by these demographic trends depends upon whether and how disability changes in concert with increases in longevity. A status quo scenario whereby the likelihood of being disabled at older ages remains unchanged surely leads to more disabled. A more sanguine scenario is one that is implicated by a compression of morbidity (Nusselder, 2003). While this concept means that life spent with morbidity is condensed to a very small time preceding death, given increasing longevity it translates into a greater proportion of life lived disability-free. In such a scenario, increases in DFLE would be outpacing TLE.

To address the issue in the current analysis, changes in DFLE and TLE were compared among Chinese 65 years and older over from the period 2002–05 to the period 2008–11 with emphasis on the ratio of DFLE/TLE. Portending a compression of morbidity would be an increasing DFLE/TLE ratio. In order to assess whether the same scenario is consistent across the population or whether a compression may be occurring for some and not others, a situation we refer to as a *heterogeneous compression*, the study sample was divided into groups by sex, rural/urban residence and level of education.

The main conclusions are:

(i) There are striking increases in TLE and DFLE over this period of observation, suggesting consequential changes between 2002 and 2011. The TLE estimates in this study are not unreasonable, given World Health Organization (2012) reports of life expectancy increases at age 65 from 2000 to 2009 of about half a year for males and a year for females. One possible reason for the sharp rise in TLE and DFLE is that China witnessed rapid changes in socioeconomic conditions, access to health care, growth in urban areas, and higher levels of education, all of which are related to health outcomes (Meng *et al*., 2013; Siciliano, 2012; Chan, 2012; Meng *et al*., 2012).

(ii) Across the total population there is evidence of a compression of morbidity, with increasing ratios of DFLE/TLE. However, the compression tends to be robust and statistically significant for females more so than males, for urbanites more so than rural residents, and for older-old more so than younger-old. Some of these findings correspond to those presented by Liu *et al*. (2009), especially with respect to outcomes among the older-old. More improvement for females supports disability trend research by Zimmer *et al*. (2014). However, results contrast from those of Feng *et al*. (2013) who reported more favorable changes in ADL from 1998 to 2008 in Shanghai for females, and Gu *et al*. (2009) who showed generally similar improvements across sexes.

(iii) Overall patterns of change hide heterogeneity. Heterogeneity exists across rural/urban residence such that a compression of morbidity is more likely being experienced by urban Chinese than by rural Chinese. Education appears to be affecting changes in DFLE less than place of residence. A variety of evidence exists (Yip, 2010; Liu *et al*., 2003; Beach, 2001; Zimmer *et al*., 2007) that indicates increasingly better health conditions in urban areas of China as opposed to rural . The fact that education has no impact is perhaps more surprising. However, other evidence hints that the association between education and health may be suppressed in some societies (Montez and Friedman, 2015). The association between education and health in China may be less robust than elsewhere because other indicators of socioeconomic status better distinguish social hierarchy in China, such as state sector employment and party membership. A report by the Population Reference Bureau (2015) indicates that education has surprising effects on health in China that include substantial differences for males versus females. We emphasize that the current study did not suggest a non-association between education and DFLE, but rather that *changes* over the short period are not observed.

In some ways, the current results contrast from the findings from the United States where the issue of changes in disability has been examined for a longer period of time. Crimmins *et al*. (2009) provide evidence of both increasing life and disability-free life expectancy in the United States, and although they do not test for it directly, the gains in each appear to be parallel. While some studies have examined TLE and DFLE by education (Crimmins *et al*., 1996 and 2001), whether and how this might be changing over time has only been assessed with the monitoring of disability trends. Schoeni *et al*. (2001) showed declining rates of disability in the U.S. with the more educated benefiting the most. Martin *et al*. (2010) confirmed declining rates of disability and demonstrated that males were faring a bit better than females.

The current study has limitations. The length of time between the two observation periods is short. Although various datasets with information about the health of older persons are beginning to become available for China, data for the type of examination provided here, for a population aged 65 and older, are still not readily available over a long-term. The current study can provide a baseline for future longer-term studies. Small numbers within certain sub-groups is another obvious weakness. However, this is mostly a problem for the high educated females, of whom few exist in China. Examination of confidence intervals indicates findings that are robust for other sub-groups. Increases in life expectancy over time are a little greater than those reported officially. Some of this may be due to missing mortality in loss to follow-up or to those who are not healthy being uninterested in responding in the first place. Moreover, while follow-up rates for this survey are high and data assessments have suggested that attrition would not play a role in our estimations (Zeng *et al*., 2002; Gu, 2007), we note that these data are based on longitudinal panel data and there is always a risk that whatever minimal attrition exists could be non-random across variables of interest. Yet, there is no reason on the surface to believe that any non-random attrition would be systematic across age, sex, education and rural/urban residence.

In sum, the findings portend heterogeneous compression of morbidity in China. During the study period changes in both TLE and DFLE tended to be more favorable for females than males and more favorable for urban than rural residents. In contrast, changes across levels of education are not very consequential. Those in older age brackets benefitted more than younger elderly. Rural residents of China are a population of policy concern. Already having worse health status than others, and less access to health resources, rural residents do not seem to be sharing equally in health gains experienced by others, which, if extrapolated into the future, will only put them even further behind and create greater inequalities.

Conflict of Interest and Funding

No conflict of interest has been reported by the authors.

Ethics Statement

Ethics approval was obtained from the Institutional Review Board at Duke University Medical Center, the Division of Social Sciences, Peking University, and the National Bureau of Statistics of China.

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