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Health Inputs and Cumulative Health Deficits among the Older Chinese

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Abstract

Using a health economics framework, we examined how both individual-level investments at different life stages and current community-level environmental factors affect individual health stock and flows at old ages. We used a nationwide dataset from the 2002 and 2005 waves of the Chinese Longitudinal Healthy Longevity Survey, which included more than 15,000 adults aged 65 and older from 22 provinces in mainland China. We measured health stock with a cumulative health-deficit index, a measure developed in geriatrics and gerontology that reflects deficits, illnesses, and functional impairment in numerous domains of health. The cumulative health deficit index has not been used in health economics before, but is a significant contribution because it captures the health stock concept very well and overcomes the problems of inconsistency resulting from the use of different measures of health stock in research. Our results show that several proxy measures for individual health investments in both childhood (nutritional status and parental survival status) and adulthood (family financial condition and access to healthcare) yielded positive returns to health stock measured by the cumulative health deficit index. Investments in social connections and healthy behaviors (religious involvement, alcohol use, and exercise) also produced positive returns in health stock. Current community-level factors such as air quality and labor force participation rate were also significantly associated with levels of health deficits in old age. Yet, most of these individual investment and community environment variables did not significantly affect short-term health flows (improvement or deterioration in health status over three years). Our findings have important implications for developing preventive health programs in the context of population aging by focusing on policy-relevant predictors and a comprehensive indicator of health status in later life.

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Keywords

China; cumulative health deficits; Health stock; earlier life investments; older adults

Introduction

A central question in research on healthy longevity asks why some people live to old ages in relatively good health while others die relatively young and suffer from various chronic diseases. Many studies in the fields of demography, epidemiology, gerontology, and genetics have made valuable contributions to this research agenda (Foster, 1997; Hernandez & Blazer, 2006; Rowe & Kahn, 1998; Singer & Ryff, 2001; Zeng et al., 2006). We contribute to this literature on healthy longevity by using a health economics approach applied to data on Chinese elders, and incorporating life course and ecological perspectives. We interpret factors predicting health over the life course as ‘health investments’ that are associated with subsequent health and health transitions.

Traditionally, health economists have viewed health as a durable capital stock that is determined by initial capital and depreciates with age. Health stock can increase with positive inputs (e.g., positive lifestyle and health behaviors, investments in education, exercise, nutrition, purchase of and access to healthcare services, etc.) and decrease with negative inputs (e.g., low access to healthcare, risk behaviors, social isolation) (Becker, 1964; Grossman, 1972; Guimaraes, 2007; Leibowitz, 2004). According to this health economics framework, health stock is unlikely to remain static, but rather will depreciate across the life course (Liljas, 1998:155) with accelerating speed at older ages (Grossman, 1972; Zhao, 2008). The more an individual has invested in his or her health, the longer he or she is likely to live (Liljas, 1998:155). However, individuals with low or quickly depreciating health stock are likely to experience disability, impairment, or even death as health stock depletes to a critical level (Guimaraes, 2007; Zhao, 2008).

One shortcoming of such a framework is that it infrequently incorporates inputs at earlier life stages into the function predicting health stock at later ages. It assumes that health stock at a given time (t) is determined by health stock at preceding time ($t-1$) and investment during the period from $t-1$ to t , but this time interval is usually short (e.g., one month, or one year). The life course perspective emphasizes that individual health outcomes should be viewed in the long-term, examining earlier conditions that shape how later life is experienced (Alwin & Wray, 2005). Empirical studies have demonstrated that adult health status is significantly affected not only by current or adult conditions, but also by earlier life conditions (Finch & Crimmins, 2004; Hayward & Gorman, 2004; Preston, Hill, & Drenstedt, 1998; Smith & Kington, 1997; Zeng, Gu, & Land, 2007), and even some fetal conditions (Barker, et al. 1991).

Furthermore, many previous health economics studies have assumed that individuals make rational choices regarding health investment, and therefore emphasize the importance of individual characteristics such as willingness or capability. These studies have overlooked the importance of family resources like financial capital available and number of children in influencing individual health status. Indeed, investments in health, like consumptions of other goods, are performed by maximizing the utility function for all household members, not just a single person (Jacobson, 2000; Muirinen, 1982; Smith & Kington, 1997). Epidemiological studies have shown that support from family and social networks and religious participation significantly improve health status in old age by enhancing healthy life styles and psychological well-being (Koenig et al., 1999; Uchino, 2004; Waite, 1995). In

this regard, family and social support and engagement in religious activities are also important investments in health stock that are seldom integrated in health economics studies.

With few exceptions (e.g., Cropper, 1981; Erbsland, Ried, & Ulrich, 1995), the health economics literature has also neglected ecological factors, including structural community and neighborhood factors. Importantly, epidemiological research has shown that ecological factors may significantly influence level and dynamics of health stock (Balfour & Kaplan, 2002; Kawachi & Berkman, 2003). Good community/neighborhood conditions (e.g., clean air, medical facilities, etc.) may indicate a positive community-level investment, creating an environment that enables individuals to yield better returns for their individual investments; this improved efficiency produces a lower health stock depreciation rate (Leibowitz, 2004). Conversely, poor environmental conditions (e.g., air pollution, prevalent disease, etc.) may offset the efficiency of individual investments or even have a direct negative effect on individual health stock; in these poor conditions one must invest more positive health inputs to maintain or increase the stock level (Cropper, 1981). For example, at least to some extent, good community socioeconomic conditions might be an indicator of positive community-level investments for residents, whereas air pollution might be an indicator of negative societal inputs. This argument is important because environmental deterioration has been a major concern of international and national societies and the current financial crisis has reduced the community's capacity for investments.

Based on these concerns, some economists have called for the study of investments at earlier life stages and potential ecological impacts on health stock (e.g., Erbsland, Ried, & Ulrich, 1995; Leibowitz, 2004; Smith & Kington, 1997). Another promising research direction is to model short-run health dynamics as a function of various investments at different life stages (Smith & Kington, 1997). The present paper, echoing such appeals, extends the concept of health stock inputs to including those related to very early life and the current ecological environment of the respondents. Based on the 2002 and 2005 waves of the Chinese Longitudinal Health Longevity Survey (CLHLS), we examine how these inputs as well as other health risk factors influence health stock and dynamics (deterioration and recovery) at old ages.

Furthermore, there is no consensus on how to measure the stock of health capital in health economics. Previous studies have employed different indicators of health stock, yielding inconsistent results and conclusions (Gerdtham & Johannesson, 1999). The cumulative health-deficit index recently developed in gerontology and geriatrics (Kulminski et al., 2006; Kulminski, Ukraintseva et al., 2008; Mitnitski et al., 2005; Rockwood et al., 2007; Yashin et al., 2007) provides a promising avenue to more accurately measure health stock. The deficit index measures the presence of multiple health deficits in numerous dimensions of health. The validity of these indices has been verified in various populations as a proxy for biological age; as a robust predictor of health change, healthcare utilization, and death; and as an effective tool among geriatricians and others to study the determinants of aging and its implications for public health monitoring and intervention (Goggins et al., 2005; Kulminski et al., 2006; Mitnitski et al., 2005; Yashin et al., 2007).

Finally, little research has linked health inputs (either positive or negative) to health stock among older adults in the context of developing countries, where individuals usually lack personal economic resources to invest in health (e.g., through purchasing insurance or increasing nutritional intake) but may invest in health in many ways that are distinct from those in western society. We fill this gap by examining the case of China, a social environment with a unique culture, population structure, and political and socioeconomic system.

The present study moves beyond a recent study using CLHLS data by Gu, Zhang, and Zeng (2009). That study emphasized the role of healthcare access both in childhood and at present in elevating probabilities of survival and healthy survival among Chinese elders. We acknowledge that purchase or utilization of healthcare services is a central component of health inputs. However, health stock is determined by multiple factors across the entire life course, including economic, social, and health inputs mentioned above, in addition to investments in medical care service. Thus, it would be beneficial to extend the concept of health inputs to a broader range of investments and environmental factors that are likely to affect health level and dynamics. With this more holistic framework we aim to examine the potential effect of various health inputs in childhood and adulthood, as well as ecological factors, on health stock and short-term fluctuations among Chinese elders. The present study distinguishes itself from the one by Gu, Zhang, and Zeng (2009) in several significant ways. First, we include several more accurate measures of health inputs than those in Gu, Zhang, and Zeng (2009), including childhood measures and physical environmental quality. Second, we improve the validity of health stock and short-term health flow (i.e., deterioration or improvement) measures through comprehensive sensitivity analyses which make results more robust and generalizable. Third and most importantly, this study not only examines cross-sectional associations between childhood, adult and community inputs and health stock at a *fixed* life stage, but also investigates prospectively how these inputs relate to subsequent improvement or deterioration health stock during a three-year follow-up period. The examination of dynamic change in health stock is important from the perspective of health economics because it captures the full range of health flows, one of the core components of health stock.

Data and Measurement

Data

This study utilized the 2002 and 2005 waves of the CLHLS, a nation-wide longitudinal survey of healthy longevity in China. The detailed description of the survey can be found elsewhere (e.g., Gu, Zhang, & Zeng, 2009; Zeng et al., 2008), and thus we do not repeat here. Duke University Health System's Institutional Review Board (IRB) reviewed and approved ethics for this study.

We restricted our analyses to the third and forth waves of the CLHLS (2002 and 2005) because the first two waves of the CLHLS (1998 and 2000) did not recruit adults ages 65 to 79. Of the 15,972 participants sampled in 2002, 4,845 were ages 65-79 and 11,074 were ages 80-109, with 4,238 octogenarians, 3,747 nonagenarians and 3,142 centenarians. Of the total participants ($n=15,972$), 8,113 (50.8%) were re-interviewed in the 2005 wave, 5,832 (36.5%) died before 2005, and 2,027 (12.7%) were lost to follow-up. Systematic assessments show that the data quality of the CLHLS is high (Gu, 2007), although the data quality assessments also show that respondents who are female, living in urban areas, physically impaired, and with low levels of social contact were more likely to have higher attrition rates (Gu, 2007). Nevertheless, the loss to follow-up is unlikely to introduce significant biases in the analysis because the sample distributions of the followed-up respondents in key variables are very close to those for all sampled respondents regardless of re-interview status (see Table 1). Our multiple imputation strategy noted in the method section below showed that results were similar when we imputed survival status for those lost to follow-up in 2005, suggesting that the re-interviewed sample was similar to the entire sample including those lost to follow-up. Empirical study has shown that the effects of sample attrition on models of factors predicting outcomes do not depend on how the loss to follow-up samples differ from all those who are eligible to be re-interviewed, but on how re-interviewed respondents differ from all eligible sampled respondents (Kempen & van Sonderen, 2002).

Cumulative Health-Deficit Index

We measured health stock with the cumulative health-deficit index. Following established research (Gu et al., 2009; Kulminski et al., 2006; Mitnitski et al., 2005), we defined the cumulative health-deficit index as an unweighted count of the number of deficits divided by the total number of possible deficits for a given person. We used 39 indicators of self-reported health, cognitive functioning, disability, auditory and visual ability, depression, heart rhythm, and numerous chronic diseases that were collected in the 2002 CLHLS. The items comprising our cumulative health-deficit index are similar to those used in studies from Canada (Mitnitski, et al., 2005), the United States (Kulminski et al., 2006), and Hong Kong (Goggins et al., 2005). We dichotomized individual items and coded them as one when a deficit was present. Consistent with prior research, we assigned a score of two if the respondent had a serious illness that caused him or her to be hospitalized or bedridden two or more times during the last three years (Goggins et al., 2005). Thus, the total number of possible deficits is forty. We then computed the deficit index by summing all deficits and dividing by the total number of possible deficits (range=0~1). A lower index score indicates better health. A new deficit adds 0.025 to the original deficit index score (or + 0.025), while recovery from a deficit reduces 0.025 from the original deficit index score (or -0.025). The validity of the health deficit index in the CLHLS datasets has been verified (Gu et al., 2009). A detailed list of variables used to construct the health deficit index is published elsewhere (Gu et al., 2009, Gu, Zhang, & Zeng, 2009).

Individual and Community Level Health Inputs

We selected our covariates based on the well-established epidemiological literature on the association between risk factors and health of older adults (Ferrucci et al., 2003; Gerdtham & Johannesson, 1999; Liang et al., 2003; Nocera & Zweifel, 1998; Strawbridge et al., 2001; Stuck et al., 1999) and the health economics literature on the association between health inputs and health stock (Erbsland, Ried, & Ulrich, 1995; Leibowitz, 2004; Salas, 2002; Smith & Kington, 1997; Wagstaff, 1993; Zhao, 2008). We examined many predetermined factors and proxy measurements of investments at the individual level, including basic demographic factors (age, sex, ethnicity, and urbanicity), childhood conditions (measured by having both parents alive at age 10, access to medical care in childhood, and arm-span), adult socioeconomic status (SES) (measured by education, family economic condition, and access to healthcare), family/social support (measured by marital status, number of living children, and religious participation), and health practices (regular exercise and smoking and alcohol use in the past five years). We used two questions to assess access to healthcare: “Could you get adequate medical services in childhood when necessary?” (yes versus no) and “Could you get adequate medical services at present when necessary?” (yes versus no) to measure access to healthcare in childhood and in adulthood, respectively. All these variables were derived from the 2002 wave.

We paid particular attention to nutrition status in childhood, as sufficient nutrition in childhood directly improves the level of health stock in childhood, an advantage that may persist into old ages (Smith & Kington, 1997). Sufficient nutrition also enables a child to have normal brain development and to receive normal education (Fritsch et al., 2007), which in turn improves the efficiency of health investment at adult and late ages. To capture childhood nutritional status, we relied on an anthropometric measurement: arm span. Although anthropometric measures such as arm span may be partly linked to genotypes, it reliably reflects diet, diseases, and infection in childhood (Mitchell & Lipschitz, 1982; Thomas & Strauss, 1997; Huang & Elo, 2009). Previous studies using the CLHLS used “whether went to bed hungry” as an alternative indicator of nutrition status in childhood (Gu, Zhang and Zeng, 2009), but this measure is subjective and may be subjected to serious recall error among very old people (Benjet, Borges, & Medina-Mora, 2010). In addition, we

included parents' survival status, which is highly relevant to health inputs in childhood (Campbell & Lee, 2009). To better reflect the roles of family resources and psychological well-being in health production, as reviewed earlier, we included family economic conditions (instead of individual's own financial status) and religious involvement.

Community in the CLHLS is a county or a district of a city; there are 864 communities in the 2002 sample. Our community-level variables included per capita GDP, labor force participation rate and air pollution index (API). These three community-level variables reflect socioeconomic dimensions of an area's overall level of development and environmental quality in epidemiological research (e.g., Andersen et al., 2002; Balfour & Kaplan, 2002; Kawachi & Berkman, 2003; Sandtröm et al., 2003). We obtained these measures from the National Bureau of Statistics of China (2003) and the Chinese Natural Resources database. The first two measures are for the year of 2000. API is widely used in environmental research as a measure of the general air quality (WHO, 2003). It assesses the concentration of three pollutants: sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and inhalable particulates (consisting of particulate matter less than 10 microns in diameter (PM₁₀), carbon monoxide (CO), and ozone (O₃)). Because our cumulative health deficit index reflects a health status rather than immediate, specific health responses, we measured APIs for the year 1995 to take into account the chronic or lagged response to air pollution. API was graded from one to seven with lower scores indicating better air quality.

For the sake of simplicity, all individual level factors were coded dichotomously except for age and number of living children; three level-two variables are continuous. We tried other categorizations and found only minor difference between dichotomous and non-dichotomous results. The non-dichotomous results are available upon request from the authors. Table 1 provides frequency distributions of all these variables for the whole sample and those who were re-interviewed in 2005. The percentage of missing data is less than 2% for all variables except for having both parents alive at age 10. Following recommendations by Landerman et al. (1997), we used modal and mean values to impute missing data for the categorical and continuous variables, respectively. We used the multiple-imputation method suggested by Allison (2002) to impute missing values for parents' survival, including basic demographic variables and SES in the imputation regression.

Methods

We used three sets of analyses to address health stock and flows. The first set of analyses examines factors that are associated with severely depleted health stock, measured by the cumulative health-deficit index. We dichotomized the deficit index to minimize the skewness of its distribution, which is heavily right tailed. We carried out sensitivity analyses using the highest quintile, quartile, and tertile of deficit index score as cut-points to define high cumulative deficit (low health stock). For example, for the quintile indicator, if a respondent's deficit index value was in the top 20%, he or she was classified into the severe cumulative deficit group. In a similar vein, we classified respondents using quartile and tertile cut-points. This strategy enabled us to check the sensitivity of results to different cut-point specifications.

The second and third sets of analyses focus on health flows (i.e., short-term health deterioration or improvement), which have rarely been examined in existing studies among Chinese elders. We restricted the analyses on health flows to those respondents who were interviewed in 2002 and re-interviewed in 2005. We defined a health flow as the difference in health deficit index between 2002 and 2005. If the health deficit index score increased from 2002 to 2005, this was defined as a decline or *deterioration* in health stock. If the health deficit index score decreased from 2002 to 2005, this was defined as an *improvement* in health stock. We applied four criteria to define decline or improvement in health stock to

test sensitivity to degree of change. Specifically, we used four different thresholds: (plus or minus) one, two, three, or four deficit items. These criteria define various scales of improvement from the smallest unit (i.e., improved by 1 item represented by a difference in deficit index score of -0.025 over three years) to relatively large scale decline (decreased by 4 items indicated by a difference in deficit index score of +0.10 over three years). The purpose of this strategy is to investigate the sensitivity of outcomes to different criteria and magnitudes of improvement or deterioration. The baseline deficit index was always included in the second and third sets of analyses. We did not include those who were lost to follow-up in 2005 in the latter two sets of analyses because we did not know their survival status in 2005. As an alternative way of dealing with the loss to follow-up, we imputed missing respondents' survival status using multiple imputations based on 2002 covariates. The results (available from the authors upon request), only showed minor differences suggesting that our analyses are not seriously biased by including only respondents who were followed up to 2005.

We used a multilevel logistic regression model with a random intercept to examine inputs that are associated with cumulative health deficits. Level one is the individual level and level two is the community level (i.e., county in the present study). The random-intercept and fixed-slope design is widely used in multilevel analyses (Raudenbush et al., 2004). We checked for multicollinearity among study variables and found no significant problems. We included all study variables in the model at once for each set of analyses because only minor changes were found if we used nested modeling strategies. The nested modeling results are available upon request. We performed all analyses with Stata version 10.0. We did not use a sampling weight in our multivariate analyses, which is acceptable when sampling factors are included in the analysis as covariates (Winship & Radbill, 1994). Preliminary analyses confirmed that the overall patterns and conclusions were similar between the weighted and unweighted data.

Results

Predictors of Health Stock in 2002

Results in Table 2 show a consistent pattern across models based on three different cut-points for high deficit index (severely depleted health stock) in 2002. In line with the associations found by Gu, Zhang, and Zeng (2009), gender, age, and urban/rural status showed significant associations with health stock at old age. Several new variables also produced significant effects. For example, having both parents alive at age 10 decreased the odds of having low health stock by 20-22% compared to those whose parents were not alive at age 10. Being in the top 90% of arm-span reduced the odds of low health stock by nearly 30-38% compared to those in the bottom 10%. These objective proxy measures of childhood 'health investments' provide strong and significant associations with health stock that were not found in prior studies that use more subjective measures of childhood conditions subject to recall bias. Respondents from families enjoying good economic conditions were 23-31% less likely to have low health stock as compared to those from economically poor families. Although marriage did not significantly reduce the odds of severe health stock deficit when measured by the highest quintile health deficit score, marriage did significantly reduce the odds by 15-17% if health stock was measured by the highest quartile or the tertile criteria. Religious activity was associated with a lower risk of depleted health stock (reducing the odds by more than half). Individuals who drank alcohol in the past five years had 24-30% lower odds of having severe health stock deficit than those who did not. After adding these measures of childhood and adulthood conditions, social investments, and health behaviors, we did not find a significant independent association between access to healthcare in childhood and health stock that was reported by Gu, Zhang, and Zeng (2009).

At the community level, Table 2 further shows that a 1% increase in labor force participation rate of the local population reduced each individual's odds of having severe health deficits by 1-2%. Each additional increase in API score increased odds of having low health stock by 12-14%.

In summary, Table 2 shows that, as expected, demographics, childhood SES, adult SES, social support, health practices, and community socioeconomic development significantly and independently affect the odds of having severe health stock deficits (depleted health stock), in old age. Also, air pollution tends to increase the odds of health stock deficit. Greater investment in health of individuals, in both childhood and adulthood, could yield substantial benefits for health stock at later ages, although aging is an inevitable factor that depletes the health stock. At the community level, overall socioeconomic development level and equity and reduction of air pollution might help to reduce the individual risk of having health stock deficit. These results are robust regardless of various cut-off points employed. Our results here demonstrate strong and significant associations with proxy measures of 'health investments' in childhood (having both parents alive to age 10 and top 90% arm length), in adulthood (good family economic conditions), and at the community level (labor force participation rate and air pollution index). The association between childhood access to health care and later health stock is attenuated, becoming insignificant when these 'health investment' measures are included in our model. This finding is in contrast with our previous work (Gu, Zhang, & Zeng, 2009), which used different measures of childhood health investments, that may have been more susceptible to recall and reporting bias.

Short-term Health Flows: Improvement and Decline 2002- 2005

Table 1 indicated that the mean deficit index for 8,113 re-interviewed survivors was 0.04 higher in 2005 than 2002. In other words, average health stock deteriorated by 1.6 items over three years. By 2005, 49% of survivors experienced at least one additional deficit and 28% of survivors had four or more additional deficits. Yet, many respondents experienced health stock improvement; more than 41% of survivors had at least one fewer deficit in 2005 and 15% of survivors had at least four fewer deficits in 2005.

With few exceptions, patterns predicting health stock improvement in Table 3 were similar across the various criteria for improvement. Each additional year of age significantly decreased the odds of health stock improvement by 5-7%. Generally speaking, participation in religious activity increased the odds of improvement by 14-29%. Regular exercise tended to increase the odds of improvement by 15-24%, with the exception of Criterion I (i.e., improvement in one item, the smallest scale). Men were more likely to experience improved health stock under Criterion I. In other criteria requiring improvement on more items to qualify as health stock improvement, this gender difference was not significant. No childhood conditions or adult SES factors were found to be significantly associated with health improvement from 2002 to 2005. Use of alcohol in the past five years significantly increased the odds of improvement measured with a relatively large scale criterion (i.e., improvement defined by four items). Importantly, prior deficit index score was consistently associated with likelihood of improvement. Higher deficit index (greater impairment), was positively associated with odds of health improvement, likely because individuals with a greater number of deficits have more room for improvement. At the community level, poor air quality was negatively associated with health improvement under Criterion IV and each additional score in API reduced the odds of health improvement by 10%.

Results in Table 4 were also quite consistent among different criteria. Overall, aging continues to be a major factor in short-term health decline. Each additional year of age increased the odds of health decline (or increase in health deficits) by 7-8%. A gender difference was also pronounced. Men were 13-20% less likely to experience worsening

health than women. Although childhood SES was not associated with short-term health deterioration, higher childhood SES likely played some protective role in postponing short-term deterioration in health stock. Those who had both parents alive at age 10 were 13-16% less likely to have a health decline than those who did not (note that this association did not hold for the largest scale criterion—addition of four or more deficits from 2002 to 2005). Deficit index score in 2002 was negatively associated with odds of health deterioration, so that individuals with higher impairment at baseline were less likely to experience further health decline. No other variables were significantly associated with short-term health stock reduction. Thus, although several measures of health investments (proxy measures of childhood and adult SES, social investments, and healthy behaviors) were significantly associated with health stock level in later life, very few were significantly associated with short-term health stock improvement and deterioration. When considering short-term health dynamics, factors like age and initial health status were the most important predictors of improvement or deterioration.

Discussion and Conclusion

Based on data from a national and longitudinal study on older people in China, the world's largest aging population, we examined how 'health investments', at individual level and at different life stages, as well as community-level environmental factors affect individual health stock and its dynamic flow at old ages. Our study is unusual in that it integrates both a life course approach and an ecological framework to examine the potential impact of health investment on both health stock and short-term health transitions at very old ages. In general, we found that inputs during childhood and current ecological environment, two dimensions that were seldom addressed in previous health economics literature, as well as inputs at old ages, contribute to health stock at old ages.

Our results revealed that for this Chinese sample, proxy measures that address childhood conditions (having both parents alive at age 10), early nutritional status (arm-span), and access to medical care in childhood were associated with better health stock at old ages, net of conditions during adulthood and community environment. Childhood adversities and lack of related health investments may reduce an individual's reserve capacity to resist disease, thus decreasing health stock at later ages. Having both parents alive in childhood may enable a child to have sufficient nutrition and psychological development that are crucial to his or her health and development, including educational attainment (Fritsch et al., 2007; Hayward & Gorman, 2004; Smith & Kington, 1997), eventually benefiting health at old ages. Literature in epidemiology has indicated that inability to access healthcare for severe childhood illnesses could affect psychological development (Cohen et al., 1989; Preston, Hill, & Drevenstedt, 1998) and accelerate the degradation of the functional level of specific organs in adulthood (Kuh & Ben-Shlomo, 2004). We found access to healthcare in childhood, a significant predictor of late life health stock measured by mortality in previous literature (Gu, Zhang, & Zeng, 2009), was not significant when we controlled for proxy measures of nutritional input and childhood conditions (arm span and parental survival). This suggests that living conditions, as much as access to healthcare, have been important to long term health prospects for people in China. Overall, our finding of long-term positive effects of investments in childhood on health stock at old age has important implications, especially for developing countries, where more than half a billion children suffer from poverty (UNICEF, 2002) and more than 150 million children under age five suffer from insufficient nutrition (UNICEF, 2010). Investments in improving children's health capital will not only improve the health stock of children today, but also have large and lasting effects on the health stock of future elders and thus the society as a whole.

Our findings for this Chinese population are in accordance with most studies in health economics from Western countries (Salas, 2002; Smith & Kington, 1997) and a very extensive research literature in social epidemiology (e.g., Liang et al., 2003, to cite just one example), showing that adult SES, measured by more advantaged family economic conditions, is associated with better health stock. The causal pathways accounting for this association in the Chinese case, as in other countries, may include the links between socio-economic conditions and improved purchasing power for healthy diets, increased utilization of healthcare, and better standard of living (Gerdtham et al., 1999; Goodman, Stano, & Tilford, 1999; Smith, 1999). The indicator of SES we have used is an improvement over other measures (e.g., economic independence, white collar occupation) that less directly address capacity for health investments in later life.

In most health economics research, education is the most powerful SES factor predicting health stock among the working age population (Grossman & Kaestner, 1997; Wagstaff, 1993) and among the elderly (Salas, 2002). This might be because education can influence health either by increasing the returns from investment or by augmenting one's efficiency in producing additions to health stock (Leibowitz, 2004: 665). People with more education are more informed about the effects of unhealthy behavior on health outcomes, and are likely to adopt healthier lifestyles than those with less education (Leibowitz, 2004). However, education is not significant in our health stock model. This might be because the majority of Chinese elders are illiterate, and so the differential investment behavior reflected by educational attainment does not provide a stark educational contrast under the Chinese social political system (Zeng, Gu, & Land, 2007). It is noteworthy that we did not find any significant association between adult proxy investments and short-term changes in health stock. We speculate that such insignificant results may be due to insufficient length of follow-up, or to the possibility that health at old ages is largely affected by individual's physiological or psychological capacity. Further study is needed to shed more light on this.

In addition, inputs such as involvement in religious activities and regular exercise increase the level of health stock as expected, although they have limited impacts on short-term deterioration or improvement of health stock. These findings are in line with theoretical hypotheses of the health economics framework and empirical studies in epidemiology (Grossman, 1999; Koenig et al., 1999; Yates et al., 2008).

An important finding is that in this Chinese sample, community-level factors, poor air quality and labor force participation rate, have significant and independent effects on individuals' health stock level, which is in line with findings in the international epidemiology literature (e.g. Balfour & Kaplan, 2002; Kawachi & Berkman, 2003) as well as in health economics (Cropper, 1981; Erbsland, Ried, & Ulrich, 1995; Leibowitz, 2004). This finding has a critical implication in developing public health and preventive health programs in the context of population aging and environmental degradation, especially in developing countries, where most communities have suffered declines in socioeconomic development due to economic crisis.

However, none of our measures of childhood investments, adulthood investments, and community development and air quality variables had significant short-term changes in the level of health stock. There are several possible explanations for the non-significant effects of individual investments in health and external physical environments on short-term dynamics of health stock. First, our proxy measures, although improved from previous studies, may not accurately measure factors important for short term health trajectories during the later stages of life. Second, resource and behavior measures may have a direct effect only on health investments and not on health stock (Smith & Kington, 1997). Third, health stock is a cumulative construct that is largely determined by both early life and

current investments and behaviors. It is likely that, compared to 65 or more years of cumulated positive and negative investment that produce health stock level at initial measurement, the three-year observation period for health dynamics may be too short to detect significant associations between these measures and the subsequent increments among older adults. Our findings clearly warrant an extended interval of the follow-up period to verify our hypotheses.

We also contribute to the literature by incorporating a new measure of depleted health stock: the cumulative health-deficit index, which is the sum of deficits expressed as a proportion of all possible deficits for a given individual (Kulminski et al., 2006; Mitnitski et al., 2005; Rockwood et al., 2007). We argue that it is important in health economics to use comprehensive and aggregated indicators such as health deficit index to measure health stock. This is because the deficit index represents a comprehensive and cumulative measure of an individual's physiological reserve capacity that best captures the meaning of health stock (Kulminski et al., 2006; Mitnitski et al., 2005; Yashin et al., 2007). Nevertheless, we welcome more research to verify this.

We must address several limitations of this study. First, we do not have concrete measures of investments. We use indicators of parents' survival status, respondent's arm-span, and access to healthcare in childhood and adult SES as proxies of health investments. Research has indicated that socioeconomic condition is not necessarily linearly linked with investment, although higher socioeconomic condition increases the likelihood of health purchases (Grossman, 1999). Further, we did not consider willingness to purchase or invest in health stock. Literature has suggested that individuals adjust their behavior over time according to both their stock of health and level of wealth (Picone et al., 1998). Unfortunately, we do not have the data to explore these relationships. Second, childhood condition measures are retrospective, which may introduce some recall bias. Fortunately, prior research has partially confirmed the validity of self-reported childhood conditions similar to the measures used in the present study (Hayward & Gorman, 2004; Kim et al., 2003; Krieger et al., 1998; Smith & Kington, 1997). Additionally, measures such as arm span (measured objectively in childhood) and whether parents were alive at age 10 are less subject to recall bias than other measures. Third, although we integrated some factors at the community level, we did not include supply factors (such as the availability of relevant facilities) that affect the individual's investment behavior or efficiency (Wagstaff, 1993). We also did not include dynamic measures of community level factors over time. Fifth, the cumulative health-deficit index was created based on 39 variables without considering weighted contributions to the index. Recent epidemiological studies call for a consideration of weighting health deficits, although there is little empirical guidance on appropriate weighting strategies at this stage (Rockwood et al., 2007). Finally, each individual's level of health should be considered as a stochastic process since it is affected by numerous endogenous and exogenous factors (Liljas, 1998). However, the CLHLS has collected data on elders aged 65 and older for only two waves so far, which is insufficient for us to capture each individual's health stock trajectory. These limitations might bias the estimates. Further research, with more accurate measurements and applications in other populations, is clearly warranted to verify our findings.

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Table 1
Percentage or mean distribution of the sample

	Health Stock analysis sample ^a	Health flow analyses sample ^b
Individual Level Factors		
Total number of respondents	15,972	8,113
Average cumulative health-deficit index in 2002	0.23	0.16
Average cumulative health-deficit index in 2005	---	0.20
% at least 1 deficit more in 2005 than in 2002 (DI diff. ≥ 0.025)	---	49.2
% at least 2 deficits more in 2005 than in 2002 (DI diff. ≥ 0.05)	---	40.9
% at least 3 deficits more in 2005 than in 2002 (DI diff. ≥ 0.075)	---	33.6
% at least 4 deficits more in 2005 than in 2002 (DI diff. ≥ 0.10)	---	28.2
% at least 1 deficit fewer in 2005 than in 2002 (DI diff. ≤ -0.025)	---	41.2
% at least 2 deficits fewer in 2005 than in 2002 (DI diff. ≤ -0.05)	---	29.8
% at least 3 deficits fewer in 2005 than in 2002 (DI diff. ≤ -0.075)	---	21.1
% at least 4 deficits fewer in 2005 than in 2002 (DI diff. ≤ -0.10)	---	15.0
Demographic Characteristics		
Mean age	86.2	81.8
% Men	42.8	45.3
% Non-Han ethnicity	5.7	6.5
% Urban residence	46.1	43.9
Childhood Conditions		
% Having both parents alive at age 10	63.2	68.1
% Access to healthcare in childhood	51.0	49.8
% Top 90% arm length	89.7	90.7
Adult SES		
% Good family economic condition	17.3	17.5
% Received 1+ years of schooling	38.2	42.3
% Access to healthcare at present	88.7	90.3
Family/Social Support and Connections		
% Currently married	31.4	41.8
Average No. of surviving children	3.23	3.50
% Religious involvement	17.5	20.0
Health Practice		
% Smoked in the past five years	22.9	25.2
% Used alcohol in the past five years	24.5	25.8
% Regularly exercise	34.1	36.9
Community Level Factors		
Number of total communities	864	773
Per capita GDP (*1000) RMB, Yuan)	6,432	6,435
% Labor force participation rate	75.2	75.3
Air pollution index	3.5	3.5

Note: (1) % or means are unweighted. (2) All individual level variables were derived from the 2002 wave unless indicated, while community level variables were measured in 2000 except for air pollution index in 1995. (3) DI diff. meant cumulative deficit index score in 2005 minus cumulative deficit index score in 2002. (4)

^a whole sample;

^b restricted to respondents who were interviewed in 2002 and re-interviewed in 2005.

Table 2
Odds ratios_for variables predicting severe health deficit, 2002

	Highest 20% of DI	Highest 25% of DI	Highest 33% of DI
Individual Level Factors (# of individuals: 15,972)			
<i>Demographic Characteristics</i>			
Age	1.10***	1.11***	1.12***
Men (women)	0.81**	0.77***	0.70**
Non-Han ethnicity (Han)	0.93	0.84	0.89
Urban residence (rural)	1.28***	1.23***	1.24***
<i>Childhood Conditions</i>			
Having both parents alive at age 10 (no)	0.79***	0.78***	0.80***
Access to healthcare in childhood (no)	1.05	1.09	1.10
Top 90% arm length (bottom 10%)	0.64***	0.62***	0.70***
<i>Adult SES</i>			
Good family economic condition (no)	0.77***	0.74***	0.69***
Received 1+ years of schooling (no)	1.02	0.98	1.01
Access to healthcare at present (no)	0.50***	0.54***	0.53***
<i>Family/Social Support and Connections</i>			
Currently married (no)	0.89	0.85*	0.83**
Number of surviving children	0.99	0.99	0.99
Religious involvement (no)	0.49***	0.48***	0.48***
<i>Health Practice</i>			
Smoked in the past five years (no)	0.90	0.93	0.91
Used alcohol in the past five years (no)	0.71***	0.74***	0.76***
Regularly exercise (no)	0.38***	0.41***	0.41***
Community Level Factors (# of communities: 846)			
Per capita GDP (*1000) (RMB, Yuan)	1.00	1.00	1.01
Labor force participation rate	0.98***	0.99***	0.98***
Air pollution index	1.12*	1.14***	1.14***
-LL	6177.1***	6898.5***	7344.8***
rho	0.080***	0.077***	0.077***

Note: (1) All odds ratios were estimated from models that include all variables in the table. (2) All individual level variables in the leftmost column were derived from the 2002 wave, while community level variables were measured in 2000 except for air pollution index, which was measured in 1995. (3) The category in the parentheses of each variable label is the reference category. (4) rho is the coefficient of correlation between level one and level two. (5)

* p<0.05,

** p<0.01,

*** p<0.001.

Table 3
Odds ratios of variables predicting decline in cumulative health deficit index (health improvement), 2002-2005

	Criterion I	Criterion II	Criterion III	Criterion IV
Individual Level Factors (# of individuals: 8,113)				
<i>Demographic Characteristics</i>				
Age	0.93 ^{***}	0.94 ^{***}	0.94 ^{**}	0.95 ^{***}
Men (women)	1.23 ^{**}	1.10	1.12	1.10
Non-Han ethnicity (Han)	0.99	1.06	1.07	1.07
Urban residence (rural)	0.98	0.94	0.91	0.86
<i>Childhood Conditions</i>				
Having both parents alive at age 10 (no)	1.06	1.04	1.06	1.05
Access to healthcare in childhood (no)	1.03	1.01	0.95	0.97
Top 90% arm length (bottom 10%)	1.11	0.97	0.89	1.01
<i>Adult SES</i>				
Good family economic condition (no)	0.95	0.89	0.85	0.84
Received 1+ years of schooling (no)	0.93	0.92	0.89	0.86
Access to healthcare at present (no)	1.03	0.98	0.95	0.84
<i>Family/Social Support and Connections</i>				
Currently married (no)	0.97	0.88	0.83 [*]	0.87
Number of surviving children	1.00	1.00	0.99	1.00
Religious involvement (no)	1.14 [*]	1.23 ^{**}	1.16	1.29 ^{**}
<i>Health Practice</i>				
Smoked in the past five years (no)	1.10	1.05	0.93	0.86
Used alcohol in the past five years (no)	1.01	1.07	1.16	1.21 [*]
Regularly exercise (no)	1.08	1.15 [*]	1.23 ^{**}	1.24 [*]
<i>Deficit Index in 2002</i>	1.06 ^{***}	1.08 ^{***}	1.09 ^{***}	1.10 ^{***}
Community Level Factors (# of communities: 773)				
Per capita GDP (*1000) (RMB, Yuan)	0.99	0.99	0.99	0.99
Labor force participation rate	1.00	1.00	1.00	1.00
Air pollution index	0.97	0.97	0.96	0.90 [*]
-LL	4998.0 ^{***}	4327.8 ^{***}	3481.6 ^{***}	2717.4 ^{***}
Rho	0.074 ^{***}	0.071 ^{***}	0.078 ^{***}	0.105 ^{***}

Note: (1) (1) All odds ratios were estimated from models include all variables in the table. (2) All individual level variables in the leftmost column were derived from the 2002 wave, while community level variables were measured in 2000 except for air pollution index, which was measured in 1995. (3) In Criterion I an improvement was defined as having a 0.025 lower deficit index score (one fewer deficit item) in 2005 than in 2002; In Criterion II an improvement was defined as having a 0.05 lower deficit index score (two fewer deficit items) in 2005 than in 2002; In Criterion III an improvement was defined as having a 0.075 lower deficit index score (three fewer deficit items) in 2005 than in 2002; In Criterion IV an improvement was defined as having a 0.10 lower deficit index score (four fewer deficit items) in 2005 than in 2002. (4) The category in the parentheses of each variable label is the reference category. (5) rho is the coefficient of correlation between level one and level two. (6)

*
p<0.05,

**
p<0.01,

p<0.001.

Table 4
Odds ratios of variables predicting increase in cumulative health deficit index (health decline), 2002-2005

	Criterion I	Criterion II	Criterion III	Criterion IV
Individual Level Factors (# of individuals: 8,113)				
<i>Demographic Characteristics</i>				
Age	1.07***	1.07***	1.07***	1.08***
Men (women)	0.83***	0.80***	0.86*	0.87*
Non-Han ethnicity (Han)	1.05	1.15	1.09	1.11
Urban residence (rural)	1.06	1.05	1.06	1.07
<i>Childhood Conditions</i>				
Having both parents alive at age 10 (no)	0.84**	0.86**	0.87*	0.92
Access to healthcare in childhood (no)	0.94	0.98	0.98	0.96
Top 90% arm length (bottom 10%)	0.89	0.89	0.84	0.85
<i>Adult SES</i>				
Good family economic condition (no)	1.04	1.10	1.00	1.09
Received 1+ years of schooling (no)	1.01	0.96	0.92	0.93
Access to healthcare at present (no)	0.99	1.03	1.12	1.15
<i>Family/Social Support and Connections</i>				
Currently married (no)	0.98	0.97	0.95	0.95
Number of surviving children	0.99	0.98	0.99	0.98
Religious involvement (no)	0.91	0.92	0.92	0.96
<i>Health Practice</i>				
Smoked in the past five years (no)	0.97	1.04	1.02	1.07
Used alcohol in the past five years (no)	1.00	1.01	1.02	1.00
Regularly exercise (no)	0.90	1.10	0.96	0.94
<i>Deficit Index in 2002</i>	0.95***	0.96***	0.96***	0.96***
Community Level Factors (# of communities: 773)				
Per capita GDP (*1000) (RMB, Yuan)	1.01	1.02	1.02	1.02
Labor force participation rate	1.00	1.00	1.00	1.00
Air pollution index	1.02	1.02	1.04	1.03
-LL	5142.7***	5031.6***	4742.3***	4395.9***
Rho	0.079***	0.074***	0.069***	0.069***

Note: (1) All odds ratios were estimated from models include all variables in the table. (2) All individual level variables in the leftmost column were derived from the 2002 wave, while community level variables were measured in 2000 except air pollution index, which was measured in 1995. (3) In Criterion I a decline was defined as a 0.025 higher deficit index score (one more deficit item) in 2005 than in 2002; In Criterion II a decline was defined as a 0.05 higher deficit index score (two more deficit items) in 2005 than in 2002; In Criterion III a decline was defined as a 0.075 higher deficit index score (three more deficit items) in 2005 than in 2002; In Criterion IV a decline was defined as a 0.10 higher deficit index score (four more deficit items) in 2005 than in 2002. (4) The category in the parentheses of each variable label is the reference category. (5) rho is the coefficient of correlation between level one and level two. (6)

*
p<0.05,

**
p<0.01,

p<0.001.