Three Papers on Social Contexts and Older Adult Health in China

by

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DEDICATION

This dissertation is dedicated to my parents,

for their unconditional love and support.

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ABSTRACT

China is a country with vast contextual heterogeneity and a growingly aging population. Against this backdrop, this dissertation seeks to understand how regional contexts shape public health challenges faced with China's older population, using the data from the China Health and Retirement Longitudinal Study (CHARLS).

Specifically, Chapter 2 and 3 explore the link of urbanization with health and physical functioning. By constructing a multi-component-based index that measures urbanicity at the neighborhood level, I show that for both men and women, urbanization is conducive to fewer physical function impairments yet a higher prevalence of metabolic syndrome (MS), a common pathophysiological pathway to many chronic diseases. Further stratifying by rural/urban location finds the association between urbanicity and MS significant only among rural women and urban men. These findings reveal that the "urban health penalty" and "urban health advantage" thesis can be both true depending on the health outcome of interest and highlight a gender- and context-specific effect of urban living on metabolic health among older adults.

Chapter 4 shifts focus from structural to cultural context and examines the link between the ingrained culture of son preference and gender inequality in cognitive functioning. My analysis shows that the early exposure to local practices of son preference may significantly increase the women's relative disadvantage in mental capacity to reason and perform basic cognitive tasks in later life. This widened gender gap can be partially explained by the fact that son preference tends to create more gender disparity in education.

Taken together, my dissertation contributes to the understanding of how social contexts get under the skin to affect the health of older Chinese adults. by showing the role of urbanization in health and functioning. This work is guided by and contributes to research influenced by nutrition transition and fundamental cause theories, and research about the role of son preference in gendered health inequalities based on the life course perspective. Findings from my studies are also relevant to other low- and middle-income countries with health burdens brought by accelerating population aging, urbanization, and the need to further improve gender equality.

CHAPTER 1: Introduction

This dissertation consists of three papers studying the links between social contexts and individual health among middle-aged and older adults in China. As a country with a population experiencing accelerating aging, rapid social change, and tremendous contextual variations, China provides an ideal setting to investigate how social context shapes health, health behaviors, and functioning of older adults. Using the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative study of people over age 45, my dissertation centers on the impact of two social contextual determinants on health: urbanization and son preference.

Urbanization and the culture of son preference play nontrivial roles in the lives of middle-aged and older Chinese adults such as those who make up the CHARLS cohorts. In China, the share of the urban population has more than tripled from 18% to 62% during the four decades following the economic reform in 1978 (Lu and Liu 2019). Given the persistent policy-driven urban-rural gap in wealth, infrastructure and social welfare (Whyte 2010), urbanization (including in-situ urbanization or rural-to-urban migration) has been a key driver for the change in living standards and lifestyles. Meanwhile, China has seen less change in many sexist cultural practices, especially in the form of the traditional son preference culture. Studies have documented the skewed sex ratio as the result of sex-selective abortion under the restrictive one-child policy, underreporting of baby girls, and neglect or low parental investment in daughters (Ho, Gu, and Zhang 2018; Mungello 2008; Zhou et al. 2012). Notably, despite the improvement in women's education and social status in the past century (Hershatter 2007), China has only begun to see a significant decline in sex ratio in the most recent decade (Jiang et al. 2017).

These larger social contexts are linked with health and health inequalities through micro- and meso-level resource and risk factors. The studies in my dissertation are grounded in the sociological and epidemiological literature that has long documented the effect of such resources and risk factors, including education and economic resources (Phelan, Link, and Tehranifar 2010), housing (Gibson et al. 2011), social networks/social support (Smith and Christakis 2008), lifestyles (Cockerham 2005), and the meso-level social environment (e.g., neighborhood physical/built environment (Cohen et al. 2003; Renalds, Smith, and Hale 2010), collective efficacy (Sampson 2003) on health. As a general approach, my studies start with establishing robust links between larger social contexts and health outcomes and then move on to examine how these micro- and meso-level health resources/risk factors can help explain the observed contextual effects.

China's rapid urbanization and the associated lifestyle change have been the soil for nutrition and epidemiological transition and new public health challenges (Cook and Dummer 2004; Popkin 1999). I focus in this dissertation on 1) diseases of affluence as the result of nutrition transition, and 2) limitations in physical functioning, as it is increasingly becoming a public health burden in an aging society. My investigation of urbanization as the determinant of the two health outcomes offers two substantive contributions to the literature. First, I adapt a validated urbanicity scale to CHARLS, and examine its validity. Second, I show that a complex social process such as urbanization can lead to health benefits and penalties at the same time and for the same population, depending on the health outcome of interest and how the micro-level risk factors variously act.

Specifically, chapter 2 examines the association between the level of urbanization (urbanicity) and metabolic syndrome, a crucial pathophysiological outcome and a leading cause for cardiovascular diseases and Type 2 diabetes. Using a high-quality multicomponent-based urbanicity scale and a novel matching approach, I find that community-level urbanicity is significantly associated with a higher level of metabolic abnormalities. However, when examined *within* the broadly defined rural/urban area, I show that this relationship is only salient among rural women and urban men. These findings overall lend support to the Nutrition Transition theory that predicts urbanization and associated shift toward Western-style diets and physical inactivity would increase the prevalence of metabolic-related conditions. However, I highlight that the relationship between urbanization and metabolic health is gendered and context-specific.

Chapter 3 continues the investigation of the link between urbanization and physical health from yet a different aspect of health - functioning. Physical functioning is a core component of health in an older population, and studies have shown that it predicts well-being and mortality independently of diseases/conditions. Using measures of frailty and activities of daily living (ADL), I show that urban living slows the process of functional decline in mid-life and older age. An examination of three groups of theory-guided pathways reveals that economic resources, especially housing quality, can account for the observed health benefit of urban living in physical functions. Together with the first chapter, this chapter unravels the double role urbanization plays in health. While unhealthful lifestyles induced by urban life are associated with "diseases of affluence", the general improvement in standards of living may help one function better in later life.

Chapter 4 shifts the focus from structure to culture. Past research has found that in less developed countries and regions older women have more disadvantaged cognitive functioning (Lei et al. 2014; Onur and Velamuri 2016). While most prior studies have attributed the phenomenon to socioeconomic factors (e.g., Weir, Lay, and Langa 2014), this chapter strives to understand the underlying cultural root of this pattern. Specifically, taking China as a case study, I investigate the impact on the later-life gender gap in cognitive functioning of son preference, a cultural practice that prevails in many Asian settings. I find that son preference (captured by the city-level sex ratio) puts middle-aged and older women in more disadvantaged places on the test results of mental status, which measures the mental capacity to reason and perform basic cognitive tasks. I triangulate my finding using two alternative measures of the source of son preference. Mechanistically, educational attainment partially mediates the effect. The finding highlights the cultural significance in understanding the later-life gender inequality in cognitive functions that has accumulated over the entire life course.

CHAPTER 2: Urbanicity and Metabolic Syndrome among Older Adults in China

Introduction

Urbanization, a process of increasing urban population size, density and heterogeneity (Wirth 1938), has progressed rapidly in the recent history of the developing world. According to the United Nations' Department of Economic and Social Affairs, the percentage of urban dwellers in low- and middle-income countries (LMICs) rose from 25% to 45% between 1970 and 2010. Against the backdrop of fast-paced urbanization in developing countries including China, India and Sri Lanka, researchers have documented an association of urbanicity with a higher prevalence of diabetes, overweight/obesity, high blood pressure and worse self-rated health (Allender et al. 2010, 2011; Chen et al. 2014; Miao and Wu 2016; Van de Poel, O'Donnell, and Van Doorslaer 2009, 2012).

Pathways linking urbanicity to increasing chronic disease prevalence include the spread of Western-style diets (Popkin and Du, 2003), physical inactivity (Monda et al., 2007), environmental hazards (Chen et al., 2013), and psychosocial factors (e.g., depressive distress (Chen et al. 2014)). These coinciding patterns have led some to propose an "urban penalty" of increased chronic conditions in urbanizing low and middle-income countries (Harpham 2009; Van de Poel et al. 2012; Vlahov and Galea 2002). However, urbanization also often brings health-enhancing developments including closer proximity to health-care facilities, improved sanitation, and better health education and awareness, which have greatly reduced the prevalence of communicable diseases and may lower the prevalence and slow the progress of chronic conditions (Chen et al., 2010; Moore et al., 2003). Given these countervailing forces, the nature and pathways underlying the association between urbanicity and chronic conditions remain empirical questions, shaped by the particular social context and historical time.

Among developing countries, China has experienced fast and uneven urbanization since economic reforms in the 1970s, with the urban population surging from 18% that year to just over 50% in 2011(National Bureau of Statistics 2012). This development emerged in the context of drastic rural-urban status differences created by the legal *hukou* (household registration) system and associated migration barriers since the 1950s (Whyte 2010). Building on this historical urban/rural divide, recent urbanization has led to vast regional variation in urban development. The fast and non-uniform urbanization in China over the past three decades (Gong et al. 2012) provides an ideal setting to study the links between urbanicity and chronic disease patterns.

The current study builds on the existing urbanicity literature by exploring an important yet less studied pathophysiological outcome linking urbanicity and chronic disease – metabolic syndrome – among middle-aged men and women in China. Metabolic syndrome is defined as a cluster of vascular risk factors that share insulin resistance and central obesity as common underlying mechanisms, including increased blood pressure, high blood sugar, excess body fat around the waist, and abnormal cholesterol and triglyceride levels (K. Alberti, Zimmet, and Shaw 2006). It is an immediate precursor to the development of cardiovascular diseases and Type 2 diabetes (Misra and Khurana 2008), and is a strong predictor of old-age mortality (Ford 2004; Tancredi et al. 2015). An earlier study estimated that metabolic syndrome affected about 16.1% of urban men, 21.3% of urban women and 8.3% of men and 17.3% of women in rural areas aged 35 to 74 in the early 2000s, and that the prevalence is rising rapidly (Gu et al. 2005; Shen, Goyal, and Sperling 2012).

In addition to studying a novel chronic condition outcome in a rapidly and unevenly urbanizing context, this study contributes to the literature in other ways. First, while a few studies have explored the urbanicity-health association using a continuous urbanicity scale, they often treat the association as linear. Doing so ignores the possibility that mechanisms underlying the urbanicity-health association may be different at different levels of urbanicity, even within a single country. As Popkin (1999) points out, “in the same population where undernutrition and food insecurity are found, other subpopulations suffer dietary excess and obesity”. Second, adopting a counterfactual framework, I use a *non-bipartite matching* approach to more rigorously adjust for potential confounders, especially those linked with selective migration of healthy and better educated into urban areas and megacities (Lu and Qin 2014; Tong and Piotrowski 2012; Wu and Treiman 2004). Finally, guided by prior literature on the risk factors of metabolic dysregulation, I examined how behavioral pathways might potentially mediate the association between metabolic syndrome and urbanicity.

Theoretical Background

Urbanization, nutrition transition, and lifestyle change

Urbanization matters to metabolic syndrome in the context of developing countries. As a place urbanizes, it not only gains population size and density, but also more “urban features” such as job opportunities in the non-agricultural sectors, infrastructure (e.g., mass transportation, electricity and sanitation), facilities (e.g., markets, hospitals, schools and recreational facilities) and social services (e.g., non-profit organization medical insurance, and kindergarten for young children) (Allender et al. 2011; Dahly and Adair 2007; Jones-Smith and Popkin 2010). As indicated by studies of neighborhood effects, these features can be risk (or protective) factors for chronic conditions. Mechanistically, while urban features present in the local neighborhood can directly affect diseases outcomes as environmental hazards or psychological stressors, such as pollution (Astell-Burt et al. 2013) and noise (Willich et al. 2006), most scholars have adopted an approach that highlights behavioral change to understand the pathways linking urbanization and health (e.g. Allender et al. 2010; Miao and Wu 2016; Van de Poel et al. 2012). Specifically, urban features such as more modernized housing, and altered occupation structures (with more income) can have profound influence on individual behaviors by which social contexts "get under the skin" to affect important health outcomes such as chronic conditions.

Among the pathways, the dual-process of diet change and reduced level of physical activities associated with urbanization, as suggested by the Nutrition Transition Theory (Popkin 1993, 1999, 2014) is hypothesized to play a major role. Urbanization and the associated income growth bring a diet change toward increased intake of fat, sugar and processed food, which feature in the Western-style diet. Meanwhile, industrialization and the rise of the service sector during urbanization fundamentally changes the occupation structure, with a shift from agricultural to manufacturing and service employment. The result is a marked shift in activity patterns at work, and a trend toward fewer jobs requiring heavy physical activity. As illustrated by Popkin (1993), the health consequence of these changes in lifestyles is the advent of the "degenerative disease" nutrition transition pattern, featuring increasing rates of obesity and chronic conditions for people from all age groups.

Nevertheless, while "degenerative disease" might be one of the dominant nutrition transition patterns associated with the urbanization process in the developing world, it may characterize certain geographic and socioeconomic subpopulations, but not others (Popkin 1999).

For large urbanizing countries, a highly urbanized region with nutritional conditions exceeding basic needs may need policy intervention to discourage a high-carbohydrate and high-fat diet, and thus fits the "degenerative disease" pattern. At the same time, an urbanizing but lower income rural region in the same society may need to be subsidized to combat malnutrition and still be in an earlier "receding famine" nutrition transition pattern, featuring nutritional deficiency (Popkin 1993). Given the possibility of within-society variation, it is important to examine the association between urbanicity and chronic diseases as context-dependent and potentially nonlinear.

Gender context

Previous studies have documented a higher prevalence of metabolic syndrome among women in a number of developing countries, such as China, India, Iran and Turkey (Misra and Khurana 2008). While part of this gender difference can be attributed to biological mechanisms (Vlassoff 2007), two literatures have also implied a potential gender disparity in the association between urbanicity and metabolic syndrome in China. The first literature highlights the gender – urban/rural crossover in the prevalence of metabolic functioning (Weng et al. 2007), related conditions such as overweight/obesity (Zhang and Wang 2013), and hyperglycemia/prediabetes (Gu et al. 2003). Specifically, while urban men have a higher age-adjusted prevalence for these conditions compared to urban women, the pattern is inversed in rural areas, thus creating a relative ordering of urban men, urban women, rural women and rural men in terms of disease prevalence. A few have speculated that the relatively high incidence seen in rural women may be a result of urban women having more desire to lose weight (Luo, Parish, and Laumann 2005) and the urban-rural gap in fertility rate (e.g. Weng et al. 2007). As according to the 2000 census in

China, the total fertility rate (TFR) was 1.3 in urban areas and just under 2.0 in rural areas (Hesketh, Lu, and Xing 2005), and prospective studies have linked women's increasing parity and parenthood with future development of metabolic syndrome and obesity (Gunderson et al. 2009; Yakusheva, Kapinos, and Weiss 2017). Whatever the mechanism, the gender–urban/rural crossover in the incidence of metabolic syndrome suggests a gender difference in the association between urbanicity and metabolic syndrome in China.

Neighborhood studies conducted in developed countries have also implied a potential gender difference in the association between local social/physical environment and metabolic health in China. Particularly, these studies have explored the differential importance of the neighborhood environment for the health of men and women. Findings to date are mixed, depending on the measure of neighborhood environment and specific health outcome. While a few studies have found a larger effect of neighborhood characteristics, such as economic indicators, amenities and physical environment, on women's health (Robert and Reither 2004; Stafford et al. 2005), others have documented a stronger association between multiple deprivations in the neighborhood and life expectancy (Raleigh and Kiri 1997) and mortality (Macintyre 2001) for men. Some have argued that the gender difference in the neighborhood effect on health might be attributable to the level of exposure or vulnerability to the local environment (Read and Gorman 2010; Stafford et al. 2005). These findings cannot be directly applied to the Chinese context, given their focus on the US and UK and different measures of neighborhood conditions. However, they provide the useful insight that men and women, especially those living in less urbanized areas, may spend different amounts of time in and outside the home, and thus do not have equal exposure to the residential neighborhood's environment.

Existing research on urbanicity and chronic conditions in China

Though no researchers have linked urbanicity with metabolic syndrome in China, a few recent Chinese studies have developed an urbanicity scale and examined its association with chronic health conditions. Using the China Health and Nutrition Survey (CHNS), Van de Poel et al. (2009, 2012) developed a factor-analysis-derived measure using indicators of the community-level built environment and socioeconomic context and found dynamic urbanization associated with obesity, hypertension and reported illness symptoms. Using the same data, Jones-Smith and Popkin (2010) identified 12 urban attributes ranging from economic factors to urban infrastructure and social services, then used an equally weighted scoring method to measure overall community-level urbanicity. Employing this scale, ensuing studies have found a positive association between urbanicity and obesity (Fu and Land 2017), reported chronic conditions (Miao and Wu 2016), and moderate inflammation and diabetes, and associations with individual urbanicity components were also documented (Attard et al. 2012; Thompson et al. 2014). Furthermore, studies have suggested that the link of urban living with risk factors for metabolic syndrome is gender-specific and dependent on the rural/urban context. For instance, since the 1980s the rate of overweight and obesity was found high among urban men (vs. rural men) and rural women (vs. urban women) (Weng et al. 2007).

Building on the previous research, this study examines the association between urbanicity and metabolic syndrome, a chronic condition that shares similar pathological pathways (insulin resistance and visceral obesity) and environment-related mechanisms to obesity, CVDs and diabetes. I used the 2011 baseline interview of the China Health and Retirement Longitudinal

Study (CHARLS) that surveyed mid-aged and elderly Chinese (age 45+) and constructed an urbanicity index based on nine urban attributes, following the lead of Jones-Smith and Popkin 2010. Specifically, I hypothesize a positive association between urbanicity and metabolic abnormalities among middle-aged and elder Chinese. Also, I hypothesize the association can be explained by dietary change and a decline in physical activities, as suggested by the nutritional transition theory. Finally, in light of the aforementioned literature regarding the gendered pattern of neighborhood effect on health, I hypothesize the association to be gender-specific.

Data and Sample

Data for this analysis were derived from the 2011 baseline wave of the China Health and Retirement Longitudinal Study (CHARLS), the only wave in which community information (for building the urbanicity index) is collected. Based on stratified multistage probability sampling, 450 urban neighborhoods and rural villages were sampled (referred to as "communities" in the protocol and the current study hereafter). Within each community, 80 households were randomly selected and interviewed. Overall, the survey successfully interviewed 17,708 individuals among whom 11,847 and 13,974 agreed to participate in the collection of blood samples and non-blood biomarkers, respectively. A comparison among the three samples does not reveal a systematic difference in urbanicity or other covariates used in my analysis and thus the data was assumed to be missing at random. Furthermore, one or several community respondents, usually members of the village/neighborhood committee, were also interviewed for a community survey. As the only nationally representative data for middle-aged and elder Chinese that includes a community-level survey and biomarkers, CHARLS provides an ideal data source to link urbanicity with metabolic syndrome in China.

I included all respondents with valid measures on all the biomarkers required for constructing the risk factors defined by metabolic syndrome (N = 9,955). Among these respondents, I further restricted the analytic sample to those who had lived at their current address for at least five years (N = 9,491) to ensure a sufficient exposure window to the local environment, and who had fasted overnight before the collection of blood (N = 8,903) to ensure the biomarker measurements were valid. After multiply (n = 5) imputing missing values (with chained equations using the R package "mice") for study covariates, the final sample size was 8,690 for the main analytic sample with metabolic abnormalities (see below) as the outcome variable. It should be noted that since no missing values for variables that served as outcome were imputed, the size of specific analytic sample varied by the outcome variable under focus (See Table 2.1 for details).

Measure

Metabolic syndrome

I used *metabolic abnormalities* to capture metabolic syndrome. Following guidelines from the International Diabetes Federation (IDF) and National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III), I employed 5 biomarkers: blood pressure, HDL cholesterol, triglycerides, (fasting) glucose and waist circumference. Specifically, blood pressure and waist circumference were collected as part of the main survey by the CHARLS field team. To measure other biomarkers, including HDL cholesterol, triglycerides and (fasting) glucose, venous blood samples were collected by the Chinese Center for Disease Control and Prevention (China CDC) and transported to Beijing and assayed in a national lab. China CDC staff asked respondents to have fasted overnight before the procedure for blood collection based on a standard protocol. Assay results were later merged with CHARLS data and a variable indicating fasting status was produced by CDC staff, where 92% of the sample reported that they had fasted.

Following the lead of IDF and NCEP ATP III guidelines, each of the five biomarkers was recoded to a dichotomous variable to indicate whether the value falls into the high-risk range. Specifically, I drew on the IDF Worldwide Definition of metabolic syndrome (G. Alberti et al. 2006) for the Chinese specific values to define the cut-off points, presented in APPENDIX A. These recoded biomarkers were then summed up to create a composite count of *metabolic abnormalities* (range 0-5), the key outcome used for the following analyses.

Urbanicity & Urban/rural status

Building on the method applied in Jones-Smith and Popkin (2010) to the Chinese Health and Nutritional Study (CHNS) data to yield a high-quality scale for measuring neighborhood-level urbanicity in China (Cyril, Oldroyd, and Renzaho 2013), I created a similar multicomponent scale to measure neighborhood-level urbanicity for the CHARLS sample. The components used herein have been shown to have high reliability and validity for constructing the composite urbanicity measure and provide information beyond what could be determined from the traditional urban/rural dichotomous variable (Jones-Smith and Popkin 2010). Specifically, nine components were included. Two components capture demographic characteristics: population density and economic activities – measuring the proportion of non-agricultural population. Seven components measure urban infrastructures and social institutions including markets, transportation, sanitation, housing, communication, public facilities and social service/security. I added up the individual score from each component and rescaled it to create an urbanicity scale ranging between 0 and 1. For details see Appendix B and C regarding how each component was measured and the reliability/validity check on the composite measure.

I further examined the potentially nonlinear/context-dependent association between urbanicity and metabolic syndrome in ways. First, I included a quadratic form of urbanicity in the model that used the full men/women sample. Second, I examined the metabolic syndrome – urbanicity association separately in urban and rural areas, given the vast socioeconomic differences between these contexts in modern China. To define urban/rural area, I employed a dichotomized status of the local community determined by the National Statistics Bureau in 2009, two years prior to the implementation of CHARLS baseline. The classification method reflects the location of the community in relation to the local county-level and town-level government station, population density and economic activities (mainly the proportion of non-agricultural population) (Zhang, LeGates, and Zhao 2016). A key reason to use this measure lies in its non-arbitrariness in defining the contexts, compared to data-driven definitions (e.g. dividing the sample into quantiles based on sorted urbanicity levels). Furthermore, stratifying on urban/rural areas could reflect the social process/fact that during the late 1950s – early 1980s the *hukou* barrier greatly limited one's chance for rural to urban migration, resulting in mostly internal migrations in China within rural or urban areas, not across this boundary. Thus, to address the question of my interest within urban and rural areas conveyed more practical sense for the CHARLS cohorts (mostly born in 1950s-1970s).

Covariate

In addition to restricting the sample to respondents who had lived in the current community for at least five years – to ensure the local environment would have enough time to shape the individual's health – I included a rich set of variables capturing socio-demographic characteristics and prior health status to control for potential confounding of the association between urbanicity and respondents' health, especially the selection of healthy and better-educated migrants into highly-urbanized areas (Lu and Qin 2014; Wu and Treiman 2004). Also, I avoided the inclusion of intervening variables that are strongly endogenous to the urbanicity of the surveyed community, such as current income, hukou status (household registration) and pension or family wealth. The first battery of covariates in the final list included age, level of educational attainment, type of one's first *hukou* (for most it was determined either at birth or when the *hukou* system established around 1958), and region of the residing community. Additionally, a dichotomized indicator of underage marriage (for the first marriage) was included, given early marriage was a strong predictor of low educational attainment and early childbearing (Singh and Samara 1996), which might in turn influence one's potential for migration to more urbanized areas. I used the marriage age set by the first marriage law of PRC (1950) to determine if the respondent had an underage marriage. Furthermore, regarding prior health status, I included self-reported health for childhood, an anthropometric biomarker that would remain unchanged after early adulthood - arm length - and an indicator of any disabilities.

Past studies have found that internal migrants in China, especially those who migrated in earlier periods, were likely to have better physical health prior to migration than non-migrants (Tong and Piotrowski 2012). Therefore, I include a variable capturing migrant status (i.e., if one was a migrant) to account for the health selectivity in migration that might not be captured by other covariates. I further the length of residence in the current community to account for heterogeneity among (non-)migrants.

Behavioral Factors

As suggested by the nutrition transition theory, I investigated the associations of urbanicity with factors that directly associated with dietary shift and physical activities. A parallel pattern found with these associations across genders and urban/rural locations would help us gain confidence regarding the association with metabolic syndrome, as they are the most important behavioral pathways. For dietary shift, given that CHARLS did not collect dietary records, I used price-adjusted food expenditure as a proxy for the degree to which respondents likely had a Western-style diet. The rationale was that in China, especially at the time of the survey, red meat and dairy products, including Western-style fast food were generally more expensive than fruits, vegetables and homemade meals. To capture physical activities, I employed the measure of the number of weekly hours spent in three types of activities - vigorous activities, moderate activities and walking.

Method

Matching

I took a *non-bipartite matching* approach (Lu et al. 2011), given that I treated urbanicity as a treatment with continuous levels. I used the non-bipartite matching algorithm with the aim to match individuals with similar characteristics but different dose levels of the treatment. More specifically, following the spirit of (Joffe and Rosenbaum 1999) and Lu et al. (2011), I first constructed a single-variable *balancing score* using a linear regression model that estimates the association between the observed covariates ($\boldsymbol{x}_i$) and urbanicity (T_i) as follows:

$$T_i = \beta^T \boldsymbol{x}_i + \varepsilon$$

where the linear combination of covariates $b(\boldsymbol{X}) = \beta^T \boldsymbol{x}_i$ was used as the *balancing score.* One can show that the balancing score has the desirable properties of covariate balancing, unconfoundedness and bias removal (Appendix D). I then aimed to conduct a 1:1 optimal matching on individuals with similar balancing scores but different urbanicity levels for three analytic samples: (1) a sample including all respondents, and samples including respectively (2) only urban or (3) only rural dwellers. Again, following Lu et al. (2001), I constructed a particular distance between any two subjects as the following:

$$\Delta\left(x_i, x_j\right) = \frac{(\hat{\beta}^T x_i - \hat{\beta}^T x_j)^2}{(T_i - T_j)^2}$$

$$\text{where } \Delta\left(x_i, x_j\right) = \infty \; if \; T_i = T_j$$

which was used later for matching two subjects having a small difference in the balancing score but a large difference in the treatment level. In this case, one could imagine two individuals would be matched if they have the same or similar preexisting observed characteristics but live in communities with different levels of urbanicity. Lu et al. (2001) also discussed the motivation for this form distance using the concept of equal percent bias reduction (Rubin, 1976).

In practice, I averaged the five balancing scores from each imputed dataset, following the "across" method recommended by Mitra and Reiter (2016). I then implemented matching for each of the analytic sample while stratifying on gender (thus producing 3×2 subsamples for matching) since my goal is to conduct my analysis separately for each gender. I determined whether there was overall good matching based on Rubin's B and R (Rubin, 2001). I also made sure that there was no significant difference in distribution of covariates between the two groups and T-test (mean)/F-test (variance for continuous covariates). I implemented all matching using the R package nbpMatching (v 1.5.1).

Estimation of the effect of urbanicity on metabolic syndrome

Capitalizing on the matched pairs, I estimated the association between urbanicity and metabolic abnormalities using fixed-effect Poisson models with the following specification

$$E(y_{ik}|\alpha_i, X_{ik}) = \alpha_i \exp(X'_{ik}\beta)$$

where y_{ik} denotes the number of metabolic abnormalities for respondent k in matched pair i, and α_i indicates the matched-pair specific fixed effects. X_{ik} and β represent the vector of urbanicity and covariates and the corresponding coefficients. I also included a quadratic term of urbanicity to check for nonlinearity for the model that used the full men/women sample. In practice, the model was estimated using conditional fixed-effects MLE with heteroskedasticity-robust standard errors to adjust for over-dispersion (Cameron and Trivedi 2010). It should be noted that by including matched-pair FE, I no longer need to consider clustering within community or household, since it was imperative to only match two persons together when they lived in communities with different levels of urbanicity (that is, different communities). All models were stratified by gender to account for the sex difference in the incidence of metabolic syndrome and exposure to neighborhood environments. As aforementioned, I additionally stratified by urban/rural location given the association between metabolic syndrome and urbanicity may potentially vary by urban/rural context and the fact that the *hukou* barrier had constrained rural-to-urban migration for many decades in contemporary China.

Robustness checks

To test the robustness of the above analysis, first, I triangulated the results with the corresponding non-FE Poisson models. Second, I re-estimated the models while constraining the analytic sample to those who had lived in the current community for 10, 15 and 20 years and compared with results with the 5-year constraint aforementioned. Additionally, I replaced the outcome variable with a dichotomous indicator of whether the respondent would be diagnosed with metabolic syndrome based on the IDF definition for Chinese adults (G. Alberti et al. 2006), the same guidelines used for creating the measure of *metabolic abnormalities*. More specifically, I created a binary indicator for the diagnosis of metabolic syndrome, marking as positive cases those with a high-risk waist circumference (indicating visceral obesity) plus at least two additional biomarkers falling in the high-risk range, the method laid out by the IDF guideline. To model its association with urbanicity, I employed conditional logit models to avoid the incidental parameters problem (Cameron and Trivedi 2010).

Auxiliary analysis

Like the main analysis, I tested how food expenditure and physical activities were associated with urbanicity, stratified by gender and urban/location, and based on the matched-pair FE models laid out above. It should be noted that as a function of the CHARLS survey design, less than half of the respondents were sampled for answering the physical activities questions. Hence, the analysis of physical activities was based on a subset of the analytic sample and reduced statistical power.

Result

Descriptive Statistics

The distribution of urbanicity for the three study samples is presented in Figure 2.1. Overall, as shown in Figure 2.1(a), the distribution of urbanicity is right-skewed, consistent with the general idea that the majority of mid-aged and elderly Chinese were residents of rural areas and small towns as classified by the National Bureau of Statistics (NBS). Moreover, as displayed by Figure 2.1b and 2.1c, when I further split the sample into an urban and rural subsample using the classification method from NBS, considerable heterogeneity in urban attributes was evident within both urban and rural areas. Notably, while in general, the mean urbanicity is higher in urban than rural areas, some urbanicity levels overlapped for both the rural and urban subsamples, a pattern that could only be shown by using continuous urbanicity index rather than an urban-rural dichotomy. Little gender difference was found concerning the shape of urbanicity distribution (results not shown).

[Figure 2.1 about here]

Table 2.1 further displays the summary statistics stratified by gender. Overall, the sample included more females (53.3%) than males (46.7%) and a higher mean of metabolic abnormalities (2.67 vs. 2.03, $p<0.001$) for women than men. Given that the sample consisted only of cohorts educated prior to the implementation of China's 9-year compulsory education law (for those below ages 6 in 1986), unsurprisingly, only about 65% of men and 40% of women had achieved any formal educational levels (at least elementary school). Notably, men were more likely to be cross-county migrants than women, yet had lived longer in the surveyed community. This pattern can be mainly attributed to the practice of the culture of patrilineal families in China that women are far more likely to marry into a household of their spouse (residing in a neighboring community) than men (Fan and Huang 1998). Regarding health status, men, compared to women, had a slightly higher likelihood to report that they had good health for childhood years (before age 15) (76% vs. 73%, $p<0.05$) but were more likely to report any disability (21% vs. 18%, $p<0.001$). Furthermore, I found men spending substantially more time doing vigorous activities compared to women (8.77 hours/week vs. 5.82 hours/week, $p<0.001$) but not activities with less physical effort. This might suggest that men in these cohorts were more likely to engage in jobs requiring occupational physical activities with high intensity (Monda et al. 2007).

[Table 2.1 about here]

Matching

Drawing on the results from the regression of urbanicity on all covariates, I constructed a balancing score for the full, urban and rural samples, stratified by gender. I then applied non-bipartite matching for each of the six samples. I identified the respondent with the higher urbanicity level in the matched pair as “high-urbanized” and the other as “low-urbanized” to make sure the urbanicity “treatment” would always indicate an increase from a less urbanized community to a more urbanized one. As expected, the matching results regarding covariate balance and the difference in urbanicity (see APPENDIX E for details) reveal that there was a large mean difference in urbanicity for the matched samples; for instance, regarding the full sample, two subjects in the same matched pair were on average 0.178 and 0.179 apart in terms of urbanicity – equivalent to 1.37 and 1.38 absolute standardized difference for men and women, respectively. Here, absolute standardized difference is defined as $|\bar{x}_{treatment} - \bar{x}_{control}|/\sqrt{(s^2_{treatment} + s^2_{control})/2}$ for continuous variables and $|\hat{p}_{treatment} - \hat{p}_{control}|/\sqrt{(\hat{p}_{treatment}(1-\hat{p}_{treatment}) + \hat{p}_{control}(1-\hat{p}_{control}))/2}$ for dichotomous variables (Austin 2009). By contrast, the sample as intended was well matched for covariates; all matched subjects had an absolute difference in age of less than one year. Additionally, a two-sample t-test showed that except for one category of the variable *region* for the subsample of urban women, all covariates were balanced as none of the differences in means were significant for $\alpha = 0.05$. Regarding global metrics for covariate imbalance, Rubin's B and R indicated that all matched samples were well-balanced (Rubin 2001).

Urbanicity and metabolic syndrome

Table 2.2 presents the association of urbanicity and metabolic abnormalities from matched-pair fixed-effects Poisson regression models. In the initial analysis, I found none of the squared urbanicity terms were significant at α=0.1 and few BIC-based model comparisons indicated a preference for models with quadratic terms. Therefore, only models with linear form of urbanicity are shown.

[Table 2.2 about here]

Starting from the "All" sample in Table 2.2, I found that metabolic abnormalities are significantly and positively associated with urbanicity, for both men and women. Specifically, I found that men in communities that are one standard deviation (0.16) higher in urbanicity were predicted to have a count of metabolic abnormalities higher by 12% (=$e^{0.701*0.16}$-1). Thus, for a man with average metabolic abnormalities in the sample (2.03), the counterfactual metabolic abnormalities count would increase by 0.24 (=2.03*12%) if he moved to a community with urbanicity one standard deviation higher. For women, the two numbers, correspondingly, were 5% (=$e^{0.343*0.16}$-1), and 0.13 (=2.67*5%), which indicated a weaker association than that for their male counterparts, as confirmed by statistical test. On average, these findings for the sample overall supported the hypothesis for a stronger association between urbanicity and metabolic syndrome among men, but the association was present for all adults.

By further breaking the sample down to urban and rural subsamples, the results reveal that the association between urbanicity and metabolic syndrome were urban/rural context and gender-specific. For men, the significant urbanicity association is only found for urban dwellers (0.497, $p<0.01$) but not rural dwellers (0.212, $p>0.1$). The pattern was reversed among women (0.032, $p>0.1$, for urban dwellers vs. 0.496, $p<0.01$ for rural dwellers). Thus, the urbanicity-metabolic syndrome association was heterogeneous for both genders, given that it differed on the rural end versus the urban end of the urbanicity distribution.

Taken together, the results showed that there was not only a gender difference in the overall association between urbanicity and metabolic syndrome, but the pattern of the urban/rural specific association between urbanicity and metabolic syndrome was gendered as well. For urban dwellers, when exposed to a more urbanized environment, only men became more susceptible to metabolic syndrome; by contrast, among rural dwellers, a more urbanized local environment tended to contribute to metabolic syndrome only for women.

Robustness Check

Several sensitivity analyses were conducted to investigate whether the results above were robust to altered modeling choices. First, I found the patterns of the urbanicity-metabolic syndrome association was nearly the same in non-FE models and when one changed the criterion of sample selection from continuously living in the surveyed community for five years to 10, 15 and 20 years (see Appendix F). Second, I obtained a set of similar findings when employing a measure of diagnosable metabolic syndrome (following the IDF criteria), compared to the results above (Appendix G). Taken together, these analyses suggest the results based on matched-pair FE models with sample restricting to at least 5 years' residence in surveyed communities were robust.

Auxiliary Analysis

Table 2.3 presents the results investigating the association between urbanicity and food expenditure (price-adjusted and logged). Overall, I found urbanicity positively associated with food expenditure for all urban dwellers and rural women (though marginally significant for the latter). The results could account for the differential association between urbanicity and metabolic syndrome across urban/rural locations (Table 2.2), but only for men.

[Table 2.3 about here]

While the differential pathways suggested in Table 2.3 shed light on the urban/rural difference in the association between urbanicity and metabolic syndrome for men, the investigation of the relationship between urbanicity and physical activities may offer more insights for both genders. As shown in Table 2.4, I found that while for men, the rate of decline in the level of vigorous physical activities along the urbanicity gradient was higher in the urban than rural context, the pattern was reversed among women. Since in China vigorous physical activities are mainly occupational physical activities that account for the major share of daily energy expenditure for the study cohorts (Monda et al. 2007), this gendered pattern could partly explain why it was urban men and rural women who were more susceptible to the "urban penalty". In other words, the shift toward occupations requiring less physical effort, as a place urbanizes, might be more salient among rural women and urban men. A similar pattern was not observed for moderate activities and walking, though.

Discussion

Building on previous studies linking urbanicity with chronic disease prevalence (Fu and Land 2017; Miao and Wu 2016; Van de Poel et al. 2009, 2012), this study employed a multicomponent urbanicity measurement based on a high-quality scale devised in Jones-Smith and Popkin's earlier work (Jones-Smith and Popkin 2010), adapted to the CHARLS sample. Unlike previous studies, however, I treated the association between urbanicity and the health outcome under focus as gender- and context-dependent. Additionally, adopting a counterfactual framework, the present study used an innovative *non-bipartite matching* approach to more rigorously adjust for potential confounders, especially those linked with the selection of healthy and better educated into more urbanized areas (Lu and Qin 2014; Tong and Piotrowski 2012; Wu and Treiman 2004). While conventionally a researcher would need to convert a continuous treatment into a binary or a multinomial treatment before applying a distance-based matching method (e.g., propensity score matching, Mahalanobis matching), non-bipartite matching allows directly matching individuals who are similar on the covariates but experience a different treatment level across multiple possible levels.

Overall, consistent with previous studies, the results have shown that middle-aged and elder Chinese men and women living in more urbanized communities are more likely to have a higher number of metabolic abnormalities and meet the criteria for metabolic syndrome, with a slightly stronger association for men. Moreover, results further stratified by the urban/rural context reveal that the gendered pattern for the association between metabolic syndrome and urbanicity is also urban/rural context-specific: urbanicity is positively associated with metabolic syndrome for urban men but not urban women, while the pattern is reversed in rural areas. This second finding suggests that while past literature has shown that higher chronic disease prevalence is linked with urban context and a higher level of urbanicity in China, it is important to also pay attention to the moderation of the impact of urbanicity by rural/urban context, given the different nature of urbanization across contexts.

Auxiliary analyses provide some clues to why urban men and rural women are more susceptible to the (negative) impact of urbanicity on metabolic syndrome. Vigorous physical activities account for a significant share energy expenditure and indicate the nature of one's occupation regarding the intensity of physical effort in China (Monda et al. 2007). I show that the decline in vigorous physical activities to be more pronounced for rural women and urban men (Table 2.4). Given past studies have shown a robust link between metabolic syndrome with the level of physical activity (Carnethon et al. 2004), this pattern might provide a mechanism through which urbanization imposes more health penalty for urban men and rural women.

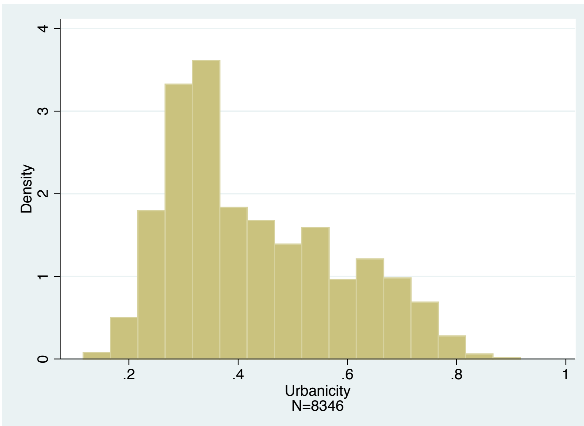
Clearly, the decline in physical activity is not the only factor that can explain the gender difference in the urbanicity effect on metabolic syndrome. A more fundamental factor may relate to the difference in gender roles and values. In rural China, women's roles are concentrated in the household and they spend significantly less time on off-farm work but do more domestic work (Chang, Dong, and MacPhail 2011; Entwisle et al. 1995). If it is the case for the CHARLS sample that rural women tend to spend less time outside the household than rural men, this might help to explain why rural women benefit less from the improvement in public facilities (especially leisure facilities) associated with urbanicity level. On the other hand, studies on overweight/obesity in urban China have argued that there is a preference for thinness due to stigma or health concerns that are more adopted by women than men, especially in a more obesogenic urban environment in modern China (Jones-Smith et al. 2012). Some evidence also suggests that being tall and thin has been the desired body shape for Chinese urban women since the 1970s (Leung, Lam, and Sze 2001). Given the discrepancy in body shape preference and health concerns, women in more urbanized areas with more wealth may be more aware of and feel more pressure to avoid the risk factors of metabolic syndrome that are associated with urbanization.

There are limitations to this study. First, though I excluded people who reported that they did not fast before the blood test, some people who did not strictly follow the 8-hour fast instructions could still be in the analytic sample. If the degree to which respondents followed this instruction is a function of urbanicity, the urbanicity effect may be biased. Second, given CHARLS has only collected community-level data in the baseline wave of the year 2011, I was not able to observe the change of urbanicity and response in the population levels of metabolic syndrome, or apply more robust methods that can eliminate time-invariant confounders for urbanicity at both the community and individual levels. However, the non-bipartite matching approach allowed me to match individuals with similar individual-level characteristics but living in communities with different levels of urbanicity, hence I can best leverage the available information in my data to avoid potential confounders and the extrapolation of regression results. Using a matching method within a counterfactual framework is the first step to examining the causal effect of urbanicity/urbanization on health. Finally, I was unable to fully explore the pathway of dietary shift, given there was no information about the specific diet one followed from the CHARLS survey. For future research, repeated collection of community-level characteristics and dietary information can provide stronger evidence.

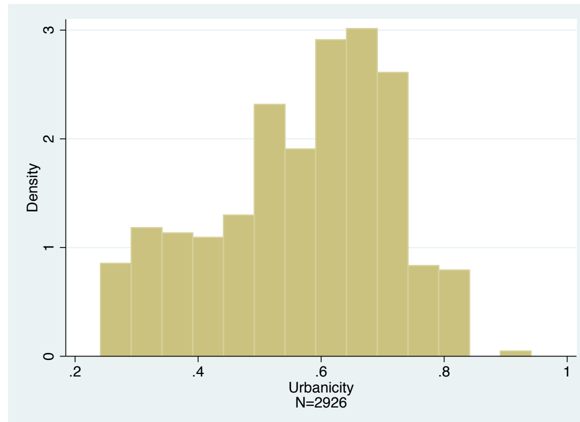
Despite the limitations, this study has shed light on the declining effect of increases in urbanicity level on metabolic syndrome when one moves from the least to more urbanized areas, but only for women, similar to a recent study (Fu and Land 2017) documenting no effect of urbanization on overweight among women and urban residents in China. For men, however, there is a very different story: the association between the level of urbanicity and metabolic syndrome becomes much stronger when shifting from the rural to the urban context. Taken together, these findings may suggest that for China, the nutrition transition may happen at a different pace for women and men, with women leading men in these transition patterns. This raises several interesting questions and directions for future studies. First, future research could empirically examine whether a change toward a healthier diet and more health concerns happens with urbanization, especially for urban women. Second, to generalize the current study to a global perspective, it may be interesting to compare how gender moderates the association between societal development and health outcomes across national contexts with different gendered distinctions.

Figure 2. 1 Distribution of Urbanicity for the Analytic Samples

All sample (a)



Urban subsample (b)



Rural subsample (c)

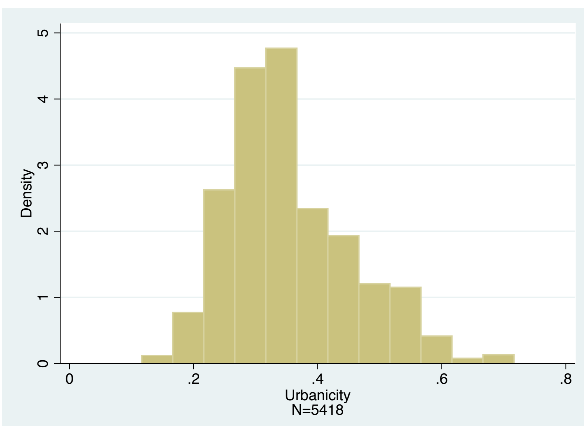


Table 2. 1 Descriptive Statistics for the Study Sample

VARIABLES	Men		Women	
	Mean	SD	Mean	SD
Metabolic abnormalities (count)	2.03	1.43	2.67	1.45
Urbanicity	0.43	0.16	0.43	0.16
Age	60.67	9.37	59.36	9.64
Education				
Illiterate	0.14	0.35	0.44	0.50
Can Read & Write	0.20	0.40	0.18	0.38
Elementary School	0.27	0.44	0.18	0.38
Middle School	0.25	0.43	0.14	0.35
High School & Above	0.13	0.34	0.07	0.25
First *Hukou* Non-Agricultural	0.11	0.31	0.09	0.29
Migrant	0.23	0.42	0.17	0.37
Underage Marriage	0.21	0.41	0.20	0.40
Any Disability	0.21	0.41	0.18	0.38
Upper Arm Length	35.27	2.33	32.64	2.19
Good Health in Childhood	0.76	0.43	0.73	0.44
Years Living in Surveyed Community	50.41	18.43	41.14	16.67
Region				
Northeast	0.10	0.30	0.09	0.28
Northern Coast	0.18	0.38	0.16	0.37
Eastern Coast	0.09	0.29	0.09	0.29
Southern Coast	0.06	0.23	0.06	0.24
Yellow River (Mid. Reach)	0.24	0.43	0.26	0.44
Yangtze River (Mid. Reach)	0.11	0.31	0.13	0.34
Southwest	0.17	0.38	0.16	0.37
Northwest	0.05	0.22	0.05	0.22
Food Expenditure[1]	5.28	1.59	5.23	1.71
Vigorous Activities[2]	8.77	11.66	5.82	10.10
Moderate Activities[3]	10.22	11.06	10.28	10.98
Walking[4]	13.01	9.01	12.49	9.24
N	4026		4664	

Note:

1. N = 3,818 (men), 4,403 (women)
2. N = 1,631 (men), 2,015 (women)
3. N = 1,634 (men), 2,003 (women)
4. N = 1,631 (men), 1,995 (women)

Table 2. 2 Estimated Association Between Metabolic Abnormalities and Urbanicity, Stratified by Gender and Urban/Rural Locations

	Men			Women		
	All	Urban	Rural	All	Urban	Rural
Urbanicity	0.70***	0.50**	0.21	0.34***	0.03	0.50**
	(0.11)	(0.18)	(0.21)	(0.08)	(0.12)	(0.15)
Matched-pair FE	YES	YES	YES	YES	YES	YES
Observations	3,954	1,374	2,566	4,642	1,648	2,954
Number of pairs	1,977	687	1,283	2,321	842	1,477

Note:

a. Robust standard errors are in parentheses; ***p<0.001, **P<0.01, *p<0.05
b. Covariates include age, education, type of first hukou (household registration), migration status, if had underage marriage, any disability, upper arm length, if had good health during childhood, length of residence in the current locale, and region
c. The reduction in sample sizes (from Table 1) is due to the fact that the Poisson model with fixed-effects drops groups with all-zero outcomes

Table 2. 3 Estimated Association Between Food Expenditure and Urbanicity, Stratified by Gender and Urban/Rural Locations

	Men		Women	
	Urban	Rural	Urban	Rural
Urbanicity	1.14**	0.38	1.31**	0.75
	(0.41)	(0.47)	(0.40)	(0.45)
Matched-pair FE	YES	YES	YES	YES
Observations	1,332	2,486	1,613	2,790
Number of pairs	693	1,313	846	1,478

Note:

a. Robust standard errors are in parentheses; ***p<0.001, **P<0.01, *p<0.05
b. Covariates include age, education, type of first hukou (household registration), migration status, if had underage marriage, any disability, upper arm length, if had good health during childhood, length of residence in the current locale, and region

Table 2. 4 Estimated Association Between Physical Activities (Vigorous Activities, Moderate Activities and Walking) and Urbanicity, Stratified by Gender and Urban/Rural Locations

	Vigorous (hour/week)		**Moderate (hour/week)**		**Walking (hour/week)**	
	Urban	Rural	Urban	Rural	Urban	Rural
Men						
Urbanicity	-19.77**	-12.93	4.64	-18.02**	7.49	-9.42
	(5.47)	8.02	(7.74)	(6.45)	(6.08)	(5.73)
Matched-pair FE	YES	YES	YES	YES	YES	YES
Observations	575	1,056	576	1,058	573	1,058
Number of pairs	448	842	449	843	448	842
Women						
Urbanicity	-12.06**	-16.83*	-9.12	-10.21	-2.12	-4.06
	(3.77)	(6.60)	(5.71)	(7.13)	(5.44)	(5.46)
Matched-pair FE	YES	YES	YES	YES	YES	YES
Observations	743	1,272	736	1,267	737	1,258
Number of pairs	576	1,021	572	1,061	573	1,011

Note:

a. Robust standard errors are in parentheses; ***p<0.001, **P<0.01, *p<0.05
b. Covariates include age, education, type of first hukou (household registration), migration status, if had underage marriage, any disability, upper arm length, if had good health during childhood, length of residence in the current locale, and region

Appendix

APPENDIX A. Measurement of Metabolic Syndrome - Cutoff for High-Risk Range

Appendix Table 2. 1 Cutoffs for High-Risk Range (IDF Criteria for Chinese Adults)

Biomarker	*High-risk range*
Blood pressure	>=130 mmHg (systolic) or
	>=85 mmHg (diastolic)
HDL Cholesterol	<40mg/dL (Male)
	<50mg/dL (Female)
Triglycerides	>=150mg/dL
Glucose (Fasting)	>=100mg/dL
Waist Circumference (For Chinese)	>=90cm (Male)
	>=80cm(Female)

Source: International Diabetes Federation Consensus Worldwide Definition of metabolic syndrome (K. Alberti et al. 2006)

APPENDIX B. Components and Sub-Components for Urbanicity Index

Appendix Table 2. 2 List of Components and Sub-Components for Urbanicity Index

Component	Sub-component	Remark	Source
Population Density		city-level population density	China City Statistical Yearbook 2011
Economic Activities	Primary lifetime occupation composition	proportion non-farm work	Aggregated from household survey
	Hukou status composition	proportion non-agricultural *hukou*	Aggregated from household survey
Market	Convenience Store	number and location	V/N respondent
	Farmer's market	number and location	V/N respondent
	Supermarket	number and location	V/N respondent
Transportation	Road	number	V/N respondent
	Bus	number	V/N respondent
	Train	number	V/N respondent
Sanitation	Sewer system	type	V/N respondent
	Waste Management	type	V/N respondent
	Restroom	type	V/N respondent
Housing	Shower	percent	Aggregated from household survey
	Flush water	percent	Aggregated from household survey
	Electricity	percent	Aggregated from household survey
	Gas	percent	Aggregated from household survey
Communication	Post office	availability	V/N respondent
	Library	availability	V/N respondent
	Landline	percent	Aggregated from household survey
	Internet	percent	Aggregated from household survey

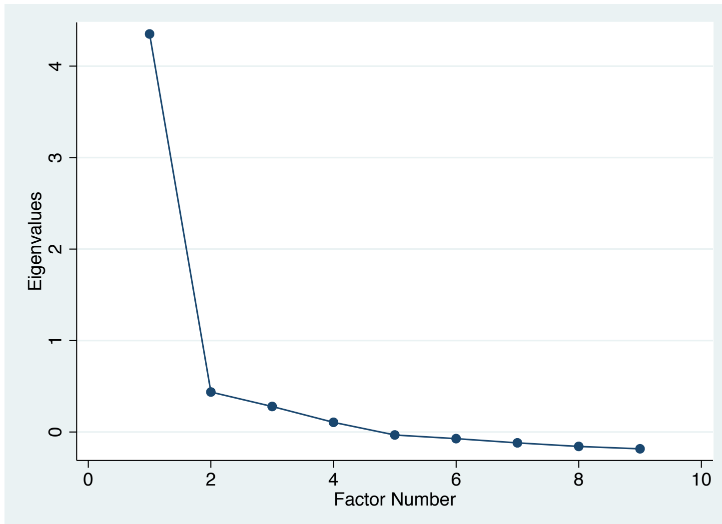
	Computer	percent	Aggregated from household survey
	Cell phone	percent	Aggregated from household survey
Public facilities	Medical	number and type	V/N respondent
	Educational	number and location	V/N respondent
	Cultural and leisure	number and location	V/N respondent
	Other	number and location	V/N respondent
Social service/security	Social service organizations	number and location	V/N respondent
	Kindergarten	number and location	V/N respondent
	Medical insurance	availability and coverage	Aggregated from household survey; V/N respondent
	Pension	coverage	Aggregated from household survey
	Unemployment subsidies	availability	V/N respondent
	Minimum living allowance	availability	V/N respondent
	Subsidy for elders 80+	availability	V/N respondent

Note:

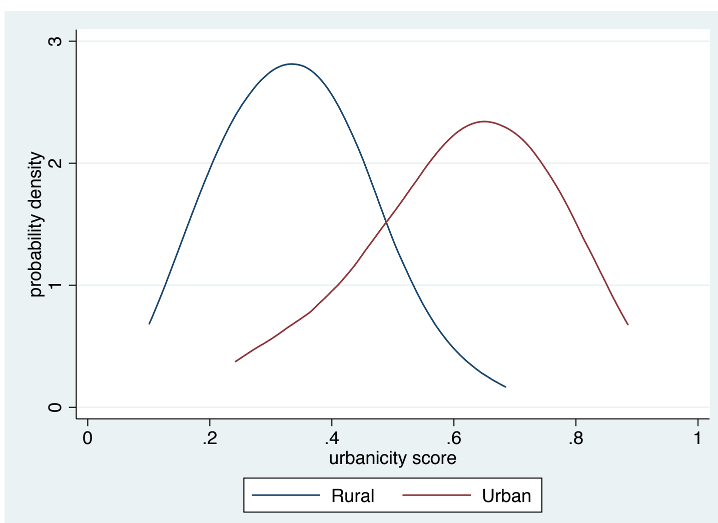
a. V/N = (rural) village/ (urban) neighborhood
b. Compared to the 12-component measurement employed in Jones-Smith and Popkin (2010), I adjusted/excluded a few components, due to the features of the CHARLS data. In particular, I used educational facilities (availability of primary and secondary schools) as a measure of education and combined it into the public facilities component, given that I regarded one of immediate effects of urbanization as the increase of *opportunity* in education rather than the increase of average level of educational achievement, which can be shaped by the joint influence of increase educational opportunity and selectivity in migration. I excluded the diversity component (measuring variance of income and education) given the data limitation of CHARLS sample, since the sample only includes people 45 or older, many of whom are living in rural areas and most of whom do not have any form of monetary income. I also collapsed the *traditional markets* and *modern markets* into a single *market* component given that there are fewer measures of market activities in CHARLS.

APPENDIX C. Checking the Validity of the Urbanicity Measurement

Appendix Figure 2. 1 Scree Plot After Factor Analysis (Principle Factor Model)



Appendix Figure 2. 2 Kernel Density Distribution of Urbanicity by Rural and Urban Locations (National Statistical Bureau Official Classification)



Note: Bandwidth = 0.1

Appendix Table 2. 3 External Validity Check of Urbanicity Index

Urbanicity	Proportion having non-agricultural *hukou*		Average number of children per household	
Quartile 1	0.03	(0.03)	2.88	(0.48)
Quartile 2	0.06	(0.15)	2.91	(0.62)
Quartile 3	0.26	(0.35)	2.60	(0.55)
Quartile 4	0.76	(0.28)	2.07	(0.53)

Note: Standard Deviation in Parenthesis

To evaluate whether the nine urbanicity components can be synthesized as a unidimensional scale, I first conducted an exploratory factor analysis. The scree plot (Fig. 1) revealed that all factors except the first have an eigenvalue considerable smaller than 1. A factor with eigenvalue of 1 indicates that it can account for as much variance as a single variable and is thus worth keeping separate. The plot also flattened after the first factor, both suggesting that all urbanicity components seem to contribute to a single-factor variable. Additionally, I estimated Cronbach's α, an estimate of the shared covariance among the scale components (DeVellis, 2003) and of the internal consistency. The result showed I had good internal consistency given α =0.86 (DeVellis, 2012).

I also examined the validity of my urbanicity scale by comparing it with known dichotomous measurement of urbanicity. More specifically, I compared my scale to the official classification of rural/urban areas from the National Statistical Bureau. As expected, the mean urbanicity is considerably higher in areas classified as urban (0.61) than those classified as rural areas (0.34). However, as shown in Fig. 2, the overlap in distribution reveals the heterogeneity in classified urban/rural areas and the added value of using a continuous urbanicity scale.

Finally, I inspected the construct validity of my urbanicity measure by relating it to other known phenomenon that differed by urbanicity (DeVellis, 2003). More specifically, I computed the proportion of the sample having urban *hukou* (family register) and the average number of children per household by urbanicity quartiles. For the former, I expected a higher proportion of urban *hukou* holders in more urbanized areas as people are more likely to have an urban *hukou* when working in cities and towns or if married to an urban resident; for the latter, it was calculated as the community-averaged number of children (including those not living with their parents) a surveyed family has. Given that China's One-child policy (implemented from 1980-to 2015) only allowed *Han* (which constitute 91.51% of the Chinese population in 2010) in rural areas to have a second child if the first is a girl, I expected a lower number of children per household in highly urbanized areas. The results are shown in Table 2, where both expectations were confirmed.

APPENDIX D. Proofs of the Properties of the Balancing Score

Proof for the balancing property

By first regressing urbanicity (T_i) on observed covariates ($\boldsymbol{X}$) and specifying the balancing score $b(\boldsymbol{X})$ a as linear combination of covariates using estimated coefficients, that is, $b(\boldsymbol{X}) = \beta^T \boldsymbol{x}_i$, one can show that $b(\boldsymbol{X})$ has the properties of balancing covariates, weak unconfoundedness, and bias removal when assuming i.i.d. normal errors for the linear regression model and weak unconfoundedness given covariates (Imbens, 2000). To make these assumptions more reasonable, I used Box-cox transformation on T_i before running the regression. The above-mentioned properties mean that by conditioning on a balancing score one can use the averaged observed outcomes Y at a treatment level $T=t$ as the estimate of the expected potential outcome $Y(T=t)$.

Following Lu et al. (2001), I define a global propensity score by modeling the relationship between $\mathbf{X}$ and T under a linear regression scenario $T = \beta^T \boldsymbol{X} + \varepsilon$, let $b(\boldsymbol{X}) = \beta^T \boldsymbol{X} = \mathrm{E}(T \mid \boldsymbol{X})$. When assuming homoscedasticity and normality, that is, $T \mid \boldsymbol{X} \sim \boldsymbol{N}(b(\boldsymbol{X}),\ \sigma^2)$, I can claim $\boldsymbol{X} \perp T \mid b(\boldsymbol{X})$ or formally $f_{T,X}(T, \boldsymbol{X} \mid b(\boldsymbol{X})) = f_T(T \mid b(\boldsymbol{X}))\, f_X(\boldsymbol{X} \mid b(\boldsymbol{X}))$ by the following arguments: Since generally $f_{T,X}(T, \boldsymbol{X} \mid b(\boldsymbol{X})) = f_T(T \mid \boldsymbol{X}, b(\boldsymbol{X}))\, f_X(\boldsymbol{X} \mid b(\boldsymbol{X}))$, as $b(\boldsymbol{X})$ is a function of $\boldsymbol{X}$, $f_T(T \mid \boldsymbol{X}, b(\boldsymbol{X})) = f_T(T \mid \boldsymbol{X})$, thus I only need to show $f_T(T \mid \boldsymbol{X}) = f_T(T \mid b(\boldsymbol{X}))$, which is obvious due to the fact $T \mid b(\boldsymbol{X}) \sim \boldsymbol{N}(b(\boldsymbol{X}),\ \sigma^2)$.

Proof of the weak unconfoundedness given the balancing score $\boldsymbol{b}\ (\boldsymbol{X})$

Following Hirano and Imbens (2004), I first assume weak unconfoundedness given $\boldsymbol{X}$, that is,

$$Y(t) \perp T \mid \boldsymbol{X}\ for\ all\ t \in \mathcal{T}$$

where $Y(t)$ denotes the potential outcome under the scenario $T=t$.

To prove $Y(t) \perp T|b(\boldsymbol{X})$, I need to show that

$$f_T(t|b(\boldsymbol{X}), Y(t)) = f_T(t|b(\boldsymbol{X})).$$

For the right-hand side of the equation I have

$f_T(t|b(\boldsymbol{X})) = f_T(t|E(t|\boldsymbol{X})) = \frac{1}{\sigma}\phi(\frac{t-b(\mathbf{X})}{\sigma})$ (assuming homoscedastic and normal $T|\boldsymbol{X}$);

for the left side of the equation I have

$$f_T(t|b(\boldsymbol{X}), Y(t)) = \int f_T(t|\boldsymbol{x}, b(\boldsymbol{X}), Y(t))\mathrm{d}F_X(\boldsymbol{x}|Y(t), b(\boldsymbol{X}))$$

By weak unconfoundedness $f_T(t|\boldsymbol{x}, b(\boldsymbol{X}), Y(t)) = f_T(t|\boldsymbol{x})$, so

$$f_T\big(t\big|b(\boldsymbol{X}), Y(t)\big) = \int f_T(t|\boldsymbol{x})\mathrm{d}F_X\big(\boldsymbol{x}\big|Y(t), b(\boldsymbol{X})\big)$$

$$= \int \frac{1}{\sigma}\phi(\frac{t-b(\boldsymbol{x})}{\sigma})\mathrm{d}F_X(\boldsymbol{x}|Y(t), b(\boldsymbol{X})) = \frac{1}{\sigma}\phi(\frac{t-b(\boldsymbol{X})}{\sigma})$$

Proof for the bias removal property

Again, assuming homoscedastic and normal $T|\boldsymbol{X}$, and weak unconfoundedness given $\boldsymbol{X}$, I can further show that $b(\boldsymbol{X})$ is useful to eliminate biases associated with differences in covariates by estimating the conditional expectation of the outcome, that is,

$$E[Y(t)|b(\boldsymbol{X})] = E[Y(t)|T = t, b(\boldsymbol{X})]$$

Here by applying the Bayes rule and the fact that $f_T(t|b(\boldsymbol{X}), Y(t)) = f_T(t|b(\boldsymbol{X}))$, I have

$$f_{Y(t)}(y|t, b(\boldsymbol{X})) = \frac{f_T(t|y, b(\boldsymbol{X}))f_{Y(t)}(y|b(\boldsymbol{X}))}{f_T(t|b(\boldsymbol{X}))} = f_{Y(t)}(y|b(\boldsymbol{X}))$$

Hence, $E[Y(t)|b(\boldsymbol{X})] = E[Y(t)|T = t, b(\boldsymbol{X})]$

APPENDIX E. Covariate Balance Check of Matched Sample

Appendix Table 2. 4 Comparison of Difference in Urbanicity and Covariate Balance Check

	Male: Full Sample			Female: Full Sample			Male: Rural Sample		
	high	low	ASD	high	low	ASD	high	low	ASD
Urbanicity	0.517	0.339	1.366	0.523	0.344	1.379	0.410	0.295	1.383
Age	60.651	60.681	0.003	59.357	59.371	0.001	60.911	60.903	0.001
EDUCATION									
Illiterate (Ref.)	0.135	0.144	0.024	0.424	0.449	0.050	0.168	0.185	0.043
Can Read & Write	0.198	0.206	0.020	0.180	0.175	0.012	0.219	0.220	0.002
Elementary School	0.282	0.261	0.048	0.178	0.173	0.012	0.301	0.269	0.072
Middle School	0.248	0.258	0.024	0.147	0.141	0.018	0.221	0.237	0.038
High School & Above	0.136	0.131	0.015	0.071	0.062	0.036	0.090	0.090	0.003
First *Hukou* Non-agricultural	0.111	0.100	0.037	0.094	0.086	0.027	0.015	0.014	0.013
Migrant	0.230	0.233	0.008	0.160	0.175	0.041	0.185	0.190	0.012
Underage Marriage	0.201	0.221	0.050	0.208	0.201	0.019	0.228	0.235	0.016
Any Disability	0.201	0.219	0.043	0.170	0.184	0.036	0.239	0.228	0.027
Upper Arm Length	35.285	35.258	0.011	32.681	32.609	0.033	35.256	35.259	0.001
Good Health in Childhood	0.761	0.755	0.014	0.742	0.726	0.036	0.742	0.741	0.003
Years Living in Surveyed Community	50.204	50.619	0.022	41.152	41.121	0.002	54.058	53.846	0.013
REGION									
Northeast (Ref.)	0.102	0.091	0.037	0.093	0.082	0.041	0.131	0.125	0.020
Northern Coast	0.181	0.169	0.030	0.165	0.161	0.010	0.197	0.200	0.008
Eastern Coast	0.086	0.100	0.048	0.089	0.096	0.025	0.099	0.095	0.013
Southern Coast	0.062	0.055	0.028	0.060	0.058	0.005	0.030	0.034	0.026
Yellow River(Mid. Reach)	0.243	0.237	0.013	0.256	0.256	0.001	0.236	0.229	0.018

Yangtze River(Mid. Reach)	0.109	0.113	0.013	0.130	0.129	0.005	0.074	0.090	0.058
Southwest	0.169	0.180	0.029	0.162	0.165	0.008	0.175	0.172	0.010
Northwest	0.049	0.054	0.025	0.046	0.054	0.036	0.058	0.056	0.007
Obs.		4,664			4,026			2,634	

	Male: Urban Sample			Female: Rural Sample			Female: Urban Sample		
	high	low	ASD	high	low	ASD	high	low	ASD
Urbanicity	0.657	0.484	1.487	0.413	0.297	1.431	0.660	0.483	1.522
Age	60.240	60.171	0.007	59.429	59.409	0.002	59.254	59.203	0.005
EDUCATION									
Illiterate (Ref.)	0.069	0.071	0.006	0.524	0.522	0.003	0.293	0.276	0.038
Can Read & Write	0.169	0.170	0.002	0.185	0.184	0.001	0.164	0.166	0.006
Elementary School	0.245	0.246	0.003	0.160	0.167	0.019	0.187	0.209	0.055
Middle School	0.288	0.311	0.050	0.104	0.104	0.000	0.218	0.210	0.020
High School & Above	0.229	0.203	0.064	0.028	0.023	0.032	0.137	0.138	0.003
First *Hukou* Non-agricultural	0.291	0.265	0.058	0.006	0.006	0.007	0.255	0.219	0.085
Migrant	0.318	0.308	0.021	0.127	0.133	0.018	0.242	0.222	0.048
Underage Marriage	0.160	0.184	0.065	0.232	0.238	0.014	0.138	0.164	0.073
Any disability	0.158	0.171	0.035	0.192	0.198	0.015	0.142	0.148	0.017
Upper Arm Length	35.360	35.234	0.054	32.472	32.593	0.056	32.829	32.852	0.010
Good Health in Childhood	0.796	0.782	0.036	0.715	0.696	0.043	0.783	0.787	0.010
Years Living in Surveyed Community	43.376	44.124	0.037	43.577	43.522	0.004	36.430	37.352	0.051
REGION									
Northeast (Ref.)	0.035	0.039	0.023	0.121	0.113	0.025	0.035	0.039	0.019
Northern Coast	0.134	0.127	0.021	0.179	0.192	0.035	0.110	0.137	0.083
Eastern Coast	0.083	0.088	0.015	0.098	0.098	0.002	0.090	0.076	0.051
Southern Coast	0.111	0.105	0.019	0.034	0.038	0.018	0.110	0.089	0.071
Yellow River(Mid. Reach)	0.260	0.250	0.023	0.253	0.238	0.034	0.280	0.269	0.024
Yangtze River(Mid. Reach)	0.161	0.171	0.027	0.094	0.102	0.027	0.191	0.178	0.033

Southwest	0.167	0.187	0.053	0.162	0.162	0.002	0.146	0.184	0.102
Northwest	0.049	0.033	0.080	0.060	0.058	0.009	0.038	0.028	0.053
Obs.		1,390			2,968			1,694	

Note: ASD = absolute standardized difference; it is defined as $|\bar{x}_{treatment} - \bar{x}_{control}|/\sqrt{(s^2_{treatment} + s^2_{control})/2}$ for continuous variables and $|\hat{p}_{treatment} - \hat{p}_{control}|/\sqrt{(\hat{p}_{treatment}(1 - \hat{p}_{treatment}) + \hat{p}_{control}(1 - \hat{p}_{control}))/2}$ for dichotomous variables

APPENDIX F. Robustness Check with Varying Years of Residence

Appendix Table 2. 5 Estimated Association Between Metabolic Abnormalities and Urbanicity With Varying Years of Residence in the Surveyed Community

	All		Urban		Rural	
	(1)	(2)	(3)	(4)	(5)	(6)
Men						
5-year	0.679***	0.701***	0.509***	0.497**	0.171	0.212
N	4,026	3.954	1,390	1,374	2,625	2,548
10-year	0.688***	0.708***	0.532***	0.453*	0.150	0.164
N	3,887	3,692	1,297	1,216	2,577	2,454
15-year	0.673***	0.682***	0.545***	0.417*	0.142	0.174
N	3,743	3,452	1,211	1,098	2,523	2,358
20-year	0.694***	0.705***	0.622***	0.360	0.137	0.236
N	3,635	3,272	1,147	1,008	2,477	2,280
Women						
5-year	0.375***	0.343***	0.143	0.032	0.332**	0.496**
N	4,664	4,642	1,694	1,684	2,961	2,940
10-year	0.394***	0.369***	0.145	0.053	0.322**	0.520**
N	4,530	4,382	1,590	1,486	2,932	2,884
15-year	0.392***	0.375***	0.172	0.062	0.330**	0.547***
N	4,390	4,138	1,479	1,304	2,907	2,836
20-year	0.418***	0.444***	0.222*	0.109	0.324**	0.552***
N	4,271	3,930	1,363	1,146	2,862	2,750
Match-pair FE		YES		YES		YES
Covariates	YES	YES	YES	YES	YES	YES

APPENDIX G. Robustness Check with Dichotomized Metabolic Syndrome

Appendix Table 2. 6 Estimated Association Between Diagnosable Metabolic Syndrome and Urbanicity, Stratified by Gender and Urban/Rural Locations

	Men			Women		
	All	Urban	Rural	All	Urban	Rural
Urbanicity	2.405***	1.662*	1.440	1.267***	-0.303	1.969***
	(0.395)	(0.673)	(0.767)	(0.304)	(0.584)	(0.567)
Matched-pair FE	YES	YES	YES	YES	YES	YES
Observations	1,488	624	784	2,306	774	1,442
Number of pairs	744	312	392	1,153	387	721

Note:

a. Robust standard errors are in parentheses; ***p<0.001, **P<0.01, *p<0.05
b. Covariates include age, education, type of first hukou (household registration), migration status, if had underage marriage, any disability, upper arm length, if had good health during childhood, length of residence in the current locale, and region
c. The reduction in sample sizes (from Table 2.1) is due to the fact that the conditional Logit model drops groups with all positive or all negative outcomes

CHAPTER 3: Urban Living and Physical Functioning Among Mid-Aged and Older Adults in China

Introduction

Urbanization and population aging are the two most notable ongoing demographic changes in low and middle-income countries (LMICs) today. In these countries, the share of urban dwellers in LMICs has risen from 25% to 45% between 1970 and 2010 and is expected to rise to 70% by 2050. Concurrent with this trend, an increasing proportion of older adults will be living in urban areas: by 2050, more than 70% of the population over age 60 will be living in cities (Beard and Petitot 2010). Among all health burdens of population aging faced by these countries, functional impairments in older life remain one immense challenge for public health, financial, and governance effort. Past studies have shown that functioning is highly predictive of the need for long-term care and mortality independently of diseases (Fried et al. 1998; Gildner et al. 2019; Stuck et al. 1999), and rates of functional impairments are higher among older age in LMICs than in high-income countries (Chatterji et al. 2015). Hence, it is crucial to understand how urbanization plays a role in functioning among older adults to prepare for future public health challenges.

Studies that seek to understand the impact of urbanization on health broadly have suggested that urban living brings health risks, including the spread of Western-style diets (Popkin 1999), sedentary lifestyle (Monda et al. 2007), and environmental hazards (J. Chen, Chen, and Landry 2013). These coinciding patterns have led some to propose an "urban penalty" on physical health. Specifically, past studies have documented the adverse impact of urban living on diabetes, overweight/obesity, high blood pressure, and chronic inflammation, especially among mid-aged and older adults (Allender et al. 2010, 2011; Chen et al. 2014; Miao and Wu 2016; Van de Poel, O'Donnell, and Van Doorslaer 2009, 2012). While these accounts may be true, a smaller set of studies have shown that urban living's health benefits outweigh the health risk for physical functioning. In the context of LMICs, urbanization can lead to an increase in income and expenditure, improved housing conditions, and easier access to healthcare services with higher quality. These factors have been repeatedly shown to associate with slowing the process of onset of increase in functional impairments, as measured by frailty and activities of daily living (ADLs) (Baker et al. 2001; Fänge and Iwarsson 2005; Gobbens et al. 2010; Woo et al. 2005). It is thus still an open empirical question of how urban life affects physical functioning.

The present study attempts to address the question by focusing on China, a country experiencing rapid urbanization in recent decades. Since the "Open-Door" reform in 1978, the percentage of China's urban population has surged from 18% to 59% in 2018 (National Bureau of Statistics 2019). Coupled with the rapid increase in urban population, China has seen a dramatic rise in inequality in living standards along the gradient of urbanicity and associated consequences for health disparities. For instance, the percentage of households using biomass and coal (the leading cause of air pollution in China and a vital risk factor for pulmonary and cardiovascular diseases) as the primary fuel is 8.2%, 36.1%, and 75.8% in cities, towns (*Zhen*) and rural villages, respectively (China's 2010 Census). Thus, the monotonic trend in urbanization and resulting social and economic disparities make China an ideal setting to study the impact of exposure to urban living on health.

There are two objectives in the study. First, the study examines the association between physical functioning and level of exposure to urbanicity using a nationally representative sample of mid-aged and older adults in China. Precisely, I measure physical functioning with indices of ADL difficulties and frailty and urbanicity with a validated urbanicity index. Next, guided by known risk factors for functional impairments, I examine pathways that may mediate the link between urbanicity and physical functioning.

Possible Pathways Linking Urban Living to Physical Functioning

Existing theories and prior research provide four pathways linking urban living with physical functioning. First, as a society urbanizes, urban dwellers tend to be wealthier and enjoy improved living standards. Past literature has documented the association between better physical functioning and more income, enough expenditures, and better housing quality (Fänge and Iwarsson 2005; Woo et al. 2005). It is particularly true for LMICs since formal social security systems have limited coverage and low benefit payments. Specifically, enough expenditures can prevent malnutrition, a key determinant of frailty (Goisser, S. Guyonnet, and Volkert 2016). Moreover, studies have found connections between measures of self-report housing quality, heating, indoor temperature, and air pollution, and frailty and morbidity (e.g., Gibson et al. 2011).

Second, urban dwellers tend to have better access to healthcare of higher quality in LMICs. It is particularly true for China's case, given the history of the policy-induced rural-urban gap in the healthcare system. Studies on China have indicated a vast inequality in distributing high-quality healthcare facilities favoring more urbanized areas (Evandrou et al. 2014; Jiang et al. 2013). Moreover, despite considerable parity in health insurance coverage among urban and rural areas, urban dwellers, especially older persons, tend to enjoy the benefit of enrolling in health insurance programs specifically designed for urban residents and employees (including those retired). These insurance types tend to offer more generous benefit packages, and research has found that persons with these types of insurance are more likely to utilize health care (Li and Zhang 2013). Health care advantages may significantly benefit older adults' physical functioning as their need for health care to maintain functioning is higher than that of younger people.

Third, past studies have suggested strong associations between social networks, social support, and social participation with physical functioning (Gobbens et al. 2010; James et al. 2011; Seeman, Bruce, and McAvay 1996; Woo et al. 2005). In many urbanizing societies, younger members of rural households may choose to migrate to cities for seasonal jobs, leaving household members staying in rural areas (who are usually older persons) less supported in their daily life (Evandrou et al. 2017). Additionally, since rural residents are less likely to depend on pensions for older life and thus have to work until very old age, they tend to have less time participating in leisure activities (Liu et al. 2019) Taken as a whole, the lack of "socialness" in rural areas may provide pathway linking urban living with better physical functioning.

While the first three pathways described above suggest the benefits of urban living, urbanization can also be detrimental to physical functioning. Many health risks are associated with lifestyle changes toward increasing intakes of fat, sugar and processed food and jobs with substantially declined physical activities, especially for older adults. For instance, inactivity in later life is a crucial cause for sarcopenia and can lead to a series of physical frailties and disabilities (Fried et al. 2001). Chronic disease onset, such as diabetes triggered by overnutrition and sedentary lifestyles, can also lead to a faster decline in physical functioning in old age. For China, past studies have shown the connection between urbanization and these lifestyle changes (Popkin 2014).

Physical function impairment has become a critical public health challenge as China's population aging accelerates (Sun et al. 2009). Taken together, identifying the association of urbanicity with physical functioning and the underlying mechanisms can inform public health policymaking of *where* and *how* to intervene. Ultimately, it would reduce regional health inequalities (a by-product of China's uneven socioeconomic development) among older adults.

Method

Data

Data for the main analysis of this study were derived from the first (2011) and third (2015) waves of the China Health and Retirement Longitudinal Study (CHARLS). The baseline sample in the first wave was obtained based on multistage probability sampling. First stratified by region (province) and sorted by urban/rural classification, population size, and GDP per capita, 150 county-level units were randomly selected. Then within each county, the survey applied PPS (proportional to size) sampling to choose three urban neighborhoods/rural villages (referred to as "communities" in the protocol and the current study hereafter). Finally, within each community, 80 households were randomly selected, and for each household, a member aged 45 or older was picked as the primary respondent. The surveyor also interviewed the main respondent's spouse if possible. Overall, the survey interviewed 17,708 individuals, among whom 13,974 participated in the physical collection of non-blood biomarkers, respectively. Four years later, 14,576 persons from the baseline sample were successfully re-interviewed, among whom 11,742 again agreed to participate in the biomarkers collection. Overall, respondents who were too frail or not at home (mostly due to working or traveling) tend to be non-participants. As result, the biomarker sample contained fewer older women and younger men (Zhao et al. 2013)[1].

The study included anyone with valid responses on all the required variables for constructing the physical functioning outcomes - ADL difficulties (ADL hereafter) and Frailty Index (FI hereafter) in the 2011 and 2015 surveys. The sample sizes corresponding to the two health outcomes were 13,846 (ADL) and 8,261 (FI)[2]. I then multiply (n = 5) imputed for the missing values and only used observations that have non-missing information for building either of the outcome variables, as below mentioned.

Variable

Physical Functioning

The present study used two variables to measure physical functioning: ADL and FI. ADL was captured by the number of difficulties among the following daily activities: bathing, eating, getting in and out of bed, dressing, toileting, and maintaining bladder and bowel control. FI was

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[1] This selectivity can be adjusted by applying the non-response-adjusted biomarker sample weight, as provided in the CHARLS data. See more in the method section.
[2] See Appendix A for descriptive statistics for the study sample.

constructed based on a synthesis of two validated scales widely used in the literature - the Fried Index (Fried et al. 2001) and the Tilberg Index (Gobbens, Schols, and van Assen 2017). The choice for combining the two scales lied in the practical concern that the CHARLS survey instrument has partial overlap with both frailty indices. The final list of components used in the study included difficulty in maintaining balance, exhaustion, difficulty in walking, poor hearing, and poor vision[3]. For one component that was measured numerically – difficulty in maintaining balance, I coded the "weakest" 20% in the baseline (2011) sample as the frail phenotype (=1), and otherwise 0, following the lead of Fried et al. (2001). The same cutoff for determining the frail phenotype was then used for the 2015 survey. The components were added up to create a score indicating the number of frail phenotypes observed or reported.

Using the same FI and ADL measurement for the two waves of CHARLS (2011 and 2015), I created two outcome variables to reflect the change in physical functioning during the four years. I treated both variables as continuous for straightforward interpretations of further mediation analysis, where a positive value indicated a decline in physical functions (i.e., an increase in ADL or FI).

Urban living

[3] I did not include the component "lack of strength in the hands" that has been used in both Fried and Tilberg Index, despite its availability in CHARLS. The study of the two waves that was 4 year apart revealed a dramatic decline in grip strength (16% vs. 40%) compared to the literature, leading to concerns of survey fatigue (i.e., having known it was a relatively demanding task, the respondents chose not to do their best in the following wave).

Several measures have been proposed to assess "urban-ness" in China, including urban status defined by China's Census Bureau, urban status for administrative purposes, individual-based *hukou* (household registration) status, urbanicity based on night-time light data, and multi-component-based urbanicity index. Here, I elected to use the multi-component-based urbanicity index method, given that it is the only measurement that can capture the multi-dimensional nature of urban living (Cyril et al. 2013). Another merit of this method is that by using continuous measurement, one can make within urban area (or within rural area) comparisons and examine the potential nonlinear relationship between urbanicity and health (Champion and Hugo 2004; Montgomery and Ezeh 2005).

Specifically, drawing on an *Urbanicity Index* applied by Jones-Smith and Popkin (2010), a high-quality scale for measuring neighborhood-level urbanicity in China, I created a similar measure for the CHARLS sample. The measure was based on nine components: two components on demographic characteristics - population density and proportion of the non-agricultural population; and seven on urban infrastructures and social institutions including market, transportation, sanitation, housing, communication, public facilities, and social service/security, with each component scoring between 0-10. The components were added up and rescaled to 0-10.

Pathway

Four sets of mediating variables were created to assess the explanatory power of the pathways proposed above. First, I used logged yearly per-capita *expenditure* to gauge the flow of economic resources available to the respondent for the pathway of economic resources. Past studies have demonstrated that expenditure is a more reliable measure for low-income and rural settings compared to income, given the significant fluctuation of income from year to year (Deaton 1997). Furthermore, I chose *housing quality* over monetary wealth for measuring the stock of economic resources. Housing quality is a widely-used proxy for wealth in developing countries, for it is less subject to measurement error than monetary measures (Bollen, Glanville, and Stecklov 2002). Inspired by prior research, this study measured housing quality by scoring over 22 items, including the house's material and structure and the ownership of essential home appliances.

To assess the accessibility and quality of healthcare resources, I constructed a composite score at community-level, based on 1) the number and type of health facilities located in the local community and 2) the type and distance of the health facilities visited by residents of the community one year before the survey. This scoring method is similar to the method used by Jones-Smith and Popkin (2010). Another proxy of health care accessibility and quality was health insurance. Specifically, each respondent was classified into the following four categories by their health insurance status: urban employee, urban resident, new rural cooperative medical scheme (NCMS), or not insured. The categories were ordered descendingly here according to each insurance category's service coverage and differential benefits.

Three variables were employed to measure social network/support and participation, following a few studies measuring these concepts using CHARLS (e.g., Li et al. 2016; Zhang 2017). First, *living with spouse* indicated if the respondent is married and living with one's spouse. Next, *living with child* showed if the respondent was living with at least one child. Third, *weekly contact with child*, measured if the respondent had weekly contact with at least one child who was not living with the respondent, either physically or by phone/email. Finally, *social participation* was measured by the total frequencies of participating in the following activities: interaction with friends, playing Ma-jong, chess, cards, providing help to friends and families not living together, and engagements in sports, social or other kinds of clubs during the month before the survey.

To assess *physical activity*, I used a validated method to convert self-reported engagements in vigorous, moderate, and light activities into energy consumption in Kcals (Centers for Disease Control and Prevention (CDC) 1999). Then, a score of *physical activity* was created by summing the calories burned from all activities during the week before the survey. Only half of the CHARLS sample was asked about their daily occupational and leisure physical activities by design. The analysis of physical activity hence was not directly comparable to other pathways discussed above.

Covariate

Gender, age, and age squared were entered as covariates for all models. Specifically, as internal migrants in China tend to represent a positively selected group of individuals on health (Lu and Qin 2014), all models also controlled for an indicator for migrant status based on migration history and *hukou* status. I further controlled for the number of chronic diseases and self-assessed health. Additionally, at the community level, controls were included for terrain and geographic region, given they are important determinants of the urbanization process and population health. All variables, except for the outcome variables, were measured at the baseline (2011) to limit potential reverse causality.

Analytic Approach

I first employed generalized estimating equations (GEE) adjusting for clustering in communities to examine the association between urbanicity and ADL/FI. Given the direction of the association, I then added corresponding pathways to the model to assess how each proposed pathway mediated the association. Since this approach relies on the hard-to-test ignorability (i.e., unconfounded treatment) assumption, all results below should be interpreted as associational. To account for sample attrition due to migration, death, and partial non-response, I created an inverse probability weight (IPW), based on a logistic regression of having valid information concerning either FI or ADL in 2011 and 2015 on socio-demographic characteristics and health statuses measured in 2011. The analytic weights were the product of the attrition IPWs and non-response adjusted weight at the baseline. Finally, to examine the degree to which sample attrition due to death may bias my results, I ran a separate analysis for respondents who had died by 2013[4] and had valid information about their ADL and FI components before death (made available by their families).

Result

[4] Ideally, I would use the same information collected in 2015 but it was not available.

Table 3.1 presents the change in ADL and FI from 2011 to 2015 (i.e., from baseline to the more recent wave of CHARLS released). Overall, respondents to both waves of the survey averaged 0.16 points increase in ADL. Breaking down by individual components, all six ADL components contributed almost equally to the change in ADL. FI, surprisingly, saw an 0.013 decrease over the four years. Specifically, the data showed a slight decrease in the proportion of respondents in the frail phenotype for components including maintaining balance, exhaustion, and vision. Given the consistency in the measurement, this might imply improved living standards and healthcare, given China's rapid economic growth during the period. For instance, reflooring the house might lead to a flatter floor that was advantageous for achieving a high score on the balance test, and better access to treatment for eye diseases may benefit vision. Overall, Figure 3.1 shows that compared to ΔADL (derived from 6-component ADL), ΔFI (derived from 5-component FI) had a slightly higher variance, suggesting more diversity in the frailty trajectory.

[Table 3.1 and Figure 3.1 about here]

Table 3.2 and 3.3 present the results on the association between urbanicity and ΔADL and ΔFI, respectively. I employed a few different specifications of urbanicity, including linear and quadratic form and categories by quantile. All results were consistent with treating the relationship between urbanicity and physical functions as linear, as presented[5]. Specifically,

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[5] I also conducted the same set of analyses stratifying by gender despite of no "theoretical" reason for doing so. Results were not shown given very little gender difference found.

model 1 shows that urban living was associated with less decline of physical functions: one S.D. (1.7 units) increase in urbanicity was linked with less increase in ADL and FI from the baseline by 0.038 (0.3 S.D.) and 0.08 (0.07 S.D.), respectively. Next, a few potential confounders/mediators - education and health statuses at the baseline were added to the models (model 2). Not surprisingly, less education, more chronic diseases, and poorer self-assessed health were related to more physical function decline. Adding these variables accounted for 53% and 28% of the "urban advantage" on ADL and FI from model 1. Notably, for both specifications, initial worse physical function was linked to less decline in the next four years, in part reflecting the nature of using bounded scales.

[Table 3.2 and Table 3.3 about here]

Model 3 introduces measures of economic resources. I found that housing quality was significantly associated with less decline of physical functions: with each S.D. (4.4 units) increase in housing quality, ΔADL and ΔFI were expected to reduce by 0.048 (0.04 S.D.) and 0.083 (0.07 S.D.). Logged yearly expenditure was also associated with less decline of functioning but only marginally significant in FI's model. Taken together, adding the pathway of economic resource more than halved the coefficients of urbanicity, compared to model 2. The association was no longer significant for the model of ADL.

Model 4 added the pathway of health care accessibility and quality to model 3. The results were as expected for the FI model. Specifically, based on the direction and magnitude of the coefficients, I found having public insurance with more benefits, having private insurance, and living close to high-quality health infrastructure were all associated with less increase in FI. Adding these variables had the coefficient of urbanicity further declined and became not statistically significant. However, the results from the ADL model did not confirm my expectation. Specifically, having public insurance with more benefits (urban resident vs. NCMS) and access to quality care was positively associated with an increase in ADL index, leading to a slight increase in the magnitude of the coefficient of urbanicity compared to model 4. The difference between ADL and FI on model 5 might suggest the varying degree to which the selection on death biased the healthcare/urbanicity effect on physical functioning. Specifically, deceased respondents living in urban areas might have more ADL difficulties before death thanks to the urban advantage in healthcare quality (e.g., life-prolonging treatments).

Finally, model 5 incorporated social network/support and social participation. Contrary to the earlier expectation, most social network/support and participation measures were associated with more functional decline, or had coefficients close to zero. I repeated the analysis by examining these associations individually (i.e., leaving out other social network/support variables) and obtained similar results. The result might indicate that some respondents' health might have declined before the baseline and thus required/received more social support from their family and friends [6].

Table 3.4 provided auxiliary analysis on how sample attrition due to death might have biased my results. Interestingly, I found the association of urbanicity positive with ADL and mixed for FI components. Specifically, urbanicity had a positive association with fatigue yet a

[6] Since the models suggested urbanicity provided benefit rather than harm to physical functioning, the pathway of physical inactivity was not examined.

negative association with weight loss among decreased respondents in the 2013 survey. Overall, the results agreed with my speculations, suggesting that by ignoring sample attrition due to death, it might be more likely to overestimate the urban benefit regarding ADL than FI for the CHARLS data.

[Table 3.4 about here]

Discussion

While past studies have mainly focused on the impact of urbanization on diseases and conditions in LMICs, the present study is among the first to study the association between exposure to urban living and the functional aspect of health. Using CHARLS, a longitudinal and nationally representative sample of Chinese mid-aged and older adults, I showed that urbanicity was associated with a more moderate increase of ADL difficulties and frailty phenotypes. I also found that individual-level economic resources, specifically housing quality, was the most crucial pathway for the association.

The current study was not the only one that has documented a strong association between housing quality and health in China. For instance, based on CHARLS, Li et al. (2016) show that household assets are the most critical determinant of mental health and mediator for the rural-urban disparity. Wang et al. (2019) demonstrate the link between housing space, condition, facility, and physical functioning, employing another representative sample of the Chinese population. Like my analysis, both studies find that housing quality is more predictive of physical functioning than income (or proxy of income). Then why does housing quality matter? The answer might be two-fold. First, multiple health risk factors linking housing characteristics to health have been revealed by past literature, including crowding, lack of heating and cooling, dampness, indoor air pollution, pest/rodent infestation, among others (Collins 1986; Donald 2009; Fang et al. 2019; Fänge and Iwarsson 2005). Given that older persons spend more time at home, these risk factors can be more influential to their health functioning. Second, in LMICs, housing quality is a good proxy for wealth and income. Generally, errors of estimating market value based wealth and income can be substantial in poor settings of these countries, since many households are primary consumers of their own products and make few purchases from the market (Bollen, Glanville, and Stecklov 2002). In my case, given the almost linear and robust association between housing quality and urbanicity, it is not surprising that housing quality alone accounts for a significant proportion of the association of urbanicity with physical functioning.

Finding regarding the roles of health care access appeared to be mixed. Adding health care to the model reduced the magnitude of the coefficient for urbanicity to not statistically significant in the model of frailty but not ADL difficulty. This result might be attributed to the fact that ADL difficulty is a more severe form of functional impairment than frailty and thus more sensitive to selective mortality. In urban settings with better healthcare resources (esp. with life-prolonging treatments), one may experience more ADL difficulties before death; this hidden healthcare/urbanicity -ADL association could not be captured by conditioning on respondents surviving to the "next" survey. Similarly, the unexpected health benefit of not living with one's children might be due to a selection effect from living arrangements and support networks. Older persons may choose to live with their children and demand more social support when experiencing significant health decline, which was not captured in the baseline survey.

There are a few limitations to the present study. First, while focusing on the change instead of the onset of function impairment helps to mitigate the possibility of reverse causality, the one-time measure of urban living can still be confounded by unobserved individual characteristics that sort people into more urbanized places. The finding, hence, should be interpreted as associations rather than causal. Second, as mentioned, despite the multiple controls of health status at baseline, it is unsure to what extent the behavioral pathways (e.g., having private insurance, living with children) reflect short-term health needs rather than long-term life choices unrelated to health reasons. It calls for more information on *why* the respondents behaved in such a way and repeated measurements. Finally, given deceased urban and rural respondents may have varying levels of physical functioning before death, the results presented above were generalizable only to persons alive.

Overall, this study has suggested the health benefit of urban living regarding physical functioning using nationally representative data. While most prior studies tested the "urban health penalty" proposition for chronic disease/condition outcomes, the present study's findings can inform policymakers in China to focus on the functional aspect of health and the functionally impaired rural population. Specifically, as shown, programs that help improve economic well-being (esp. improve the housing quality in the least urbanized areas) can be a key to slowing the decline of physical function in later life and help more age successfully.

Figure 3. 1 Distribution of Change in ADL Difficulties and FI (2011-2015)

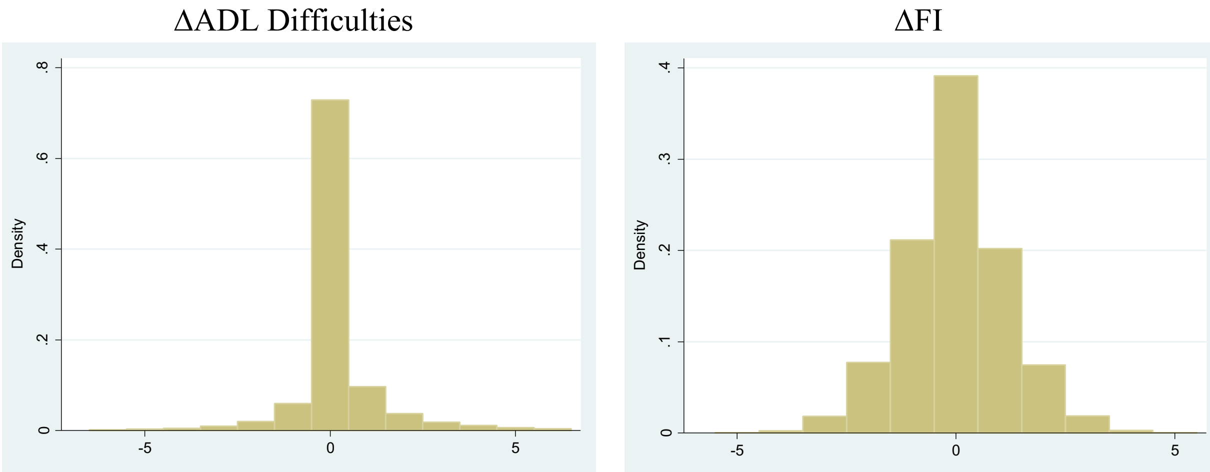

Table 3. 1 Change in Frailty and ADL Components (2011-2015)

ADL	2011	2015
Difficulty with Dressing	0.045	0.070
Difficulty with Bathing or Showering	0.057	0.089
Difficulty with Eating	0.024	0.031
Difficulty with Getting into or out of Bed	0.048	0.082
Difficulty with Using the Toilet	0.109	0.153
Difficulty with Controlling Urination and Defecation	0.038	0.052
ADL Difficulties	0.321	0.479
N	13,846	
FRAILTY	2011	2015
Difficulty in Maintaining Balance	0.188	0.163
Exhaustion	0.353	0.317
Difficulty in Walking	0.096	0.155
Poor Hearing	0.126	0.131
Poor Vision	0.345	0.328
Frailty Index	1.108	1.095
N	8,261	

Table 3. 2 Regression of Change in ADL Difficulties (2011-2015) on Urbanicity and Hypothesized Pathways

	(1)		(2)		(3)		(4)		(5)	
	coeff.	se	coeff.	se	coeff.	se	coeff.	se	coeff.	se
Urbanicity	-0.038***	0.008	-0.018*	0.009	-0.001	0.012	-0.005	0.012	-0.004	0.012
Female	0.089***	0.020	0.035	0.021	0.039+	0.021	0.037+	0.022	0.041+	0.022
Age	-0.020	0.016	-0.038*	0.015	-0.039*	0.015	-0.038*	0.015	-0.036*	0.016
Age^2	0.000*	0.000	0.000***	0.000	0.000***	0.000	0.000***	0.000	0.000**	0.000
ADL in 2011	-0.577***	0.026	-0.625***	0.025	-0.625***	0.026	-0.625***	0.025	-0.626***	0.025
Any Chronic Condition			0.064**	0.021	0.066**	0.021	0.067**	0.021	0.067**	0.021
Self-rated Poor Health			0.336***	0.032	0.328***	0.032	0.327***	0.032	0.325***	0.032
Migrant Status (ref: Non-migrant)										
Rural-Urban Migrant			0.031	0.067	0.039	0.067	0.039	0.067	0.039	0.066
Other Migrant			-0.059	0.043	-0.052	0.043	-0.053	0.044	-0.051	0.044
Education (ref: No Education)										
Part Elementary			-0.051	0.038	-0.045	0.038	-0.045	0.038	-0.045	0.038
Elementary			-0.068+	0.040	-0.060	0.040	-0.058	0.040	-0.056	0.040
Middle School			-0.147***	0.034	-0.131***	0.035	-0.128***	0.036	-0.128***	0.035
High School and Vocational			-0.155***	0.046	-0.130**	0.048	-0.123*	0.050	-0.120*	0.049
College and Above			-0.176**	0.064	-0.128+	0.067	-0.105	0.072	-0.098	0.072
Logged Expenditure					-0.009	0.016	-0.007	0.016	0.000	0.015
Housing Quality					-0.011*	0.004	-0.010*	0.004	-0.012**	0.005
Health insurance (ref: Urban Employee)										
Urban Resident							0.072	0.070	0.067	0.071
NCMS							0.021	0.044	0.014	0.045
Not Insured							0.107+	0.057	0.102+	0.057
Have Private Insurance							-0.034	0.043	-0.031	0.042

Health Facility							0.001	0.008	0.000	0.008
Living with Spouse									0.039	0.034
Living with Child									0.053+	0.029
Weekly Contact w/ Child									0.006	0.045
Social Participation									-0.007	0.005
Constant	0.584	0.456	1.139*	0.457	1.293**	0.483	1.223*	0.487	1.006*	0.495
Observations	13846		13846		13846		13846		13846	

Note: 1. All models control for geographic region, terrain, and climate of the community
2. Community-clustered robust standard errors (se) are shown
3. NCMS = The New Rural Cooperative Medical Scheme

Table 3. 3 Regression of Change in Frailty Index (2011-2015) on Urbanicity and Hypothesized Pathways

	(1)		(2)		(3)		(4)		(5)	
	coeff.	se	coeff.	se	coeff.	se	coeff.	se	coeff.	se
Urbanicity	-0.080***	0.010	-0.058***	0.010	-0.026*	0.012	-0.020	0.013	-0.019	0.013
Female	0.236***	0.028	0.186***	0.029	0.194***	0.029	0.192***	0.028	0.194***	0.028
Age	-0.015	0.019	-0.039*	0.019	-0.039*	0.019	-0.038*	0.019	-0.035+	0.019
Age^2	0.000+	0.000	0.000**	0.000	0.000**	0.000	0.000**	0.000	0.000*	0.000
Frailty Index in 2011	-0.650***	0.014	-0.721***	0.014	-0.727***	0.014	-0.728***	0.014	-0.728***	0.014
Any Chronic Condition			0.135***	0.030	0.139***	0.030	0.143***	0.030	0.143***	0.030
Self-rated Poor Health			0.330***	0.039	0.317***	0.038	0.318***	0.038	0.316***	0.038
Migrant Status (ref: Non-migrant)										
Rural-Urban Migrant			0.014	0.116	0.017	0.119	0.030	0.119	0.034	0.119
Other Migrant			-0.074	0.050	-0.053	0.049	-0.046	0.050	-0.045	0.050
Education (ref: No Education)										
Part Elementary			-0.069	0.044	-0.059	0.045	-0.059	0.045	-0.058	0.045
Elementary			-0.087+	0.046	-0.070	0.045	-0.064	0.045	-0.063	0.045
Middle School			-0.192***	0.046	-0.161***	0.047	-0.148**	0.045	-0.146**	0.045
High School and Vocational			-0.208***	0.058	-0.159**	0.059	-0.132*	0.058	-0.130*	0.058
College and Above			-0.394***	0.099	-0.307**	0.100	-0.254*	0.104	-0.250*	0.103
Logged Expenditure					-0.027	0.022	-0.024	0.022	-0.022	0.023
Housing Quality					-0.019***	0.005	-0.018***	0.005	-0.019***	0.005
Health insurance (ref: Urban Employee)										
Urban Resident							0.072	0.083	0.068	0.084
NCMS							0.083	0.052	0.082	0.051
Not Insured							0.084	0.080	0.080	0.079
Have Private Insurance							-0.062	0.103	-0.059	0.102

Health Facility							-0.008	0.013	-0.009	0.013
Living with Spouse									-0.006	0.038
Living with Child									0.043	0.034
Weekly Contact w/ Child									-0.073	0.064
Social Participation									0.002	0.007
Constant	0.907+	0.546	1.656**	0.570	1.965**	0.595	1.790**	0.584	1.720**	0.609
Observations	8261		8261		8261		8261		8261	

Note: 1. All models control for geographic region, terrain, and climate of the community
2. Community-clustered robust standard errors (se) are shown
3. NCMS = The New Rural Cooperative Medical Scheme

Table 3. 4 Estimated Associations between Urbanicity and ADL/Frailty among the Deceased (2011-2013)

	ADL		Weight Loss		Fatigue	
Urbanicity	0.028	0.043	-0.070	-0.124	0.017	0.065
	(0.079)	(0.093)	(0.096)	(0.101)	(0.080)	(0.092)
Gender	0.502*	0.541*	-0.244	-0.097	-0.672**	-0.715*
	(0.217)	(0.235)	(0.256)	(0.278)	(0.252)	(0.286)
Age	0.145	0.150	0.181	0.163	0.118	0.071
	(0.118)	(0.117)	(0.152)	(0.157)	(0.192)	(0.210)
Age^2	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ADL Index (2011)	-0.629***	-0.683***				
	(0.058)	(0.068)				
Frailty Index (2011)			0.044	0.070	0.285*	0.152
			(0.151)	(0.156)	(0.125)	(0.134)
Any Chronic Disease (2011)		-0.038		0.365		0.899*
		(0.295)		(0.395)		(0.363)
Self-rated Poor Health		0.423		-0.018		0.718*
		(0.286)		(0.291)		(0.285)
Migrant Status (ref: Non-Migrant)						
Rural-Urban Migrant		-0.121		0.770		-0.166
		(0.774)		(0.699)		(0.732)
Other Migrant		-0.047		0.466		0.423
		(0.471)		(0.449)		(0.488)
Education (ref = No School)						
Part Elementary		0.265		0.481		-0.022
		(0.337)		(0.368)		(0.363)
Elementary		0.038		0.436		0.315
		(0.326)		(0.407)		(0.413)
Middle School		0.485		0.476		-0.604
		(0.434)		(0.469)		(0.560)
High School and Above		-0.124		0.578		-0.249
		(0.521)		(0.597)		(0.661)
Constant	-3.465	-4.016	-5.462	-5.517	-3.706	-3.382
	(4.159)	(4.098)	(5.212)	(5.321)	(6.555)	(7.164)
Observations	377	375	309	309	293	293

Appendix

APPENDIX A. Summary Statistics

Appendix Table 3. 1 Descriptive Statistics for the Studied Variables (Original Sample)

Variable	Mean/Proportion	SD	N
ΔADL	0.158	1.126	13,846
ADL in 2011	0.321	0.925	13,846
ΔFI	-0.014	1.207	8,261
FI in 2011	1.108	1.100	8,261
Urbanicity	4.312	1.616	13,935
Gender	0.519		13,925
Age	58.898	9.301	13,934
Any Chronic Disease (2011)	0.682		13,911
Self-rated Poor Health	0.257		13,924
Migration Status			13,920
Non-Migrant	0.891		
Rural-Urban Migrant	0.024		
Other Migrant	0.085		
Education			13,920
No School	0.296		
Part Elementary	0.184		
Elementary	0.219		
Middle School	0.207		
High School and Vocational	0.095		
College and above	0.021		
Logged Expenditure	8.672	0.843	13,761
Housing Quality	9.619	4.197	13,791
Health Insurance			13,864
Urban Employee	0.106		
Urban Resident	0.050		
NCMS	0.776		
Not Insured	0.068		
Have Private Insurance	0.024		13,925
Health Facility	2.049	1.271	13,935
Living with Spouse	0.817		13,901
Living with Child	0.615		13,588

Weekly Contact w/ Child	0.925		13,620
Social Participation	1.316	1.811	13,146
Region			13,935
Northeast	0.083		
Northern	0.170		
Eastern Coast	0.090		
Southern Coast	0.067		
Yellow River (mid. reach)	0.243		
Yangtze River (mid. reach)	0.131		
Southwest	0.158		
Northwest	0.058		
Terrain			13,905
Plain	0.412		
Hill	0.303		
Mountain	0.210		
Plateau	0.046		
Basin	0.030		

CHAPTER 4: Son Preference and Gender Disparity in Cognitive Functioning among Mid-aged and Older Chinese

Introduction

Cognitive functioning is increasingly recognized as a key to successful aging. To date, studies have generally found that while Western and more developed countries and regions see relative gender parity in cognitive functioning in advanced age (i.e., women have comparable strength and weakness on different measures of cognition), less developed areas have seen a larger female cognitive disadvantage across all dimensions (Deary et al. 2004; Gerstorf, Herlitz, and Smith 2006; Lei et al. 2012; Meinz and Salthouse 1998; Onur and Velamuri 2016).

Why is gender disparity in cognitive functioning greater in some regions and countries than in others? The question is important because knowledge of disparity in cognitive function is key to understanding the gender inequalities in health and wellbeing, financial decision making, and adherence to medical treatment, especially in old ages when cognitive functions are declining (Campbell et al. 2012; Glover et al. 2021; Serper et al. 2014). It may be even more crucial to women since they live longer and are more likely to become caregivers for other family members in old ages (Morgan et al. 2016; Oliker 2011). Reviewing the literature showed that while most prior research has answered this question by investigating the contribution of macro-level economic factors (e.g., income growth, urban living, and educational expansion) (Lei et al. 2014; Weir et al. 2014), few have examined the question from a socio-cultural perspective (with one notable exception of Bonsang, Skirbekk, and Staudinger 2017 who examine the influence of gender-role attitudes). Here, my concern with socio-cultural explanation is driven by two lines of research. First, research has long established the influence of gender discrimination and sex-typed roles on gender disparities in health (esp. in developing countries), cognitive development and education in the early years (Buchmann, DiPrete, and McDaniel 2008; Mitra 2014; Reilly, Neumann, and Andrews 2019). Second, it is well documented in the literature that these early outcomes can have a lasting impact on cognition across the life span (Deary et al. 2004; Luo and Waite 2005; Richards and Sacker 2003). Thereby, we expect that socio-cultural factors would play a crucial role in forming gender disparity in cognitive functioning in later life.

In the present study, I aim to examine one of such critical socio-cultural factors - the role of son preference in shaping the gender gap in later-life cognitive function in China. As a primary form of gender discrimination that prevails in many Asian countries (especially China, South Korea, and India), son preference can be generally defined as a belief that girls have less value than boys. It can often result in neglect or low parental investment in girls compared to boys, leading to gender differentials in early outcomes, as mentioned above (Das Gupta et al. 2003; Hesketh, Lu, and Xing 2011; Murphy, Tao, and Lu 2011). I, therefore, argue that the culture and practice of son preference can help explain gender disparity in cognition in later life in societies or areas where it is practiced.

Son Preference and Early (Later) Gender Disparity

Son preference can contribute to differential parental treatment in boys and girls in many ways. In Asian countries with son preference, studies have found that parents tend to favor their boys at the expense of girls regarding childcare, healthcare, nutrition and education (Alderman and Gertler 1997; Ganatra and Hirve 1994; Gao and Yao 2006; Jayachandran and Kuziemko 2011; Yueh 2006).

Consequently, girls, especially those from economically less developed regions, often face a significant disadvantage in educational attainment, health, and physical growth in early life (Altindag 2016; Arnold, Choe, and Roy 1998; Barcellos, Carvalho, and Lleras-Muney 2014; Zeng et al. 2014).

Taking the life course perspective (Elder 1998), these early gender differentials might translate into women's disadvantage in cognitive function in later life. Among them, education and nutrition might be two crucial mediators. A large body of studies has shown the key role education plays in maintaining high levels of cognitive functioning and lower degrees of neuropathology (Falch and Massih 2011; Schneeweis, Skirbekk, and Winter-Ebmer 2014; Sharp and Gatz 2011). Early life nutritional deficiency may lead to mental and physical conditions/health deficits that affect cognitive abilities directly, or through the pathway of education, especially in less developed countries (Maluccio et al. 2009; Nyaradi et al. 2013; Zhang, Gu, and Hayward 2010).

Son Preference in China

As in other Asian societies that show son preference, practices of gender discrimination have been documented in (pre-)modern China, such as sex-selective abortion, female infanticide, neglect and preferential parental investment (Mungello 2008; Zhou et al. 2012). Scholars have attributed the root of these practices to the cultural practice of the patrilineal family system that stresses male superiority, where traditionally sons remain in the family to care for parents in old age and daughters marry into their spouse's household (Das Gupta 2010; Jin, Li, and Feldman 2007). This tradition, coupled with economic drivers such as the gender disparity in wages (Qian 2008) and the lack of reliable pension programs among rural populations (Ebenstein and Leung 2010), has led many parents to place more value on sons over daughters. Even today, Chinese families tend to invest more in sons than daughters in terms of education expenditures and nutrition (Yueh 2006; N. Zhang, Bécares, and Chandola 2016).

Despite the common causes of son preference in Asian countries, China is unique for its birth control policy's unintended consequence. From 1979 to 2015, the stringent "one-child" policy had incentivized the misuse of diagnostic ultrasound for determining fetal sex, making abortion of daughters a popular choice among parents who wanted boys, especially in rural areas (Y. Chen, Li, and Meng 2013). Additionally, studies have shown that parents were less likely to register their baby girl for *Hukou* (namely household registration) or chose to delay the registration to wait for another child (Shi and Kennedy 2016).

Importantly, though, there is considerable spatial variation in son preference in China, given that the exposure to the aforementioned factors varies across regions and populations. For instance, many non-Han populations/regions were historically less rooted in the patrilineal family system (Du 2016; Mattison et al. 2016). Among the Han population, Mandarin-speaking regions, which were more influenced by non-Han cultures in history, have shown less cohesion around their patrilineal family clan and hence less son preference (Gong, Duan, and Gürel 2013). Also, compared to urban areas, rural residents tended to show stronger son preference ideation (Lei and Pals 2011). Policy-wise, minority groups[1] and rural residents[2] were faced with less restrictive birth-control policies (Hesketh et al. 2005; Li, Yi, and Zhang 2011). Finally, scholars have documented spatial and temporal variation in the diffusion of ultrasonography in the 1980s and 1990s, making some areas earlier adopters of sex-selective abortion than others (Chen et al. 2013).

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[1] Minority women were allowed to give birth to at least two children.
[2] Rural residents were allowed to have a second child if the first was a girl since mid-1980s.

The spatial variation in son preference in China has made this research possible. Empirically, this study exploits regional variation in the level of son preference, captured by the sex ratio, and analyzes how it moderates the association between gender and cognitive function for middle-aged and older Chinese adults. The sex ratio, typically measured at birth/early ages, has been widely used as a proxy for son preference in the literature (Clark 2000; Edlund 1999; Guilmoto 2012; Park and Cho 1995). As various reflections of son preference, selective abortion, neglect and underreporting of daughters are the sources of a skewed sex ratio at birth/early ages (Das Gupta et al. 2003). As noted, in China, the main cause among these depends on the historical time of interest, especially relative to the time when the one-child policy was introduced (1979) and when ultrasound technology for gender identification before birth became widespread (the mid-1980s) (Chen et al. 2013; Zhang 2017)[3].

Method

Data

The main data sources for this study were the pooled data from the first three waves (2011, 2013, 2015) of the China Health and Retirement Longitudinal Study (CHARLS) [4] and the 1982 China Census 1% Sample (IPUMS International). Based on stratified multistage probability sampling, CHARLS included 450 urban neighborhoods and rural villages (referred to as "communities" in the protocol and the current study hereafter). Within each community, 80 households were randomly selected and interviewed. Overall, the survey successfully

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[3] See next section for a discussion of the implications of using sex ratio to measure son preference in different historical time periods.
[4] The study did not use the most recent (2018) wave of CHARLS as that wave did not collect biomarker data (for generating the nutrition status variable "knee height" this paper, as discussed below).

interviewed 17,708 individuals at the baseline, and subsequently, 3,426 and 3,824 new respondents were added to the sample to adjust for attrition. The IPMUS Census 1% dataset was identifiable with cities (prefectures) as the smallest geographical unit, and thus I linked it with CHARLS at the city level. For cities with changed boundaries or for cases where one city prefecture was divided into two cities since 1982, I matched the cities in 2011 to their counterparts in 1982 by carefully examining their overlap on maps and affiliated county-level units. This resulted in successfully matching 125 cities in 2011 to 121 in 1982. Since my interest was to investigate the respondents' exposure to the practice of son preference in early life, I restricted the analysis to the subsample who were living in their city since birth as no information regarding the birthplace for those who had moved was available in the data. Because this restriction resulted in a somewhat different sample (~82% of the original sample), I included a factor that represented the inverse probability of remaining in the birthplace in the calculation of sample weights (see below for more details).

Cognitive function

Based on similar measures used in the Health and Retirement Study (HRS), I devised two variables to capture cognitive function. The first measured *episodic memory*, based on tests of the ability to repeat Chinese words immediately or four minutes after hearing a word list (that is, immediate or delayed word recall). Similar to McArdle et al. (2007), the measure was formed by summing the scores from the two tests. Given that it is the ability to recollect information from the direct witness of the recent past, episodic memory is essential for information processing and reasoning. The second variable captured *mental status*, which broadly measures the respondent's mental capacity to reason and perform basic cognitive tasks. Following the lead of Lei et al.

2012, the variable consisted of serial seven subtraction from 100, naming date and season during the survey, and the ability to recreate a drawing previously shown. Individual scores from these questions are aggregated into a mental status score ranging from 0 to 11.

For all respondents to CHARLS, I only included the first wave they participated in the test of cognitive function to prevent correlation within individuals and retest effect (Scharfen, Peters, and Holling 2018). I used predictive mean matching (PMM) to multiply imputed the data for any missing values on the study variables but only used the sample with non-missing outcome variables. The final sample sizes in terms of the two key outcome variables were 16,074 (episodic memory) and 16,153 (mental status)[5].

Son Preference

I computed for each city prefecture the juvenile sex ratio (JSR) as the ratio of men to women aged 4-17 from the 1982 Census (i.e., the cohort born in 1965-1978), proposing it as a measure of the regional level of son preference. Since the success of using the measure to capture the son preference relies on the assumption that it is unconfounded by unobserved macro-level factors that can be associated with my outcomes of interest, there were a few important reasons for using this cohort. First, though ideally one would want to capture son preference for each cohort in the CHARLS sample (born before 1966), the 1982 Census of China was the first computerized Census data that enables the calculation of sex ratio at the regional level. Second, compared to later ages, the sex ratio at birth or in early ages is a more proper proxy for measuring the intensity of the practice of son preference, given little gender difference in cross-regional migration patterns in early ages. In fact, the gendered pattern of migration was

[5] See Appendix A for descriptive statistics of study variables based on the non-imputed sample.

most pronounced in early adulthood due to marriage across regional boundaries, since China's 1950 Marriage Law (effective 1950-1980) set the minimum marriageable age as 18 for women and 20 for men (Engel 1984). Thus, 17 was selected as the upper bound for the calculation of the sex ratio. Third, a prior study has documented an abrupt decline in sex ratio at birth in 1960-1963 (from a cohort that would reach age 19-22 in 1982), as the result of mothers with poor nutrition during the Great Leap Forward Famine being more likely to give birth to daughters (Song 2012). Hence, the choice of a cohort aged under 18 in 1982 can also avoid introducing variation in sex ratio due to varying levels of exposure to the famine. Finally, past studies have demonstrated a strong effect of regional heterogeneity in the enforcement of the "one-child policy" introduced in 1979/80 and availabilities of fetal sex determination technology on the sex ratio at birth and in early ages (Y. Chen et al. 2013; J. Zhang 2017); to avoid the confounding of these influential factors, I excluded children aged 0-3 in 1982 (born in 1979-1982) (Loh and Remick 2015).

Essentially, the listed reasons for selecting this cohort reflect the various sources of change in sex ratio and son preference practiced in different historical periods, as noted above. While the practice of son preference for the 1965-78 cohort might differ from the CHARLS cohorts, I assumed that the *culture* of son preference had been relatively stable at the regional level, especially when we compare regions cross-sectionally. Hence, by avoiding the temporal "shock" from the great famine, and heterogeneous exposure to the one-child policy and sex determination technology, the sex ratio measured in 1982 using the 1965-78 cohort might offer a reasonable choice for capturing the son preference culture at the regional level.

Covariates

I adjusted for several potential confounding factors that could reflect the association between son preference as measured by the juvenile sex ratio (JSR) and cognitive function. Specifically, past studies have shown that being a non-Han minority, having more education (especially among men), economic growth, and urbanization are associated with more egalitarian gender attitudes (Li and Lavely 2003). Therefore, models include city-level measures from the 1982 Census of the proportion of non-Han minorities; average years of schooling among adults; per capita GDP, and proportion of urban dwellers (urbanization). I also controlled for age and indicators for the larger geographic region.

Auxiliary Analysis

Despite the effort to control for potential confounders, it is generally difficult to find a perfect identification strategy for studying the impact of a long-standing cultural practice (in our case, son preference). Thus, I conducted auxiliary analyses to triangulate the main findings by substituting the JSR with other proxies of son preference. First, since the culture of son preference is partly the legacy of the traditionally agrarian *Han* culture that highly values patrilinear family clans, I proxied son preference using the city-level proportion of the population speaking Mandarin as the primary language (*% speaking Mandarin* hereafter). Historically, Mandarin as China's official language can be traced to Jin (1115-1234) and Yuan (Mongol, 1271-1368) Dynasties when the northern Chinese dialect was established as the common Chinese language during the conquest of Jurchens and Mongols (Norman 1988). During the same period, Han Chinese (who were speaking the traditional Middle Chinese Language) had gradually settled away from the northern China plain to escape wars and formed large family clans in southern China. The geographic pattern of language speaking has remained relatively stable since then, as observed by historians (Zhou and Lo 1991). Thus, the % speaking Mandarin can serve as a good measure for the *loss* of the traditional *Han* culture. Past studies have shown that adherence to a lifestyle guided by such traditional values serves as a strong determinant of son preference (Murphy et al. 2011). In practice, I measured % speaking Mandarin at the city level based on the 1982 Census and The Language Atlas of China (Lavely and Berman 2012; Wurm et al. 1987).

I employed the number of dominant surnames (defined as over 20% of residents taking this surname) present in the local village as another proxy of son preference. Research has shown that son preference tends to be stronger in the village with one or several large surnames (Murphy et al. 2011), as these villages enforce patrilinear family clans and repress individual reproduction preference (Das Gupta et al. 2003). Notably, this measure was limited to rural areas as the survey question was asked conditional on the community being a rural village. Also, the variable was arguably noisier compared to the other two measures of son preference, for the question was administered to only one "community respondent" and entailed some estimation.

Channels

I hypothesized that education and nutrition could channel the effect of son preference on the gender gap in late-life cognition. Therefore, I further performed analyses by including the respondent's educational attainment and early nutrition level in the models. Specifically, I used a categorical variable indicating one's highest level of formal school education to capture educational attainment and knee height to proxy early nutrition status to see the extent to which these mediate the association between the indicator of son preference and later-life cognitive function.

Statistical Method

As the key variables of interest were measured at the city level, I used random intercept models to model how son preference moderated the association between gender and cognitive function. Since this approach relies on the hard-to-test ignorability (i.e., unconfounded treatment) assumption, all results below should be interpreted as associational. All models were probability-weighted to adjust for non-response and the difference in the size of the wave's data that was included in the pooled sample [6].

Result

I started my analysis by visualizing the geographic distribution of JSR on a map (Figure 4.1). While the IPUMS sample average of JSR is 1.065, the map revealed considerable variation across city prefectures. Among all, 26% of all cities (45% of China's population) had JSR over 1.07, a commonly adopted upper bound for a normal sex ratio at birth (Grech, Savona-Ventura, and Vassallo-Agius 2002)[7]. Figure 4.2 further shows the geographic distribution of the Mandarin-speaking population, indicating that non-Mandarin-speaking regions tend to have a higher JSR (the correlation was 0.32 based on the joined IPUMS - CHARLS sample). As noted,

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[6] In practice, this consisted of two steps. 1) For each wave of the CHARLS data, I calculated the wave-specific weight as the IP (inverse probability) of having valid response on the outcome variable * IP the respondent not moving since birth * survey non-response-adjusted weight (computed by the CHARLS team). Note that since I only used a respondent's first cognitive test, respondents who had valid response in a prior wave would mean that their responses (if any) in the subsequent waves treated as *invalid* for calculating the wave-specific weight. 2) I then use the wave-specific weight * % of the wave in the pooled sample as the sample weight to be used in the analysis.

[7] Considering sex ratio drops with age, sex ratio over 1.07 might seem more "abnormal" with respect to the age group (4-17) of interest.

not every city with highly skewed JSR fell under the non-Mandarin category since there are multiple determinants/confounders of JSR, as mentioned above.

[Figure 4.1 and Figure 4.2 about here]

Figure 4.3 illustrates the comparison of weighted means of episodic memory and mental status by gender. Given women in my sample tended to be slightly older than men, the gendered statistics were calculated with age-standardized using the sample that contains both genders as the reference population[8]. I found that men outperformed women on both cognition outcomes (7.03 vs. 6.58 for episodic memory and 7.97 vs. 6.32 for mental status). This finding was consistent with the patterns revealed in the literature, namely, in less developed countries, women are disadvantaged concerning nearly all aspects of cognitive functioning (Lee et al. 2014; Lei et al. 2012), though they might perform better relative to men in tests that call for fewer quantitative skills.

[Figure 4.3 about here]

Table 4.1 and 4.2 present my main results: the estimated association of JSR and the gender gap in episodic memory and mental status. The sign of the point estimate of the interaction of JSR and gender (JSR * Female) in Model 1 of Table 4.1 was consistent with the conjecture that a greater revealed level of son preference enlarges the gender gap in cognitive

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[8] Specifically, I computed the gender-specific mean cognitive outcome at each age and then averaged for each gender using the age structure of the whole sample as weights.

function in older ages, though it does not reach statistical significance. It was also interesting to see that even for men, son preference seemed harmful, as the “main” coefficient on JSR was negative. Moving over to the Model 1 of Table 4.2, a similar and more significant association can be seen. As JSR increased by 0.1, the gender gap in mental status was expected to widen by 0.38 (about 0.14 standard deviation). For other city-level measures, the coefficients on minority representation, urbanization, and average years of schooling showed that these factors lead to gains for women compared to men. Per capita GDP was noteworthy for its positive relationship with the gender cognitive function gap. One plausible explanation might be that with a similar level of son preference, for a developing country such as China in the 1970s, more income might mean more divergence in investment in boys and girls. Also, given that associations were marginal after controlling for urbanization and educational expansion, it might proxy the effect of gendered work and retirement patterns that emerged with the rapid economic growth in the 1980s.

[Table 4.1 and Table 4.2 about here]

In the second set of models (Model 2 and 3 in Table 4.1 and Table 4.2), I further explored possible mediation via the proposed channels. I found that including individual-level education explained away about half of the association of JSR with the gender gap for both cognitive outcomes. By contrast, the nutrition pathways (proxied by knee height) failed to explain the relationship, even though the coefficient on knee height was large and statistically significant. Taken together, these results supported the hypothesized pathway of education but not nutrition.

Table 4.3 presents results from the auxiliary analysis for the mental status models by replacing JSR with two other proxies of son preference. Overall, the results were in line with the main analysis. Compared to a region with all its population using non-Mandarin Chinese dialects, Model 1 shows that a 100% Mandarin region would see the gender gap in mental status narrowed by about 8%, ceteris paribus. Model 2 displays finding utilizing the number of dominant surnames instead. Albeit less clear, the results show that women tended to have less disadvantage in mental status when living in villages with a family clan composition that was more mixed. Interestingly, living in villages with no dominant surnames also seems to benefit men, suggesting these villages might have more cognitively simulating resources available to both genders.

[Table 4.3 about here]

Discussion

The present study helped reveal a crucial socio-cultural factor that may underlie the later-life gender disparity in cognitive function in China - son preference. I have shown that women's disadvantage in mental status tends to be larger in areas with a higher juvenile sex ratio – places that appear to see a stronger influence of son preference. The findings also imply that differential investment in educational attainment might partially account for the link between son preference and the gender gap in cognition. To triangulate these results, I employed two other measures to proxy son preference, level of exposure to *Han* culture and patrilineal family culture. The results based on these proxies were consistent with the main analysis.

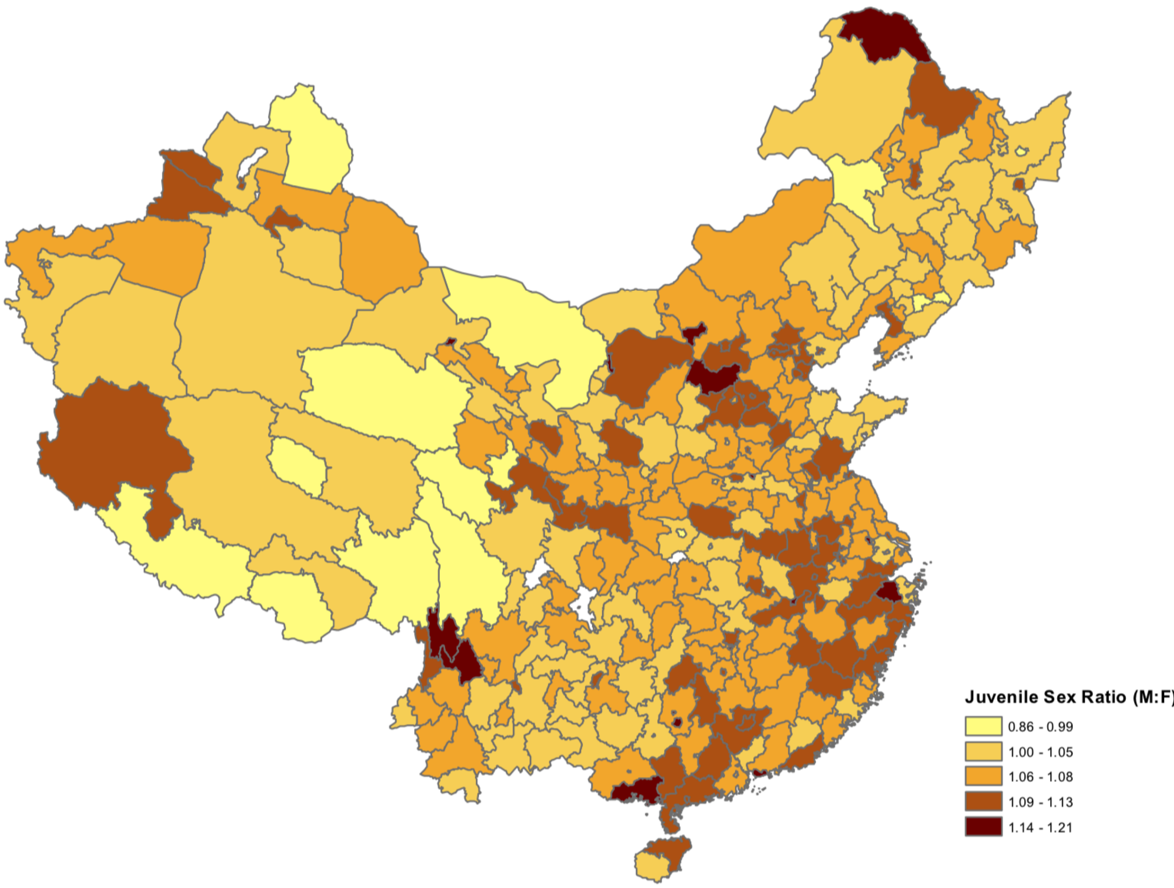
My study did not document a significant association between son preference and the gender gap in episodic memory. However, the finding should be interpreted with caution, given an overall smaller female disadvantage in the episodic memory score (shown in Fig. 3). In fact, once educational attainment was adjusted, women on average slightly outperformed men in this cognitive dimension. Furthermore, numerous studies have shown that older women outperform men in memory function tests in developed countries whereas underperform in developing countries (Deary et al. 2004; Gerstorf et al. 2006; Lei et al. 2012; Loprinzi and Frith 2018; Meinz and Salthouse 1998; Onur and Velamuri 2016). Taken together, it suggested that women, when raised in cultures that advocate gender-equitable educational opportunities, would have an edge over men in memory functioning.

There are limitations to the present study. First, since the CHARLS measurement of cognitive functions, particularly mental status, lacks critical dimensions compared to other HRS's sister studies (e.g., object naming and common-sense questions), the gender gap of cognition observed in the present mainly reflect arithmetic skill. Future research is needed to understand whether the CHARLS measures' performance is similar to that used for other surveys. Second, these estimates are inferential. While I used three ways to capture the son preference culture and its behavioral sources, and controlled for observed macro-social factors, each of the measures could still be confounded, especially considering that they were measured at the aggregate (city) level. For instance, the negative relationship between JSR and cognition among men might suggest that the JSR picks up other cultural values/practices (e.g., having a social network bounded by one's family clan) that hindered the development of cognitive abilities.

Given the limitation in my identification strategy, how likely is the observed association between son preference and gender disparity in cognition biased? An idea would be to consider the direction of this bias. As presented in Figure 1, most city prefectures that showed high son preference (JSR) are located in the eastern coastal areas with more urbanized and better-educated populations, which were known to be the soil for the rise of female education and gender equality in modern China (Lavely et al. 1990). Hence, my analysis might arguably underestimate the effect of son preference, assuming that the economic-related factors such as urbanization were not adequately controlled for.

While these findings were insightful for understanding gender inequality in cognition for the CHARLS cohorts (age 45+ at the time of the survey), the results should not be extended to younger generations. China's urbanization, education expansion, and most importantly, the sharp decline in the fertility rate has been shown to greatly improve girls' education attainment and status within the family (Adediran et al. 2012; Lee 2012; Wu, Ye, and He 2014), and considerable gender parity in cognitive ability in earlier life has been achieved (Huang, Xie, and Xu 2015). Nevertheless, in rural China, especially in areas that rely on agriculture, scholars have found that son preference remains popular as the patrilineal family is still the chief source of support in older age (Ebenstein and Leung 2010). While addressing the gender gap in cognitive functioning might be easier as women's education today is on par with men's, rural China still requires a fuller and more equitable welfare system and access to non-agricultural labor markets to mitigate son preference.

Figure 4. 1 City-level Juvenile Sex Ratio in 1982



Source: Third National Population Census 1982 (IPUMS 1% sample)

Figure 4. 2 Chinese Dialect Groups (County-level)

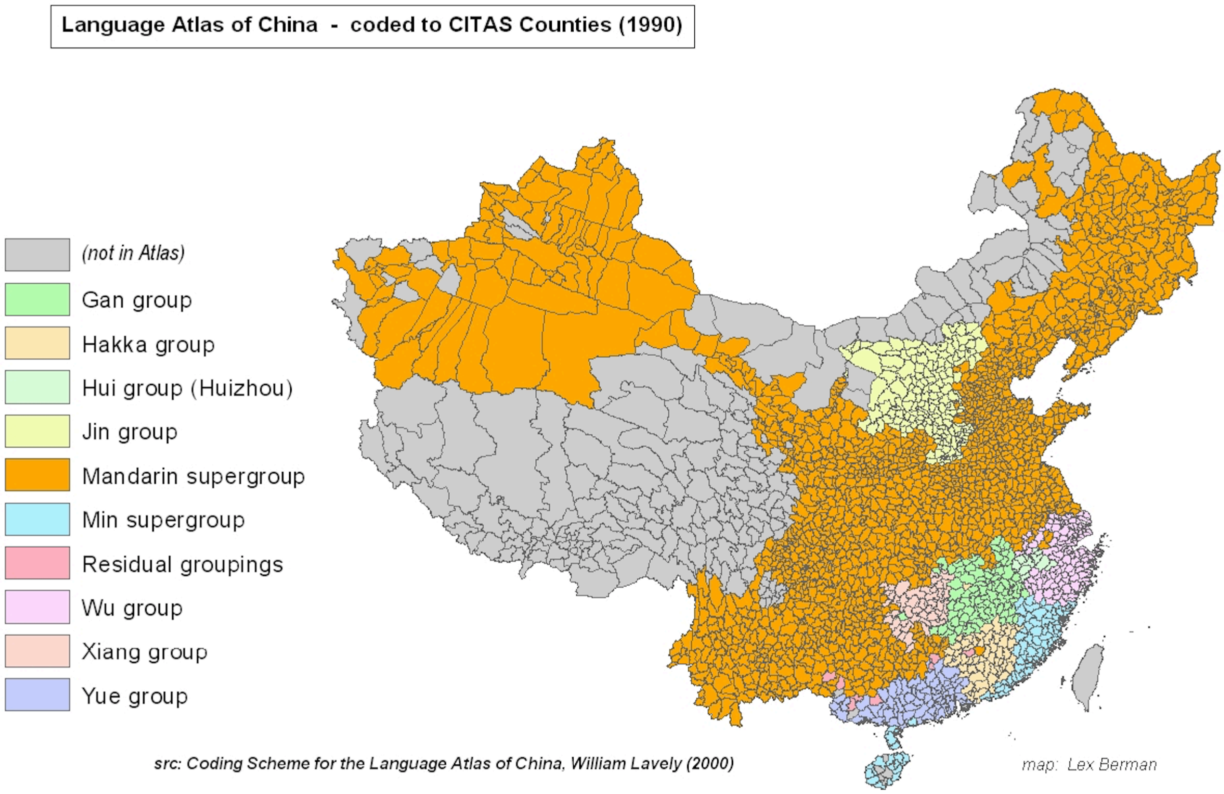


Figure 4. 3 Mean of Episodic Memory and Mental State, by Gender

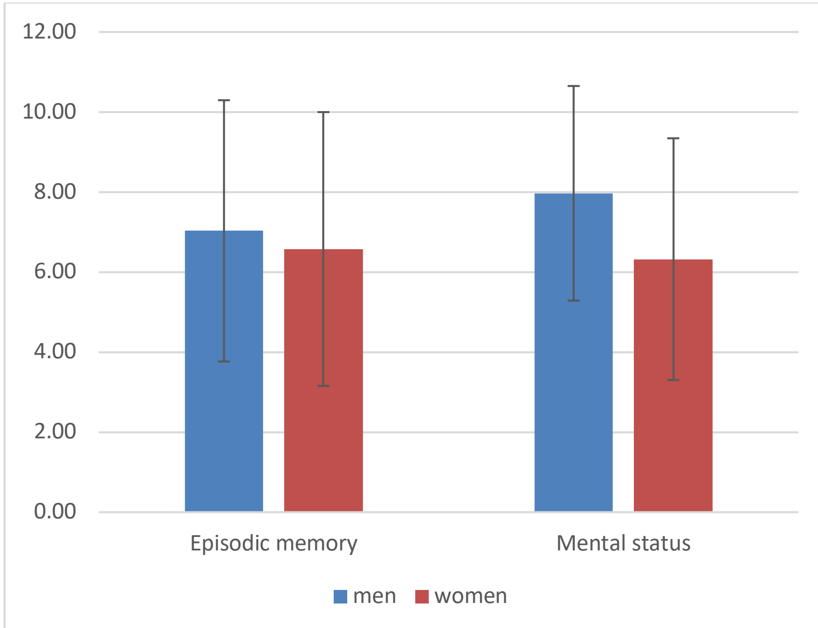


Table 4. 1 Multilevel Regression of Episodic Memory on Gender and Sex Ratio

	(1)		(2)		(3)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Age	-0.005	0.034	0.096**	0.032	-0.008	0.034
Age^2	-0.001***	0.000	-0.001***	0.000	-0.001***	0.000
Female	0.378	2.170	0.940	2.032	0.645	2.125
Juvenile Sex Ratio	-3.921	2.945	-3.680	2.469	-3.926	2.899
Juvenile Sex Ratio * Female	-2.015	1.977	-1.141	1.824	-2.115	1.932
Proportion Minority	1.124	0.916	0.948	0.854	1.070	0.918
Proportion Minority * Female	1.338**	0.433	0.977*	0.496	1.373**	0.436
Average Years of Schooling	-0.074	0.190	-0.318+	0.165	-0.082	0.191
Average Years of Schooling * Female	0.211**	0.081	0.067	0.081	0.218**	0.081
Per Capita GDP	-0.181	0.324	-0.078	0.251	-0.174	0.326
Per Capita GDP * Female	-0.017	0.144	0.034	0.129	-0.014	0.144
Urbanization	2.684*	1.189	2.287*	0.922	2.705*	1.183
Urbanization * Female	0.524	0.704	0.250	0.682	0.493	0.707
Education (Ref = No Edu)						
Part Elementary			1.017***	0.099		
Elementary			1.605***	0.093		
Middle School			2.418***	0.113		
High and Vocational			3.105***	0.135		
College and Above			4.318***	0.253		
Knee Height					0.056***	0.012
Fixed Intercept	15.096***	3.315	9.984***	2.767	12.390***	3.350
Level-2 Variance	0.893	0.068	0.745***	0.058	0.889	0.068
Observations	16074		16074		16074	
# of Level-2 Units (Cities)	126		126		126	

Note: 1) + p<0.1, * p<0.05, **p<0.01, ***p<0.001 2) All models also control for geographic regions

Table 4. 2 Multilevel Regression of Mental Status on Gender and Sex Ratio

	(1)		(2)		(3)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Age	0.099**	0.032	0.191***	0.027	0.096**	0.032
Age^2	-0.002***	0.000	-0.002***	0.000	-0.002***	0.000
Female	0.210	1.779	1.061	1.429	0.569	1.783
Juvenile Sex Ratio	-2.739	2.195	-1.964	1.829	-2.756	2.161
Juvenile Sex Ratio * Female	-3.809*	1.548	-2.270+	1.316	-3.953*	1.541
Proportion Minority	-0.492	0.636	-0.605	0.445	-0.546	0.647
Proportion Minority * Female	0.561	0.434	0.073	0.294	0.590	0.441
Average Years of Schooling	0.367*	0.155	0.047	0.116	0.357*	0.156
Average Years of Schooling * Female	0.379***	0.101	0.096	0.074	0.384***	0.101
Per Capita GDP	-0.042	0.147	0.019	0.110	-0.032	0.150
Per Capita GDP * Female	-0.356+	0.212	-0.220	0.144	-0.354+	0.211
Urbanization	0.345	0.739	0.542	0.635	0.367	0.737
Urbanization * Female	1.962**	0.697	1.565**	0.581	1.944**	0.693
Education (Ref = No Edu)						
Part Elementary			2.002***	0.077		
Elementary			2.950***	0.078		
Middle School			3.515***	0.086		
High and Vocational			3.947***	0.094		
College and Above			4.438***	0.135		
Knee Height					0.053***	0.012
Fixed Intercept	8.840**	2.792	2.322	2.178	5.630*	2.834
Level-2 Variance	0.725***	0.053	0.536***	0.041	0.723***	0.054
Observations	16153		16153		16153	
# of Level-2 Units (Cities)	126		126		126	

Note: 1) + p<0.1, * p<0.05, **p<0.01, ***p<0.001 2) All models also control for geographic regions

Table 4. 3 Multilevel Regression of Mental Status on Other Proxies of Son Preference

	(1)		(2)	
	Coefficient	SE	Coefficient	SE
Female	-4.211***	0.459	-4.140***	0.520
Proportion Mandarin-Speaking	-0.081	0.228		
Proportion Mandarin-Speaking * Female	0.292*	0.148		
# Dominant surnames (Ref = One)				
Two			0.013	0.116
Three			-0.045	0.160
Four			-0.071	0.253
No			0.208	0.159
# Dominant surnames * Female				
Two			-0.022	0.156
Three			-0.060	0.188
Four			0.721**	0.272
No			0.354+	0.206
Level-2 Variance	0.717***	0.050	0.604***	0.048
Observations	16153		12450	
# of Level-2 Units (Cities)	126		108	

Note: 1) + p<0.1, * p<0.05, **p<0.01, ***p<0.001
2) All models also control for age, age squared, geographic regions; and proportion national minority, average years of schooling, per capita GDP, urbanization and their interactions with gender.

Appendix

APPENDIX A. Summary Statistics

Appendix Table 4. 1 Descriptive Statistics of Study Variables

Variable	Mean/Proportion	SD	N
Individual-level measure			
Episodic Memory	6.83	3.55	16,074
Mental Status	7.19	3.11	16,153
Age	59.04	9.55	16,349
Gender	0.49		16,364
Education			16,353
No education	0.27		
Part elementary	0.18		
Elementary	0.23		
Middle school	0.20		
High or vocational	0.10		
College and above	0.02		
Knee height	47.89	3.45	15,107
City/community-level measure			
Juvenile sex ratio	1.06	0.03	16,366
Proportion Minority	0.07	0.15	16,366
Average Years of Schooling	5.07	1.06	16,366
Per Capita GDP	0.74	0.71	16,366
Urbanization	0.24	0.18	16,366
Proportion Mandarin-speaking	0.70		16,366
Number of dominant surnames (community-level)			12,628
One	0.30		
Two	0.30		
Three	0.17		
Four	0.04		
No	0.19		
Region			16,366
Northeast	0.07		
Northern Coast	0.14		
Eastern Coast	0.10		
Southern Coast	0.09		
Yellow River (mid. reach)	0.17		
Yangtze River (mid. reach)	0.18		
Southwest	0.21		
Northwest	0.04		

CHAPTER 5: Conclusion

Gender and socioeconomic position are among the most crucial axes of (health) inequality in all societies. Though this dissertation centers on China, my studies engage with the broader literature on the contextual determinants of socioeconomic and gender health inequality from developed and developing countries. Regarding the socioeconomic axis, past research from high-income countries has primarily focused on the neighborhood effect, since the residential neighborhood is usually patterned by social position and ethnicity and possesses physical and social attributes that may affect health (Diez Roux and Mair 2010). Specifically, SES, built environment and poverty are among the most widely studied neighborhood traits (Arcaya et al. 2016; Oakes et al. 2015). For low- and middle-income countries, however, research has shown it is important to also pay attention to the regional-level socioeconomic inequalities in living standards/lifestyle caused by unequal development, such as differential urbanization and modernization (Young 2013). For instance, in China, studies have generally indicated the urban-rural divide (vis-à-vis other individual-level and meso-level predictors) to be the largest source of socioeconomic and health inequality (Whyte 2010).

Drawing on the two lines of research, the first half of my dissertation (chapter 2 and chapter 3) explores the connection of neighborhood-level urbanicity with chronic diseases and physical health functioning in China, aiming to understand how "urban features" in one's proximate environment affect health. The two empirical chapters make a few contributions to the literature. On measuring urbanization, my work captures neighborhood-level urbanicity with a multi-component measurement based on nine facets of urbanization that are validated by prior research (Jones-Smith and Popkin 2010). This approach has advantages over widely used measurements such as categorical urban/suburban/rural status. In particular, it highlights the built environment and socioeconomic improvement in one's surroundings (i.e., neighborhood/local community) as the result of urbanization and enables comparison within broadly defined rural/urban places. Additionally, while some alternative approaches use typology based on individual's residential, *hukou* (i.e., household registration), and migration status to capture urbanization, my dissertation avoids taking this individual-based approach for two important reasons. First, although typologies offer analytical convenience, they can be confounded as individuals who have converted from rural to urban *hukou* or being a migrant tend to be healthier and socioeconomically better off than their counterparts (Lu and Qin 2014; Song and Smith 2021; Wu and Treiman 2004). Second, compared to typologies, my urbanicity scale provides a clearer account of the mechanisms for the link between urbanization and health, since some of the urbanicity components are also well-established health risk factors. Notably, I control/match for *hukou* and migration status in all my analyses to account for population heterogeneity (especially health-related) that might not be captured by other covariates.

The first part of the dissertation has also substantively added to the literature by showing that the "urban health penalty" and the "urban health advantage" theory (Galea, Freudenberg, and Vlahov 2005) could apply to the same cohorts on different health outcomes. Specifically, while unhealthful lifestyles in urban areas may have led to diseases of affluence (chapter 2), improvement in living standards and better accessibility to healthcare can be beneficial in terms of physical functioning (chapter 3).

Finally, chapter 2 contributes methodologically by applying a new approach to covariate adjustment: non-bipartite optimal matching. Particularly, this approach extends the method proposed by Joffe and Rosenbaum (1999) and Lu et al. (2011) to problems that involve treatment with continuous levels. Like other matching methods, the approach does not impose a rigid functional form on the relationship between the treatment, covariates, and the outcome and thus makes the analysis more reliable, relative to regression-based approaches.

The second half of my dissertation turns to gender health disparity. Chapter 4 shows that the practice of son preference (i.e., parents preferring having sons to daughters or investing more in their sons at the expense of daughters) in China is positively associated with a greater gender gap in cognitive functioning in later life, which can be partially accounted by gender inequality in educational attainment. Again, though I focus on but one form of sexism in China, my work adds to the broader literature on gender discrimination and health inequality. Specifically, by adopting the life course perspective, I highlight the long-term influence of exposure to sexism at early ages in later life, given that early health/developmental disparities are shown to have lifelong results (Jones et al. 2019). In addition, I explore the link between the cultural root of son preference (i.e., Han culture/patrilineality) with gender disparity in cognition and shows how culture may have shaped gender health inequality, on top of structural factors.

Returning to my research setting, China, my studies have collectively shown that the economic development introduced by the economic reform in the 80s and 90s has not always led to health benefits or mitigated health inequalities. As shown in chapter 2 and 3, while urbanization has brought improvement in living standards that benefits physical functioning, it has significantly raised the risks for diseases of affluence among older adults. Chapter 4 suggests that economic growth (captured by GDP per capita) is marginally associated with the higher gender inequality in cognitive functioning, partly due to its correlation with more practices of son preference (as reflected in sex ratio). Although this association does not indicate causation, my result parallels other findings on the link between economic development and widened gender inequality during China's economic transitional period (Appleton, Song, and Xia 2014; Liu 2011). Hence, for public health policymakers in China, it is important to abandon the notion of local economic development as a cure-all, and pay attention to the risk factors associated with the health challenges faced with an aging population, in particular, unhealthful lifestyle changes, poverty (especially poor housing quality), lack of access to medical resources, and gender discrimination, among others that are discussed in this dissertation.

My dissertation also offers insight into the role of gender in the link between social contexts and health. In chapter 2, my analysis shows that the relationship between urbanicity and metabolic syndrome (MS) appears more nonlinear among women than men, indicating women in the CHARLS cohorts who were living in the most advantaged urban neighborhoods had more awareness and/or resources (e.g., through exercising and diet change) to avoid some of the MS risk factors associated with urbanization. Though speculative, this might suggest that urban women, relative to men, have been feeling more pressure to maintain slender body shapes when the environment became obesogenic. Chapter 4 shows that though son preference does not benefit men in terms of later-life cognitive functioning, growing up in an environment with such sexist practices is significantly more harmful to women. Under the hood, I find that son preference contributes to women's disadvantage in education, in turn leading to the larger gender gap in cognitive functions, especially the ones involving quantitative skills. Taken as a whole, my analyses highlight how persistent micro-level gender disparities/inequalities modify or mediate larger contextual health effects.

There are limitations to my dissertation. First, my studies rely on imperfect identification strategies to examine the contextual effect. For instance, despite the advantages as discussed in chapter 2, the matching-based approach assumes that the matching model includes all relevant covariates (i.e., the "strong ignorability" assumption) (Joffe and Rosenbaum 1999), a strong assumption that is often violated in practice. Second, because the key social context variable - urbanicity and son preference was measured at only one point in time due to the data limitation, the claims about "long-term" contextual effects would need to rest on the assumption that the level or the rank of the region's social context had remained relatively stable over time. Finally, given China's rapid social change since the 1980s, my findings based on the CHARLS cohort (age 45+) in 2011-15 – a relatively short period - might not be generalizable to other periods.

These limitations have pointed to a few directions for future research. First, because China is still undergoing fast-paced urbanization and modernization, the relationship of social contexts such as urbanicity and SES with health may be evolving. For instance, while China's urbanization in the 1990s featured a shift toward the Western diet (Popkin 1999), more recent research has shown that urbanization in the 2000s tends to contribute to healthier diets, especially in rural areas (Ren et al. 2021). It is hence crucial for future research to understand how the *change* in micro- and meso-level health risk factors has driven the change in the relation between social context and health inequality. Second, among other social/policy changes such as the relaxation of strict birth-control policies (Jiang and Liu 2016), China has seen a significant improvement in gender equality regarding women's educational attainment (Zeng et al. 2014) as well as weakened son preference (Ho et al. 2018) and traditional gender roles (Hu and Scott 2016) in the past decades. Therefore, to advance our knowledge on gender inequality in China, it would be worthwhile for future research to explore if/how these trends have benefitted women's health and reduced gender health disparity, especially among younger cohorts, and how these changes will be likely to play out over the life course of health and aging.

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