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Socioeconomic gradients in the Westernization of diet in China over 20 years

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ABSTRACT

Introduction: In low-middle income countries, urbanization leads to changes from traditional to Western diet, which are often accompanied by reductions in cardiometabolic health. Whether socioeconomic status buffers these urbanization-related diet changes over time is unknown.
Objective: To examine whether the association between urbanization and a key indicator of Western diet, percent of calories from animal-source foods (1) varies depending on income and (2) whether this association changes over time.
Materials and methods: We used data from nine waves of the longitudinal, population-based China Health and Nutrition Survey [n = 22,360 Chinese adults (1991–2015)], followed across 24 years, including diet data from 3 repeated 24-h dietary recalls. We used simultaneous year-stratified linear regression models to examine whether changes in the association between urbanization level and percent of calories from animal-source foods differed by income. Models allowed for variation in associations across the 24 years of urbanization, accounting for within-individual correlation over time and controlling for age, sex, region, physical activity, and caloric intake.
Results: In 1991, on average 15% of calories for Chinese adults came from animal source foods and by 2015, this percentage rose to approximately one quarter of total calories. Over the 24 years of follow-up, urbanization and income were each strongly related to percent of calories from animal-source foods with differential association across income levels ($p < 0.0001$). We also found evidence that this association changed over time ($p < 0.0001$). Income gradients in animal source food consumption were smallest in the most urban areas in early years with some temporal variation, but over time income gradients narrowed in some later years in low and moderately urbanized areas. However, by 2015 there were few income differences in animal source food consumption across urbanization levels.
Conclusions: Throughout 24-years of urbanization, income seemed to buffer the transition from traditional to Western diet. However, the degree to which income buffered these urbanization-related changes depended on the level and history of community urbanization. At later stages of urbanization when Western diet behaviors were more widespread, urban-rural differences in Western diet behaviors varied little by income.

1. Introduction

In low and middle-income countries, rising urbanization and income have mixed consequences for health and well-being, with adoption of urban-related lifestyle behaviors that associate with chronic disease risk (Lallukka et al., 2007; Mendez & Popkin, 2004; Popkin & Du, 2003; Swinburn et al., 2004; Zhai et al., 2014). A key indicator of dietary urbanization from traditional to Western diet behaviors is the increase in

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consumption of animal-source foods like meat, dairy, and eggs (Delgado, 2003; Delgado et al., 2001), as well as away-from-home eating and fried foods as areas transition from rural to become more urban (Mendez & Popkin, 2004; Regmi & Dyck, 2001, pp. 23–30; Wu et al., 2016). Furthermore, Westernized dietary behaviors (Du et al., 2004; Monteiro et al., 2004), particularly higher consumption of animal-source foods, are frequently seen as markers of high income at early stages of urbanization, since they are culturally valued and relatively more expensive in earlier stages of urbanization (Drewnowski, 2000; Popkin & Du, 2003). As such, urbanization likely relates differently to Westernized diet, depending upon income, with percent animal source foods as a key indicator. Yet few studies have examined the interaction between income and degree of urbanization (rural to more urban) in relation to diet changes within a single geographic area or country, over a single period of time (Jaacks et al., 2014; Lallukka et al., 2007; Popkin & Slining, 2013). Even fewer have examined whether these relationships change throughout the course of urbanization (Dearth-Wesley et al., 2008; Du et al., 2004). Thus, we know little about whether an increase in Westernized diet behaviors with urbanization is disproportionately borne by lower versus higher income individuals and whether these relationships change over the course of urbanization.

There are several reasons for this knowledge gap. First, most research examining Western diet behaviors in urbanizing countries has used simplistic or ecologic measures of diet (Delgado, 2003; Kearney, 2010; Schmidhuber & Shetty, 2005) masking potential differences in dietary behaviors across socioeconomic subpopulations (Schmidhuber & Shetty, 2005). Second, the literature on Westernized diet relies primarily on a stable classification of urbanization (Drewnowski, 2000; Mendez & Popkin, 2004; Popkin & Du, 2003; Van de Poel et al., 2009), rather than longitudinal assessments of community-level urbanization to capture environmental changes as they unfold over time across different communities. This is particularly important as income has been shown to play an important role in the nutrition transition associated with urbanization (Drewnowski, 2000; Hawkes et al., 2017; Miao & Wu, 2016; Monteiro et al., 2004; Popkin, 1999; Popkin & Gordon-Larsen, 2004). For example, higher income individuals are often the first in urbanizing areas to have access to new foods and subsequently shift their dietary behaviors at earlier stages of urbanization. Third, the bulk of the literature has focused on diet changes occurring in highly urbanized areas (Popkin et al., 2012; Schmidhuber & Shetty, 2005). All three of these limitations result in a lack of understanding about the underlying socioeconomic gradients in diet changes with urbanization. This is of critical concern as markers of Westernized diet are associated with increases in obesity and cardiovascular disease (CVD) in China (Du et al., 2004; Mendez & Popkin, 2004; Popkin & Du, 2003; Zhai et al., 2014), and many other low and middle-income countries (Boutayeb & Boutayeb, 2005; Ezzati & Riboli, 2013; Hu, 2011; Prentice, 2005; Uauy et al., 2001).

To address these limitations, we used detailed dietary, income and community-level data collected from adults (ages 18–75) seen up to 9 times across 24 years (1991–2015) in the China Health and Nutrition Survey (CHNS). The CHNS was designed to capture changes in lifestyles and health with urbanization, thus providing representation of rural, urban, and suburban areas over time. We used the CHNS data to examine changes in consumption of a key indicator of Westernizing diet, percentage consumption of animal source foods, by income and urbanization over time. We used simultaneous linear regression models to estimate year-specific effects while accounting for correlation of diet measures over time to identify across- and within-year differences. Thus, allowing us to explicitly test the hypothesis that the association between urbanization and diet differs by income level over time. . These simultaneous linear regression models included interactions between income and urbanization and allowed associations with diet to change over time, while controlling for total caloric intake and for repeated measurements collected from the same individuals over time.

2. Materials and Methods

2.1. Study design and participants

We used data from the China Health and Nutrition Survey (CHNS), a prospective household-based study across 12 provinces (Heilongjiang, Liaoning, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou, Shaanxi, Yunnan, and Zhejiang) and 3 mega-cities (Beijing, Chonqing, and Shanghai) in China. Surveys began in 1989, with subsequent surveys every 2–4 years, for a total of 10 rounds between 1989 and 2015. Prior to 2011, the sample included only data from 9 provinces (Heilongjiang, Liaoning, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou) but three megacities were added to the sample in 2011 and three new provinces (Shaanxi, Yunnan, and Zhejiang) were added in 2015. The CHNS was designed to provide representation of rural, urban, and suburban areas varying substantially in geography, economic development, public resources, and health indicators (Popkin et al., 2010) and is the only large-scale, longitudinal study of its kind in China. A stratified, multistage, clustered sampling design was used to select the sample within each province or mega-city. Specifically, two cities (one large and one small city – usually the provincial capital and a lower income city) and four counties (stratified by income: one high, one low, and two middle income counties - for a total of four counties per province) were selected. Within cities, two urban and two suburban communities were selected; within counties, one community in the capital city and three rural villages were chosen. Twenty households per community were then selected for participation. Over time many of these rural areas remain rural while others experience some urbanization. The study met the standards for the ethical treatment of participants and was approved by the Institutional Review Boards of the University of North Carolina at Chapel Hill and the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention. Participants gave informed consent for participation. More detailed survey procedures can be found elsewhere (Popkin et al., 2010; Zhang et al., 2019).

2.2. Analysis sample

The eligible sample for this analysis included 23,355 adults aged 18–75 seen during at least one of the 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, or 2015 exams (82,112 observations [obs]). To ensure comparability over time, we excluded individuals living in the three mega-cities added in 2011 and the three new provinces added in 2015. We excluded observations when an individual was pregnant (obs = 452), when the individual was missing income (obs = 1831) or urbanization (obs = 2) or missing covariate data (obs = 986 missing physical activity data, obs = 92 with unreasonable and obs = 2339 with missing caloric intake data). This resulted in the exclusion of individuals who were pregnant or had missing data at all available survey waves. Specifically, as seen in the flow chart in Fig. 1, we excluded a total of 995 individuals due to: pregnancy at time of exam (n = 82), missing household income data (n = 224), physical activity (n = 86), or unreasonable ($\geq$10,000 or $\leq$ 500) or missing caloric intake (n = 11 and 592, respectively), resulting in an analytic sample of 22,360 individuals (mean: 3.4 exam visits). Compared to the 995 individuals excluded due to pregnancy or missing data at all available exams, the 22,360 in the analytic sample included a higher proportion of females and older adults, had higher income, lived in more urban areas, had higher total caloric intake, and higher percent of calories from animal source foods. Response rates for the CHNS are complex since individuals, or a household, can miss one survey and then return at the next survey. Response rates from one survey round to the next ranged from 68.7% to 88.1% across the full period of follow-up (Zhang et al., 2019).

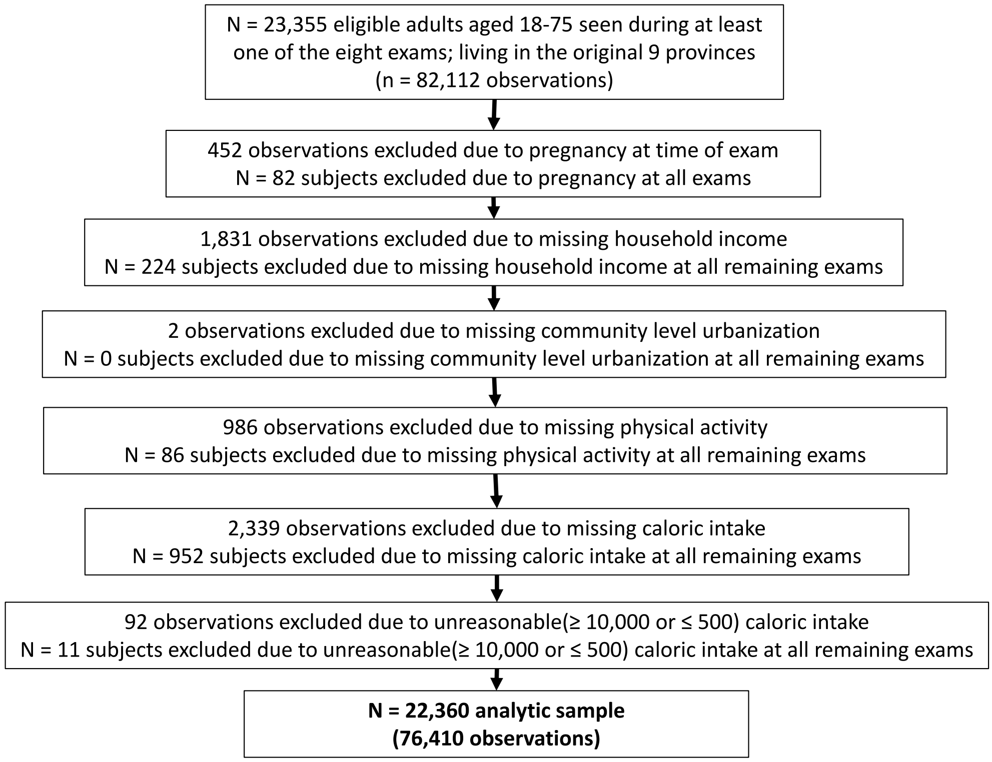

Fig. 1. Flow diagram for inclusion and exclusion.

2.3. *Diet measures*

At each survey visit, participants completed three consecutive day 24-h dietary recalls and a household inventory (He et al., 2011; Zhai et al., 1996). For the 24-h dietary recalls, trained interviwers recorded the types of foods and the amounts consumed. For the housheold inventory, every day all foods in the household were measured and this data was used to generate a food inventory. We used Chinese food composition tables to derive total caloric intake and caloric intake from animal-source food groups (dairy, meat, and eggs) directly from complex recipes (i.e., mixed dishes) (Popkin et al., 2002). We used average total daily caloric intake across the repeated 24-h recall data, which was validated using doubly labeled water (Yao et al., 2002). Previous research demonstrated differences in urbanized diet reflecting a "Northern" pattern, high in wheat products, maize or tubers, and a "Southern" pattern, high in rice, vegetables, seafood, pork and poultry (Li et al., 2011; Zhang et al., 2008). These provincial differences create lack of comparability in urbanized diet patterns across China. Thus, we used a consistent marker of urbanized diet, % animal source foods, which we have shown to be a consistent marker of urbanization across all provinces and regions (Popkin et al., 2015; Zhai et al., 2014). We calculated percent of calories from animal source foods (% of calories from animal-source foods) using total consumption of any animal source food or food product, including dairy products, which was our indicator of Western diet (Popkin & Du, 2003).

2.4. *Main exposure variables*

To capture the complex process of urbanization, we used the multi-component and validated continuous index, derived from 12 components (i.e., population density, economic activity, traditional markets, modern markets, transportation infrastructure, sanitation, communications, housing, education, diversity, health infrastructure and social services) (Jones-Smith & Popkin, 2010). The urbanization index captures the full spectrum from rural to urban environments, with lowest urbanization classified using this index considered rural. Given the dramatic increase in urbanization over the study period, we defined year-specific tertiles of urbanization (low, medium, and high urbanization) for a measure of relative urbanization that retains comparability over time.

We derived household income from individual and household questionnaires from time-use, asset, and economic activity at each survey and inflated to 2015 yuan currency for comparability over time. To capture relative income level at each survey wave, income was categorized into wave-specific tertiles.

2.5. *Independent variables*

Age and sex were self-reported at each survey. We categorized age based on *a priori* classifications as young adulthood (18–35 years) middle adulthood (35–55 years), and older adulthood (55–75 years) for statistical models to account for any potential non-linear association between age and dietary measures. Region was categorized as Northern, Central, or Southern China.

We used a detailed weekly physical activity recall to measure occupational and domestic physical activity, which constituted the vast majority (>94% of weekly METs activity on average) of the physical activity for this population. Metabolic equivalents of task (MET) hours per week were calculated for occupational and domestic activity using the Compendium of Physical Activity (Ainsworth et al., 1993, 2000, 2011). Details on how METs were calculated can be found elsewhere (Ng et al., 2009; Ng & Popkin, 2012). A total physical activity variable was defined by summing the total MET hours per week of occupational and domestic activity.

2.6. *Statistical analysis*

In descriptive analyses, we examined individual-level characteristics at baseline and the final study year (1991 and 2015) across tertiles of urbanization (low, medium, and high). Differences in characteristics by urbanization level were tested by unadjusted linear regression and chi-squared tests with statistical significance set at the $p < 0.05$ level. We conducted all descriptive analyses in SAS 9.4.

We used MPlus 8.1 (MPlus, Los Angeles, California, USA) for statistical modeling. We used simultaneous linear regression models to estimate percent of calories from animal-source foods and total caloric intake over 24 years of surveys (9 time points), accounting for the correlation between percent of calories from animal-source foods and total caloric intake, while testing for differences by survey year. Using these models, we tested the hypothesis that the association between urbanization and diet differs by income level over time. We used simultaneous regression models to estimate across and within year differences, while accounting for the correlation between total caloric intake and percent of calories from animal source foods. We accounted for within-individual correlation over time using complex survey standard errors via the Huber-White sandwich estimator (Skinner et al., 1989). The main exposures in our model were income (in wave-specific tertiles), urbanization (in wave-specific tertiles), and time. Model fit was assessed using a Root Mean Square Error of Approximation (RMSEA) < 0.06 (Hu and Bentler, 1998), and Comparative Fit Index (CFI) (Bentler, 1990) and Tucker-Lewis Index (TLI) (Tucker & Lewis, 1973) values approaching 1.0, suggesting good model fit with an RMSEA value of 0.02 with a 95% confidence interval of (0.02–0.03) and a CFI and TLI of 0.997 and 0.967 respectively. We tested for interaction between urbanization and income across all years and for between-year differences in this interaction, using Wald tests. We also tested for interactions within each survey year, using a Bonferroni correction to account for multiple comparisons. We controlled for region (North, Central, or South), total MET hours per week of physical activity, sex and age at each survey (18–35, 35–55, or 55–75) in all models. To aid interpretation of results, we used model coefficients to generate adjusted percent of calories from animal-source foods for every income and urbanization combination at each year. We generated these adjusted values for a given profile for a woman aged 18–35 years old living in the Southern region (the most common profile at baseline) with average MET hours per week of physical activity. We then present these differences in adjusted % calories from animal source food for low versus moderate, high versus low, and moderate versus high income at low, moderate, and high urbanization, holding age, sex, physical activity level, and region constant.

3. Results

3.1. Descriptive statistics

At baseline (1991), we observed differences in all measures (except sex) across low, moderate, and high urbanization (Table 1). Of note, percent of calories from animal source food differed widely (10% at low urbanization versus 21% at high urbanization), as did total calories (2756 kcals at low urbanization versus 2332 kcals at high urbanization) and calories from animal source foods (540 kcals at low urbanization versus 632 kcals at high urbanization). Similarly, baseline physical activity differed as well (580 METs at low urbanization versus 214 METs at high urbanization). Descriptive statistics by year can be found in Supplemental Table 1, including demonstration of relative comparability in low, medium, and levels of urbanization over time.

3.2. Simultaneous linear regression results

Parameter estimates from our simultaneous linear regression models are shown in Supplementary Table 1. To aid in interpretation of these model-based results, we present the adjusted % calories from animal source foods by income and across all urbanization levels at each year for an exemplar case, a woman aged 18–35 years old living in the Southern region with average MET hours per week of physical activity (Fig. 2, Table 2).

We found an increase in calories consumed from animal source foods over time across all urbanization and income levels. Across time, within each urbanization level highest consumption was at highest income levels and similarly within income level highest consumption was at highest urbanization levels. Conversely consumption of animal source foods was lowest at low urbanization and low income levels across time. Yet there was temporal variation in these patterns, with narrow differences at high income, low urbanized and low income, high urbanized areas. For example, in 1997, the adjusted percent of calories from animal source foods was 15.11% (0.54 SE) for participants of high income living in low urban areas and 15.37% (0.46 SE) for participants of low income in moderate urbanization areas. Yet, these differences in consumption of animal source foods became large in the middle years of follow up (1997–2007), ranging from 9.75% at low urban, low income to 29.37% in high urban, high income in 1997 for our exemplar profile. By 2015, we saw a reduction in the range in percent of calories from animal source foods across urbanization and income levels (e.g., 27.41% in low income, low urbanization to 35.58% in high income, high urban areas).

Within income levels, adjusted percent calories from animal source food was higher in high versus low urbanization areas (Supplemental Table 1). Yet, within-income category differences diminished in later years. For example, at low urbanization levels, the high-low income differences in percent calories from animal source foods went from 16.9% to 11.3% (5.6 percentage points) in 1991 and from 30.55% to 27.41% (3.1 percentage points) in 2015. In contrast, in high urbanized areas, the high-low income differences in percent calories from animal source foods rose from 23.03% to 20.18% in 1991 and lowered from 35.58% to 32.55% in 2015.

We found that urbanization modified the association between income and percent of calories from animal source foods overall ($p < 0.0001$; Wald test for overall differences in the association across all years) and the magnitude of this association differed by study year ($p < 0.0001$; Wald test for differences in effect modification by year). After

Table 1
Characteristics of CHNS participants at baseline (1991) by urbanization category.

		Low Urbanization	Moderate Urbanization	High Urbanization	P-value for Test of Differences by Urbanization
% Female		52%	54%	53%	0.4542
Age Group	18-35y	40%	44%	39%	<.0001
	35-55y	44%	39%	36%	
	55-75y	15%	17%	25%	
Region	North	4%	16%	14%	<.0001
	Central	41%	36%	33%	
	South	55%	49%	53%	
Income	Low	45%	37%	19%	<.0001
	Moderate	33%	29%	37%	
	High	23%	34%	45%	
Total caloric Intake – mean (std)		2756 (721)	2537 (637)	2332 (606)	<.0001
Calories from animal source foods – mean (std)		520 (415)	507 (384)	632 (400)	<.0001
% Calories from animal source foods – mean (std)		10% (12%)	14% (12%)	21% (12%)	<.0001
Total MET hrs/wk – mean (std)		580 (220)	468 (262)	214 (145)	<.0001

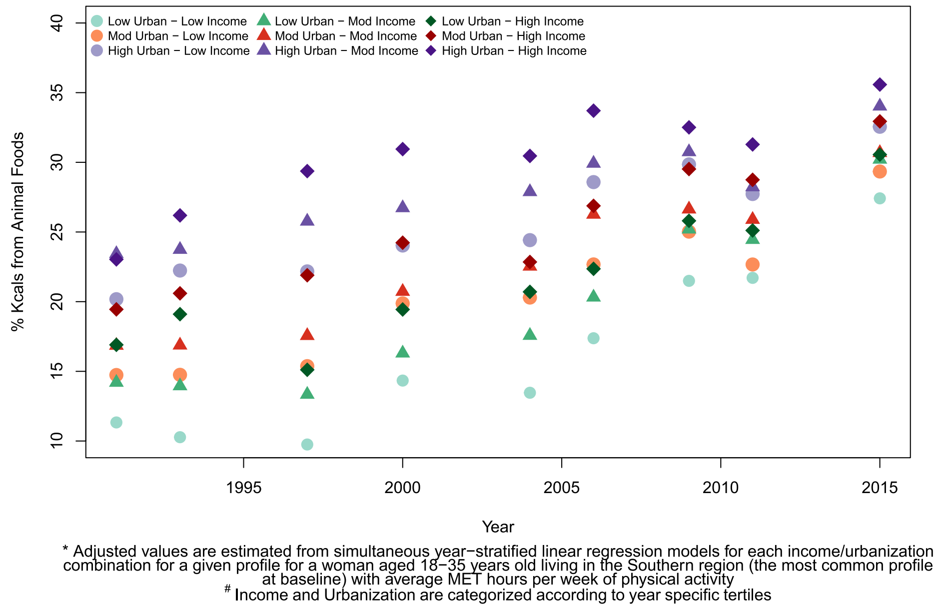

Fig. 2. Percent of calories from animal source foods* over time by urbanization and income level category#: Estimated from simultaneous year-stratified linear regression models.

Table 2
Model-based, adjusted Percent of Calories from Animal Source Foods (SE) Over Time* by Urbanization and Income Levels.

	Low Urban			Moderate Urban			High Urban		
	Low Income	Moderate Income	High Income	Low Income	Moderate Income	High Income	Low Income	Moderate Income	High Income
1991	11.33% (0.43)	14.2% (0.48)	16.9% (0.55)	14.74% (0.46)	16.85% (0.49)	19.45% (0.46)	20.18% (0.63)	23.44% (0.46)	23.03% (0.42)
1993	10.27% (0.42)	13.95% (0.51)	19.1% (0.68)	14.75% (0.5)	16.87% (0.51)	20.6% (0.49)	22.23% (0.63)	23.74% (0.48)	26.19% (0.43)
1997	9.75% (0.41)	13.34% (0.49)	15.11% (0.54)	15.37% (0.46)	17.56% (0.43)	21.9% (0.42)	22.17% (0.6)	25.77% (0.47)	29.37% (0.43)
2000	14.34% (0.45)	16.3% (0.49)	19.44% (0.56)	19.88% (0.53)	20.73% (0.49)	24.23% (0.5)	24.03% (0.61)	26.73% (0.52)	30.95% (0.46)
2004	13.46% (0.45)	17.57% (0.49)	20.7% (0.59)	20.3% (0.56)	22.54% (0.53)	22.85% (0.52)	24.42% (0.64)	27.88% (0.52)	30.46% (0.45)
2006	17.38% (0.5)	20.32% (0.53)	22.36% (0.67)	22.67% (0.57)	26.26% (0.54)	26.88% (0.51)	28.58% (0.62)	29.92% (0.54)	33.71% (0.49)
2009	21.49% (0.52)	25.2% (0.55)	25.8% (0.56)	25.03% (0.49)	26.64% (0.49)	29.52% (0.5)	29.85% (0.61)	30.75% (0.52)	32.51% (0.49)
2011	21.71% (0.56)	24.45% (0.56)	25.11% (0.65)	22.67% (0.58)	25.89% (0.55)	28.75% (0.56)	27.73% (0.61)	28.23% (0.53)	31.28% (0.51)
2015	27.41% (0.59)	30.21% (0.61)	30.55% (0.67)	29.34% (0.58)	30.69% (0.6)	32.94% (0.56)	32.55% (0.71)	34.02% (0.56)	35.58% (0.53)

* Using model-based coefficients from simultaneous linear regression models estimating percent of calories from animal-source foods and total caloric intake over 24 years of surveys (9 time points), accounting for correlation between percent of calories from animal-source foods and total caloric intake, while testing for differences by survey year, these adjusted % Calories from Animal Source Foods are shown for every income and urbanization combination at each year for an exemplar profile, a woman aged 18–35 years old living in the Southern region with average MET hours per week of physical activity

adjusting for multiple comparisons, these income differences in consumption of animal source foods were particularly marked in 1991, 1993 and 2004 ($p < 0.001$; Wald test for effect modification within each year). While we found suggestive evidence of income differences in 2006, 2009, and 2011, these differences disappeared in 2015, based on Bonferroni corrected p-values, with similar consumption of animal source foods across income and urbanization levels.

3.3. Model-based adjusted income and urbanization differences

Given the difficulties in interpreting the model coefficients with these complex interaction terms, we used these coefficients, shown in Supplementary Table 2, to produce adjusted differences in percent consumption of animal source foods between high and moderate income and between high and low income adjusted income gradients across urbanization levels for all years (Fig. 3). In this Figure, the larger income differences across urbanization level for 1991, 1993, and 2004 are evident. In 1991 and 1993 there were smaller income gradients in high urban areas. For example, in 1993 the difference in adjusted % calories from animal source food between low and high income at low urbanization was 8.83% (0.69 SE) compared to a difference of 3.96% (0.67 SE) between low and income at high urbanization. However, by 2004 the smallest income gradients were in the moderate urbanization areas and by 2015 income gradients were similar across urbanization levels.

4. Conclusions

Among Chinese adults, consumption of animal source foods, a key marker of Westernized diet, increased substantially over a 24-year period, rising from 15% to 24% from 1991 to 2015 as areas moved from rural to more urban. Throughout the earlier stages of urbanization, we found clear income gradients in animal source food consumption across levels of urbanization, ranging from rural to more highly urbanized. In 1991 these income gradients were most prominent at low and moderate urbanization levels. In 2004, there were larger income differences in low and high urbanized areas compared to moderate urban areas. This shifted in 2006, 2009, and 2011 when income differences were generally smallest in moderate or high urbanized areas. However, by 2015, these income gradients had almost disappeared with similar consumption of animal source foods across all levels of urbanization, even at the rural end of the spectrum.

These observed differences underlie the observed time-varying differential association between urbanization and Western diet, by income. In the earliest waves, 1991 and 1993, we found comparatively larger differences in consumption of animal source foods in low and moderately urban (versus high urban) areas, suggesting a potential buffering of

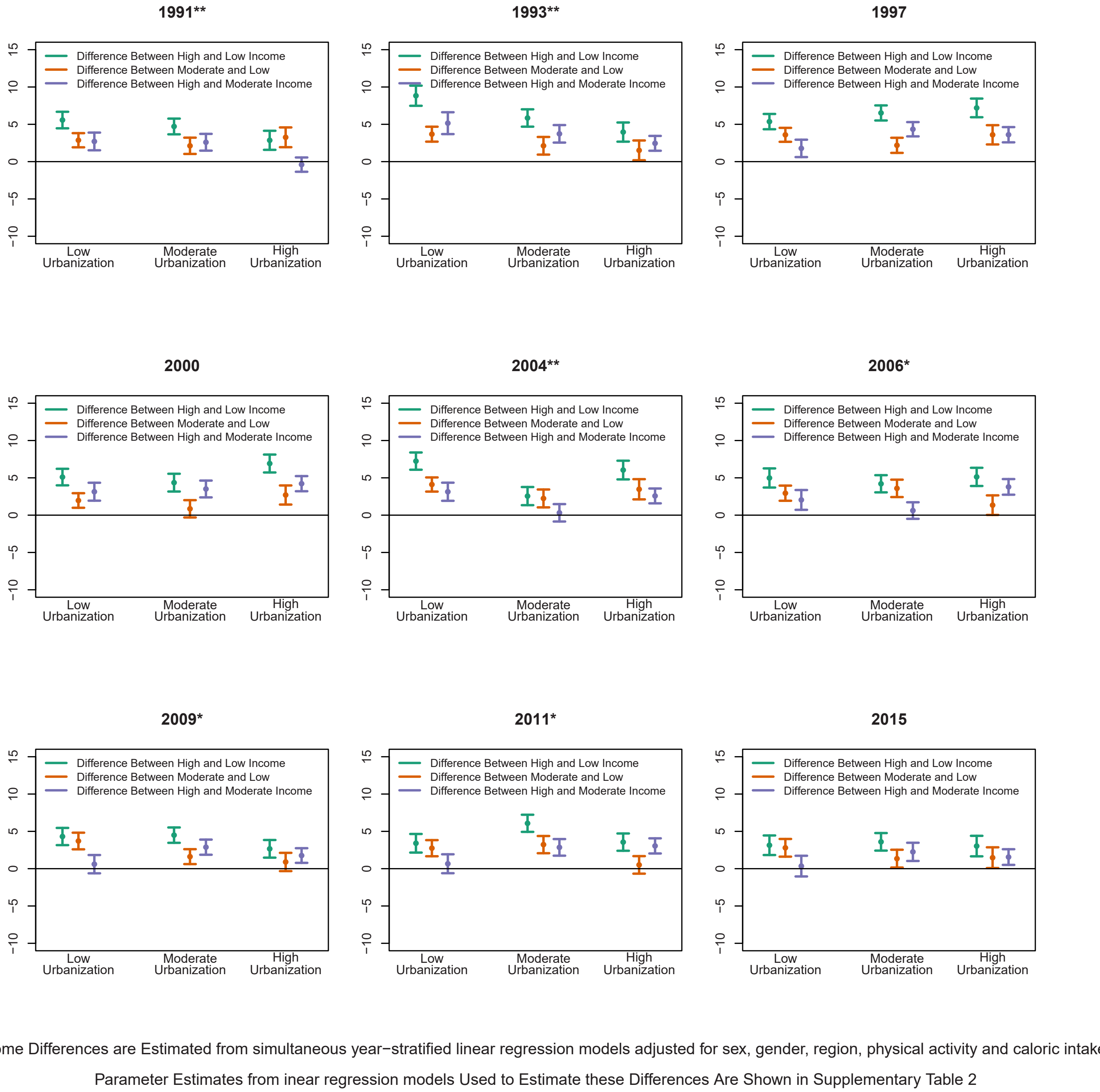

Fig. 3. Average income differences* in percent calories from animal source food by urbanization level: Estimated from simultaneous year-stratified linear regression models.

urbanization-related changes in diet across income levels. These larger income-related differences in animal source food consumption in the low- and moderately urban areas at early waves could relate to increased access to Westernized foods for individuals of high income even if they lived in less urbanized areas. In contrast, at earlier stages of urbanization access to Western foods may have been affordable across all income levels in the most urban areas. In 1997 and 2000, differences in animal source food consumption by income were relatively consistent across urbanization level, potentially due to more widespread availability of Western foods across all areas of China, even the most rural areas. It is also possible that the nutrition transition brought increased health consciousness for higher income individuals across China, resulting in a deceleration in the urbanization-related increases in animal source food intake among high income individuals. Yet at the same time, low income individuals who were first becoming exposed to more modern foods may have had social or prestige incentive to consume Western foods, leading to higher consumption for these groups. From 2004 to 2011, we observed a return of more pronounced income gradients at certain urbanization levels, in which case income served to buffer urbanization-related changes in diet in high urban areas. By 2015, as in 2000, we observed again found no statistical difference in income gradients across urbanization levels.

Using our simultaneous regression models, we observed secular increases in the percent of calories from animal source foods for all urbanization (even in the most rural areas) and income groups over 24 years. Furthermore, we observed overall increases in animal source food consumption regardless of urbanization or income with a narrowing of the range across all urbanization and income categories. Thus, differences in the percent of calories consumed from animal-source foods by urbanization and income narrowed over time as more rural and lower income individuals “caught up” to more urbanized and higher income individuals.

In addition, at several waves individuals of high income living in moderately urban areas differed only slightly in percent of calories from animal source food from individuals of low income, living in highly urbanized areas at any survey year. For example, in 1991 the adjusted estimate of average calories from animal source foods was 22.30% (0.57 SE) for a high income living in moderately urban areas and 23.03% (0.65 SE) for a low income individual living in a high urban area. A similar pattern emerged at several waves when looking at high income individuals in low urban environments compared to low-income individuals in moderate urban environments.

The literature on the increasing burden of lifestyle-related diseases in urbanizing countries has provided limited insights into the association between urbanization and income with lifestyle behaviors (Schmidhuber & Shetty, 2005). Most studies have not addressed population-level changes in lifestyle behaviors with urbanization due to a paucity of detailed, longitudinal dietary data in population-based samples. Instead, researchers have used cross-sectional data to examine static associations between Westernized diet and disease outcomes by urbanization (Mendez & Popkin, 2004; Monteiro et al., 2004; Popkin et al., 2012; Popkin & Slining, 2013) or income (Monteiro et al., 2007; Popkin & Slining, 2013; Prentice, 2005). The few studies which have examined these questions using longitudinal data focus on how the associations between urbanization (Pingali, 2007; Regmi & Dyck, 2001, pp. 23–30) or income (Du et al., 2004) vary over time but have not explored how the impact of income on the relationship between urbanization and diet and health outcomes changes over the course of urbanization (Miao & Wu, 2016).

Cross-country comparisons suggest that in the initial stages of urbanization, there is higher obesity and CVD risk in more urban versus rural areas and in high versus low income individuals, but these differences in risk narrow over time in urban versus rural areas (Dearth-Wesley et al., 2008; Jaacks et al., 2014; Popkin & Slining, 2013) and by low versus high income (Dearth-Wesley et al., 2008; Jones-Smith et al., 2011; Monteiro et al., 2007). Rarely have studies examined interactions between income and urbanization in relation to Westernizing diet while incorporating timing of urbanization-related changes (Popkin et al., 2012; Schmidhuber & Shetty, 2005), resulting in limited understanding of the scope of urbanization-related dietary changes across different sociodemographic subgroups.

In contrast to these earlier studies, we examined within-country variation in dietary behaviors across the full scope of urbanization (from rural to highly urbanized) and income over a period of rapid urbanization. Thus, our study provides insight into the appropriate subpopulations to target for interventions to reduce diet-related CVD risk. Our findings point to diminishing differences in the percent of calories from animal-source foods in more versus less urban communities over time, reflecting expansion of Westernized diet behaviors in more rural communities (Du et al., 2004). Further, in less urban areas, high versus low income was associated with higher total percent of calories from animal-source foods across almost all time points.

Thus, even in the initial stages of urbanization, individuals of low income residing in more rural areas should be targeted to reduce chronic disease-related Westernized diet behaviors. However, animal-source foods might be difficult to intervene on because of their cultural value. In this analysis, we used animal-source foods as a marker of a Westernized dietary pattern, and thus, our findings point to subpopulations who may benefit from dietary interventions to improve overall healthfulness of the diet, not simply targeting the consumption of animal products. Our analysis is in line with findings from earlier longitudinal studies from China that have found that in less urban areas, the prevalence of overweight has increased over time and differed by socioeconomic status (Dearth-Wesley et al., 2008; Jones-Smith et al., 2012).

While our findings make a substantial contribution to the literature on the nutrition transition in low-middle income countries, there are some limitations of note. First, we focused only on animal-source foods. We did so because these foods are highly relevant markers of urbanized diet and are consistent as markers of urbanization across different regions of China, and, as such, they provide an important illustration of the nature of dietary changes in China (Popkin & Du, 2003; Popkin et al., 2015). Second, as with any study reporting statistical significance, there is the possibility that some of our findings in some years might be statistically significant by chance instead of reflecting true between year differences. However, with sample sizes in the similar range at all years (Supplementary Table 1), we have adequate power at all years to detect similarly small differences within each year. In addition, we used a Bonferroni correction, one of the most conservative methods, to account for multiple comparisons. Additionally, like all large-scale epidemiologic studies, we do not have a direct measurement of energy expenditure, and thus we are unable to determine whether an individual's total calories simply reflect their energy requirements necessary for a stable body weight, or whether they are consuming excess (or deficient) calories. Similarly, our study was not designed to address the impact of increases in the percent of calories from animal-source foods on health in Chinese adults. However, the CHNS is one of the only longitudinal, population-based studies with weighed and measured food intake data, and as such, is unique in that we can even measure and study quantitative calories and the percent of calories from animal-source foods. Thus, our work is an important first step in understanding individual-level dietary intake during a period of urbanization.

Despite these limitations, our analysis has the great strengths of using a rich, longitudinal data set with detailed, time-varying measures of urbanization, income, and diet to address critical gaps in the literature on differential changes in dietary behaviors over a period of urbanization.

Over a period of rapid urbanization in China, we observed more rapid dietary changes in more rural areas, resulting in narrowing differences in dietary behaviors in more versus less urban areas. Because income gradients in dietary behaviors remained in less urbanized areas even as the percent of calories from animal source foods became more similar in more versus less urbanized areas over time, tailored nutrition-related policies for urban and rural areas in countries undergoing urbanization may be necessary. Further, our findings suggest that implementing dietary intervention early in the urbanization process is important in both urban and rural areas in low-middle income countries to help shape the nutrition transition towards more healthy eating options.

Declaration of interest form

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Author statement

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Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2021.100943.

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