Economics
Working Papers

2021-03

Offspring Migration and Nutritional Status of Left-behind Older Adults in Rural China

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Abstract

Improvements in nutritional status is a principal pathway to good health. This study examines the effect of migration of adult children on the nutrient intake of left-behind older adults in rural China. We use data from four waves (2004–2011) of the China Health and Nutrition Survey and utilize individual fixed effects methods to panel data. Results show that the migration of offspring is associated with significantly higher nutritional status of their left-behind parents, especially higher intake of proteins, carbohydrates, vitamins B1–B3, phosphorus, magnesium, iron, selenium, and copper. The intake of some of these nutrients is below recommended levels. The magnitude of the estimated effects vary between 4% and 24%. Older adults who live with their grandchildren in rural households or have a low income benefit more from having adult child migrants in the household. The improvement of nutrition outcomes of left-behind older adults is mainly due to increased consumption of cereals, meat, eggs, and fish.

Keywords: Offspring migration, Nutrient intake, Food composition, Left-behind older adults

JEL codes: J61 I15 O12

Acknowledgments: We thank the UNC Carolina Population Center for providing the data. We are very grateful to the editor and two referees for their constructive suggestions. We also thank Zhigang Xu; Xu Tian; Kunlun Wang; the seminar audiences at the Institute for Social Research at Stockholm University, Xiamen University of Technology and Sichuan University; and the participants at the 33rd Annual Conference of the European Society for Population Economics for their helpful comments and suggestions. We gratefully acknowledge the financial support from the National Natural Science Foundation of China (Grant Nos.: 72003091 and 71673137) and the Project of Philosophy and Social Science in Colleges and Universities of Jiangsu Province (Grant 2020SJA0120). Most of the work on this paper was conducted when the first author was a visiting doctoral student at Aarhus University (2018–2019), funded by a grant from the China Scholarship Council.

1. Introduction

The Chinese population is aging rapidly as the result of falling mortality rates at younger ages and decreasing fertility rates. In the next 10 years, the percentage of people in China age 60 years and above is expected to double, from 12.2% (167 million people) in 2010 to 24.8% (364 million) in 2030 (UN DESA, 2019). Coinciding with the aging trend, China has experienced a massive wave of internal migration over the past decades (Lee and Park, 2010; Liu, 2014). China's *hukou* (household registration) system and the high living costs and healthcare expenditures in urban areas make it difficult for adult children to have their parents living with them. As a consequence, the large-scale rural-to-urban migration has geographically separated many adult children from their aging parents, which contributes to even more rapidly aging populations in rural areas. By 2030, the proportion of people age 60 years and above in rural and urban areas will be 21.8% and 14.8%, respectively (Cai and Wang, 2005). Some recent studies have investigated how migrant offspring affects the physical and psychological health of left-behind older adults (Ao et al., 2016; Song, 2016; Yi et al., 2019). In the current study, we examine the effect of migrant offspring on a major determinant of left-behind parents' health, that is, the level of their nutrient intake and its composition.

Nutrition is known to be a vital factor in healthy aging (de Groot et al., 2004). Malnutrition (defined as deficiency, excess, or imbalanced intake of energy, protein, and other nutrients) is more common in older population (Ahmed and Haboubi, 2010). The National Chronic Disease Risk Factor Surveillance Survey (2010) indicates that the prevalence of insufficient diet is 56.6% for people over 60 years old and slightly higher for older women (58.5%) than men (54.6%). The prevalence of insufficient nutrient intake of macronutrients, vitamins, macroelements, and trace elements is considerably higher among older people in China (Chor et al., 2013; Zhang et al., 2014; Shi et al., 2015). Moreover, poor diets are more common among rural residents (60%) than in urban populations (49.5%), and the average intake of nutrients is considerably lower among rural older adults than their urban counterparts (NCCNDC, 2012). Given that the population in China is aging rapidly, problems with insufficient nutrition among older adults can worsen, especially in rural areas.

Rural old adults usually have worse functional status, and they are more depressed than their urban counterparts (Zimmer et al., 2010; Li et al., 2015). In addition to large differences in income and healthcare systems, differences in nutritional status (Biao, 2007; Chang et al., 2011; He and Ye, 2014) has been found to be a key determinant of the large urban–rural health differential (Fang et al., 2009; Liu et al., 2013). Malnutrition is strongly associated with negative physical health outcomes (Stratton et al., 2003; Brownie, 2006). Undernutrition is an important predictor of morbidity and mortality, associated with an increased risk of complications that lead to a decline in functional status and survival time (Omran and Morley, 2000; Chen et al., 2001; Vellas et al., 2001). Pollution and population density are considerably greater in urban areas where people are less physically active. This phenomenon tend to reduce the urban–rural divide; however, the urban–rural disparities in health seem large, and older adults left behind are one of the most vulnerable groups.

This study aims to examine the effect of offspring migration on the nutritional status of left-behind older adults in rural China. For this purpose, we use a rich panel data from four waves (during the period of 2004–2011) of the China Health and Nutrition Survey (CHNS) and utilize individual effects methods to control for unobservables. We find strong and robust evidence that the nutritional status of the left-behind parents of adult child migrants is significantly better than for those living in households without migrant offspring. The nutritional status of left-behind older adults who live together with their grandchildren or in lower-income households is improved more by their offspring's migration. The left-behind older adults' higher nutrient intake is mainly explained by their higher consumption of cereals, meat, eggs, and fish. The higher nutrient intake associated with migrant offspring is predominantly driven by migrant sons.

The remainder of this paper is organized as follows. Section 2 reviews some of the related empirical literature, and Section 3 describes a conceptual framework to link offspring migration to nutritional status among older adults. Section 4 describes the empirical framework and data used in the study, and the estimation results are presented in Section 5. The final section concludes the study and suggests some topics for further research.

2. Literature review

Studies from several countries have demonstrated that migration is closely related to the health of left-behind household members (Kanaiaupuni and Donato, 1999; Hadi, 1999; Nguyen et al., 2006; Abas et al., 2009; Antman, 2010, 2013; Sharma, 2013; Böhme et al., 2015). However, the evidence remains mixed regarding how migration affects household members, young children, and older adults. On the basis of the Indonesian Family Life Survey, Kuhn et al. (2011) find a positive link between migration and parental health outcomes, such as activities of daily living, self-rated health, and mortality. Böhme et al. (2015) find positive migration effects on body mass index, functionality, and self-rated health of left-behind older adults in Moldovia.

However, migration has not only been found to positively affect left-behind family members. Lee and Park's (2010) results for rural China indicate that fathers' migration has a negative effect on the psychosocial wellbeing of left-behind boys and girls. Conversely, Abas et al. (2009) find that the migration of children is not associated with increased depression for older parents in a study based on survey data from rural Thailand. For Mexico, Antman (2010) find a statistically significant relationship between migrant children and poor parental health outcomes, that is, lower self-reported health quality, including mental health, and a higher prevalence of heart attacks and strokes.

The effect of migration can be divided into the effects of remittances and the loss of household labor. The sign of the migration effect on the health of left-behind family members depends on whether the positive effects of remittances compensate for the negative effects from loss of labor, including the time spent taking care of left-behind family members (Yi et al., 2019).

Only a few studies have analyzed the effect of migration on food consumption and nutrition. Generally, a higher income plays an important role in reducing food insecurity and malnutrition (Azzarri and Zezza, 2011). As noted by Quartey (2006), remittances are used to maintain consumption in the poorest migrant households. Karamba et al. (2011) find that the migration in Ghana increases the overall food expenditures only in high migration regions; thus, the overall effect is rather small. For Vietnam, Nguyen and Winters (2011) explore the relationship between short- and long-term migration and household food consumption patterns, as measured by per capita food expenditures, per capita calorie consumption, and food diversity. Their results indicate that short-term migration has a positive effect on the overall food consumption through increased per capita food expenditures and greater per capita calorie consumption. In addition to food expenditures and caloric intake, Romano and Traverso (2019) also make use of dietary diversity indicators and find that international migration has a significantly positive effect on all food security indicators in a study on data from Bangladesh.

Most studies of nutritional outcomes have focused on left-behind children in rural areas. de Brauw (2011) finds higher child height-for-age z-scores (HZA scores) in rural households in El Salvador that send out migrants and in the context of rapidly increasing food prices and declining child HZA scores. On the basis of the analysis of data from Tajikistan Living Standard Study Survey, Azzarri and Zezza (2011) conclude that migration plays a positive role in enhancing child growth (as measured by HZA scores) via increases in households' calorie consumption. Gibson et al. (2011) find evidence of left-behind children in Tonga experiencing declines in HZA scores and weight-for-age scores (WZA scores), whereas those who migrate together with their parents to New Zealand have higher HZA and WZA scores. For rural China, similar effects are documented in the study of Mu and de Brauw (2015), in which parental migration is found to have a positive effect on the weight of children; no significant effect is found on their height.

Evidence directly describing the link between the migration of adult children and the nutritional status of left-behind older adults is scant. Studies usually pay attention to the consequence of malnutrition on health outcomes, such as a decline in function status, immune dysfunction, delayed recovery from surgery, and mortality (Stratton et al., 2003; Ahmed and Haboubi, 2010; Chor et al., 2013). Zhang et al. (2014) find in northern parts of rural China severe deficiencies in folate and vitamin B12, as well as a high prevalence of hyperhomocysteinemia among older adults. Chor et al. (2013) find that less than half of older people fulfil the recommended intake levels, and less than 10% meet the required daily intake of fiber, calcium, vitamin D, iodine, and copper.

This study is related to a rather small literature on the effects of adult children's behaviors on their older parents. Thus, although numerous scholars have studied how parental human capital affects their offspring as adults, considerably less research is available on the effect of adult children's education on their parents' health. Some recent exceptions aiming at establishing causal effects include Lundborg and Majlesi (2018) and De Neve and Fink (2018) on the effect of children's education on parents' longevity, Ma (2019) on parental health and cognition, and Jiang and Kaushal (2020) on children's caregiving to parents during their last years of life. A major challenge in these studies is the endogeneity of offspring's education. The current study faces the same issue regarding the endogeneity of adult children's migration.

3. Conceptual framework

Migration can influence the nutrition of left-behind household members through a number of channels (see Zezza et al. (2011) for a summary). The remittances from migrants can have direct and indirect effects on food consumption and nutrition. Migration implies fewer members in household, which indicates not only a higher per capita food consumption but also loss of family farm labor. Migrant household members can possibly obtain information, which is transmitted to left-behind members and improves their knowledge of healthy nutrient intake. Although distinguishing the effect of information from migrants and income from remittances is difficult, both are expected to enhance nutrition outcomes (Karamba et al., 2011). As the effect of migration may be positive and negative, the overall effect of migration on nutrition is ambiguous; and the effect on nutrition may vary with individual, household, and community characteristics.

Thus, the relationship may differ by individual characteristics of older adults. In comparison with older men, the nutritional status of older women is, on average, lower; thus, learning whether possible gains in nutritional status are equally shared by males and females is a topic of interest. Another comparison is between households living with grandchildren and those without. In China, family assistance typically flows down the generations, and an important type of assistance is caring for grandchildren, which is especially the case in rural areas. Earlier research of the health effect of caring for grandchildren has produced evidence of positive and negative effects (Waldrop and Weber, 2001; Pruchno and Mckenney, 2002; Hughes et al., 2007; Ku et al., 2012). Adult migrants may send back more remittances to their left-behind parents if the remittances are taking care of the grandchildren, and this situation can have an additional positive effect on the household's daily diet. In rural areas, remittances from migrant household members play an instrumental role in adding to rural households' typically low monetary incomes (Stark and Levhari, 1982; Stark and Bloom, 1985). Hence, we also test the effect of migration on the nutrition outcomes of older adults living under different financial conditions.

In addition, the gender of migrant offspring may play a crucial role. According to the Confucian filial piety family system, which is strongly rooted in rural areas, the family is the main provider of old-age support, and sons are particularly expected to take on this responsibility, whereas daughters are expected to mainly take care of their husbands' family members. This notion suggests that the effect of migrant children may have differences depending on their gender. One hypothesis is that migrant sons send more remittances to their parents than daughters do. To examine this hypothesis, rural older adults are divided into four groups, those who (i) have no migrant children, (ii) have only migrant sons, (ii) have only migrant daughters, and (iv) have migrant sons and daughters.

To the best of our knowledge, the current study is the first to investigate the effect of adult child migration on the nutrient intake and food consumption patterns of left-behind older adults in rural China while controlling for a host of other determinants. Considering the heterogeneity of the old population in rural areas, we examine the nutrient intake response to migration among different subsamples. We also test for differences in nutrition outcomes of older adults with regard to the gender of migrant children. Malnutrition causes several illnesses for older adults, but it is also likely to reduce the quality of their lives before they become ill or disabled. Thus, it is an additional reason why it is important to enhance our understanding of the determinants of deficient nutrient intake among older people in rural China.

4. Data and empirical framework

4.1 Empirical model

We specify a reduced form of relationship between children's migration status and nutritional outcomes of their parents. Consider an older individual i in year t; one of his nutrient intakes is assumed to be determined by

$$N_{it}^{j} = \beta_0 + \beta_1 M_{it} + \beta_2 X_{it}^{I} + \beta_3 X_{it}^{H} + \beta_4 X_{it}^{V} + T_t + u_i + \delta_c v_t + \varepsilon_{it} \qquad j = 1, 2, \ldots, 21, \qquad (1)$$

where N_{it}^{j} refers to the jth nutritional outcome of individual i in year t; M_{it} refers to the migration status of children within the household; X_{it}^{I} denotes the older adults' individual characteristics (i.e., age, marital status, employment status, and health status); X_{it}^{H} represents household characteristics (i.e., household per capita income, household size, and age, gender, and education level of the main cook in household); X_{it}^{V} is the village-level characteristics (i.e., food price level, accessibility to markets, and regional advantages); T_t denotes the time fixed effects, including year–month dummies; u_i denotes the individual fixed effects; $\delta_c v_t$ is an interactive term of village fixed effects and year fixed effects; and ε_{it} is the idiosyncratic error term (See Section 4.4 for more details about the measurement of dependent and independent variables.).

We estimate the above equation with an individual fixed effects model, allowing us to control for time-invariant individual characteristics, as well as time-varying village-level characteristics. In computing standard errors, we need to consider the potential correlation in the residuals across households. As individuals from the same family might have similar dietary patterns, we estimate robust standard errors by clustering on households.[1] In regression where standard errors are cluster-robust and the fixed effects are nested within clusters, the statistical significance of the coefficients can be overstated and lead to incorrect inference if singletons exist, that is, observations from only one of the four waves (Cameron et al., 2011; Correia, 2015). Consequently, singletons are dropped from the estimation sample for all regressions.[2]

4.2 Endogeneity

Migration is a choice. In addition to the determinants of migration emphasized by standard economic models (Sjaastad, 1962), the migration decision in the current context can be affected by parents' health status, which is strongly correlated with their nutrient intake. Consequently, the estimates of the effect of migration can be biased due to sample selection, that is, due to the offspring being more likely to migrate when their parents are in good health (Kuhn et al., 2011). Shared observable and unobservable factors of migrant children and their parents, such as genetic predisposition and dietary habits, can also give rise to biased estimates. Moreover, unexpected shocks and accidents outside households, such as natural disasters (e.g., drought and flood) may simultaneously affect the offspring's migration decision and the nutritional status of left-behind older adults, giving rise to omitted variable bias.

We attempt to account for the endogeneity of offspring migration with a dual approach, that is, controlling for more confounding variables in the estimation and through an improved modeling design, namely, a panel data model. First, as chronic diseases are chiefly influenced by genetic and long-term determinants and are not likely to be causally affected by recent migrant episodes (Böhme et al., 2015), we use the number of chronic diseases as a proxy variable for the general health status of older adults. We

[1] We also attempt to estimate standard error clustering on villages obtaining similar results.
[2] Estimations with singletons included are shown in Table B4 of Appendix B.

include several individual-, household-, and village-level control variables to reduce unobserved heterogeneity that is likely to affect offspring migration and the nutritional status of older adults.

Second, we use fixed effects to control for unobserved individual heterogeneity. We initially estimate a model for the nutritional status of older adults, including individual fixed effects and time fixed effects to account for time-invariant unobservables; this model constitutes a two-way fixed effects model.[3] Furthermore, we include interactive fixed effects of each village and survey time to reduce potential bias caused by time-varying unobservables at the village level, such as natural disasters (e.g., drought and flood) and other shocks to farming. Interactive effects represent unobservable common shocks and their heterogeneity effects on cross sections (Bai, 2009). The same natural and geographical environment guarantees that the omitted time-varying unobservables are highly likely to be shared by individuals within villages. Therefore, the village-level interactive term can control for the time-varying unobservables to some extent.

4.3 Data

Our empirical analysis is conducted on data from the CHNS, collected by the Carolina Population Center at University of North Carolina at Chapel Hill, the Institute of Nutrition and Food Hygiene, and the Chinese Academy of Preventatives Medicine. CHNS is a longitudinal survey covering nine provinces (i.e., Henan, Hubei, Heilongjiang, Liaoning, Shandong, Guizhou, Jiangsu, and Hunan), which vary substantially regarding geography, economic development, public resources, and measures of health conditions. A multistage, random cluster process is used to draw the samples that can be treated as representative of the Chinese population. A detailed description of the survey design can be found on the CHNS webpage: https://www.cpc.unc.edu/china/about/proj_desc/survey and in the survey by Zhang et al. (2014). Extensive information is collected on individual, household, and community levels, such as demographics, work activities and income, lifestyle and food consumption, and measures of physical and mental health. Most importantly, for this study, dietary intake at the individual level is surveyed by 24-hour recalls for three consecutive days, asking the individuals to report all their food consumption for each day, at home and away from home.

We construct a panel dataset based on four waves from years 2004, 2006, 2009, and 2011.[4] Individuals include those who (1) reside in a rural household, (2) is of age 50 or older, and (3) has complete records of food intake for three days in the database.

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[3] Two-way fixed effects regressions estimate weighted sums of the average treatment effects (ATEs) in each group and period, with weights that may be negative. Negative weights may be an issue when the ATEs are heterogeneous across groups and periods. In the paper by de Chaisemartin and D'Haultfoeuille (2020), a new method is proposed to address this potential issue.

[4] The reason for not using earlier waves is that the CHNS changed its food code system in 2004.

In rural China, most children are expected to move out of their parents' home as they grow up and get married, establishing a new family or being household members of their spouses' family. At the same time, some of the siblings, usually sons, live together with and take care of their parents, sharing incomes and expenditures (Sun, 2002; Xie and Zhu, 2009). The offspring who remain household members and are registered as rural *hukou* holders are involved in close economic interactions within the household. In the subsequent analysis, older parents with migrant children constitute the treatment group, whereas those who have their adult children living together with them make up the control group. Thus, we only include in the sample the households with older parents who, according to the Chinese *hukou* system, are registered to live together with their offspring. We compare households in which none of the adult children are migrants with those in which at least one adult child is a migrant. Older adults who live alone or only together with other family members (no children in the household) are not included in our sample.

4.4 Variables and their measurement

4.4.1 Nutrient intake

Based on China Food Composition Vol. 1 (Second Edition, 2009) and Vol. 2 (2004), as well as the food consumption records in CHNS, we compute the three-day average intake of 21 nutrients for each respondent, which can be divided into four categories, namely, macronutrients, vitamins (lipid- and water-soluble vitamins), macroelements, and trace elements (For a detailed description, see Appendix A.).

4.4.2 Nutritional status of older adults

We need a nutrient reference index to obtain information about the nutritional status of older adults in rural China. The Chinese Dietary Reference Intakes (2017) provides a set of reference values that are used to plan and assess the nutrient intakes of healthy people in China. They vary by age and gender, and the most commonly used index is the Recommended Nutrient Intake (RNI),[5] which we also use in this study. RNI is the most comprehensive individual-level measure meeting the nutrient requirements of almost all (97%–98%) apparently healthy individuals in an age- and sex-specific population group. According to the Chinese Dietary Reference Intakes (2017), the Adequate Intake (AI) index should be used when evidence cannot sufficiently develop an RNI and is set at a level assumed to ensure nutritional adequacy.[6]

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[5] RNI is also called Recommended Dietary Allowance.

[6] Reference values are based on a representative sample in China (Chinese Nutrition Society, 2014). The AI numbers are marked with stars in Tables 1, 2, B1, and B2.

To make for an easier assessment when comparing the malnutrition (under- and over-) across nutrient groups that have different units, as well as when comparing malnutrition across gender and age groups that have different reference values, we construct the percentage of deviation (deficiency/excess) for each nutrient based on the RNI values by gender and age groups. Specifically, a negative value shows inadequate intake, whereas a positive value indicates the excess intake for each nutrient. The indicator is constructed as follows:

$$Deviation\ (\%) = \frac{Nutrient\ \ intake - RNI}{RNI} \times 100\%. \qquad (2)$$

Older adults are divided into three subgroups by gender and age and matched with their corresponding RNI values. Table 1 shows the average nutrient intake of older men for each age group. All age groups have moderate or severe deficits in their dietary energy intake. The oldest group (age 80 years and above) suffers from the most seriously inadequate energy intake (374 kcal or 17% lower than RNI per day). Protein intake levels are below recommended for the two oldest age groups. However, for the youngest age group, the average protein intake is 9.6% (around 6 g) higher than the RNI.

Similar patterns are observed for vitamin intake, and vitamin deficiency is common. The average intake of vitamins A and B2 is particularly low, around 50% lower than the RNI. In rural China, the main cause for the prevalence of vitamin deficiency is likely due to insufficient diet and lack of nutritional knowledge (WHO, 2015). Vitamin deficiency can cause a number of diseases or syndromes. For instance, vitamin A deficiency can cause keratomalacia; vitamin B1 deficiency causes beriberi and Wernicke–Korsakoff syndrome; and vitamin B2 and B3 deficiency can cause ariboflavinosis and pellagra, respectively. Short-term deficiency of vitamin C can lead to weakness, weight loss, and general aches and pains, and longer-term and persistent deficiency may affect the connective tissue and lead to scurvy.

For the macroelements, older men consume extremely low quantities of calcium, amounting to 33%–40% of recommended levels (RNI). Insufficient intakes of calcium over long time periods may cause osteopenia (low bone mass) and increases the risk of osteoporosis and bone fractures, which are especially harmful for older adults. Similarly, potassium and magnesium intakes are lower than the RNI for each age group. The gap between the average intake and RNI is largest for the oldest age group. By contrast, phosphorus and sodium intakes are considerably higher than their RNI levels. Especially, sodium intake is two times higher than the RNI, but decreases with age. One reason may be the dietary habit of eating salted products, which has been associated with negative health outcomes (He and Macgregor, 2008; Strazzullo et al., 2009).

Of the trace elements, the average intake of iron, copper, and manganese are higher than the RNI in each age group; whereas zinc and selenium intakes do not meet the recommended standards. Insufficient zinc intake is closely related to certain symptoms, such as hair loss, lack of alertness, a decreased sense of smell and taste, and loss of appetite. Selenium deficiency can cause muscle weakness, mental fog, and weakening of the immune system.

Table 2 shows the average nutrient intakes of older women. As expected, nutrient deficiency is prevalent among older women in rural areas. They consume less food and thus have lower nutrient intake levels in comparison with their male counterparts.[7] The average nutrient intakes of urban older adults are shown in Tables B1 and B2 of Appendix B. Similarly, in urban China, older adults, males and females, have moderate or severe deficits in various nutrients, and the oldest groups suffer from the most seriously inadequate nutrient intake. However, a comparison between urban and rural areas suggest that malnutrition is not necessarily higher among rural older adults but varies by nutrients, gender, and age group. Overall, for most nutrients, lower intake level is observed for older adults in rural areas, especially for proteins, fats, vitamins, calcium, and selenium; the higher carbohydrate intake among older adults in rural areas could be due to their higher consumption of staple food.

4.4.3 Migration

In the CHNS, data on migrant status of household members come from the household roster. Each household member is asked about the reason for his/her absence if he/she is not residing in the household at the time of the interview. One of the answers is employment elsewhere.[8] The subsequent question is about the duration of the absence. We define offspring seeking employment elsewhere for more than three months as migrants. We use two measures for the key explanatory variable—presence of migrant offspring in the household. First, a simple dummy variable indicates whether the older adults have migrant children in their households. Second, in view of the variation in the number of children and migrant offspring, we use the proportion of migrant children in the household.

Two reasons can explain why rural migrants do not bring their families with them to urban areas and thus leave their family members behind. One is simply that they cannot afford it because of their low wages and the high urban living costs. The other is the *hukou* system, which creates obstacles for migrants to move with their children or parent(s) to urban areas.[9]

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[7] The nutritional status of older adults who live alone or live with other household members are also included in Tables 1, 2, B1, and B2.

[8] Other options for one’s absence in the roster are: 1) in education elsewhere, 2) doing military service, 3) moved abroad, and 4) others. International migration (“moved abroad”) is rare and is not included among migrants.

[9] The *hukou* refers to the household registration system according to which every Chinese citizen is registered as a resident in a specific place and with a rural or urban *hukou*. Although the earlier strong barriers to mobility between

Most migrants lack social security in urban areas and will, for these and other reasons, return to their families (Davin, 1996). For instance, if an adult child migrated in 2004 and returned in 2006 (or in later waves), then the family would be recorded as having a migrant in 2004 but as not having one in 2006. Obviously, the existence of return migrants can contaminate the estimated effect of migration.[10] Therefore, we remove all families with return migrants from the sample.

4.4.4 Control variables

The individual characteristics of older adults, as well as household- and village-level variables, are included as controls. More specifically, the individual characteristics include age, marital status, employment status, and number of chronic diseases (as proxy variable for general health status of older adults); whereas household characteristics include the number of household members, per capita annual income, and age, gender, and education level of the main cook in household.[11] Moreover, we enter village-level controls that have been suggested by earlier studies to affect left-behind older adults' nutrient intake, such as the number of food markets and dummy for being close (within two hours bus ride) to an open trade area or special economic zone (Huang and Tian, 2019). The price level within villages can also affect households' consumption choices and nutrient intake (Schroeter et al., 2008; Cornelsen et al., 2014). Therefore, village-level market prices of rice, vegetables, and pork are entered as controls in the estimations.

In addition to yearly variation, seasonal differences in the availability of food ingredients can also rise to variations in nutrient intake (Shell-Duncan, 1995; Sellen, 2000; Fujita et al., 2004; Astrup et al., 2008; Du et al., 2014). Notably, the CHNS is not conducted simultaneously in each province (survey dates range from July to December for each wave). Thus, we construct and include year–month dummies to eliminate seasonal diet variations of left-behind older adults.

Table 3 reports the descriptive statistics of nutrient intake and control variables, where the total sample is divided into two subgroups: the left-behind older adults and the older adults without migrant children in their household. A little over half of older adults are in households without migrant children. Of those who have migrant offspring, the average is 1.4, indicating that having two or more children who are migrants is not

rural and urban areas have been loosened up, city governments can still impose restrictions on employment of migrants and particularly make it extremely expensive for them to bring their families with them; see Knight and Song (2005) for detailed description and analysis.

[10] Large-scale migration from rural to urban areas is a fairly new phenomenon in China. In the CHNS database, 0.3% of all individuals surveyed between 2000 and 2004 were return migrants. Thus, we do not consider migrants returning before 2004 to be a major concern in our analysis.

[11] Household cook is not the same as the household head; it is the person who spends the longest time cooking for his/her household members.

uncommon. Households with migrant offspring differ from those without in some aspects; they are slightly younger and more likely to work, although their per capita household income is approximately 30% lower.

We further compare the differences in the distribution of nutrient intake between older adults with migrant children and those whose children are not migrants at the time of the surveys. The percentage deviation from the RNI is used in comparing the nutrient intake distributions. As shown in Figure 1, the distribution of dietary energy, protein, and carbohydrate intakes for left-behind older adults with migrant children lies to the right of that for older adults without migrant offspring. The difference between the distributions for fat intake is small, and the distributions for dietary fiber intake do not seem to differ.

For vitamins (see Figure 2), a distinct difference in the distributions can be observed for vitamin B3; whereas for vitamins B1, B2, and C, the distributions for older adults with migrant children have slightly thicker upper part tails. A similar pattern with a slightly thicker upper tail can be observed for the macroelements and the trace elements in Figures 3 and 4. Another feature of the data that stands out from Figure 2 is that most peak values of the distributions are to the left of zero (vitamin E is an exception), indicating a prevalent deficiency of vitamins among older adults. The variance of intake differs considerably between nutrient categories; it is largest for macronutrients and small for macro- and trace elements.

5. Estimation results and discussion

5.1 Baseline estimates

Our baseline estimates are displayed in Table 4.[12] To save space, we only report the coefficient of the key variable from each regression with the percentage deviation from the RNI for the 21 nutrients as the dependent variable.[13] Error terms of left-behind older adults within the same household may plausibly be correlated. To account for this, we estimate the model clustering on the household level.

As shown in Table 4, the hypothesis that adult offspring migrants have positive effects on left-behind older parents' nutrient intake is supported. The coefficients of the key variable, having migrant children in the household, are significantly positive for dietary energy, proteins, carbohydrates, vitamin A, vitamins B1–B3, phosphorus, potassium,

[12] In Appendix B, estimates with singleton groups are reported in Table B4. Although the standard errors are smaller, coefficient significance levels are virtually unchanged, indicating the same direction and magnitude of effect.

[13] In view of the probability of over-rejection of the null hypothesis in multiple inference, we adjust the p-values of the baseline results by computing the sharpened false discovery rate q-values (Benjamini et al., 2006; Anderson, 2008). As shown in Table B3, for the majority of nutrients, sharpened q-values are larger than unadjusted p-values, whereas the other of which are smaller than its unadjusted counterparts. Overall, the sharpened q-values indicate similar results with the baseline estimates.

magnesium, iron, selenium, and copper. The magnitude (marginal effect) of the estimated effects vary between 4% and 24%. As each coefficient refers to the marginal effect on the deviation for the RNI of the corresponding nutrient, Table 3 provides the benchmark—reference mean values for each nutrient (deficiency/excess) when interpreting the magnitude and the sign of the coefficient. The comparison of the percentage of deviation for older adults in Table 3 show significantly lower deficiency in vitamins (A, B1, and B2) and macro- and trace elements (potassium, magnesium, and selenium) among the older adults with migrant children. Moreover, some nutrients of which the older adults have an excess consumption, such as carbohydrates, phosphorus, copper, and iron, are even higher in households with by migrant children. Notably, excess intake will not cause adverse health effects, unless individuals' nutrient intake is below the tolerable upper intake level (UL). Hence, excessive intake is not a concern in our analysis because no abovementioned nutrients have met the UL.[14] In addition, not all nutrients are affected by offspring migration. Large deficits are observed in calcium and vitamin C intakes among older adults in rural areas, and offspring migrants seem to have no effect on the consumption of these nutrients.

In Table 4, the estimates in Column (2) are from a specification with interactive fixed effects to correct for possible biases caused by time-varying unobservables, such as natural disasters and other shocks to older adults. The latter seems to be of little concern because the differences between Columns (1) and (2) are small. Moreover, the results in Table 5, where the offspring migrant dummy is replaced by the proportion of offspring who are migrants, are qualitatively similar for the simple dummy specification in Table 4.

Turning next to the gender of the offspring, we begin by briefly describing the gender composition of migrant children (Table 6). The majority of older adults with migrant children (1,538 observations) have migrant sons, either only migrant sons (1,128 observations) or migrant sons and daughters (204 observations). Table 7 reports the coefficients to three dummies capturing the gender composition; the omitted category is those without migrants. The results show that the parents in households with exclusively male migrants or male and female migrants have significantly higher nutrient intake, whereas for most nutrients, older adults with only female migrant offspring do not differ from those with no migrant children.[15] Thus, the improvement of nutritional status among left-behind older adults comes mainly from their sons' migration behaviors. However, because of the small subsample size, we should be careful in interpreting the results as decisive evidence that daughters' migration has a negligible effect on their left-behind parents' nutrient intake.

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[14] The UL of phosphorus for the older adults is 3000–3500 mg/day, copper is 8 mg/day, and iron is 42 mg/day (Chinese Nutrition Society, 2014). Evidence was insufficient to set a UL for carbohydrates. However, the 1997 FAO/WHO Expert Consultation and the 2002 WHO/FAO Expert Consultation recommended that the total carbohydrates should provide 55%–75% total energy (Mann et al., 2007).

[15] Two exceptions: older adults with female migrants consume more proteins and vitamin A.

In conclusion, the regression estimations of the fixed effects models provide strong and robust evidence of migrant offspring's positive effect on the nutritional status of left-behind older adults in rural China. Within rural households, the higher nutritional status among older adults is more pronounced for those with migrant sons who also make up the majority of migrant offspring.

5.2 Heterogeneity analysis

We subsequently examine subsamples of rural older adults with different individual characteristics to understand how adult migrants affect their left-behind parents' nutrient intake.

First, we compare the migration effect by gender of left-behind parents. The estimates are shown in Columns (1) and (2) of Table 8, which indicate that adult child migration improves the nutritional status of left-behind parents of both genders. The estimates for macronutrients (dietary energy, proteins, and carbohydrates), microelements (phosphorus, potassium, and magnesium), and most trace elements (iron, selenium, and copper) are qualitatively similar for the older adults, males and females. Although both benefit from adult child migration, female older adults probably benefit more from offspring migration than their male counterparts because the intakes of vitamins A, B2, and zinc are only statistically significant for females.

Columns (3) and (4) of Table 8 show that migrant children are associated with a higher dietary energy intake of their left-behind parents, regardless of their living arrangements with or without grandchildren. However, significant differences exist regarding the intake of macronutrients (proteins and carbohydrates), vitamins (A and B1–B3), and trace elements (iron and selenium). Older adults who live together with their grandchildren and have offspring migrants have significantly higher intake in the consumption of these nutrients, which is in accordance with the evidence of health improvements for grandparents documented in previous studies (Lou, 2010; Ku et al., 2012; Zhou et al., 2016). The likely mechanism behind the result is that grandchildren constitute an important link between adult children and older parents. Consequently, adult migrants may send back more remittances to their left-behind parents who are responsible for taking care of grandchildren. Moreover, spillover effects of grandchildren may also be observed in the household's daily diet. Especially, families with teenagers may focus more on their nutrient intake and try to keep a more balanced diet.

Next, left-behind older adults are divided into quartiles according to their per capita disposable income. Low- and high-income households are defined as belonging to the lowest and the highest quartile of the household income distribution in our sample, respectively. Estimates for these groups are shown in Columns (5) and (6) of Table 8. These results suggest that older parents in migrant households in both income quartiles are better off nutritionally. However, the effect is smaller for parents in the highest quartile, which be attributed to the remittances contributing relatively more to older adults in lower-income households.[16]

5.3 Food consumption patterns

The above analysis demonstrates that the left-behind older parents' nutrient intake is improved by having migrant offspring in their households. Next, we look at how adult child migration affects the left-behind older adults' food consumption patterns. More specifically, we investigate the changes of parents' consumption structure associated with offspring migrants.

For this purpose, we initially classify food consumption for each individual into four categories[17]: (1) cereals, mixed beans, tubers, and starches; (2) vegetables and fruits; (3) meat, poultry, eggs, fish, and shellfish products; and (4) soybean, nuts, and dairy products. As mentioned previously, the CHNS records three days of each individual's food consumption. For each individual, we compute the average of three days' food consumption (in grams) recorded by the CHNS.[18] Similarly, for each food category, we calculate the percentage deviation (deficiency/excess) from the Reference Daily Intake provided by the Chinese Food Pagoda (2016).[19]

Table 9 shows the estimates for the four food categories.[20] Older adults with migrant offspring consume more cereals, mixed beans, tubers, and starches and meat, poultry, eggs, fish, and shellfish products. The difference is also positive but insignificant for the other two categories. This finding is consistent with our baseline results, particularly the positive effect of offspring migrants on left-behind parents' intake of protein, vitamin B, iron, and phosphorus.

Notably, a higher consumption of meat, eggs, and fish is not necessarily beneficial for

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[16] We also look at the differences in diet knowledge among the older adults. Migrant offspring can transfer knowledge to their older parents about the healthier nutrition they have acquired by experiences outside the farm. The CHNS has some information about the respondents' dietary knowledge that can be used to create crude indicators of dietary knowledge. We find that parents with migrant offspring are more knowledgeable about healthy diets than those without migrant offspring. A more detailed analysis, which includes the relationship between dietary knowledge and nutrition, is a topic for future research.

[17] Although the survey dates were randomly chosen, each individual's food consumption should be summed up over three days because what people eat during a single day may overstate items consumed that day. For instance if you eat at home and have caught/bought fish, you might have for both lunch and dinner during the same day.

[18] Note that cakes, ethnic food and fast food are not included because of mixed food ingredients.

[19] According to the Chinese Food Pagoda (2016), the Reference Daily Intake of cereals and cereal products is 250–400 g (including mixed beans, tubers and starches), vegetables and fruit is 500–850 g, poultry and meat products is 40–75 g, aquatic products is 40–75 g, eggs and egg products is 40–50 g, dairy products is 300g, and soybean and nuts is 25–35 g. Values at the middle of the range are used as the reference values for each food category.

[20] We also looked at the consumption of liquor and alcoholic beverages and the absolute value is used as dependent variable since a Reference Daily Intake is not available. The estimate is very tiny and insignificant, indicating offspring migration has little, if any, effect on older adults' consumption of liquor and alcoholic beverages.

a person's health status and especially not for the older people population. If the left-behind older adults have sufficient food consumption, then more food with high calories and high fat content (e.g., meat and eggs) will not contribute to improving their health. Excess nutrition can be harmful. According to the Chinese Food Pagoda (2016), the Reference Daily Intake of meat, eggs, and fish is approximately 120–200 g, whereas the average intake level of rural older adults is 105 g (the intake level of older men is 114 g and 96 g for older women), which is considerably lower than the recommended quantity. Thus, excessive nutrition of meat, eggs, and dairy products is not a relevant concern in the case of most of older adults in rural China. The estimated magnitude of the higher consumption due to offspring migrants is sizable (7%–8%).

The average intake of vegetables and fruits is 334.1 g (the intake level of older men is 347.1 g and 321.5 g for older women), which is considerably lower than the Reference Daily Intake (500–850 g). However, we do not find significant effect on vegetable and fruit consumption among older parents with migrant offspring, which can be due to the relatively large supply of vegetables and fruits in rural areas. Moreover, they are mostly cheap. Although we control for household income, the difference observed can be due to an income effect because the level of incomes of older adults in rural areas is low. Income elasticities are higher for these food products in China (Chen et al., 2016).

5.4 Attrition

Attrition between the panel cohorts are also a potential source of bias in the estimates (Doyle et al., 2013; Howe et al., 2013). As older adults leave the sample, estimates may be biased if the missing individuals are systematically different from those included (Dillon et al., 2019; Briody et al., 2020). After dropping observations with missing information on any of the individual-, household-, or village-level characteristics used in the empirical analysis, we are left with 4528 observations (including singletons). Table 10 documents the attrition rates in the sample.[21] We also compare the baseline characteristics for older adults by attrition status (Table B5 of Appendix B). Generally, older adults with poor baseline characteristics (that is, tend to be older, less likely to work, in worse health status, and lower nutrient intake) are more likely to have missing data. Hence, the effect of offspring migration on nutrition may be underestimated in our estimations.

We address the issue of attrition by using the inverse probability weighting technique,[22] which is commonly used to address survey nonresponse and attrition (Jones et al., 2013). First, we estimate the probability of being a stayer using binary logit models, including all the regressors in the baseline model for each wave.[23] Standard errors are clustered

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[21] A similar table is used in Van de Poel et al. (2012).

[22] This method accounts for attrition bias caused by observable characteristics. It cannot be ruled out that unobservable characteristics may show bias estimates (Wooldridge, 2002).

[23] Take the 2004 wave as an example, a dummy variable is created, which is equal to 1 if the older adult appears in

at the village level. Second, we reweigh the regression estimates with the inverse of this predicted probability to correct for attrition bias,[24] in which older adults who have a lower probability of being a stayer are given a higher weight in the analysis, compensating for similar older adults who are missing (Wooldridge, 2007). Table 11 shows the inverse probability weighted results, which indicate no substantive differences when compared with the baseline results in Table 4.

6. Conclusions

In this study, we examine the relationship between the migration of adult children and the nutrient intake of left-behind older adults in rural China using data from four waves of the CHNS panel. The results clearly show that the older adults in rural areas have notable deficits in their intake of important nutrients, such as proteins, vitamins, and calcium. We control for a host of nutrient intake determinants, and our estimation results show that the nutritional status of older adults is significantly higher in households with adult child migrants than in those without. Thus, we find large or moderate improvement in intakes of dietary energy, proteins, and several vitamins. However, large deficits in vitamin C and calcium are not affected.

To account for the heterogeneity of left-behind older adults in rural areas, we study subsamples, classified by gender, living arrangements (with grandchildren or not), and household income levels. Overall, the results for the subsamples are consistent with the baseline estimates. The nutrient intakes of older adults, males and females, benefit from having migrant offspring. However, the magnitude of the positive effect for several nutrients is considerably higher for the older women. Left-behind grandparents, who live together with migrants' children, are more likely to consume food with more proteins, vitamins, and calcium than grandparents not living together with left-behind children. Adult migrants have a larger positive effect on their left-behind older parents in lower-income households.

To provide further insights into the food consumption of rural older adults, we test for how migration affects the structure of left-behind older adults' food consumption. The results indicate that migrant offspring is associated with a significantly higher consumption of cereal products, meat, eggs, and fish. The magnitude of the effect (evaluated at the mean) hovers around 10%. This finding explains the improvement of nutrition outcomes observed in the baseline estimations.

Establishing a relationship between migration and nutritional outcomes has important implications for policy, given that high-quality diets have been proven important means

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any following waves (2006–2011); and 0 otherwise, which indicates that the older adult is drop out of the study from this wave.

[24] Older adults in 2011 are adjusted with the average weight because of the lack of information after 2011.

of promoting healthy aging. Despite the estimated positive effect and important role that migration apparently plays, malnutrition in rural areas remains a challenging issue, especially for older Chinese people. More targeted action should be taken by dieticians and healthcare professionals to promote adherence to recommended dietary guidelines. In comparison with the nutritional benefit of offspring migration for older adults, other costs of migration, such as psychological effects in the long term, may be more hidden and deserve policy attention in rural areas.

A limitation of the CHNS data is that they do not provide information on remittances from migrant children and on food expenditures in the household. Therefore, the effect of migration on nutrient intake of left-behind older adults in our study is an overall effect, which includes the effect of the loss of labor and of remittances. Further research would benefit from more detailed data on migration patterns, remittances, and food expenditures. Further research into what improves dietary knowledge among older adults (as well as others in rural areas) would also be most valuable. A potential candidate as the transmitter of knowledge about healthier diets is migrant offspring.

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Table 1. Average nutrient intake of older men in rural China

Nutrient	Unit	50–64	RNI	Deficiency/Excess (%)	65–79	RNI	Deficiency/Excess (%)	≥80	RNI	Deficiency/Excess (%)
Macronutrients:										
Dietary energy	kcal	2438.93	2450	−0.5	2175.33	2350	−7.4	1825.60	2200	−17.0
Protein	g	71.24	65	9.6	62.51	65	−3.8	51.42	65	−20.9
Fat	g	78.62	20–30*	214.5	72.26	20–30*	189.0	65.57	20–30*	162.3
Carbohydrate	g	354.38	120*	195.3	315.60	120*	163.0	255.25	120*	112.7
Dietary fiber	g	11.39	25–30*	−58.6	10.13	25–30*	−63.1	8.31	25–30*	−69.8
Lipid-soluble vitamins:										
Vitamin A	μg	437.11	800	−45.4	428.50	800	−46.4	373.76	800	−53.3
Vitamin E	mg	33.68	14*	140.5	31.33	14*	123.8	28.48	14*	103.4
Water-soluble vitamins:										
Vitamin B1	mg	1.06	1.4	−24.3	0.94	1.4	−33.1	0.76	1.4	−45.9
Vitamin B2	mg	0.77	1.4	−44.9	0.70	1.4	−50.3	0.61	1.4	−56.4
Vitamin B3	mg	15.23	14	8.8	13.28	14	−5.2	10.86	13	−16.4
Vitamin C	mg	83.36	100	−16.6	81.47	100	−18.5	61.68	100	−38.3
Macroelements:										
Calcium	mg	395.44	1000	−60.5	389.33	1000	−61.1	328.95	1000	−67.1
Phosphorus	mg	1058.09	720	47.0	943.26	700	34.8	772.61	670	15.3
Potassium	mg	1750.47	2000*	−12.5	1619.32	2000*	−19.0	1293.63	2000*	−35.3
Sodium	mg	5171.80	1400*	269.4	4940.89	1400*	252.9	4251.42	1300*	227.0
Magnesium	mg	328.64	330	−0.4	302.17	320	−5.6	243.71	310	−21.4
Trace elements:										
Iron	mg	22.74	12	89.5	20.72	12	72.7	16.57	12	38.1

Zinc	mg	12.42	12.5	−0.6	11.16	12.5	−10.7	10.02	12.5	−19.8
Selenium	μg	46.09	60	−23.2	40.23	60	−32.9	32.99	60	−45.0
Copper	mg	2.07	0.8	158.3	1.86	0.8	132.0	1.51	0.8	89.1
Manganese	mg	7.10	3.5*	102.8	6.38	3.5*	82.2	5.03	3.5*	43.8
Number of observations			4074			1717			177	

Notes: RNI is the daily intake, which meets the nutrient requirements of nearly all (97%–98%) apparently healthy individuals in an age- and sex-specific population groups. Nutrients for which no RNI (numbers with *) is available are replaced by the AI. RNI and AI are based on Chinese Dietary Reference Intakes (2017).

Table 2. Average nutrient intake of older women in rural China

Nutrient	Unit	50–64	RNI	Deficiency/Excess (%)	65–79	RNI	Deficiency/Excess (%)	≥80	RNI	Deficiency/Excess (%)
Macronutrients:										
Dietary energy	kcal	2106.38	2050	2.8	1885.74	1950	−3.3	1608.94	1750	−8.1
Protein	g	61.29	55	11.4	53.99	55	−1.8	44.06	55	−19.9
Fat	g	71.76	20–30*	187.0	67.16	20–30*	168.6	60.92	20–30*	143.7
Carbohydrate	g	311.89	120*	159.9	273.17	120*	127.6	224.20	120*	86.8
Dietary fiber	g	10.45	25–30*	−62.0	8.92	25–30*	−67.6	6.66	25–30*	−75.8
Lipid-soluble vitamins:										
Vitamin A	μg	405.20	700	−42.1	419.09	700	−40.1	396.12	700	−43.4
Vitamin E	mg	32.52	14*	132.3	29.60	14*	111.5	24.98	14*	78.4
Lipid-soluble vitamins:										
Vitamin B1	mg	0.91	1.2	−24.3	0.80	1.2	−33.3	0.66	1.2	−45.1
Vitamin B2	mg	0.68	1.2	−43.4	0.62	1.2	−48.5	0.54	1.2	−55.1
Vitamin B3	mg	13.01	12	8.4	11.38	11	3.5	9.08	10	−9.2
Vitamin C	mg	79.43	100	−20.6	73.07	100	−26.9	54.35	100	−45.6
Macroelements:										
Calcium	mg	358.53	1000	−64.1	343.58	1000	−65.6	301.71	1000	−69.8
Phosphorus	mg	923.50	720	28.3	816.81	700	16.7	669.88	670	0.0
Potassium	mg	1583.11	2000*	−20.8	1396.71	2000*	−30.2	1095.59	2000*	−45.2
Sodium	mg	5051.89	1400*	260.8	4815.98	1400*	244.0	4082.98	1300*	214.1
Magnesium	mg	293.68	330	−11.0	261.91	320	−18.2	208.77	310	−32.7
Trace elements:										
Iron	mg	20.32	12	69.4	18.39	12	53.2	14.57	12	21.5

Zinc	mg	11.40	7.5	52.0	9.64	7.5	28.5	7.39	7.5	−1.5
Selenium	μg	39.35	60	−34.4	33.66	60	−43.9	28.05	60	−53.3
Copper	mg	1.84	0.8	129.7	1.63	0.8	103.4	1.30	0.8	61.9
Manganese	mg	6.29	3.5*	79.6	5.47	3.5*	56.3	4.60	3.5*	31.4
Number of observations			3771			1719			179	

Notes: RNI is the daily intake, which meets the nutrient requirements of nearly all (97%–98%) apparently healthy individuals in an age- and sex-specific population groups. Nutrients for which no RNI (numbers with *) is available are replaced by the AI. RNI and AI are based on Chinese Dietary Reference Intakes (2017).

Table 3. Summary statistics

Variables	All		Older adults without migrant children		Older adults with migrant children		Test of difference in variables between two groups
	Mean	S.D.	Mean	S.D.	Mean	S.D.	
Nutrient intake:							
Dietary energy	0.91	31.93	−2.70	29.44	5.30	34.22	***
Protein	8.75	40.49	7.57	39.84	10.19	41.22	*
Fat	182.92	154.73	172.25	150.55	195.89	158.76	***
Carbohydrate	182.84	107.00	169.62	96.40	198.92	116.65	***
Dietary fiber	−6.03	2.76	−6.06	2.57	−5.98	2.98	-
Vitamin A	−42.76	66.29	−46.98	64.74	−37.62	67.79	***
Vitamin E	113.68	158.18	116.68	156.71	110.02	159.93	-
Vitamin B1	−23.25	35.66	−24.31	34.26	−21.97	37.26	*
Vitamin B2	−45.59	23.17	−45.44	24.45	−45.77	21.52	-
Vitamin B3	8.69	49.29	4.88	48.03	13.32	50.40	***
Vitamin C	−18.01	68.31	−21.06	62.58	−14.31	74.53	***
Calcium	−62.84	29.41	−63.40	28.06	−62.16	30.96	-
Phosphorus	37.36	54.50	34.77	51.56	40.50	57.74	***
Potassium	−17.12	43.80	−19.06	41.59	−14.77	46.24	***
Sodium	241.29	316.33	236.68	300.08	246.91	335.03	-
Magnesium	−5.36	42.72	−7.93	40.23	−2.24	45.39	***
Iron	77.57	87.95	73.43	87.44	82.61	88.35	***
Zinc	22.00	146.82	21.93	160.59	22.09	128.15	-
Selenium	−33.03	37.84	−31.96	36.58	−34.32	39.28	*
Copper	145.89	115.71	139.43	109.55	153.73	122.36	***
Manganese	96.13	160.03	92.66	169.48	100.35	147.68	-
Food consumption:							
Cereals, mixed beans, tubers, and starches	38.77	59.39	32.41	52.89	46.50	65.64	***
Vegetables and fruits	−50.50	26.87	−52.46	25.40	−48.11	28.38	***
Meat, poultry, eggs, fish, and shellfish	−34.38	55.18	−33.22	56.97	−35.78	52.91	-

Soybean, nuts, and dairy products	−85.09	21.97	−84.52	23.21	−85.78	20.34	*
Individual characteristics:							
Age	59.53	7.24	59.99	7.59	58.98	6.75	***
Male	0.49	0.50	0.49	0.50	0.50	0.50	-
Married	0.87	0.33	0.86	0.35	0.89	0.31	***
Education in years	5.18	3.95	5.43	4.08	4.88	3.76	***
Dummy for working	0.59	0.49	0.49	0.50	0.71	0.45	***
Number of chronic diseases	0.21	0.49	0.24	0.54	0.17	0.43	***
Household characteristics:							
Per capita income in thousand yuan	7.89	9.33	9.05	10.17	6.48	7.98	***
Number of household members	3.47	1.55	4.09	1.49	2.70	1.26	***
The percentage of having more than one child	0.34	0.47	0.20	0.40	0.52	0.50	***
Age of household cook	55.52	10.94	54.43	11.94	56.84	9.41	***
Male household cook	0.17	0.37	0.14	0.34	0.21	0.40	***
Household cook’s education (in years)	4.79	4.01	5.27	4.16	4.21	3.73	***
Village-level characteristics:							
Market price of rice (500 g/yuan)	1.60	0.43	1.57	0.39	1.63	0.47	***
Market price of vegetables (500 g/yuan)	1.40	1.25	1.29	1.30	1.53	1.17	***
Market price of pork (500 g/yuan)	9.11	3.41	8.56	3.11	9.79	3.62	***
Number of markets in the resident village	3.74	6.52	4.62	7.69	2.67	4.49	***
Dummy variable for being close to an open trade area or special economic zone (within two hours by bus)	0.40	0.49	0.40	0.49	0.41	0.49	-
Number of observations	3408		1870		1538		

Notes: *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Estimation of the effect of migration on left-behind older adults' nutrient intake (fixed effects model)

	Independent variable: Having migrant children	
	(1)	(2)
Dietary energy	7.492***	7.014***
	(2.611)	(2.675)
Protein	10.733***	10.390***
	(3.205)	(3.318)
Fat	17.912	14.365
	(12.656)	(13.515)
Carbohydrate	23.079***	22.830***
	(8.396)	(8.510)
Dietary fiber	0.154	0.311
	(0.190)	(0.190)
Vitamin A	6.114	13.157**
	(5.011)	(5.125)
Vitamin E	7.412	0.987
	(12.051)	(11.115)
Vitamin B1	7.559***	7.747***
	(2.832)	(2.816)
Vitamin B2	3.972**	4.244**
	(1.920)	(1.902)
Vitamin B3	10.238**	12.360***
	(4.031)	(3.972)
Vitamin C	0.666	4.793
	(5.504)	(5.552)
Calcium	0.357	0.664
	(1.834)	(1.857)
Phosphorus	11.833***	11.422***
	(3.775)	(3.915)
Potassium	2.415	5.151*
	(3.199)	(3.045)
Sodium	−41.979	−34.332
	(31.599)	(31.020)
Magnesium	4.666	6.264*
	(2.982)	(3.198)
Iron	14.755**	18.891**
	(7.095)	(7.610)
Zinc	−2.940	3.438
	(11.838)	(7.548)
Selenium	7.562**	6.836**
	(3.071)	(2.776)

Copper	18.771**	24.160**
	(9.190)	(9.655)
Manganese	1.184	8.573
	(18.465)	(17.612)
Individual FEs	Yes	Yes
Time FEs	Yes	Yes
Interactive FEs	No	Yes
Number of observations	3408	3365

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the household level. Interactive fixed effects are an interactive term of village fixed effects and year fixed effects. To save space, only the key variable (having migrant children) is reported for each regression. The full set of results is available upon request.

Table 5. Estimation of the effect of migration on left-behind older adults' nutrient intake (fixed effects model)

	Independent variable: The proportion of migrant children	
	(1)	(2)
Dietary energy	8.569***	9.172***
	(2.995)	(3.152)
Protein	12.732***	12.318***
	(3.722)	(3.918)
Fat	24.160	26.976*
	(14.765)	(15.946)
Carbohydrate	23.977**	26.538***
	(9.459)	(9.914)
Dietary fiber	0.145	0.323
	(0.229)	(0.231)
Vitamin A	0.534	7.855
	(6.391)	(6.585)
Vitamin E	17.999	10.860
	(14.153)	(13.264)
Vitamin B1	8.958***	8.938***
	(3.198)	(3.293)
Vitamin B2	2.953	3.633*
	(2.170)	(2.185)
Vitamin B3	9.159*	13.975***
	(4.686)	(4.614)
Vitamin C	0.780	10.316*
	(6.086)	(6.134)
Calcium	1.307	3.824
	(2.186)	(2.512)
Phosphorus	13.392***	13.160***
	(4.451)	(4.681)
Potassium	1.724	6.862*
	(3.677)	(3.874)
Sodium	−23.350	−8.542
	(37.706)	(32.159)
Magnesium	5.804*	8.622**
	(3.450)	(3.844)
Iron	16.803**	22.300**
	(8.342)	(8.883)
Zinc	−11.514	−5.278
	(17.625)	(11.560)
Selenium	10.029***	8.938***
	(3.557)	(3.237)

Copper	22.700**	29.247***
	(10.513)	(11.113)
Manganese	2.008	10.291
	(20.693)	(18.745)
Individual FEs	Yes	Yes
Time FEs	Yes	Yes
Interactive FEs	No	Yes
Number of observations	3408	3365

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the household level. Interactive fixed effects are an interactive term of village fixed effects and year fixed effects. To save space, only the key variable (the proportion of migrant children) is reported for each regression. The full set of results is available upon request.

Table 6. Gender composition of migrant offspring

	Sample	Number of male migrants	Number of female migrants
Have only male migrant offspring	1128	1.24	-
Have only female migrant offspring	195	-	1.30
Have male and female migrant offspring	204	1.27	1.10
Older adults with migrant offspring	1538	1.08	0.31

Notes: The small sample is due to missing information about gender of migrant offspring in a few cases.

Table 7. Estimation of the effect of the gender of migrants on left-behind older adults' nutrient intake (fixed effects model)

	Have only male migrant offspring		Have only have female migrant offspring		Have both male and female migrant offspring	
	(1)	(2)	(3)	(4)	(5)	(6)
Dietary energy	7.669***	7.130**	4.211	5.967	10.369**	11.120**
	(2.828)	(2.863)	(4.281)	(4.412)	(4.266)	(4.555)
Protein	10.466***	9.247**	6.668	9.060*	16.398***	18.745***
	(3.485)	(3.615)	(5.843)	(5.422)	(5.257)	(5.424)
Fat	12.697	10.526	35.879*	34.617	30.346	28.437
	(13.781)	(14.444)	(20.290)	(22.962)	(21.625)	(23.658)
Carbohydrate	24.034**	24.632***	7.180	11.913	29.237**	31.722**
	(9.337)	(9.258)	(13.054)	(13.638)	(14.156)	(14.540)
Dietary fiber	0.055	0.232	−0.086	0.135	0.257	0.579*
	(0.204)	(0.207)	(0.384)	(0.382)	(0.305)	(0.311)
Vitamin A	6.607	12.379**	3.436	13.527*	9.673	18.290**
	(5.445)	(5.687)	(6.576)	(7.069)	(7.560)	(8.962)
Vitamin E	5.363	−1.150	14.983	18.134	14.875	9.246
	(13.008)	(11.832)	(19.967)	(20.802)	(18.760)	(18.535)
Vitamin B1	7.076**	6.707**	3.816	5.264	14.440***	15.395***
	(3.203)	(3.009)	(4.905)	(4.738)	(4.602)	(4.644)
Vitamin B2	4.181**	3.962*	1.564	3.901	5.060*	7.286**
	(2.090)	(2.043)	(2.964)	(3.259)	(2.989)	(2.949)
Vitamin B3	10.505**	12.972***	7.793	4.819	17.931**	24.787***
	(4.410)	(4.163)	(6.465)	(7.066)	(7.380)	(7.375)
Vitamin C	2.662	7.145	−9.553	−9.205	0.320	23.351**
	(5.647)	(5.763)	(12.554)	(14.700)	(8.672)	(9.296)
Calcium	1.052	1.462	−3.589	−6.021	0.727	8.499**
	(2.032)	(2.038)	(4.506)	(4.677)	(2.796)	(3.578)
Phosphorus	10.873***	10.277**	6.713	7.537	19.351***	21.541***
	(4.170)	(4.259)	(7.277)	(7.303)	(6.573)	(7.011)
Potassium	2.750	5.569*	−4.254	−4.873	3.818	16.146***
	(3.484)	(3.362)	(7.056)	(7.690)	(4.739)	(5.388)
Sodium	−29.660	−2.330	−95.689	−138.296	23.063	7.485
	(35.828)	(30.068)	(81.148)	(90.750)	(45.361)	(51.096)
Magnesium	4.292	6.407*	−0.755	−1.558	7.302	13.423**
	(3.242)	(3.387)	(5.894)	(6.379)	(5.150)	(5.766)
Iron	12.328*	16.785**	11.156	18.042	22.092**	33.641***
	(7.241)	(8.210)	(14.617)	(13.653)	(10.792)	(12.248)
Zinc	0.841	6.950	−11.964	−8.929	−18.470	−8.203
	(13.090)	(8.031)	(13.717)	(14.445)	(23.001)	(15.925)
Selenium	7.745**	6.139**	3.234	5.349	13.791***	15.334***

	(3.167)	(3.049)	(5.989)	(4.577)	(4.802)	(4.864)
Copper	19.990**	23.147**	2.577	20.129	27.876*	41.035**
	(9.930)	(10.502)	(16.654)	(15.666)	(14.346)	(16.658)
Manganese	0.774	4.881	−1.907	15.857	10.944	25.601
	(20.647)	(20.205)	(15.974)	(22.849)	(17.793)	(26.797)
Individual FEs	Yes	Yes	Yes	Yes	Yes	Yes
Time FEs	Yes	Yes	Yes	Yes	Yes	Yes
Interactive FEs	No	Yes	No	Yes	No	Yes
Number of observations	3408	3365	3408	3365	3408	3365

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the household level. Interactive fixed effects are an interactive term of village fixed effects and year fixed effects. According to the gender composition of migrant children, four dummy variables are constructed for older adults, of which without migrant offspring is the reference category in the regressions. To save space, only the key variables (have only male migrant offspring, have only female migrant offspring, and have male and female migrant offspring) are reported for each regression. The full set of results is available upon request.

Table 8. Estimation of the effect of migration on left-behind older adults' nutrient intake (fixed effects model, with different subsamples)

	Independent variable: Having migrant children					
	Gender		Living arrangement		Income level	
	(1)	(2)	(3)	(4)	(5)	(6)
	Male	Female	With grandchildren	Without grandchildren	Low	High
Dietary energy	6.266*	7.011**	9.015	2.762	33.181***	8.740
	(3.540)	(3.479)	(5.751)	(5.970)	(11.805)	(22.743)
Protein	9.420**	11.434***	19.539***	3.915	18.439	11.967
	(4.268)	(4.051)	(7.357)	(6.832)	(14.959)	(26.750)
Fat	9.476	20.709	12.124	−16.092	125.715**	56.992
	(18.462)	(16.301)	(34.423)	(24.709)	(52.564)	(134.993)
Carbohydrate	23.346*	17.364*	29.829**	18.085	91.093**	18.620
	(12.226)	(10.092)	(14.922)	(20.381)	(41.080)	(57.765)
Dietary fiber	0.359	0.235	0.692*	−0.301	0.014	1.848
	(0.270)	(0.193)	(0.364)	(0.337)	(0.767)	(1.455)
Vitamin A	3.012	21.978***	26.385**	4.926	9.604	42.168
	(7.313)	(5.392)	(12.636)	(7.666)	(17.249)	(50.959)
Vitamin E	5.167	−3.244	15.086	−28.800	78.308	−40.966
	(14.560)	(14.223)	(19.686)	(21.782)	(70.603)	(113.986)
Vitamin B1	8.361**	7.123**	10.790**	0.507	24.305	−3.685
	(3.667)	(3.382)	(4.767)	(6.113)	(16.075)	(8.225)
Vitamin B2	2.559	5.764***	12.788***	−0.852	4.661	−1.652
	(2.496)	(1.967)	(3.869)	(3.609)	(7.967)	(25.076)
Vitamin B3	11.266**	12.819***	15.391*	5.174	23.364*	−1.474
	(5.686)	(4.491)	(8.305)	(7.949)	(13.611)	(27.069)

Vitamin C	4.320	6.131	15.724	8.388	24.606	26.381
	(6.604)	(8.507)	(13.327)	(11.594)	(24.285)	(46.603)
Calcium	1.102	1.309	3.767	−2.542	5.147	−2.768
	(2.716)	(1.884)	(4.056)	(4.106)	(4.273)	(18.327)
Phosphorus	10.799**	12.617***	19.532**	1.419	25.400	6.541
	(5.465)	(4.239)	(8.252)	(7.967)	(16.152)	(30.892)
Potassium	4.167	5.614*	11.690	0.986	9.531	19.238
	(4.417)	(3.028)	(7.101)	(7.048)	(10.277)	(19.079)
Sodium	−8.729	−49.067	−68.811	−43.819	49.073	−260.489
	(35.914)	(37.586)	(45.622)	(37.449)	(88.740)	(362.886)
Magnesium	6.583	5.538*	7.247	−1.475	16.486	6.125
	(4.472)	(3.137)	(6.091)	(7.242)	(11.543)	(22.120)
Iron	21.034*	15.663**	31.302**	7.320	31.058	68.254
	(11.193)	(5.990)	(15.398)	(12.496)	(28.478)	(60.577)
Zinc	4.688	20.445*	15.740	1.903	20.742	153.958
	(5.921)	(11.841)	(9.664)	(6.630)	(12.753)	(211.515)
Selenium	7.453*	6.184**	14.367**	2.433	10.965	−6.952
	(4.208)	(2.978)	(6.081)	(4.705)	(14.182)	(29.013)
Copper	22.715*	25.201**	29.672	17.520	33.653	77.637
	(13.678)	(11.129)	(18.232)	(23.057)	(38.547)	(82.369)
Manganese	17.882	4.733	−14.387	28.863	48.975*	28.564
	(30.988)	(11.890)	(24.124)	(28.092)	(25.515)	(41.848)
Individual FEs	Yes	Yes	Yes	Yes	Yes	Yes
Time FEs	Yes	Yes	Yes	Yes	Yes	Yes
Interactive FEs	Yes	Yes	Yes	Yes	Yes	Yes

Number of observations	1539	1564	1176	1524	413	373

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the household level. To save space, only the key variable (having migrant children) is reported for each regression. The full set of results is available upon request.

Table 9. Estimation of the effect of migrants on left-behind older adults' food consumption (fixed effects model)

	Independent variable: Having migrant children	
	(1)	(2)
Cereals, mixed beans, tubers, and starches	11.388**	9.347**
	(5.009)	(4.762)
Vegetables and fruits	0.791	3.298
	(2.453)	(2.474)
Meat, poultry, eggs, fish, and shellfish	8.267**	7.039*
	(3.993)	(3.872)
Soybean, nuts, and dairy products	1.563	0.124
	(1.782)	(1.739)
Individual FEs	Yes	Yes
Time FEs	Yes	Yes
Interactive FEs	No	Yes
Number of observations	3408	3365

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Standard errors in parentheses are clustered at the household level. Interactive fixed effects are an interactive term of village fixed effects and year fixed effects. To save space, only the key variable (having migrant children) is reported for each regression. The full set of results is available upon request.

Table 10. Attrition in sample

Wave	Individuals	Dropouts	Returners	Survival rate	Raw drop-out rate	Net drop-out rate	Later joiners
2004	977	-	-	-	-	-	-
2006	566	411	0	0.58	0.42	0.42	482
2009	432	247	113	0.44	0.44	0.24	457
2011	360	152	80	0.37	0.35	0.17	521

Notes: The survival rate is the percentage of original sample members remaining at wave t. The dropout rate is the difference in observations between waves $t-1$ and t relative to the number of observations at $t-1$. The raw dropout rate excludes returners, whereas the net dropout rate includes them. This table only considers individuals who are included in the 2004 wave; later joiners are sample members who join in after the 2004 wave, which are presented in the last column.

Table 11. Estimation of the effect of migration on left-behind older adults' nutrient intake (fixed effects model, inverse probability weights)

	Independent variable: Having migrant children	
	(1)	(2)
Dietary energy	7.150***	7.182***
	(2.623)	(2.674)
Protein	9.844***	10.249***
	(3.196)	(3.301)
Fat	17.848	13.183
	(12.596)	(13.465)
Carbohydrate	22.075***	24.026***
	(8.292)	(8.512)
Dietary fiber	0.184	0.343*
	(0.187)	(0.187)
Vitamin A	5.261	13.705***
	(4.910)	(4.956)
Vitamin E	10.120	0.462
	(12.838)	(11.563)
Vitamin B1	6.779**	7.804***
	(2.825)	(2.832)
Vitamin B2	3.803**	4.460**
	(1.893)	(1.898)
Vitamin B3	9.755**	12.598***
	(3.945)	(3.958)
Vitamin C	1.959	6.847
	(5.530)	(5.537)
Calcium	0.369	0.885
	(1.782)	(1.800)
Phosphorus	11.308***	11.580***
	(3.759)	(3.899)
Potassium	2.695	6.055**
	(3.136)	(3.006)
Sodium	−40.609	−27.994
	(32.562)	(29.050)
Magnesium	4.605	6.801**
	(2.963)	(3.198)
Iron	13.083*	18.097**
	(6.955)	(7.356)
Zinc	−0.676	4.381
	(9.700)	(6.724)
Selenium	7.163**	6.821**
	(3.266)	(2.829)

Copper	16.963*	25.253***
	(9.033)	(9.761)
Manganese	0.257	9.058
	(17.807)	(17.351)
Individual FEs	Yes	Yes
Time FEs	Yes	Yes
Interactive FEs	No	Yes
Number of observations	3408	3365

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the household level. Interactive fixed effects are an interactive term of village fixed effects and year fixed effects. To save space, only the key variable (having migrant children) is reported for each regression. The full set of results is available upon request.

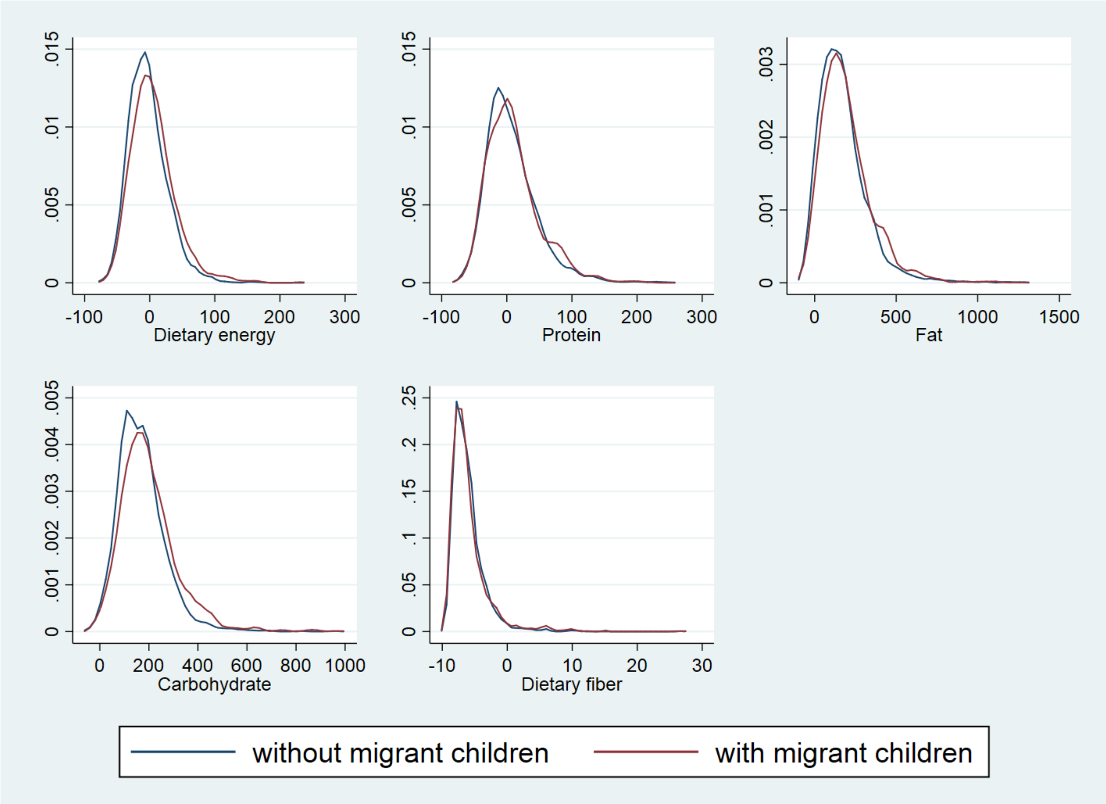

Fig. 1 Macronutrients of older adults by offspring's migration status: CHNS, 2004–2011.

Notes: RNI is not available for fats, and AI is used instead as the reference index.

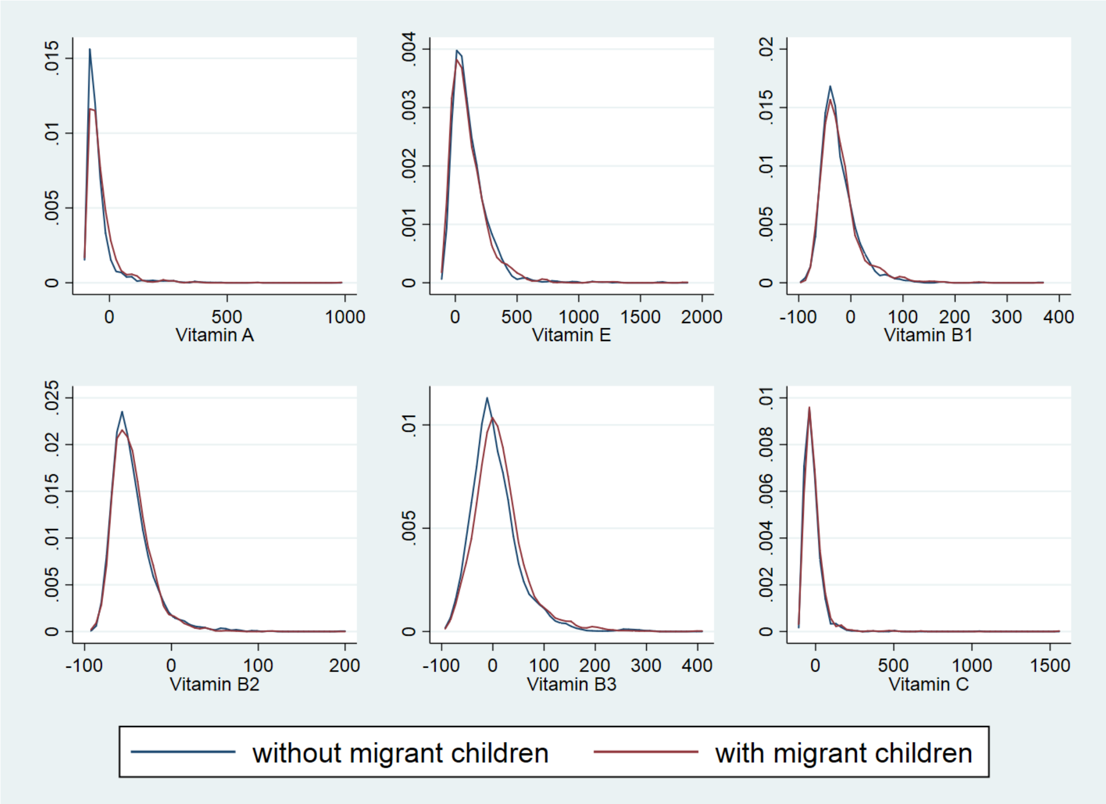

Fig. 2 Vitamins of older adults by offspring's migration status: CHNS, 2004–2011.

Notes: RNI is not available for vitamin E, and AI is used instead as the reference index.

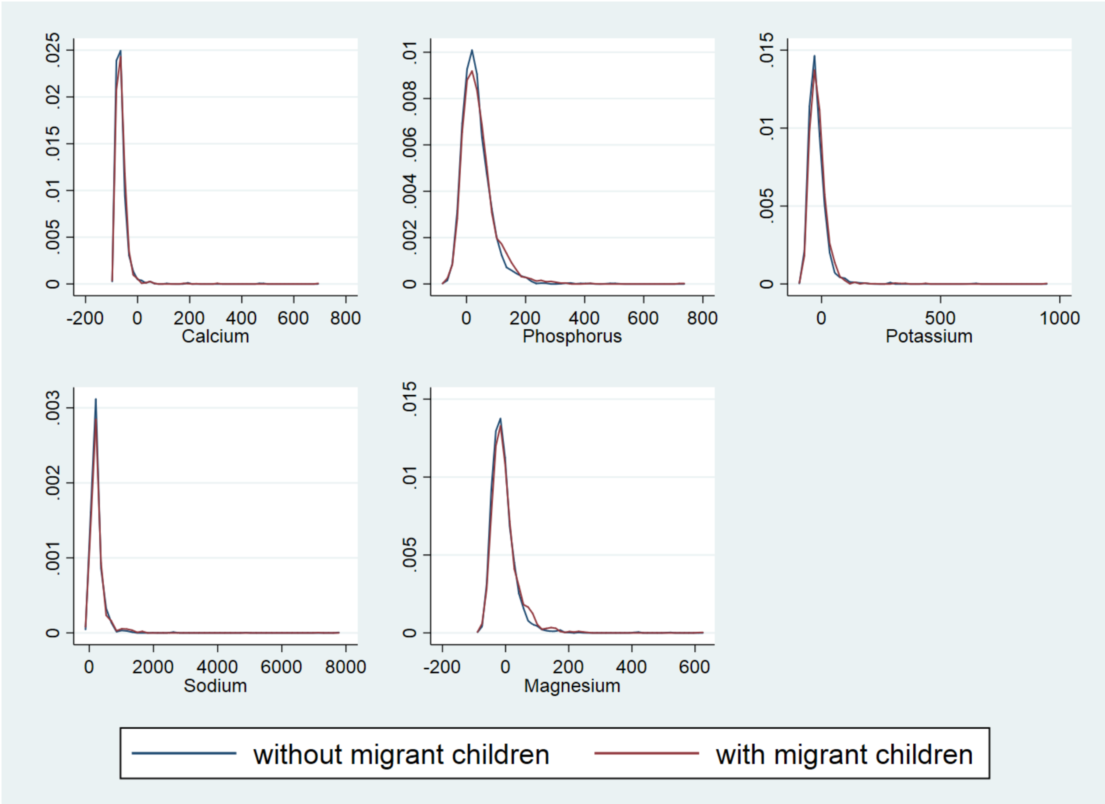

Fig. 3 Macroelements of older adults by offspring's migration status: CHNS, 2004–2011.

Notes: RNI is not available for potassium and sodium, and AI is used instead as the reference index.

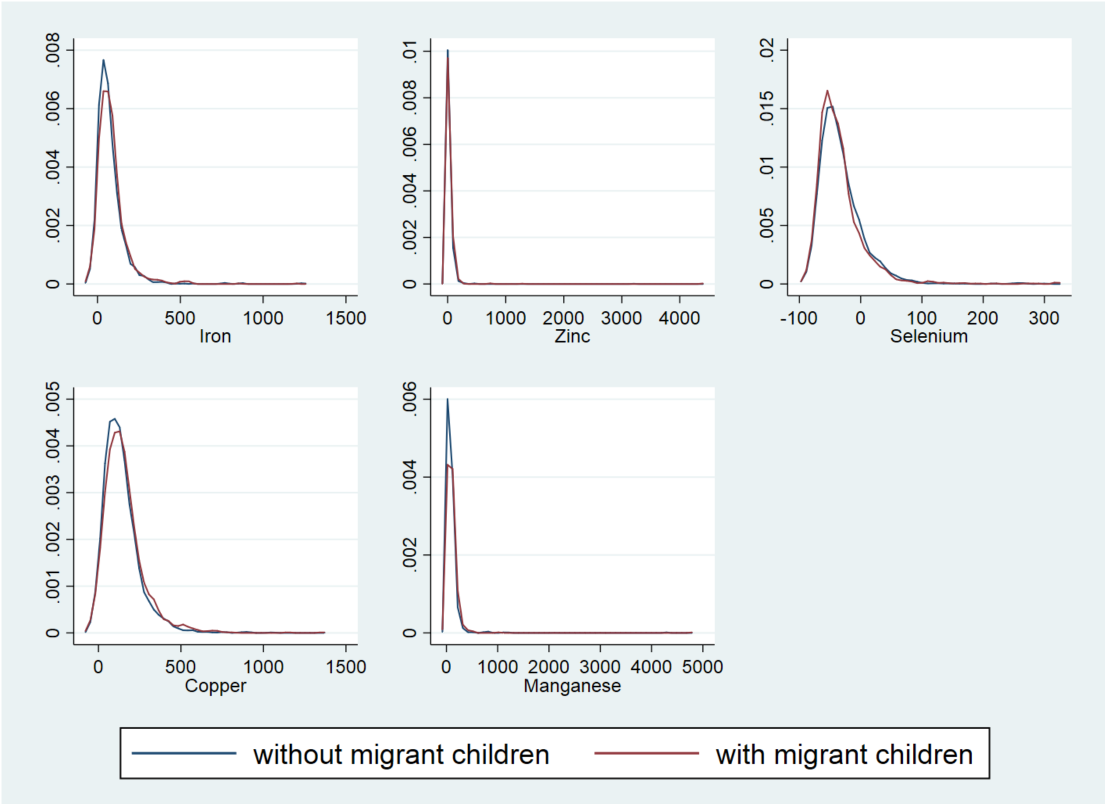

Fig. 4 Trace elements of older adults by offspring's migration status: CHNS, 2004–2011.

Notes: RNI is not available for manganese, and AI is used instead as the reference index.

Appendix A

As mentioned in the main text, nutrients are divided into four categories: macronutrients, vitamins, macroelements, and trace elements. For macronutrients, we have information on the intake of dietary energy, protein, fat, carbohydrate, and dietary fiber. Dietary energy is an overall index that measures an individual's energy intake in a day.[25] Proteins, fats, and carbohydrates are the three main macronutrients. Proteins do most of the work in cells and are required for the structure, function, and regulation of the body's tissues and organs. Research has shown that a greater protein intake than the RNI helps improve muscle mass, strength, and function of older people and can improve immune status, healing of wounds, and stabilize blood pressure (Wolfe et al., 2008). Fats serve structural and metabolic functions and play a vital role in maintaining healthy skin and hair, insulating body organs against shocks, maintaining body temperature, and promoting healthy cell functions. Carbohydrates are the most common source of energy. Although humans can acquire energy from fats and proteins, they still need carbohydrates because of their importance for brain functions.

Vitamins can be grouped into two categories: lipid-soluble vitamins (vitamins A and E) and water-soluble vitamins (vitamins B1–B3 and C). As the name implies, water-soluble vitamins dissolve easily in water and are readily excreted from the body generally. Given that they are not as readily stored, more consistent intake is important (Fukuwatari and Shibata, 2008). Correspondingly, lipid-soluble vitamins are absorbed through the intestinal tract with the help of lipids.

Of the lipid-soluble vitamins, vitamin A helps in forming and maintaining healthy teeth, bones, soft tissue, mucus membranes, and skin; whereas vitamin E helps the body to produce red blood cells and use vitamin K. Of the water-soluble vitamins, vitamin B1 (thiamine) helps the body cells to transform carbohydrates into energy. Working with the other B vitamins, vitamin B2 (riboflavin) is important for body growth and the production of red blood cells. Vitamin B3 (niacin) helps in maintaining a healthy skin and nerves. In larger doses, it can also have cholesterol-lowering effects. Vitamin C is an antioxidant that promotes healthy teeth and gums. It helps the body absorb iron and maintain healthy tissues, and it promotes the healing of wounds (Medlineplus Medical Encyclopedia). A vitamin deficiency can cause several health problems (Meydani et al., 1990; Shibata et al., 1992).

The last two categories are macroelements (calcium, phosphorus, potassium, sodium, and magnesium) and trace elements (iron, zinc, selenium, copper, and manganese). Macroelements are chemical elements required by the body in relatively large

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[25] Following Tian and Yu (2013), we drop all abnormal observations that have an energy intake lower than 520 kcal (the estimated energy requirement for a female newborn younger than 0.5 years old) and higher than 6,000 kcal (i.e., exceeding three standard deviations in the sample).

quantities (0.1%–1.5% of the total human body weight) for the normal physiological processes, whereas trace elements are chemical elements, the concentration of which is extremely low (about 0.02% of the total body weight). A major outcome of trace element deficiencies is reduced activity of the relevant enzymes. However, given that each trace element is related to many enzymes, deficiency of a single trace element is often not associated with any specific clinical manifestation but rather manifests as a combination of various symptoms (Osamu, 2004).

Appendix B

Table B1. Average nutrient intake of older men in urban China

Nutrient	Unit	50–64	RNI	Deficiency/Excess (%)	65–79	RNI	Deficiency/Excess (%)	≥80	RNI	Deficiency/Excess (%)
Macronutrients:										
Dietary energy	kcal	2209.30	2450	−9.8	2047.10	2350	−12.9	1710.42	2200	−22.3
Protein	g	73.82	65	13.6	66.97	65	3.0	58.02	65	−10.7
Fat	g	82.32	20–30*	229.3	80.13	20–30*	220.5	69.51	20–30*	178.1
Carbohydrate	g	291.37	120*	142.8	266.24	120*	121.9	215.70	120*	79.7
Dietary fiber	g	10.79	25–30*	−60.8	10.12	25–30*	−63.2	7.85	25–30*	−71.5
Lipid-soluble vitamins:										
Vitamin A	μg	551.30	800	−31.1	509.02	800	−36.4	489.97	800	−38.8
Vitamin E	mg	31.15	14*	122.5	32.72	14*	133.7	27.67	14*	97.7
Water-soluble vitamins:										
Vitamin B1	mg	1.01	1.4	−28.2	0.89	1.4	−36.1	0.74	1.4	−46.9
Vitamin B2	mg	0.88	1.4	−37.1	0.84	1.4	−39.8	0.73	1.4	−47.6
Vitamin B3	mg	16.37	14	16.9	14.05	14	0.4	11.53	13	−11.3
Vitamin C	mg	91.46	100	−8.5	86.75	100	−13.3	66.42	100	−33.6
Macroelements:										
Calcium	mg	466.21	1000	−53.4	462.79	1000	−53.7	395.83	1000	−60.4
Phosphorus	mg	1041.11	720	44.6	961.64	700	37.4	818.46	670	22.2
Potassium	mg	1854.40	2000*	−7.3	1736.77	2000*	−13.2	1459.75	2000*	−27.0
Sodium	mg	4704.93	1400*	236.1	4742.45	1400*	238.7	4462.26	1300*	243.3
Magnesium	mg	310.93	330	−5.8	289.90	320	-9.4	237.51	310	−23.4

Trace elements:										
Iron	mg	23.06	12	92.1	21.28	12	77.4	17.93	12	49.4
Zinc	mg	13.50	12.5	8.0	12.23	12.5	−2.2	12.58	12.5	0.6
Selenium	μg	53.15	60	−11.4	47.07	60	−21.6	40.56	60	−32.4
Copper	mg	2.00	0.8	149.4	1.82	0.8	127.2	1.44	0.8	79.7
Manganese	mg	6.98	3.5*	99.5	6.59	3.5*	88.2	5.13	3.5*	46.6
Number of observations			2179			1059			153	

Notes: RNI is the daily intake, which meets the nutrient requirements of nearly all (97%-98%) apparently healthy individuals in an age- and sex-specific population groups. Nutrients for which no RNI (numbers with *) is available are replaced by the AI. RNI and AI are based on Chinese Dietary Reference Intakes (2017).

Table B2. Average nutrient intake of older women in urban China

Nutrient	Unit	50–64	RNI	Deficiency/Excess (%)	65–79	RNI	Deficiency/Excess (%)	≥80	RNI	Deficiency/Excess (%)
Macronutrients:										
Dietary energy	kcal	1973.94	2050	−3.7	1820.78	1950	−6.6	1635.22	1750	−6.6
Protein	g	65.21	55	18.6	59.22	55	7.7	54.42	55	−1.1
Fat	g	79.43	20–30*	217.7	74.52	20–30*	198.1	68.05	20–30*	172.2
Carbohydrate	g	257.20	120*	114.3	234.90	120*	95.8	207.26	120*	72.7
Dietary fiber	g	10.21	25–30*	−62.9	9.18	25–30*	−66.6	7.57	25–30*	−72.5
Lipid-soluble vitamins:										
Vitamin A	μg	523.87	700	−25.2	448.25	700	−36.0	453.35	700	−35.2
Vitamin E	mg	31.64	14*	126.0	30.83	14*	120.2	26.42	14*	88.7
Lipid-soluble vitamins:										
Vitamin B1	mg	0.87	1.2	−27.4	0.79	1.2	−34.5	0.75	1.2	−37.8
Vitamin B2	mg	0.82	1.2	−32.0	0.76	1.2	−36.7	0.69	1.2	−42.4
Vitamin B3	mg	13.96	12	16.3	11.93	11	8.5	11.27	10	12.7
Vitamin C	mg	91.20	100	−8.8	78.51	100	−21.5	64.67	100	−35.3
Macroelements:										
Calcium	mg	444.43	1000	−55.6	428.07	1000	−57.2	385.42	1000	−61.5
Phosphorus	mg	934.73	720	29.8	866.36	700	23.8	785.58	670	17.3
Potassium	mg	1717.74	2000*	−14.1	1552.43	2000*	−22.4	1383.44	2000*	−30.8
Sodium	mg	5040.86	1400*	260.1	4907.49	1400*	250.5	4745.54	1300*	265.0
Magnesium	mg	282.95	330	−14.3	260.65	320	−18.5	227.16	310	−26.7
Trace elements:										
Iron	mg	20.79	12	73.3	19.39	12	61.5	16.88	12	40.6

Zinc	mg	11.45	7.5	52.6	10.74	7.5	43.2	8.37	7.5	11.6
Selenium	μg	46.69	60	−22.2	43.82	60	−27.0	37.24	60	−37.9
Copper	mg	1.84	0.8	129.5	1.66	0.8	107.9	1.48	0.8	85.5
Manganese	mg	5.83	3.5*	66.5	5.21	3.5*	48.8	4.80	3.5*	37.0
Number of observations			2357			1127			129	

Notes: RNI is the daily intake, which meets the nutrient requirements of nearly all (97%–98%) apparently healthy individuals in an age- and sex-specific population groups. Nutrients for which no RNI (numbers with *) is available are replaced by the AI. RNI and AI are based on Chinese Dietary Reference Intakes (2017).

Table B3. Estimation of the effect of migration on left-behind older adults' nutrient intake (fixed effects model with sharpened q-values)

	Coefficient	p-value	sharpened q-value
Dietary energy	7.014	0.009***	0.028**
Protein	10.390	0.002***	0.022**
Fat	14.365	0.288	0.173
Carbohydrate	22.830	0.007***	0.028**
Dietary fiber	0.311	0.101	0.078*
Vitamin A	13.157	0.010**	0.028**
Vitamin E	0.987	0.929	0.449
Vitamin B1	7.747	0.006***	0.028**
Vitamin B2	4.244	0.026**	0.031**
Vitamin B3	12.360	0.002***	0.022**
Vitamin C	4.793	0.388	0.191
Calcium	0.664	0.721	0.338
Phosphorus	11.422	0.004***	0.026**
Potassium	5.151	0.091*	0.076*
Sodium	−34.332	0.269	0.173
Magnesium	6.264	0.051*	0.050*
Iron	18.891	0.013**	0.028***
Zinc	3.438	0.649	0.315
Selenium	6.836	0.014**	0.028**
Copper	24.160	0.013**	0.028**
Manganese	8.573	0.627	0.315

Notes: * indicates that the corresponding p-value and the sharpened q-value are less than 10%, ** less than 5%, and *** less than 1%. The sharpened q-values are adjusted on the basis of the baseline results in Table 4 with interactive fixed effects.

Table B4. Estimation of the effect of migration on left-behind older adults' nutrient intake (fixed effects model, including singleton groups)

	Independent variable: Having migrant children	
	(1)	(2)
Dietary energy	7.492***	7.014***
	(2.607)	(2.642)
Protein	10.733***	10.390***
	(3.201)	(3.276)
Fat	17.912	14.365
	(12.639)	(13.345)
Carbohydrate	23.079***	22.830***
	(8.385)	(8.403)
Dietary fiber	0.154	0.311*
	(0.189)	(0.187)
Vitamin A	6.114	13.157***
	(5.004)	(5.061)
Vitamin E	7.412	0.987
	(12.035)	(10.975)
Vitamin B1	7.559***	7.747***
	(2.828)	(2.780)
Vitamin B2	3.972**	4.244**
	(1.918)	(1.878)
Vitamin B3	10.238**	12.360***
	(4.026)	(3.922)
Vitamin C	0.666	4.793
	(5.496)	(5.483)
Calcium	0.357	0.664
	(1.832)	(1.834)
Phosphorus	11.833***	11.422***
	(3.770)	(3.866)
Potassium	2.415	5.151*
	(3.194)	(3.006)
Sodium	−41.979	−34.332
	(31.557)	(30.630)
Magnesium	4.666	6.264**
	(2.978)	(3.158)
Iron	14.755**	18.891**
	(7.085)	(7.515)
Zinc	−2.940	3.438
	(11.822)	(7.453)
Selenium	7.562**	6.836**
	(3.067)	(2.741)

Copper	18.771**	24.160**
	(9.178)	(9.534)
Manganese	1.184	8.573
	(18.441)	(17.390)
Individual FEs	Yes	Yes
Time FEs	Yes	Yes
Interactive FEs	No	Yes
Number of observations	4528	4528

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the household level. Interactive fixed effects are an interactive term of village fixed effects and year fixed effects. To save space, only key variable (having migrant children) was kept for each regression. The full set of results is available upon request.

Table B5. Baseline characteristics of older adults by attrition status (stayers, rejoiners, and dropouts)

Variables	Stayers	Returners	Dropouts	t-test[a]	t-test[b]
Nutrient intake:					
Dietary energy	7.40	1.87	1.66	**	*
Protein	11.75	9.56	8.70	-	-
Fat	174.88	167.23	169.68	-	-
Carbohydrate	218.18	197.17	187.08	**	***
Dietary fiber	−5.76	−5.55	−5.72	-	-
Vitamin A	−42.76	−44.81	−54.68	-	**
Vitamin E	100.26	113.84	103.60	-	-
Vitamin B1	−18.33	−21.30	−21.31	-	-
Vitamin B2	−42.23	−45.63	−46.51	*	*
Vitamin B3	17.25	12.31	9.51	-	-
Vitamin C	−2.27	−10.13	−20.10	*	***
Calcium	−64.59	−62.16	−63.56	-	-
Phosphorus	42.13	41.24	39.82	-	-
Potassium	−19.47	−18.87	−21.76	-	-
Sodium	205.57	298.06	289.47	***	***
Magnesium	−4.06	−0.65	−1.12	-	-
Iron	83.74	86.81	88.86	-	-
Zinc	24.80	25.73	17.90	-	-
Selenium	−36.86	−36.42	−34.66	-	-
Copper	162.62	160.17	162.06	-	-
Manganese	115.84	116.50	100.91	-	-
Food consumption:					
Cereals, mixed beans, tubers, and starches	51.68	42.53	38.05	**	***
Vegetables and fruits	−47.53	−50.21	−55.46	-	***
Meat, poultry, eggs, fish, and shellfish	−40.17	−44.39	−43.72	-	-
Soybean, nuts, and dairy products	−86.91	−84.78	−85.48	-	-
Individual characteristics:					
Age	57.63	57.68	60.65	-	***
Male	0.46	0.52	0.50	-	-
Married	0.89	0.88	0.84	-	-
Education in years	5.21	5.33	5.38	-	-
Dummy for working	0.68	0.61	0.46	*	***
Number of chronic diseases	0.11	0.16	0.18	-	*
Household characteristics:				-	-
Per capita income in thousand yuan	5.83	6.37	5.14	-	-
Number of household members	3.92	3.50	3.21	***	***
The percentage of having more than one child	0.35	0.34	0.25	-	**

Age of household cook	53.69	52.61	53.57	-	-
Male household cook	0.19	0.11	0.17	***	-
Household cook's education (in years)	4.80	4.93	5.73	-	**
Village-level characteristics:				-	-
Market price of rice (500 g/yuan)	1.31	1.29	1.28	-	**
Market price of vegetables (500 g/yuan)	0.73	0.68	0.62	-	*
Market price of pork (500 g/yuan)	7.65	7.42	7.14	**	***
Number of markets in the resident village	3.43	3.15	3.37	**	-
Dummy variable for being close to an open trade area or special economic zone (within two hours by bus)	0.38	0.38	0.32	-	*
Number of observations	208	512	257		

Notes: *** p<0.01, ** p<0.05, * p<0.1. The first four columns contain individual-, household-, and village-level characteristics for older adults included in the 2004 wave. A t-test[a] is performed for difference between stayers and returners, and a t-test[b] is performed for the difference between stayers and dropouts.

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