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RESEARCH ARTICLE

Is intra-household nutrient allocation equitable? Evidence from asymmetric expenditure responses in rural China

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Highlights

- The nutrient intake of rural residents responds more strongly to declines than to increases in household food expenditure.
- There are significant differences in the allocation of nutrition among household members.
- Households prioritize improving the nutritional status of nutritionally vulnerable groups when food expenditure rises, while giving priority to sustaining nutrient intake of prime-age adults when expenditure falls.

Abstract

To analyze intra-household nutrient allocation, we examine the differences in expenditure elasticities across demographic groups within rural households, employing an asymmetric model along with data from the China Health and Nutrition Survey (CHNS) from 2004 to 2011. Our analysis reveals significant heterogeneity in household nutrient allocation: during periods of expenditure expansion, households prioritize the nutritional intake of vulnerable members, specifically children and the elderly, often at the expense of prime-age adults, particularly women. Conversely, during expenditure contraction, households shift strategies to protect the nutritional intake of prime-age adults. This asymmetry underscores the complexity of intra-household distribution and provides critical insights for designing nutrition security policies that account for economic volatility.

Keywords: intra-household nutrient allocation, asymmetric model, diet variety, nutrient adequacy ratio, rural China

1. Introduction

Achieving food and nutrition security across a nation enhances social fairness and propels economic development. China has seen substantial improvements in the living standards of its rural residents over the past four decades, with starvation now a relic of the past. However, with the resolution of food scarcity, China now faces the dual challenge of undernutrition and overnutrition (Zhou *et al.* 2020). While the dual burden arises from dietary changes, marked by increased consumption of high-energy foods, it is also linked to unequal distribution of household resources, which creates nutritional disparities among family members (Luo *et al.* 2001; Piernas *et al.* 2015; Zhang *et al.* 2016). Indeed, this disparity in intra-household resource distribution is deemed a crucial factor contributing to malnutrition among family members (Marphatia *et al.* 2016).

In rural China, disparities in food allocation within households are greater than in urban areas. This inequality is driven by the dominant role that young and middle-aged individuals play in generating family income, which grants them higher status and preferential access to food according to the “contribution rule” (Engle and Nieves 1993). Meanwhile, children and elderly adults are left vulnerable and often overlooked. These intra-household disparities are intensified by cultural traditions steeped in patriarchal values, such as “son preference”, which disproportionately disadvantage women and other vulnerable groups, causing rural residents to suffer from more severe resource allocation issues than their urban counterparts (Ren *et al.* 2014; Zheng and Lu 2017).

Numerous studies have explored intra-household nutrient allocation by assessing nutrient intake, adequacy, or serving

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order, yet their findings remain inconsistent. Studies by Nelson (1986), Gittelsohn (1991), and Sudo *et al.* (2006) suggest that discrimination against women is prevalent in household food allocation. Roemling and Qaim (2013) note disparities where children are frequently malnourished and underweight, whereas adults are likely to be overweight or obese. Additionally, Vijayaraghavan *et al.* (2002) reported that in roughly 43% of households, preschool children receive insufficient energy, whereas adults consume adequate amounts. Studies by Gittelsohn *et al.* (1997) and Coates *et al.* (2018) highlight acute micronutrient deficiencies among disadvantaged groups in rural areas of Nepal and Ethiopia. However, findings from Backstrand *et al.* (1997), Graham (1997), and Pradhan *et al.* (2013) suggest no gender bias in food allocation, suggesting that households can maintain fair dietary quality despite socioeconomic and demographic hurdles.

Investigations into how nutrition is allocated within Chinese households remain inconclusive. While some studies indicate that food and nutrient allocation within families often favors middle-aged individuals (Luo *et al.* 2001; Zhou *et al.* 2018), evidence of gender biases in resource allocation persists, particularly in rural households (Luo *et al.* 2001; Daivadanam *et al.* 2014; Ren *et al.* 2014). Conversely, findings by Jensen and Miller (2010) suggest no discernible differences in food allocation between boys and girls during food price increases, and Lee (2008) finds limited support for the notion that boys are preferred over girls in rural China.

Several studies have examined familial inequalities by assessing the income and price elasticities of individual goods. It is generally accepted that if one group's consumption responds more to price or income shifts than another's, that group is more susceptible to fluctuations. This suggests that the price or income elasticity of demand and of human capital investments is generally lower for groups that are more favored within the family (Behrman 1988; Behrman and Deolalikar 1990; Alderman and Gertler 1997). However, Mangyo (2008) highlights the theoretical ambiguity regarding whether a more favored or productive family member will exhibit higher or lower elasticity in response to shifts in household income. His empirical analysis of survey data from China reveals that nutritional intake is more elastic for men than for women and significantly less so for elderly adults.

One reason for inconsistent findings in the study of intra-household nutrient allocation is the neglect of asymmetrical consumer behavior. Whether disproportionately high income or price elasticities represent advantages or disadvantages depends on the direction of income or price changes. For instance, high-income elasticity benefits individuals during periods of substantial income growth, yet it increases vulnerability during economic downturns. Additionally, consumption behaviors and resource allocation vary between scenarios of income gains and losse. Studies by Shimokawa (2010) and Villa *et al.* (2011), which employ an asymmetric consumption behavior framework, reveal that asymmetric responses in nutrient allocation do exist within households in both China and East Africa. Their research also suggests that assuming symmetric responses in resilience estimates could lead to "asymmetric bias" if the actual responses are inherently asymmetric. Therefore, a more thorough investigation using an asymmetric model is essential to accurately understand the dynamics of nutritional allocation in rural Chinese households.

Although Shimokawa (2010) concentrated on the behavior of resource allocation within Chinese families, the correlation between calorie income and essential nutrient intake changes, highlighted by studies like Skoufias *et al.* (2009) and Tian and Yu (2015), cannot be directly inferred, especially against the backdrop of changing dietary habits among Chinese consumers. Using China Health and Nutrition Survey (CHNS) data, we estimate expenditure elasticities for dietary variety and nutritional adequacy across different rural household groups, applying both symmetric and asymmetric models to examine whether nutritional status responds proportionally to expenditure changes. To enhance the robustness of our findings, we employ the asymmetric model to assess how shifts in expenditure impact the extent of allocation inequity among rural families.

2. Data and methods

2.1. Data description

Our research utilizes data from the 2004, 2006, 2009, and 2011 waves of the China Health and Nutrition Survey (CHNS), which is an unbalanced panel dataset because it rotates out certain samples in each round. The survey collects detailed information on the consumption of over 1,500 food items, both at home and outside, over three consecutive days, as well as individual, household, and community-level socioeconomic data. Given the focus on resource distribution within families, our study is confined to households comprising multiple individuals. We also excluded records where calorie intake deviated by more than five standard deviations from the average and those with missing values for key variables, resulting in a final sample size comprising 10,552 households and 30,228 individuals.

In this study, we segmented rural residents into six age and gender groups: boys and girls between the ages of 2 and 17, prime-age men and women from 18 to 60 years old, and men and women over the age of 60. Characteristics specific to each cohort from the CHNS samples are outlined in Table 1. Overall, children, prime-age adults, and elderly adults comprised 15.5%, 69.5%, and 15.0% of the population, respectively. While there is generally an equal distribution of men and women across the surveyed households, notable gender imbalances exist within specific age groups, for instance, a higher percentage of boys among children and a predominance of women in both the prime-age and elderly categories.

In columns 2 through 4, we detail the average age, education level, and work intensity for various groups. Men in the sample generally appear younger than women, with higher educational levels and more intense workloads. This trend is particularly evident among the prime-age and elderly groups. For example, prime-age men surpass their female counterparts in both educational achievement and work intensity. In the elderly cohort, men tend to be younger and

Table 1 Sample statistics

Demographic group	Proportion in household (%)	Proportion in whole sample (%)	Age	Education[1)]	Labor intensity[2)]
Men	49.421	49.809	41.488	1.627	2.932
	(14.462)		(20.481)	(1.215)	(1.143)
Women	50.579	50.191	42.913	1.244	2.750
	(14.462)		(19.786)	(1.191)	(1.159)
Children	15.469	17.150	9.720	0.844	2.410
	(16.692)		(4.349)	(0.907)	(0.942)
Boys	8.620	9.451	9.721	0.849	2.414
	(12.551)		(4.380)	(0.912)	(0.948)
Girls	6.849	7.699	9.719	0.837	2.405
	(11.660)		(4.311)	(0.901)	(0.935)
Prime-age adults	69.486	63.341	42.815	1.791	3.079
	(25.372)		(10.874)	(1.184)	(1.090)
Prime-age men	33.342	30.691	42.762	2.024	3.198
	(17.764)		(10.966)	(1.122)	(1.051)
Prime-age women	36.144	32.650	42.866	1.572	2.967
	(16.962)		(10.788)	(1.199)	(1.114)
Elderly adults	15.045	19.509	68.772	0.799	2.445
	(24.389)		(6.740)	(1.098)	(1.301)
Elderly men	7.459	9.667	68.500	1.129	2.591
	(13.268)		(6.270)	(1.205)	(1.321)
Elderly women	7.586	9.841	69.040	0.476	2.302
	(13.224)		(7.162)	(0.867)	(1.264)
Family sample size[3)]		8,127			
Individual sample size		23,574			

[1)] 0=not attended school or have not graduated from primary school; 1=primary school graduates; 2=junior high school graduates; 3=high school graduates; 4=technical school or vocational school graduates; 5=college graduates; 6=master's degree or above.
[2)] 1=engage in extremely light physical activity; 2=light physical activity; 3=moderate physical activity; 4=heavy physical activity; 5=extremely heavy physical activity.
[3)] To be consistent with the model setting in the following text, data in the table are the descriptive statistical results of the samples who have participated in the survey more than three times. Compared to the full sample of 10,552 households, a significant difference appears only in adult nutritional status at a marginal level of approximately 1%.
The statistical variables in the table are all sample means except for the "total sample proportion"; the standard deviation is in parentheses.

better educated than women. The educational disparity is more significant among elderly adults than among prime-age adults, indicating a persistent yet diminishing gender bias in education.

2.2. Measures of nutrition

In our analysis, the nutritional intake of rural residents is quantified using a dual approach comprising the Nutrient Adequacy Ratio (NAR) and the Diet Variety Score (DVS). First, the nutrient adequacy ratio serves as our direct measure of nutritional status, calculated by averaging the intake adequacy of essential nutrients, including energy, protein, insoluble fiber, vitamin A and C, calcium, potassium, iron, and zinc. These calculations are derived from daily intakes, determined by analyzing food consumption patterns and the nutrients each food contains. The NAR is defined as the ratio of an individual's actual nutrient intake to the Recommended Nutrient Intakes (RNIs) specific to their demographic cohort. Formally, for individual i and nutrient j, the adequacy ratio is expressed as $NAR_{ij}=Intake_{ij}/RNI_j(a_i, g_i, l_i)$, where $RNI_j(\cdot)$ represents the recommended intake function determined by the individual's age (a_i), gender (g_i), and physical activity level (l_i), as specified in the *Chinese Dietary Reference Intakes (2013)* (see Appendix A for details). It's important to note that these determination criteria vary across nutrients: caloric requirements depend on age, gender, and physical activity level; protein requirements rely on age and gender but exclude activity level; while guidelines for other nutrients, such as calcium and potassium, are categorized solely by age. Furthermore, as official guidelines for insoluble fiber are established only for adults, we addressed the lack of specific criteria for children by normalizing their fiber requirements based on their individual caloric needs.

Consequently, NAR provides a comprehensive picture of an individual or group's nutritional status by incorporating multiple key nutrients, indicating whether the average daily nutrient intake meets the recommended levels. This measure helps identify potential nutritional deficiencies and provides a more accurate overall nutrition and health status assessment. To focus strictly on nutritional deficiencies, any nutrient adequacy ratio exceeding 100% is capped at 100%. This truncation is methodologically necessary because nutrients are physiologically non-substitutable. Consequently, capping ensures that the excessive intake of one nutrient does not mathematically compensate for or mask the deficiency of another when calculating the overall average.

Second, to complement the NAR measure and mitigate the measurement errors and recall biases common in pure nutrient quantification (Hoddinott and Yohannes 2002), we adopt the diet variety score. As demonstrated in prior studies, dietary variety significantly correlates with overall dietary quality and nutrient sufficiency (Arimond and Ruel 2004; Torheim *et al.* 2004). Following He *et al.* (2009), the DVS is calculated based on the consumption of 12 food

types: rice, wheat products, coarse grains and tubers, dark-colored vegetables (with ≥500 μg carotene per 100 g), light-colored vegetables (with <500 μg carotene per 100 g), fruits, soybeans, dairy, red meat, poultry, eggs, and aquatic products (see Appendix B for details). The DVS utilizes a strict threshold-based scoring system: a food group contributes to the score only if its daily consumption meets a minimum threshold (5 g for soybeans; 25 g for other categories). The final score ranges from –12 to 0, where –12 indicates non-compliance with the minimums for all categories, and 0 indicates that all thresholds are satisfied. This scoring method, whereby the score exclusively improves upon meeting predefined standards, enhances the accuracy of identifying deficiencies and provides a robust check on the nutritional patterns identified by the NAR metric.

To ensure comparability across diverse demographic groups, we standardized food consumption data using the Adult Equivalent Scale (AES) based on the *Dietary Reference Intakes for Chinese Residents (2013 Edition)*. Specifically, we selected an adult male (60 kg) engaged in light physical activity with a daily energy requirement of 2,250 kcal as the reference unit. For an individual i, the AES is defined as the ratio of their specific energy requirement to that of the reference group, expressed as $AES_i=E_{RNI}(a_i, g_i, l_i)/2{,}250$, where $E_{RNI}(a_i, g_i, l_i)$ represents the recommended daily energy intake determined by the individual's age, gender and physical activity level (see Appendix C for the derived equivalent scales). These individual-specific coefficients were then applied to normalize food consumption figures, ensuring methodological consistency in our DVS estimation.

Table 2 reveals the standardized daily DVS and NAR for rural residents. The average DVS is around –6, suggesting that rural residents typically achieve the minimum required intake for only half of the 12 assessed food items. The NAR average is around 70%, with about 80% adequacy observed in nearly three-quarters of the rural demographic. The consumption of calories, protein, and zinc is generally sufficient, with an average adequacy exceeding 85%. Although total iron intake also exceeds 85% adequacy on average, this should be interpreted with caution: non-heme iron, which is abundant in plant-based foods, has poor absorption and contributes little to replenishing the body's iron reserves, whereas heme iron has high bioavailability but mainly comes from expensive animal-based foods. Therefore, adequate total iron intake does not guarantee that the absorbed amount fully meets physiological needs. Conversely, vitamin C and potassium have lower average adequacies of 77.4% and 74.5%, respectively. Critical deficiencies are noted in the intake of insoluble fiber, vitamin A, and calcium, with adequacy levels at only 35.4%, 38.4%, and 47.0%, respectively. Additionally, more than three-quarters of the population have less than 50% adequacy in insoluble fiber and calcium, and over half fall below 50% in vitamin A.

2.3. Cohort-specific nutritional status

We performed tests of equality on the DVS and NAR across diverse demographic groups, as reported in Table 3. Significant gender discrepancies are observed in the DVS among children and prime-age adults, where boys had higher DVS values than girls, and prime-age women surpassed prime-age men. Interestingly, no significant gender bias is observed among elderly adults. In terms of age disparities, the DVS of boys and prime-age adults is significantly higher than that of elderly adults, while the DVS of girls is notably lower than that of prime-age adults and similar to that of elderly adults. Overall, the DVS ranking from highest to lowest is as follows: prime-age women, boys, and prime-age men, followed by elderly men, elderly women, and girls, who display similar levels.

Variations are evident between the distributions of NAR and DVS. Notably, there are significant gender differences in NAR among children and prime-age adults, with NAR being higher in men than in women, a reversal from what is observed with DVS. No such gender differences exist among elderly adults. In terms of age disparities, both children and elderly adults show substantially lower NAR than prime-age adults, and, notably, girls exhibit lower NAR than elderly adults. Overall, the sequence of NAR from highest to lowest is prime-age men, prime-age women, elderly men and women (approximately equal), boys, and girls.

Thus, considering both the DVS and NAR, it is evident that significant gender and age disparities exist in nutrient allocation within rural households. Firstly, prime-age adults exhibit superior nutritional status compared to both children and elderly adults. Secondly, notable gender disparities are present among children and prime-age adults. Lastly, the nutritional status of girls is consistently poorer compared to other groups.

Table 2 Diet variety score and nutrient adequacy ratio of rural residents adjusted by standard person (%)

Nutrient indicator	Mean value	Standard deviation	25th percentile	50th percentile	75th percentile
Diet variety score	–5.954	1.669	–7.000	–6.000	–5.000
Nutrient adequacy ratio[1)]	70.115	13.203	61.941	71.512	79.925
Calorie	85.494	16.707	74.023	91.580	100.000
Protein	87.455	16.621	77.473	97.513	100.000
Insoluble fiber	35.386	16.994	23.501	31.826	43.053
Vitamin A	46.954	23.537	29.603	42.603	60.380
Vitamin C	77.367	24.645	59.144	84.859	100.000
Calcium	38.350	18.552	24.933	34.807	47.936
Potassium	74.548	21.061	57.989	75.383	97.261
Iron	94.736	11.980	100.000	100.000	100.000
Zinc	90.743	14.942	84.535	100.000	100.000

[1)] Nutrient adequacy ratio is the average of nine nutrient adequacies, such as calories.

Fig. 1 further illustrates the cohort-specific kernel densities for DVS and NAR. For DVS, the distribution among rural residents is uniform, showing no skewness. In contrast, the NAR displays a noticeable left-skewed distribution, largely due to the data processing method where values exceeding 100% adequacy are capped at 100%. When comparing NAR across demographic groups, prime-age adults show higher kurtosis, indicating a more concentrated distribution. This is followed by boys and elderly adults, with girls displaying the widest spread in their distribution. In line with the data presented in Table 3, this suggests that prime-age adults receive a preferential allocation of nutrients, consistently across households, whereas the nutritional status of girls is not only inferior but also shows more variation across households.

2.4. Model specification

For a comprehensive analysis of intra-household nutrient allocation, it is imperative to explore both the resource allocation among household members and the adjustment of these allocations due to income changes. In our analysis, we focus on changes in per capita household food expenditures derived from the prices and quantities of 17 different food items rather than changes in income. This approach is adopted because the CHNS dataset lacks total expenditure data. Additionally, changes in total household income, although recorded in the CHNS, fail to accurately capture variations in food expenditures due to consumption smoothing and the implications of Engel's law (Mangyo 2008).

Adapting the framework from Villa *et al.* (2011), our research investigates the effects of changes in household expenditure on the nutrient allocation. We employ a two-way fixed effects model to analyze how diet variety and nutrient adequacy are influenced by household income and food prices, alongside controls for individual, household, and regional characteristics. To explore intra-household disparities in DVS and NAR, we use cohort-specific dummy variables both as intercept shifters and as interactions with income variables, allowing for separate parameter estimations for each of the c=1,..., C demographic groups in the sample. For individual i in household h located in village v at time t,

Table 3 Equivalence test results of diet variety score and nutrient adequacy ratio of standard person in different groups in rural areas

	Boys	Girls	Prime-age men	Prime-age women	Elderly men	Elderly women
Diet variety score						
Boys	–	0.153***	0.050	–0.070*	0.167***	0.144***
Girls	–	–	–0.103**	–0.223***	0.014	–0.009
Prime-age men	–	–	–	–0.121***	0.116***	0.093**
Prime-age women	–	–	–	–	0.237***	0.214***
Elderly men	–	–	–	–	–	–0.023
Elderly women	–	–	–	–	–	–
Nutrient adequacy ratio						
Boys	–	0.021***	–0.045***	–0.040***	–0.006	–0.006
Girls	–	–	–0.066***	–0.061***	–0.027***	–0.027***
Prime-age men	–	–	–	0.006***	0.039***	0.040***
Prime-age women	–	–	–	–	0.033***	0.034***
Elderly men	–	–	–	–	–	0.001
Elderly women	–	–	–	–	–	–

Data in the table are the differences obtained by subtracting the mean value of the horizontal group from the mean value of the vertical group. The delta test is used for equality testing. *, **, and *** denote rejection of the equality hypothesis at the 10%, 5%, and 1% levels, respectively.

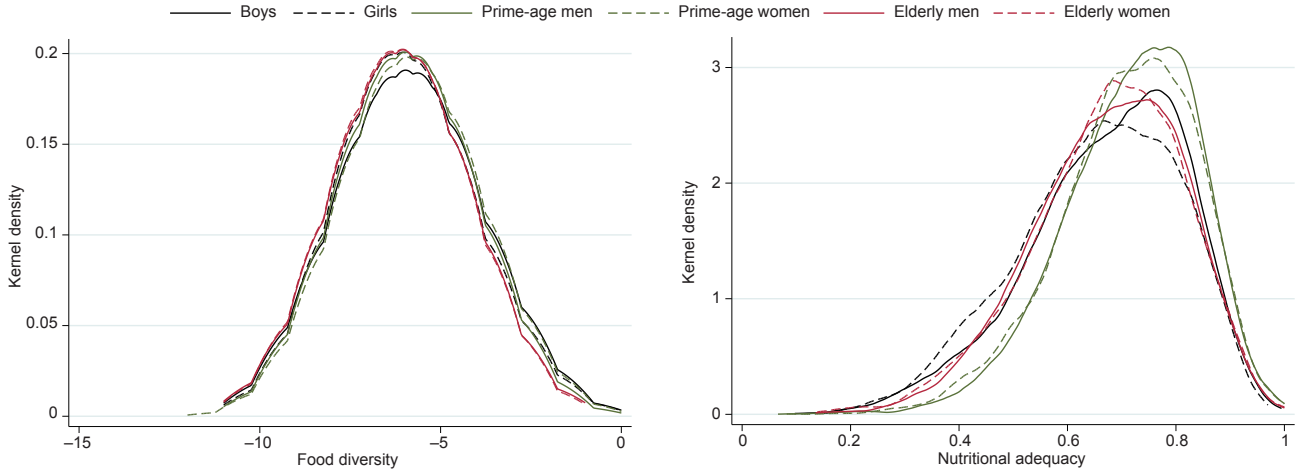


Fig. 1 Distribution of diet variety score and nutrient adequacy ratio among different groups.

DVS or NAR is determined by the subsequent equation:

$$\ln N_{ihvt}=\sum_{c=1}^{C} H_{ihvt}^{c}[\alpha^{c}+\beta^{c}\ln Y_{hvt}]+\theta X_{ihvt}+rZ_{hvt}+wP_{vt}+\mu_{h}+t_{t}+\varepsilon_{ihvt} \quad (1)$$

where N_{ihvt} represents nutritional status as proxied by DVS and NAR. c represents the demographic group: boys, girls, prime-age men, prime-age women, elderly men, and elderly women and H_{ihvt}^{c} describes dummy variables indicating membership in the household cohort c. Y_{hvt} denotes households' per capita food expenditure in year t deflated by 2011 CPI. Both DVS and NAR are logarithmically transformed — with DVS adjusted by a positive constant to account for non-positive values — so that the parameter β^{c} captures the cohort-specific income elasticities for both outcomes. X_{ihvt} indicates a matrix of individual characteristics variables, including work intensity and educational attainment. Z_{hvt} is a matrix of household characteristics variables, including average household dietary knowledge, household size, gender and age of the household head, and the proportion of boys, girls, prime-age men, prime-age women, and elderly men within the household, respectively. P_{vt} is an actual village-specific price matrix of 17 food items deflated by 2011 CPI, including the prices of rice, wheat, coarse grains, edible oil, eggs, condiments, vegetables, fruits, pork, beef, mutton, chicken, dairy products, aquatic products, dried beans and related products, alcohol, and beverages. All control variables are logarithmically transformed. μ_{h} and t_{t} represent household-specific and year-specific fixed effects, respectively, to control for household food consumption preferences and changes in preferences over time. ε_{ihvt} is the error term.

We add the interaction term between dummy variables of household member types and per capita annual household expenditure to eq. (1), allowing for expenditure elasticities of DVS and NAR to vary by cohort. The equality of expenditure elasticities of household cohorts can be determined by testing the equality of coefficients β^{c} for specific demographic groups. However, Model (1) does not capture the asymmetric reactions of DVS and NAR to anticipated reductions and increases in household expenditure. To rectify this limitation, we introduce an asymmetric model that incorporates cohort-specific expenditure elasticities, distinguishing between periods of economic prosperity and financial strain. The formulation of this asymmetric model is detailed below:

$$\begin{aligned}\ln N_{ihvt}=\sum_{c=1}^{C} H_{ihvt}^{c}[&\alpha^{c}+\beta_{1}^{c}(\ln Y_{hvt}-\ln\overline{Y}_{hv})I_{hvt}\\&+\beta_{2}^{c}(\ln Y_{hvt}-\ln\overline{Y}_{hv})(1-I_{hvt})]_{t}\\&+\theta X_{ihvt}+rZ_{hvt}+wP_{vt}+\mu_{h}+t_{t}+\varepsilon_{ihvt}\end{aligned} \quad (2)$$

where $\overline{Y}_{hv}$ represents the expected expenditure in household h in village v, and the intertemporal mean of household expenditure is used as its proxy variable. I_{hvt} is an indicator variable whose value is taken in the following way:

$$I_{hvt}=\begin{cases}1, \text{ if } Y_{hvt}\geq\overline{Y}_{hv}\\0, \text{ if } Y_{hvt}<\overline{Y}_{hv}\end{cases} \quad (3)$$

When the household expenditure is above its intertemporal mean, that is, I_{hvt}=1, the expenditure elasticity of nutritional status for cohort c will be:

$$\eta_{c}^{+}=\partial\ln N_{ihvt}^{c}/\partial\ln Y_{hvt}=\beta_{1}^{c} \quad (4)$$

and the below mean elasticity of cohort c, that is, will be:

$$\eta_{c}^{-}=\partial\ln N_{ihvt}^{c}/\partial\ln Y_{hvt}=\beta_{2}^{c} \quad (5)$$

Based on eq. (2), the following hypothesis test can be used to verify the intra-household differences in DVS and NAR response to expenditure shocks:

$$\begin{aligned}&H_{0}: \beta_{1}^{i}=\beta_{1}^{j} \text{ and } \beta_{2}^{i}=\beta_{2}^{j}, \text{ for all } i\neq j;\ i, j\in[1, ..., C]\\&H_{A}: \text{At least one of the following situations exists}\\&\beta_{1}^{i}\neq\beta_{1}^{j} \text{ or } \beta_{2}^{i}\neq\beta_{2}^{j}\end{aligned} \quad (6)$$

The following hypothesis tests can be performed to verify whether household cohorts exhibit symmetric DVS and NAR responses to expenditure above and below the household-specific mean expenditure:

$$\begin{aligned}&H_{0}: \beta_{1}^{i}=\beta_{2}^{i}, \text{ for all } i\in[1,...,C],\\&H_{A}: \text{At least one of the following situations exists}\\&\beta_{1}^{i}\neq\beta_{2}^{i}\end{aligned} \quad (7)$$

Rejecting the null hypothesis in eq. (7) would demonstrate that DVS and NAR respond differently to spending levels above or below the average. In this scenario, eq. (2) is preferred over eq. (1) for estimating the expenditure elasticities of DVS and NAR. Conversely, a failure to reject the null hypothesis would suggest no statistically significant evidence of asymmetric behavior.

3. Results and discussion

Previous studies have shown that measurement errors associated with expenditure and nutritional intake status will lead to an upward bias in estimates of nutritional expenditure elasticities (Meng *et al.* 2009; Skoufias *et al.* 2009). Also, some unobservable factors may be associated with both food expenditure and nutritional intake status (Behrman and Deolalikar 1987; Subramanian and Deaton 1996; Tian and Yu 2013). As a result, addressing the endogeneity of food expenditure is crucial when estimating the expenditure elasticities of DVS and NAR. Following Filmer and Pritchett (2001), we construct a household asset index using principal component analysis of multiple asset indicators, which is then utilized as an instrumental variable for food expenditure. These indicators are broadly classified into two dimensions: living conditions and holdings of durable goods. The former includes the source of drinking water (indoor tap water), toilet type (indoor flushing), and primary lighting (electric lamps), while the latter encompasses ownership of various items such as tricycles, bicycles, motorcycles, cars, color televisions, washing machines, refrigerators, air conditioners, computers, and mobile phones, among others. All asset indicators are binary distributed (0/1). Asset indicators reliably capture household wealth and offer insights into expenditure patterns. Meanwhile, deriving the index from household asset indicators helps address expenditure measurement errors, thus enhancing the validity of the instrument (Strauss and Thomas 1998; Doan 2014). Ultimately, the first principal component is employed as the asset index variable.

We incorporate instrumental variables (IV) estimation into eqs. (1) and (2) using control function approach. Specifically, per capita household food expenditure is regressed on the instrumental variable alongside control variables to derive the error term, which is subsequently applied to both eqs. (1) and (2). Furthermore, because the asymmetric model includes the deviation of food expenditure from its intertemporal average as the independent variable, only households surveyed in three or more rounds are retained, resulting in a

final sample of 8,127 households and 23,574 individuals. The same sample is applied in the symmetric model to maintain consistency.

3.1. Results of the symmetric model

Table 4 presents the estimation results of the symmetric model. The first-stage F-statistic is 85.431, well above the conventional threshold of 10, thereby rejecting the null hypothesis of weak instruments. Furthermore, the residuals from the first-stage regression are statistically significant at the 10% level, confirming the endogeneity of the expenditure variables and justifying the use of instrumental variables. Furthermore, the joint equality test results from the FE and IV models, based on the Wald test, show significant disparities in elasticities across rural household demographic groups. Accordingly, our analysis and interpretation will primarily focus on the IV-FE results. The DVS elasticity for demographic groups ranges from 0.298 to 0.326, while the NAR elasticity spans 0.086 to 0.101.

Table 5 presents the results of the single equality test for cohort-specific elasticity estimates. Specifically, we test the null hypothesis (H_0: if $\beta^i=\beta^j$ for all $i, j\in[1, ..., C]$) to determine whether the coefficients across different groups in Model (1) are equal. Note that the corresponding Fixed Effects (FE) model results are omitted from the table due to space constraints. The IV-FE findings reveal that, for DVS, there are no significant gender differences in the expenditure elasticities within any age cohort. Regarding age-group differences, boys exhibit a significantly higher DVS elasticity than prime-age and elderly adults, and girls also have a notably higher elasticity than elderly men. The equality test for NAR expenditure elasticity confirms these age-group distinctions, showing that children's elasticity is notably higher than that of prime-age adults and elderly adults, while prime-age adults display lower elasticity than elderly adults. Furthermore, significant gender differences appear among prime-age adults, with men exhibiting a higher NAR elasticity than women.

As a result, with increasing food expenditure, children gain more nutritionally than prime-age adults and elderly adults, while elderly adults benefit more than prime-age adults. Besides, the improvements are more pronounced among prime-age men than women; in contrast, no significant gender difference is observed for children and elderly adults. Notably, results from the symmetric model indicate that higher-elasticity groups also endure larger nutritional shocks when food expenditure declines.

Table 4 Expenditure elasticity of diet variety score/nutrient adequacy ratio for different groups: symmetric model

	FE		IV-FE	
	Diet variety score	Nutrient adequacy ratio	Diet variety score	Nutrient adequacy ratio
Boys	0.248***	0.124***	0.326***	0.100***
	(0.011)	(0.005)	(0.042)	(0.014)
Girls	0.237***	0.126***	0.315***	0.101***
	(0.011)	(0.005)	(0.041)	(0.014)
Prime-age men	0.228***	0.114***	0.306***	0.090***
	(0.009)	(0.004)	(0.041)	(0.014)
Prime-age women	0.226***	0.110***	0.304***	0.086***
	(0.010)	(0.004)	(0.042)	(0.014)
Elderly men	0.220***	0.119***	0.298***	0.094***
	(0.012)	(0.004)	(0.042)	(0.013)
Elderly women	0.226***	0.118***	0.304***	0.093***
	(0.011)	(0.004)	(0.042)	(0.013)
Error term estimated from the first stage			–0.080*	0.025*
			(0.041)	(0.013)
R^2	0.228	0.332	0.228	0.333
Observation	23,574	23,574	23,574	23,574
F-value of Joint test[1)]	3.595	108.002	4.252	107.387

[1)] To test whether the coefficient β of different groups in model (1) are equal, namely, to test H_0: if $\beta^i=\beta^j$ for all $i\neq j, i, j\in[1,...,C]$. The standard deviation is in parentheses. *, **, and *** denote rejection of the equality hypothesis at the 10%, 5%, and 1% levels, respectively.

3.2. Results of the asymmetric model

Table 6 provides a detailed summary of the estimation results

Table 5 Results of equivalence tests of expenditure elasticity of diet variety score/nutrient adequacy ratio for different groups: symmetric model (IV-FE)

	Boys	Girls	Prime-age men	Prime-age women	Elderly men	Elderly women
Diet variety score						
Boys	–	0.011	0.020**	0.022***	0.028***	0.022**
Girls	–	–	0.009	0.011	0.018*	0.011
Prime-age men	–	–	–	0.002	0.009	0.002
Prime-age women	–	–	–	–	0.007	0.000
Elderly men	–	–	–	–	–	–0.006
Elderly women	–	–	–	–	–	–
Nutrient adequacy ratio						
Boys	–	–0.001	0.010***	0.014***	0.006	0.007*
Girls	–	–	0.011***	0.015***	0.007*	0.008**
Prime-age men	–	–	–	0.004**	–0.004	–0.014
Prime-age women	–	–	–	–	–0.008***	–0.007**
Elderly men	–	–	–	–	–	0.001
Elderly women	–	–	–	–	–	–

Data in the table are the differences obtained by subtracting the mean value of the horizontal group from the mean value of the vertical group. *, **, and *** denote rejection of the equality hypothesis at the 10%, 5%, and 1% levels, respectively.

for the asymmetric model. The Wald test for based on eq. (6) in the asymmetric model, conducted using both FE and IV methods (see the penultimate line of Table 6), examines the null hypothesis that coefficients β_1 and β_2 are equal across cohorts. The results reveal that DVS and NAR responses to food expenditure changes differ significantly across demographic groups, as the test statistics exceed the critical F-values (F>1.599, 1.831, and 2.322 at the 10%, 5%, and 1% levels, respectively; 23,574 observations, 10 constraints). Meanwhile, the Wald test based on eq. (7) (last line of Table 6) verifies whether household cohorts exhibit symmetric responses to expenditure above and below the household-specific mean. The results suggest that intra-household nutrient allocation responds asymmetrically to expected increases and decreases in household food expenditure, surpassing the corresponding F-critical values (F>1.774, 2.099, and 2.803 at the 10%, 5%, and 1% levels; 23,574 observations, 6 constraints). This finding underscores the necessity for employing asymmetric models to estimate nutrient-expenditure elasticities. Consistent with the symmetric model findings, the IV estimates indicate that all first-stage residual coefficients are significant, at least at the 10% level, confirming the presence of endogeneity. Therefore, the IV-FE elasticity estimates are utilized as the preferred specification in the subsequent analysis.

The IV model yields elasticity estimates in the range of [0.255, 0.280] for DVS and [0.062, 0.089] for NAR when household expenditure exceeds the mean. Correspondingly, for below-mean expenditure, these elasticities increase to the ranges of 0.333–0.394 (DVS) and 0.108–0.132 (NAR), indicating that rural households are more sensitive to expenditure contractions. Based on Shimokawa's (2010) interpretation, these findings are consistent with the loss aversion hypothesis. The loss aversion assumption posits that households exhibit greater sensitivity to losses than gains, implying a kinked value function that is steeper in the loss domain. Specifically, households are psychologically reluctant to reduce their consumption level below their customary baseline. This strong resistance to "losing" their standard of living means that any reduction in expenditure

Table 6 Expenditure elasticity of diet variety score/nutrient adequacy ratio for different groups: asymmetric model

	FE		IV-FE	
	Diet variety score	Nutrient adequacy ratio	Diet variety score	Nutrient adequacy ratio
Boys				
Above average expenditure	0.201***	0.111***	0.280***	0.088***
	(0.022)	(0.008)	(0.049)	(0.014)
Below average expenditure	0.311***	0.155***	0.393***	0.132***
	(0.022)	(0.012)	(0.043)	(0.018)
Girls				
Above average expenditure	0.178***	0.112***	0.258***	0.089***
	(0.026)	(0.008)	(0.052)	(0.015)
Below average expenditure	0.312***	0.143***	0.394***	0.120***
	(0.028)	(0.010)	(0.044)	(0.016)
Prime-age men				
Above average expenditure	0.178***	0.094***	0.258***	0.071***
	(0.020)	(0.006)	(0.048)	(0.014)
Below average expenditure	0.274***	0.135***	0.354***	0.112***
	(0.017)	(0.006)	(0.038)	(0.015)
Prime-age women				
Above average expenditure	0.177***	0.085***	0.257***	0.062***
	(0.019)	(0.007)	(0.049)	(0.014)
Below average expenditure	0.280***	0.133***	0.361***	0.109***
	(0.017)	(0.006)	(0.039)	(0.015)
Elderly men				
Above average expenditure	0.174***	0.097***	0.255***	0.074***
	(0.023)	(0.007)	(0.050)	(0.013)
Below average expenditure	0.270***	0.150***	0.353***	0.126***
	(0.026)	(0.007)	(0.043)	(0.014)
Elderly women				
Above average expenditure	0.191***	0.101***	0.272***	0.078***
	(0.022)	(0.007)	(0.049)	(0.013)
Below average expenditures	0.252***	0.132***	0.333***	0.108***
	(0.024)	(0.008)	(0.043)	(0.015)
Error term estimated from the first stage			–0.082**	0.024*
			(0.040)	(0.013)
R^2	0.230	0.337	0.231	0.337
Observation	23,574	23,574	23,574	23,574
Wald test for eq. (6) (F-stat)	7.268	62.692	7.273	62.715
Wald test for eq. (7) (F-stat)	15.145	41.802	15.458	40.423

The standard deviation is in parentheses. *, **, and *** denote rejection of the equality hypothesis at the 10%, 5%, and 1% levels, respectively.

triggers a disproportionately large disutility. Consequently, this heightened psychological sensitivity manifests as a behavioral overreaction, resulting in greater elasticities in response to income declines compared to income increases.

A direct comparison between the asymmetric results (Table 6) and the symmetric baseline (Table 4) highlights the specific bias introduced by the symmetry assumption. For instance, the symmetric model estimates a single DVS elasticity of 0.326 for boys (Table 4). However, Table 6 decomposes this into two distinct realities: a lower elasticity of 0.280 when expenditure rises and a significantly higher elasticity of 0.393 when it falls. This contrast demonstrates that the single estimate in Table 4 effectively "averages out" these opposing behaviors, thereby masking the true volatility of household responses. Specifically, the symmetric model tends to underestimate the elasticities during economic downturns and overestimate them during upturns, further validating the necessity of asymmetric specification for characterizing the true dynamics of nutritional adjustment.

Table 7 presents the results of the equality test for the expenditure elasticities of DVS and NAR across different demographic groups. Overall, the expenditure elasticity of DVS shows little variation across groups, with significant differences appearing exclusively when expenditure decreases, where children are more adversely affected than elderly women. No significant differences are observed among the remaining groups. Consequently, it is difficult to identify specific cohort preferences for nutritional allocation based solely on the DVS metric.

Conversely, NAR expenditure elasticities show considerable differences across demographic groups, suggesting that although household members may consume similar types of foods, variations in the amounts consumed likely lead to notable disparities in nutritional intake. Thus, NAR appears to be a more effective indicator for investigating household allocation patterns.

As food expenditure increases, children and the elderly exhibit higher elasticities than prime-age adults. Within the prime-age cohort, a pronounced gender disparity is observed, with men showing greater responsiveness than women; in contrast, no significant gender discrepancies are found among children and elderly adults. When food expenditure decreases, boys and elderly men experience sharper reductions in NAR than almost all other groups, excluding girls. These findings highlight significant gender differences within elderly adults, with elderly men showing a higher sensitivity of NAR to reduced spending than elderly women. Declines in NAR among prime-age adults are smaller than in other groups, with no notable gender disparities.

Our findings, viewed through the lens of asymmetric expenditure elasticities, reveal no significant gender disparities in nutrient allocation among children. Furthermore, when expenditure increases, NAR improves more substantially for girls than other groups, while decreases in expenditure do not have a distinct effect on girls' NAR relative to other groups. Consequently, girls are more favorable than other age groups in the household nutrient allocation concerning the expenditure elasticity of NAR.

By integrating the outcomes of asymmetric elasticities with our descriptive statistical results, we observe that when food expenditures increase, households prioritize nutritional improvements for vulnerable groups, such as children and elderly adults, at the expense of prime-age adults, especially prime-age women. However, this may exacerbate gender disparities among prime-age adults while leaving the existing gender disparities in nutritional levels among children unchanged.

On the other hand, our analysis suggests that when food expenditures decline, households prioritize preserving the nutritional intake of prime-age adults, with prime-age women experiencing the smallest reduction. This pattern contributes to reducing gender imbalances among adults. Simultaneously,

Table 7 Results of equivalence tests of expenditure elasticity of diet variety score/nutrient adequacy ratio for different groups: asymmetric model (IV-FE)[1)]

	Boys	Girls	Prime-age men	Prime-age women	Elderly men	Elderly women	Difference[2)]
Diet variety score							
Boys	–	0.023	0.022	0.023	0.025	0.009	–0.113***
Girls	–0.001	–	–0.001	0.000	0.003	–0.014	–0.137***
Prime-age men	0.039	0.041	–	0.001	0.003	–0.013	–0.095***
Prime-age women	0.032	0.034	–0.007	–	0.002	–0.014	–0.104***
Elderly men	0.040	0.042	0.001	0.008	–	–0.016	–0.098**
Elderly women	0.060*	0.061*	0.021	0.028	0.019	–	–0.062
Nutrient adequacy ratio							
Boys	–	–0.001	0.017**	0.026***	0.014*	0.010	–0.044***
Girls	0.012	–	0.018**	0.027***	0.015*	0.011	–0.031**
Prime-age men	0.020*	0.008	–	0.009***	–0.003	–0.007	–0.041***
Prime-age women	0.022**	0.010	0.002	–	–0.011*	–0.015**	–0.047***
Elderly men	0.006	–0.006	–0.014*	–0.016**	–	–0.004	–0.052***
Elderly women	0.023*	0.011	0.004	0.001	0.018***	–	–0.031**

[1)] Except for the last column, data in the upper right part of the table are the differences obtained by subtracting the mean value of the horizontal group from the mean value of the vertical group, while data in the lower left part of the table are the difference obtained by subtracting the mean value of the vertical group from the mean value of the horizontal group.

[2)] The last column in the table lists the difference between the elasticity of the same group when the expenditure is higher and lower than the average expenditure.

*, **, and *** denote rejection of the equality hypothesis at the 10%, 5%, and 1% levels, respectively.

households appear to decrease the nutritional intake of boys and elderly men to a greater extent, thus narrowing gender disparities among children and elderly adults.

3.3. Robustness test

The preceding analysis shows that the nutritional status of demographic groups responds differently to growth and decline in household food expenditure, implying that shifts in expenditure trigger reallocations within households. To validate these findings, we further assess the impact of expenditure increases and decreases on allocative inequity across demographic groups. Specifically, we apply the Relative Ratio to quantify intra-household nutritional disparities across different demographic groups:

$$R_{i,j}=N_{ihvt}/N_{jhvt} \quad (8)$$

where N_{ihvt} and N_{jhvt} refer to the diet variety score/nutrient adequacy ratio of group i and j, respectively and $R_{i,j}$ is the ratio of diet variety score/nutrient adequacy ratio of group i compared to group j in the household. We use a two-way fixed effects model addressing the endogeneity issue to estimate the changes in the degree of inequity in household allocation when expenditure increases and decreases. Model estimation outcomes are outlined in Table 8.

As shown in Table 8, changes in expenditure have no significant impact on the relative ratio of DVS across all demographic groups, aligning with the findings in Table 6 that reveal no significant differences in expenditure elasticities among these groups. In contrast, expenditure changes exert a significant effect on the NAR ratio for gender cohorts, whereas no such effect is observed for age cohorts. When food expenditure rises, women experience less improvement in NAR than men, implying that gender-specific allocation inequality may worsen. However, as expenditure declines, the impact on NAR is smaller for women than for men, indicating a possible narrowing of gender-based disparities.

In detail, changes in expenditure primarily lead to gender disparities among children and prime-age adults, while the NAR ratio for elderly gender groups remains stable. As expenditure increases, the NAR ratio for prime-age women relative to men declines, with no significant shifts observed among children. This finding underscores that inequities in intra-household resource allocation are intensified specifically for prime-age women. When expenditure decreases, girls and prime-age women are less affected in terms of NAR than boys and prime-age men, respectively, suggesting a mitigation of the pro-male bias in household resource allocation during expenditure contractions. The elasticity estimates in Table 8 exhibit some discrepancy with those in Table 6. For example, despite significantly higher elasticity for children compared to prime-age adults during expenditure increases, the change in the NAR ratio remains modest, suggesting no substantial effect on the NAR ratio between children and prime-age adults.

3.4. Discussion

The empirical results reveal a complex hierarchy in intra-household nutrient allocation. While descriptive statistics show that prime-age adults enjoy superior nutritional status, the elasticity estimates uncover the dynamic "protection mechanism" underlying this distribution. Notably, we find that the Diet Variety Score (DVS) and Nutrient Adequacy Ratio (NAR) exhibit different sensitivities; the latter captures intra-household reallocations more effectively, suggesting that households may maintain dietary variety while sacrificing nutrient density during expenditure shocks.

A key contribution of this study is the identification of asymmetric responsiveness to expenditure fluctuations. The finding that nutritional adjustments are more pronounced during expenditure declines than increases suggests a "ratchet effect" or loss aversion in consumption behavior. Specifically, during economic upturns, households prioritize improving the nutrition of vulnerable cohorts (children and the elderly). However, this altruistic allocation is fragile. During expenditure contractions, households pivot to a survival strategy, prioritizing the nutritional stability of prime-age adults, the primary labor force, while significantly reducing the intake of boys and elderly men. Interestingly, robustness tests using relative ratio elasticities further clarify that while

Table 8 Expenditure elasticity of the ratio of diet variety score/nutrient adequacy ratio for different groups: the asymmetric model[1)]

	Women/Men	Girls/Boys	Prime-age women/ Men	Elderly women/ Men	Children/ Prime-age adults	Elderly adults/ Prime-age adults
Ratio of diet variety score						
Above average expenditure	–0.015	–0.152	–0.026	0.055	–0.041	–0.095
	(0.039)	(0.245)	(0.052)	(0.078)	(0.104)	(0.080)
Below average expenditure	–0.026	–0.099	–0.027	0.023	0.006	–0.104
	(0.039)	(0.249)	(0.049)	(0.074)	(0.102)	(0.076)
R^2	0.010	0.110	0.012	0.047	0.040	0.039
Observation	7,852	549	5,740	1,627	2,916	1,782
Ratio of nutrient adequacy ratio						
Above average expenditure	–0.099***	–0.294	–0.092***	0.053	0.012	0.085
	(0.027)	(0.289)	(0.035)	(0.062)	(0.087)	(0.077)
Below average expenditure	–0.101***	–0.481*	–0.081**	0.023	–0.022	0.077
	(0.029)	(0.271)	(0.035)	(0.070)	(0.095)	(0.080)
R^2	0.017	0.121	0.023	0.041	0.041	0.043
Observation	7,855	550	5,743	1,627	2,918	1,782

[1)] The ratios of diet variety score and nutrient adequacy ratio are taken in logarithmic form. The sample size for the diet variety score model is slightly less than the nutrient adequacy ratio because a few individuals have diet variety score of 0, which cannot be taken in log form. The standard deviation is in parentheses. *, **, and *** denote rejection of the equality hypothesis at the 10%, 5%, and 1% levels, respectively.

prime-age women face aggravated disproportionate allocation during increases, they (along with girls) experience a relative "mitigation" of disadvantage during declines, primarily because men's intake drops even more sharply. These patterns underscore that symmetric models fail to capture the true vulnerability of rural populations, as they mask these direction-dependent allocation behaviors.

4. Conclusion

This study concludes that intra-household nutrient allocation in rural China is governed by a strategic, yet inequitable, asymmetric adjustment mechanism. Our findings reveal that nutritional status is highly reference-dependent, with households exhibiting significantly greater sensitivity to expenditure contractions than to expansions. This asymmetry manifests as a shift in allocation strategies: during economic expansions, households prioritize improving the nutrition of vulnerable cohorts, such as children and the elderly; however, during economic downturns, they pivot to selectively protect the nutrition of prime-age adults at the expense of boys and the elderly men. Furthermore, the persistent "double burden" of low dietary variety and nutrient inadequacy among girls, coupled with the gender-based disparities observed in prime-age adults' elasticities, underscores deep-seated structural inequities that symmetric frameworks fail to identify. These results imply that general income growth alone is insufficient to redress internal allocation biases. Consequently, policymakers should prioritize the stability of rural food expenditures and implement institutionalized, gender-sensitive interventions, such as targeted school nutrition programs and specialized elderly subsidies, to buffer the most vulnerable household members against economic shocks and ensure long-term health equity.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Gemini and ChatGPT in order to translate and polish the text to assist in improving language clarity and readability. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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