Shrinking Working-Age Population and Food Demand: Evidence From Rural China

by Xinru Han and Guojing Li

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Abstract:

China is facing a fast-aging population, and the proportion of the working-age population (WAP) shows a decreasing trend. In this paper, we use a linear expenditure system-quadratic almost ideal demand system (LES-QUAIDS) framework to estimate the distribution of food demand elasticity under different proportions of WAP in rural China. Results show that rural residents' income elasticities of fruits and vegetables, animal products, oils and fats, and grains are 0.73, 0.65, 0.55, and 0.48, respectively. Meanwhile, the income elasticity of rural residents tends to increase as the proportion of WAP in the household decreases. These results provide a deeper understanding of the food consumption pattern of rural residents in China and could be used in the general equilibrium model or partial equilibrium model to forecast the food supply and demand.

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Keywords:

Food consumption; working-age population; heterogeneity; rural residents; China

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1. Introduction

During the last four decades, China has become a middle-income country and faced a fast-aging population (Cai, 2020; Zhang et al., 2013; Zhong, 2011). With rising income and changing population structure, Chinese rural residents' food consumption structure has also changed significantly (Bai et al., 2020; Han, 2020; Huang & Bouis, 2001; Huang et al., 2019; Yu, 2018; Zheng et al., 2019). The per capita consumption of grain among rural residents decreased from 247.8 kg in 1978 to 154.8 kg in 2019, and the per capita consumption of meat increased from 5.8 kg in 1978 to 24.7 kg in 2019 (National Bureau of Statistics of China (NBSC), 2020).

Meanwhile, the proportion of the working-age population[1] (WAP) out of China's total population shows a decreasing trend year by year. The proportion of WAP dropped from 74.5% in 2010 to 71.2% in 2018 (NBSC, 2020). According to the prediction in the medium variant of the *2019 Revision of World Population Prospects* proposed by the Population Division of the United Nations (UN, 2019), the proportion of WAP in China will fall to 64.6% in 2035 (equivalent to Japan's level in 2010) and to 59.8% in 2050 (equivalent to Japan's level in 2020).

Therefore, the structural change of food consumption by rural residents has brought challenges to China's food security (Du et al., 2020; Huang et al., 2017; Huang & Yang, 2017; Zheng et al., 2019). In this context, studies on the relationship between population structure change and food consumption have important practical significance in terms of meeting the national strategy of food security (Wang et al., 2019; Zheng et al., 2019).

Estimating food demand elasticity is an important aspect of food consumption research (Deaton & Muellbauer, 1980). Based on utility maximization and budget constraints, researchers have constructed various models to estimate the price elasticity of food demand and the income (or expenditure) elasticity of demand of

Chinese residents (Fan et al., 1995; Gould & Villarreal, 2006; Han & Chen, 2016; Wu et al., 2020; Yen et al., 2004; Zheng & Henneberry, 2010; Zhu et al., 2020). As reviewed by Chen et al. (2016), most income elasticities of food demand in China are positive. It indicates that income increasing will continue leading to the growth of food demand in the future.

Traditional food demand elasticity only estimates all samples' average elasticity value, which does not reflect the heterogeneity between different populations. In recent years, the heterogeneity of food demand elasticity has been addressed (Han et al., 2019; Zheng et al., 2019). Current studies on the heterogeneity of food consumption mainly cover the following four aspects.

First, there is the urban-rural heterogeneity (Fan et al., 1995; Zheng & Henneberry, 2009). Further, Han and Chen (2016) estimated the food demand elasticity of migrant workers living in urban areas and proved the heterogeneity of food demand elasticity among urban residents, rural residents, and migrant workers. Second, income heterogeneity can be quantified by estimating the difference in the elasticity of different income groups (Gould & Villarreal, 2006; Ren et al., 2018; Wang et al., 2014; Zheng & Henneberry, 2011; Zhu et al., 2020). For example, Zheng and Henneberry (2011) estimated the food demand elasticity of different groups of urban residents in Jiangsu Province in 2004. Third, the demographic heterogeneity, such as population and age structure, is examined (Gould & Villarreal, 2002; Liu et al., 2015). Specifically, studies on family characteristic heterogeneity mainly include adult equivalents, population aging, and the number of children or elderly people (Balli & Tiezzi, 2010; Chen et al., 2017; You et al., 2016). Fourth, the external environmental heterogeneity has been evaluated. Current research covers regional differences (Gould & Villarreal, 2006), time differences (Staudigel & Schröck, 2015), and climate differences (Vanham et al., 2017; Yohannes & Matsuda, 2016).

Since there are considerable differences in consumption between different individuals, the changing age structure of different families has a significant impact on food consumption (Feng et al., 2014; Gould, 2002; Sabates et al., 2001). Therefore, under the aging population in China, age structure change is a critical factor that cannot be ignored in food demand analysis (You et al., 2016; Zhong et al., 2012). Relevant research mainly uses the population equivalent (Gould & Villarreal, 2002; Zhong et al., 2012) or the non-demand system model (Liu et al., 2015). The population equivalent model is equivalent to the weighted average of the household members by age, while the non-demand system model may not satisfy the restrictions of symmetry, additivity, and homogeneity (Deaton & Muellbauer, 1980).

In this study, based on microdata, a linear expenditure system-quadratic almost ideal demand system (LES-QUAIDS) model was established to empirically study the age-structural heterogeneity of food demand elasticity among Chinese rural residents. This study's main contribution is to use the demand system model to estimate the distribution of food demand elasticity under different proportions of WAP. This study is a valuable supplement to the study of food elasticity of Chinese residents. Our findings can also be used in the general equilibrium model or partial equilibrium model to forecast the food supply and demand.

The structure of this paper is as follows. The second section is the econometric model. The third section describes the dataset and statistical methods. The fourth section is the analysis of the estimation results. The fifth section is a further analysis of the food demand elasticity and income heterogeneity of the elderly population. In the last section, the conclusions and policy implications are presented.

2. Econometric model

The basic hypothesis of this study is that rural residents employ the two-stage budgeting process and that the preferences are weakly separable (Deaton & Muellbauer, 1980). In the first stage, rural residents allocate expenditures to food and other commodities; in the second stage, rural residents make decisions among different food items. Specifically, in the first stage, we adopt the linear expenditure (LES) model proposed by Working (1943):

$$W_{food} = a + b_1 \mathrm{Ln}m + b_2 (\mathrm{Ln}m)^2 + u \tag{1}$$

where W_{food} is the share of the per capita food expenditure to per capita expenditure (m) of the rural residents. To control the effects of household characteristic variables (Ω) on food expenditure proportion (Han & Chen, 2016; Wu et al., 2020), this study defines:

$$a = a_0 + \Sigma_{k=1}^{K} a_k \Omega_k + u_0 \tag{2}$$

After Deaton and Muellbauer (1980) proposed the almost ideal demand system (AIDS) model, economists estimated the elasticity of demand for major food products in various countries and developed derivative models such as the quadratic almost ideal demand system (QUAIDS) model (Banks et al., 1997; Matsuda, 2007). In the second stage, we use the QUAIDS model proposed by Banks et al. (1997) and the improved form proposed by Poi (2012) as our model framework. The hypothesis of the consumer expenditure function is:

$$e(\mathbf{p}, \mathbf{z}, u) = m_0(\mathbf{p}, \mathbf{z}, u) \times e^R(\mathbf{p}, u) \tag{3}$$

where $\mathbf{p}$ is the price vector, $\mathbf{z}$ is the family characteristic vector, and u is the utility vector; $m_0(\mathbf{p}, \mathbf{z}, u)$ is part of the expenditure function that reflects family features, and $m_0(\mathbf{p}, \mathbf{z}, u) = \overline{m}_0(\mathbf{z}) \times \phi(\mathbf{p}, \mathbf{z}, u)$, where $\overline{m}_0(\mathbf{z})$ measures the impact of family characteristics on expenditure; $\overline{m}_0(\mathbf{z}) = 1 + \boldsymbol{\rho}'\mathbf{z}$; $\phi(\mathbf{p}, \mathbf{z}, u)$ measures the effect of multiple factors on expenditure; $\phi(\mathbf{p}, \mathbf{z}, u) = \frac{\Pi_{j=1}^{k} p_j^{\beta_j} (\Pi_{j=1}^{k} p_j^{\boldsymbol{\eta}_\mathbf{i}'\mathbf{z}} - 1)}{\frac{1}{u} - \Sigma_{j=1}^{k} \lambda_j \ln p_j}$; and $\boldsymbol{\eta}$ is an $s \times k$ matrix.

If family characteristics are not considered, the QUAIDS model can be described as:

$$w_i = \alpha_i + \Sigma_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln \left[\frac{m}{a(\mathbf{p})}\right] + \frac{\lambda_i}{b(\mathbf{p})} \left\{\ln \left[\frac{m}{a(\mathbf{p})}\right]\right\}^2 \tag{4}$$

where w_i is the share of per capita expenditure on food i out of the whole per capita food expenditure W_{food}; n is the number of food categories; $\ln a(\mathbf{p}) = \alpha_0 + \Sigma_{i=1}^{n} \alpha_i \ln p_i + \frac{1}{2} \Sigma_{i=1}^{n} \Sigma_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j$; $b(\mathbf{p}) = \Pi_{i=1}^{n} p_i^{\beta_i}$; $\lambda(\mathbf{p}) = \Sigma_{i=1}^{n} \lambda_i \ln p_i$; and

$\Sigma_{i=1}^{n}\lambda_i = 0$.

Based on family characteristics, the QUAIDS model can be modified based on equation (4) as:

$$w_i = \alpha_i + \Sigma_{j=1}^{n}\gamma_{ij}\ln p_j + (\beta_i + \boldsymbol{\eta}_i'\mathbf{z})\ln\left[\frac{m}{\bar{m}_0(\mathbf{z})a(\mathbf{p})}\right] + \frac{\lambda_i}{b(\mathbf{p})c(\mathbf{p},\mathbf{z})}\left\{\ln\left[\frac{m}{\bar{m}_0(\mathbf{z})a(\mathbf{p})}\right]\right\}^2 \quad (5)$$

where $c(\mathbf{p},\mathbf{z}) = \Pi_{j=1}^{k} p_j^{\boldsymbol{\eta}_i'\mathbf{z}}$, $\Sigma_i^n\alpha_i = 1$, $\Sigma_i^n\beta_i = 0$, $\Sigma_i^n\gamma_{ij} = 0$, $\Sigma_{i=1}^{n}\lambda_i = 0$, and $\Sigma_{j=1}^{k}\eta_{rj} = 0\ (r = 1,2,\ldots,s)$. If $\lambda_i = 0$, then equations (4) and (5) are AIDS models.

Based on the definition of $g_i = \beta_i + \boldsymbol{\eta}_i'\mathbf{z} + \frac{2\lambda_i}{b(\mathbf{p})c(\mathbf{p},\mathbf{z})}\ln\left[\frac{m}{\bar{m}_0(\mathbf{z})a(\mathbf{p})}\right]$ and $h_i = \frac{(\beta_i+\boldsymbol{\eta}_i'\mathbf{z})\lambda_i}{b(\mathbf{p})c(\mathbf{p},\mathbf{z})}\left\{\ln\left[\frac{m}{\bar{m}_0(\mathbf{z})a(\mathbf{p})}\right]\right\}^2$, the conditional expenditure elasticity of food i is $e_i = 1 + \frac{g_i}{w_i}$, and its conditional uncompensated (Marshallian) price elasticity is $e_{ij}^U = -\delta_{ij} + \frac{1}{w_i}\left(\gamma_{ij} - g_i \times \left(\alpha_i + \Sigma_{j=1}^{n}\gamma_{ij}\ln p_j\right) - h_i\right)$. In the above, δ_{ij} is the Kronecker function: if $i = j$, then $\delta_{ij} = 1$; otherwise, $\delta_{ij} = 0$. The conditional compensated price elasticity is $e_{ij}^C = e_{ij}^U + e_i w_j$.

Following Zheng et al. (2019), we use the seemingly unrelated regression (SUR) method to estimate the QUAIDS model for $n-1$ food categories. The conditional expenditure elasticity, conditional uncompensated price elasticity, and conditional compensated price elasticity of the remaining food category are $\Sigma_{i=1}^{n}e_{ij}^U w_i = -w_j$, $\Sigma_{i=1}^{n}e_i w_i = 1$, and $\Sigma_{j=1}^{n}e_{ij}^U + e_i = 0$, respectively. According to equations (1) and (2), unconditional expenditure elasticity (income elasticity) is $E_i = \left[\frac{b_1+2b_2\ln m}{W_{food}} + 1\right]e_i$.

3. Data source and statistical description

(A) Data source

In this study, we use the 2012-2018 Survey for Agriculture and Village Economy (SAVE) data from the Institute of Agricultural Economics and Development (IAED), Chinese Academy of Agricultural Sciences (CAAS). The dataset included 22,416 samples from eight provinces (autonomous regions)—Hebei, Jilin, Fujian, Shandong, Henan, Yunnan, Shaanxi, and Xinjiang—30 counties, 94 townships, and 295 villages. These data record the food consumption and food expenditure of the sampled households for the whole year. According to data from current studies, microdata including the China Health and Nutrition Survey (CHNS) (Gao et al., 2020; Ren et al., 2018) and the household survey data conducted by the NBSC (Han & Chen, 2016; Han et al., 2019; Zheng & Henneberry, 2010; Zhu et al., 2020) or macro data from the NBSC are commonly used in studies on Chinese residents' food consumption (Zheng et al., 2019). CHNS data are three-day food consumption data from sampled households, which may not fully reflect the food consumption preference of the sampled households. Household survey data of the NBSC cover the annual food consumption of the sampled households, but currently it is not open to the public.

According to the questionnaire of the SAVE data, household food consumption is divided into staple foods, beans and soy products, oils and fats, meat and poultry products, eggs and egg products, milk and dairy products, aquatic products, fruits and vegetables, and fruit and vegetable products. Each category is subdivided into subcategories such as flour and rice. To avoid having a large number of null values[2], this study combines these food categories into four categories: grains (including staple foods, beans, and soy products), oils and fats, animal products (including meat and poultry products, eggs and egg products, milk and dairy products, and aquatic products), and fruits and vegetables (including fruits and vegetables and their products). To avoid the impact of abnormal values on the estimation results of the model, this study excluded the minimum and maximum values of the main variables, such as consumption, expenditure, and income, and some of the missing average prices were replaced by the average prices of the province in the current year. After data cleansing, 15,897 valid samples can be used.

(B) Statistical description

The proportion of WAP in the household ($adultr$) is the key household characteristic variable in this study. Figure 1 shows the changes in the proportion of

WAP in the household. The proportion of WAP in the sample households generally showed a downward trend, decreasing from 79.57% in 2012 to 76.53% in 2018, which is consistent with the overall national situation.

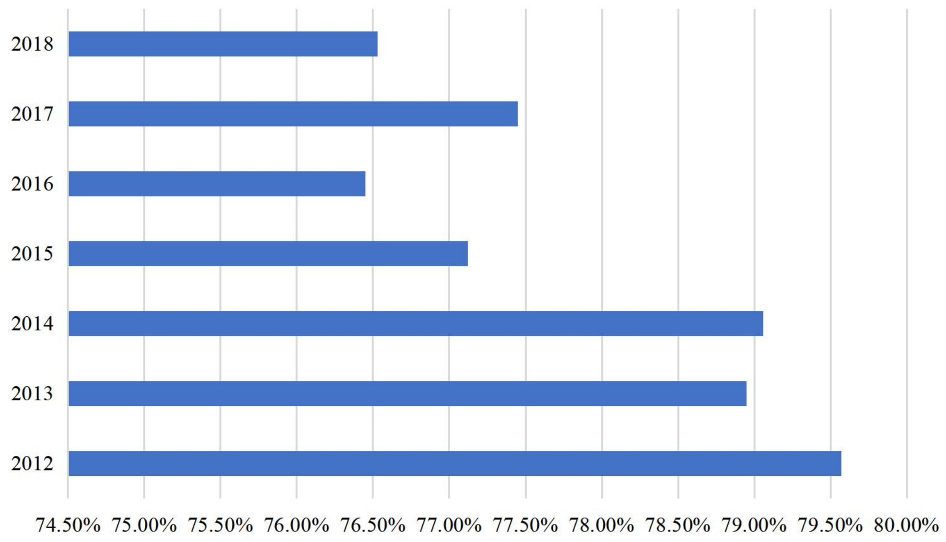

Figure 1 Proportion of WAP per household

As predicted by the Population Division of United Nations, the proportion of WAP per household will fall to 64.6% in 2035 and 59.8% in 2050 (UN, 2019). Therefore, the proportions of WAP of 60%, 65%, and 70% are chosen as cutoff points in this study. The sample families are divided into four categories: families in the G1 group have a proportion of WAP in the range [0, 60%), G2 is [60%, 65%), G3 is [65%, 70%), and G4 is [70%, 100%]. Table 1 shows that there are more rural households with a WAP greater than 70%, accounting for 10,476 households, which may be because over 50% of elderly people live alone or live with their spouses only (G5) (Dang, 2018). To further address the effects of the aging population on food consumption, we also estimate the food demand elasticities of G5.

Table 1 shows the statistical description of the variables of each sample. First, the distribution of per capita food expenditure of rural residents has a weak correlation with the household WAP. Second, the per capita food expenditure decreases with the decrease in the proportion of WAP in the household. The average per capita food expenditure of households in the G1 group is 1,368.09 yuan, which is

138.39 yuan lower than in the G4 group. The per capita total expenditure also shows the same trend, i.e., it decreases with the decline in the proportion of WAP. Therefore, the proportion of WAP shows a positive correlation with the per capita food expenditure and total expenditure of the household.

Table 1 Statistical description of major variables

Variable	Category	Unit	G1	G2	G3	G4	Whole sample
Expenditure share							
w_1	Grain (GR)		0.24 (0.17)	0.24 (0.18)	0.25 (0.17)	0.24 (0.17)	0.24 (0.17)
w_2	Oils and fats (OF)		0.12 (0.09)	0.12 (0.09)	0.11 (0.08)	0.12 (0.09)	0.12 (0.09)
w_3	Animal products (AP)		0.48 (0.18)	0.48 (0.17)	0.48 (0.18)	0.48 (0.18)	0.48 (0.18)
w_4	Fruits and vegetables (FV)		0.17 (0.13)	0.17 (0.12)	0.16 (0.13)	0.16 (0.13)	0.16 (0.13)
Price (unit value)							
p_1	Grain (GR)	Yuan/kg	78.40 (61.12)	75.08 (62.47)	84.59 (61.42)	87.18 (64.07)	84.76 (63.28)
p_2	Oils and fats (OF)	Yuan/kg	12.24 (8.07)	11.87 (7.70)	12.27 (8.21)	13.80 (8.84)	13.26 (8.62)
p_3	Animal products (AP)	Yuan/kg	39.48 (32.32)	35.19 (26.45)	40.56 (29.61)	43.86 (33.89)	42.31 (32.94)
p_4	Fruits and vegetables (FV)	Yuan/kg	61.66 (66.40)	59.44 (57.12)	62.85 (66.21)	63.08 (66.99)	62.64 (66.41)
per capita food consumption							
q_1	Grain (GR)	Kg	5.12 (5.03)	5.01 (4.91)	4.88 (4.35)	4.93 (4.27)	4.96 (4.46)
q_2	Oils and fats(OF)	Kg	12.41 (6.90)	12.47 (5.77)	12.58 (6.76)	13.35 (8.82)	13.05 (8.17)
q_3	Animal products (AP)	Kg	20.52 (15.49)	20.66 (11.52)	21.14 (14.90)	21.27 (14.57)	21.09 (14.67)
q_4	Fruits and vegetables (FV)	Kg	5.00 (3.50)	4.85 (2.87)	5.34 (3.99)	5.45 (4.47)	5.33 (4.20)
Household characteristic variable							
W_{food}	Per capita food expenditure	1,000 Yuan	1.37 (0.72)	1.29 (0.70)	1.47 (0.77)	1.57 (0.79)	1.51 (0.78)
m	Per capita total expenditure	1,000 Yuan	4.31 (2.45)	4.08 (1.99)	4.71 (2.46)	5.15 (2.80)	4.90 (2.70)
$adultr$	Proportion of WAP in the household		0.36 (0.21)	0.60 (0.01)	0.67 (0.00)	0.93 (0.11)	0.78 (0.26)
Number of samples			2943	654	1824	10476	15897

Note: The income and price variables are all deflated by the national Consumer Price Index (2012=100) from the NBSC. 1 USD=6.62 yuan in 2018. The standard deviations are shown in parentheses.

Third, out of the total per capita food consumption, the per capita grain consumption of rural households increases as the proportion of WAP in the household falls. The average per capita grain consumption of the G1 households is 5.12 kg, which is 0.19 kg higher than that of the G4 group. The average per capita consumption of oils and fats and animal products decreases as the proportion of WAP in the household decreases. The average per capita vegetable consumption decreases first and then increases as the proportion of WAP in the household decreases. Therefore, there are certain differences in the per capita food consumption between households with different proportions of WAP.

4. Estimation results

(A) Model selection and estimation

In this study, the least squares method is used to estimate the first-stage LES model. The variable Ω includes the proportion of WAP in the household and the dummy variables of provinces and years. The estimated results are summarized in Table 2.

Table 2 Estimates of the first-stage linear expenditure model

	Estimated result	Bootstrap standard error
$\ln m$	0.32***	(0.05)
$(\ln m)^2$	-0.03***	(0.00)
$adultr$	0.02***	(0.00)
Provincial dummy variable	Y	
Year dummy variable	Y	
Number of samples	15,897	

Note: *** indicates significance at the 1% level.

The second phase of food consumption estimation uses two methods to choose between the AIDS model and the QUAIDS model. The first approach uses the nonparametric method to plot the Engel curves of the four food categories (Figure 2) with reference to Banks et al. (1997). The results show that the Engel curves of the four food categories exhibit obvious nonlinear characteristics, so the QUAIDS model should be used. The second way is to test the joint significance of parameter λ_i in equation (5). If all λ_i are 0, the AIDS model should be used; otherwise, the QUAIDS model should be used (since $\Sigma_{i=1}^{n}\lambda_i = 0$, only three λ need to be tested for equality to 0 at the same time). The test result shows $\chi^2(3) = 60.28$, with a probability of

0.00, which leads us to reject the null hypothesis that all $\lambda_i = 0$, indicating that the QUAIDS model should be used. Therefore, the follow-up analysis of this study is based on the estimation results of the QUAIDS model.

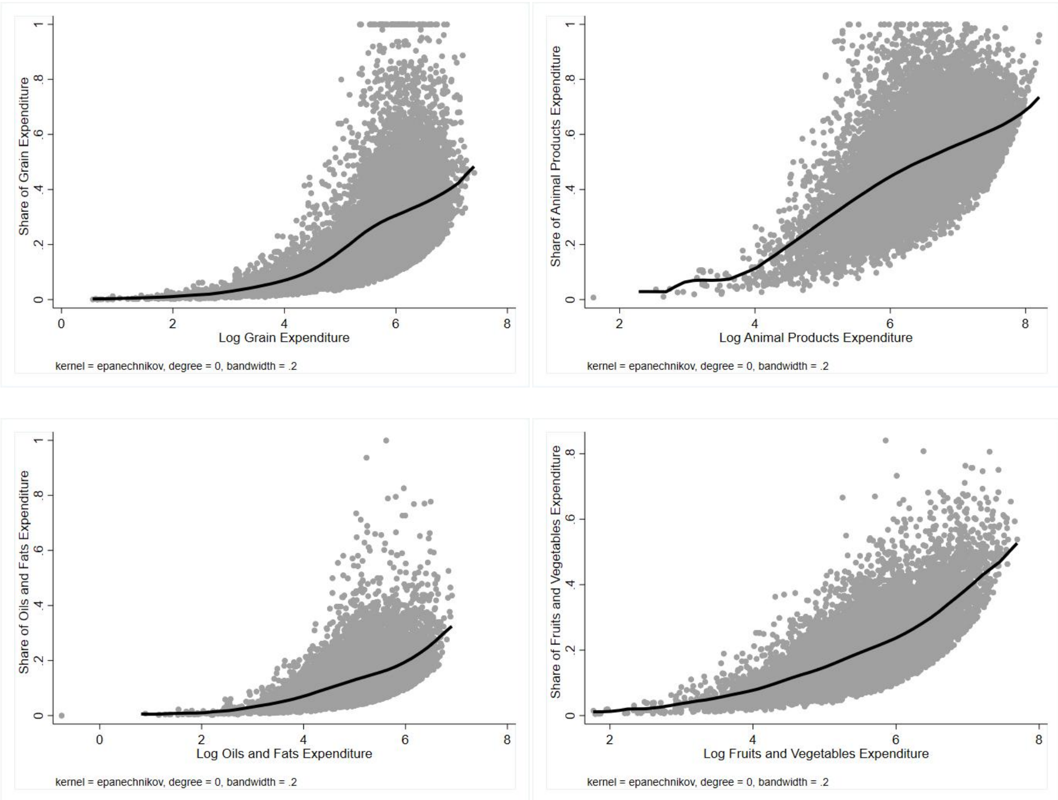

Figure 2 Engel curve of four food categories

The estimation results of the first stage show that the proportion of per capita food expenditure in the per capita total expenditure is significant. The estimated results of the AIDS model and the QUAIDS model are summarized in Table 3. The estimation results show that more than two-thirds of the variables in all models are statistically significant. The estimated results of the standard AIDS model (column 1), the standard QUAIDS model (QUAIDS1, column 2), the household characteristics QUAIDS model (QUAIDS2, excluding the provincial and year dummy variables, column 3), the household characteristics QUAIDS model (QUAIDS3, including the provincial and year dummy variables, column 4) are not significantly different. Results indicate that the estimation results in this study are robust.

Table 3 Estimation results of the demand system model in the second stage

Parameters	AIDS (1)	QUAIDS1 (2)	QUAIDS2 (3)	QUAID3 (4)
α_1	0.28***	0.28***	0.28***	0.29***
α_2	0.10***	0.10***	0.10***	0.11***
α_3	0.42***	0.42***	0.42***	0.40***
α_4	0.19***	0.19***	0.20***	0.20***
β_1	-0.02***	-0.02***	-0.01	-0.03***
β_2	-0.04***	-0.04***	-0.04***	-0.04***
β_3	0.01***	0.01***	0.00	0.02***
β_4	0.05***	0.05***	0.05***	0.04***
γ_{11}	0.02***	0.03***	0.03***	0.03***
γ_{21}	-0.02***	-0.02***	-0.02***	-0.01***
γ_{31}	-0.02***	-0.02***	-0.02***	-0.02***
γ_{41}	0.01***	0.01***	0.01***	0.01***
γ_{22}	0.06***	0.06***	0.06***	0.06***
γ_{32}	-0.04***	-0.04***	-0.04***	-0.04***
γ_{42}	-0.01***	-0.01***	-0.01***	-0.01***
γ_{33}	0.07***	0.07***	0.07***	0.07***
γ_{43}	-0.01***	-0.01***	-0.01***	-0.01***
γ_{44}	0.01***	0.01***	0.01***	0.01***
η_1			-0.02*	-0.01***
η_2			-0.00	-0.00
η_3			0.01	0.01***
η_4			0.01	0.00***
ρ			0.32***	-0.00
λ_1		-0.01*	-0.01*	0.00***
λ_2		0.00	0.00	-0.01***
λ_3		-0.00	-0.00	-0.00***
λ_4		0.00**	0.01**	0.01***
Provincial dummy variable	N	N	N	Y
Year dummy variable	N	N	N	Y
Number of samples	15,897	15,897	15,897	15,897

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

(B) Income elasticity and price elasticity

Based on the estimation results of the LES model and the household characteristics QUAIDS model (including the provincial and year dummy variables), this study calculated the conditional expenditure elasticity, income elasticity, and conditional uncompensated own-price elasticity of the whole sample and the four groups of the WAP. The results are summarized in Table 4 and Table 5[1].

[1] Due to space constraints, the estimates of conditional uncompensated cross-price elasticities and conditional compensated price elasticities are not presented, and the reader can contact the authors to request them.

Table 4 Estimated conditional expenditure elasticity and income elasticity

	GR	OF	AP	FV	FEE in the 1st stage
Conditional expenditure elasticity					
All samples	0.79(0.00)	0.90(0.00)	1.06(0.00)	1.18(0.00)	0.62(0.00)
G1 [0,60%)	0.82(0.00)	0.86(0.00)	1.05(0.00)	1.18(0.01)	0.65(0.00)
G2 [60%,65%)	0.84(0.00)	0.96(0.00)	1.04(0.00)	1.11(0.00)	0.66(0.00)
G3 [65%,70%)	0.79(0.00)	0.89(0.00)	1.06(0.00)	1.18(0.00)	0.63(0.00)
G4 [70%,100%]	0.78(0.00)	0.91(0.00)	1.06(0.00)	1.19(0.00)	0.61(0.00)
Income elasticity					
All samples	0.48(0.00)	0.55(0.00)	0.65(0.00)	0.73(0.00)	
G1 [0,60%)	0.53(0.00)	0.55(0.00)	0.68(0.00)	0.76(0.00)	
G2 [60%,65%)	0.55(0.00)	0.63(0.00)	0.68(0.00)	0.73(0.00)	
G3 [65%,70%)	0.49(0.00)	0.56(0.00)	0.66(0.00)	0.74(0.00)	
G4 [70%,100%]	0.47(0.00)	0.55(0.00)	0.64(0.00)	0.72(0.00)	

Note: The data in the parentheses are the standard errors. The first-stage food expenditure elasticity (FEE) of the four groups is the estimated value of food expenditure elasticity based on the proportion of expenditure on the four food categories out of the average total expenditure of each group.

Table 5 Estimated conditional uncompensated own-price elasticity

	GR	OF	AP	FV
All samples	-0.82(0.00)	-0.50(0.01)	-0.88(0.00)	-0.95(0.01)
G1 [0,60%)	-0.83(0.00)	-0.49(0.01)	-0.88(0.00)	-0.95(0.01)
G2 [60%,65%)	-0.83(0.00)	-0.52(0.00)	-0.87(0.00)	-0.94(0.00)
G3 [65%,70%)	-0.83(0.00)	-0.46(0.01)	-0.88(0.00)	-0.95(0.00)
G4 [70%,100%]	-0.82(0.00)	-0.51(0.00)	-0.88(0.00)	-0.95(0.01)

Note: Standard error is in parentheses.

The elasticity estimation results in Table 4 show that the significance level of all elasticity values is 1%. Among the estimated income elasticities of the whole sample, the income elasticities of fruits and vegetables and animal products of rural residents are relatively large, at 0.73 and 0.65, respectively; the income elasticities of oils and fats and grains are relatively small, with elasticity values of 0.55 and 0.48, respectively. The results showed that as income increased, the food consumption of rural residents still showed an increasing trend, and they tended to consume more vegetables, fruits, and animal products, indicating that the pressure on China's food security will persist.

The elasticity estimation results in Table 5 show that the significance level of all elasticity values is 1%. As shown by the conditional uncompensated own-price elasticity of all samples, rural residents are most sensitive to the price changes of fruits and vegetables, with an absolute value of own-price elasticity of 0.95, followed by animal products and grain products, with absolute values of own-price elasticity of 0.88 and 0.82, respectively. They are least sensitive to price changes of oil and fat products, whose absolute value of own-price elasticity is 0.5. Compared with the existing estimates of the income elasticity and conditional uncompensated own-price elasticity of China's rural residents (see Han and Chen (2016) Table IV), the estimated results of this study do not have abnormal values.

When we stratified the estimation results by the proportion of WAP in the household, the flexibility of food expenditure in the first stage indicates that the elasticity of food expenditure of rural residents tends to increase as the proportion of WAP in the household declines. The G1 group (proportion of WAP in the household less than 60%) had a food expenditure elasticity that was 0.03 higher than the food expenditure elasticity of the G4 group (proportion of WAP in the household greater than 70%). These results imply that as the proportion of the WAP in the household continues to decline in China, rural residents tend to spend their budgets on food expenditures. This result suggests that during the life cycle, food expenditure at home exhibits the pattern of being high at the two ends and low in the middle (Chen et al., 2017).

Second, the conditional expenditure elasticity of the four food categories for rural residents has age-structure heterogeneity. The G1 population was 0.04 higher than the G4 group in its expenditure elasticity of grain demand, and the expenditure elasticity of oil and fat product demand was 0.05 lower than that of the G4 group. The expenditure elasticities of animal product demand and fruit and vegetable product demand in the two groups are almost identical. The expenditure elasticity of demand of oils and fats of the G2 group is significantly higher than that of the other groups, and the expenditure elasticity of demand of fruits and vegetables of the G2 group is significantly lower than that of other groups.

Third, the comprehensive results of the food expenditure flexibility of the first stage and the conditional expenditure elasticity of the second stage lead to a trend of increasing income elasticity of rural residents as the proportion of WAP in the household decreases. The G1 group had a 0.06 higher income elasticity of grain demand, a 0.04 higher income elasticity of demand for animal products, and a 0.04 higher income elasticity of demand for fruits and vegetables than the G4 group.

Unlike income elasticity, the correlation between the own-price elasticity of food consumption of rural residents and the proportion of WAP is relatively small. The own-price elasticities of grain, oils and fats, and fruits and vegetables of G1-G4 are almost the same, while the own-price elasticity of oils and fats differs slightly. These results indicate that the proportion of WAP in the household may not be a key factor in the own-price elasticity of food consumption of rural residents. With the decline in the proportion of WAP in the household, the own-price elasticity of food consumption of rural residents remains almost unchanged.

5. Further discussion

(A) Food demand elasticity of the elderly population

Since the food consumption characteristics of elderly people living alone or with their spouses (G5) are significantly different from those of other groups, this study analyzed the food demand characteristics of G5. Due to the impact of China's one-child policy, the trend of aging in China will continue to worsen in the future, and the proportion of elderly people who live alone or with their spouses will continue to rise in social and family groups (Cai, 2020; Han & Cheng, 2020). Due to factors such as age and income level, there is a difference in consumption between elderly and young people. According to our data, the sample size of G5 is 652, which accounts for 4.1% of all sample households. The average Engel's coefficient of G5 is 34.2%, which is 0.6 percentage point higher than other households. It suggests that the food demand of elderly people who live alone or with their spouses is different from other households.

Besides, with the aggravation of the aging trend in China, the proportion of WAP is decreasing. As a result, the G1 group will be increasing. Therefore, this section focuses on the relevant characteristics of the G1 population. Table 6 shows that the income elasticity of demand for oils and fats and animal products in elderly people living alone or with their spouses (0.53 and 0.67, respectively) is lower than that of the G1 population (0.55 and 0.68, respectively), and their income elasticity of demand for fruits and vegetables (0.79) is higher than that of the G1 population (0.76). These results indicate that compared with the G1 population, the elderly population's consumption of fruits and vegetables is relatively sensitive to changes in income. Therefore, with the intensification of aging, the guarantee of the supply of fruits and vegetables will require extra attention.

Table 6 Estimated conditional expenditure elasticity and income elasticity of the elderly population

	GR	OF	AP	FV	FEE in the 1st stage
Conditional Expenditure elasticity	0.82(0.01)	0.83(0.01)	1.05(0.00)	1.24(0.01)	0.64(0.00)
Income elasticity	0.53(0.01)	0.53(0.01)	0.67(0.00)	0.79(0.01)	

Note: FEE =food expenditure elasticity. Standard error is in parentheses.

(B) Income elasticity of food demand of elderly groups under different income levels

Current studies have found that the income elasticity of food demand decreases with increasing income (Ren et al., 2018; Zheng & Henneberry, 2010; Zhu et al., 2020).To verify the heterogeneity of the income of the population with different proportions of WAP, the four groups of WAP people are divided into five equal groups according to income, and the income distribution results are shown in Figure 3. There is a certain income heterogeneity between the four groups of WAP, in which the G1 group is mainly low income and low–medium income, which is consistent with the life cycle hypothesis.

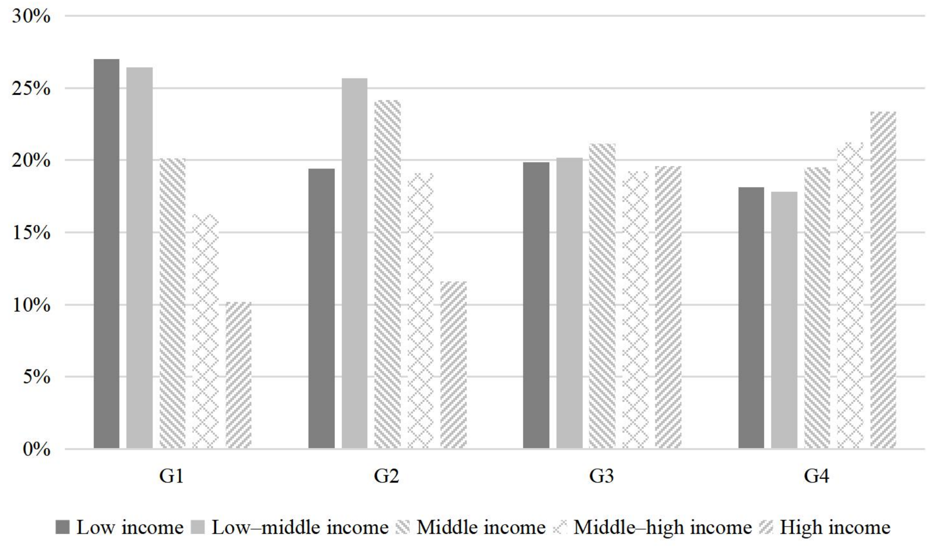

Figure 3 The income distribution of the four groups with different proportions of WAP

Note: Low, middle, low–middle, middle, high–middle, and high incomes are the 0–20th, 20–40th, 40–60th, 60–80th, and 80–100th percentiles of the per capita income of the whole sample, respectively.

Furthermore, the G1 group is subgrouped according to income to estimate the income elasticity of food demand, and the results are summarized in Table 7. The estimation results show that within G1, the income elasticity of food demand decreases with increasing income. For example, the income elasticity of grain demand in the low-income subgroup of G1 is 0.02 higher than that of the high-income subgroup. The food demand income elasticity of the whole G1 sample is close to that of the middle- and high-income subgroups of G1. Therefore, there are differences in the income elasticity of food demand for the elderly population at different income levels.

Based on the estimation results in Tables 4 and 7, it can be seen that in the context of accelerating population aging and a high income growth rate, it is necessary to simultaneously consider the heterogeneity of the family's age structure and income distribution to accurately predict the future food demand of Chinese rural residents. Furthermore, due to the rapid advancement of urbanization and significant differences in the food consumption characteristics of urban and rural residents in China (Han & Chen, 2016), to make food demand forecasts in China, it is necessary to set three-dimensional scenarios covering urbanization rate, age structure, and income distribution. Existing equilibrium models usually only include urbanization rates (Huang et al., 2017; Lu et al., 2017; Xu et al., 2015), so they may not accurately reflect the situation of food security in the complex domestic and international environment of the new era.

Table 7 Estimated results of income elasticity of different subgroups of the G1 group

	GR	OF	AP	FV	Number of samples
Low income	0.56(0.00)	0.57(0.01)	0.69(0.00)	0.79(0.01)	794
Low–middle income	0.55(0.00)	0.57(0.00)	0.70(0.00)	0.81(0.01)	778
Middle income	0.54(0.00)	0.59(0.00)	0.68(0.00)	0.74(0.01)	592
Middle–high income	0.53(0.00)	0.57(0.00)	0.69(0.00)	0.76(0.00)	479
High income	0.47(0.00)	0.51(0.01)	0.67(0.00)	0.75(0.01)	300
Whole G1 group	0.53(0.00)	0.55(0.00)	0.68(0.00)	0.76(0.00)	2,943

Note: Standard error is in parentheses.

6. Conclusions and implications

Based on the SAVE data from 2012 to 2018 provided by the Institute of Agricultural Economics and Development, Chinese Academy of Agricultural Sciences, this study constructed the LES-QUAIDS model to empirically study the household age-structural heterogeneity of the food demand elasticity of rural residents in China.

First, rural residents' income elasticities of fruits and vegetables, animal products, oils and fats, and grains are 0.73, 0.65, 0.55, and 0.48, respectively. Their conditional uncompensated own-price elasticities are -0.95, -0.88, -0.50, and -0.82, respectively, indicating that the food demand of rural residents will continue to increase with income growth and is most sensitive to the price changes of fruits and vegetables.

Second, the income elasticity of rural residents tends to increase as the proportion of WAP in the household decreases, and the households with ≤60% WAP have a higher income elasticity of food demand than those with ≥70%.

Third, as the proportion of WAP in the household declines, the own-price elasticity of food consumption of rural residents remains almost unchanged. Fourth, the income distribution heterogeneity within the population with different WAP is also applicable to the general rule that the income elasticity of food consumption declines with increasing income.

With the start of a new journey of building a fully modernized socialist country, China will face the challenge of rapid urbanization and aging, and the income level of urban and rural residents will also increase at a medium-high speed. In this complex context, to ensure food security in China, it is necessary to have a more comprehensive understanding of the food consumption pattern of rural residents. The conclusions of this study can provide the following insights.

First, the government needs to further strengthen the construction of the "vegetable basket project" in rural areas to meet the demand of rural residents for vegetables, fruits, and animal products and avoid large fluctuations in the prices of "vegetable basket" products. The food consumption data of rural residents are further monitored and shared to support scientific and precise decision-making. Second, the equilibrium model for predicting the food supply and demand can be adjusted according to the results of this study to avoid excessive simplification of the demand equation and the resulting biased results.

This study has certain limitations. First, we could not analyze the expenditures on food away from home due to the lack of data. Second, the sample coverage is of a narrow region. Third, the sample sizes of some subgroups are relatively small.

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[1] The working-age defined by the NBSC is 14-64.

[2] The Heckman two-stage model can be used to solve the problem of null values, but the subdivided food demand elasticities are not the focus of this study, and the food demand data summed by broad category do not have the problem of null values.