Forecasting China's food grain demand 2021-2050 with attention to balanced dietary and fertility policies

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Forecasting China's food grain demand 2021-2050 with attention to balanced dietary and fertility policies

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Abstract: The estimation of China's future food grain demand has become vital input for designing grain security measures. Addressing the population's age-gender and urban-rural structures under three fertility policies scenarios together with concerns for balanced diets, we established a multi-factor driven model to forecast China's food grain demand (including staple food grain and feed grain) during 2021-2050. The three scenarios are as follows; the two-child fertility policy for couples when either the husband or the wife is from a single-child family (scenario 1); universal two-child policy (scenario 2), and no limitations on the number of children (scenario 3). The results show that in scenario 3, China's food grain demand would peak in 2030 at about 329.3 million tons, about 3.7 million tons higher than that in scenario 2, and 104.7 million tons lower than that estimated with the traditional per capita method. These findings indicate that the demographic transition for fertility policy adjustment is not the main impacting factor of China's food grain security from 2021 to 2050. We might overestimate food grain demand by about 15 percent if we ignored each age-gender and urban-rural structure of the population. Then it may lead to an oversupply of grain and accumulation of stocks, which would generate about 1 billion RMB annual inventory cost burden. An important complement to the demographic strategy would come from the adoption of the proposed Dietary Guideline for Chinese Residents (2019). It can make people much healthier and save about 7.5 percent of China's food grain consumption, reducing the pressure scarce supplies of water and land in the country.

Food security means a sufficient supply of foods and nutrients (FAO,1996), which indicates one needs a diverse, balanced diet containing various foods, such as those rich in vitamins, iron, and zinc. Close to 750 million – or nearly one in ten people in the world in 2019– were exposed to severe levels of food insecurity. The majority of the world's undernourished – 381 million – are still found in Asia. At the global level, the prevalence of food insecurity at a moderate or severe level, and severe level only, is higher among women than men. The gender gap in accessing food increased from 2018 to 2019. If recent trends continue, the number of people affected by hunger will be 9.8 percent of the population by 2030, even without considering the potential impacts of the COVID-19 pandemic (FAO, 2020).

China is the most populous country and the largest food consumer in the world. During 2013-2019, China's soybean, rice consumption accounted for about 30% of the total

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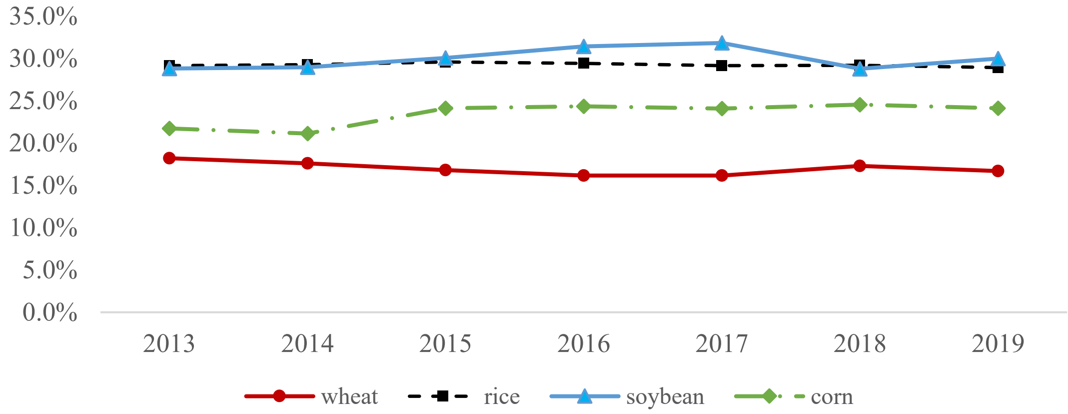
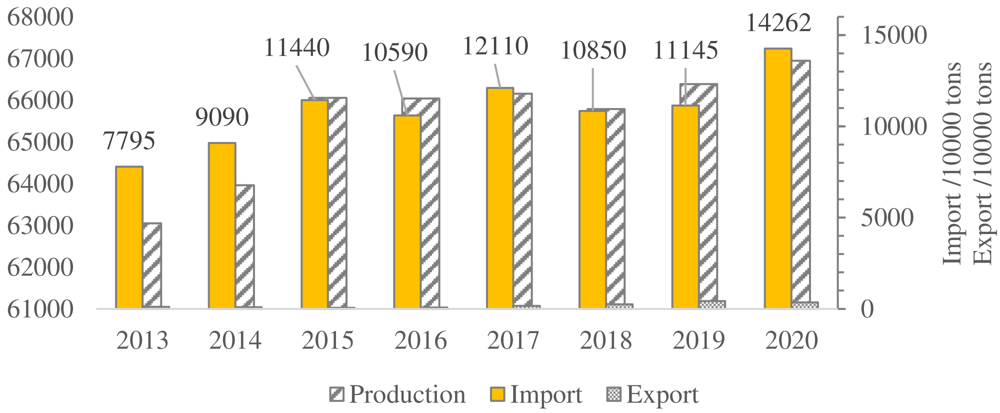
world consumption, respectively. The proportion of corn was about 25%, and for wheat, the ratio was in the range of 15%-20% (see figure 1). China's food security has been a global issue, especially since the book *Who Will Feed China?* (Brown, 1995) was published.



Data source: FAOSTAT

Figure 1. The proportion of China's grain consumption in the world's grain consumption, 2013-2019.

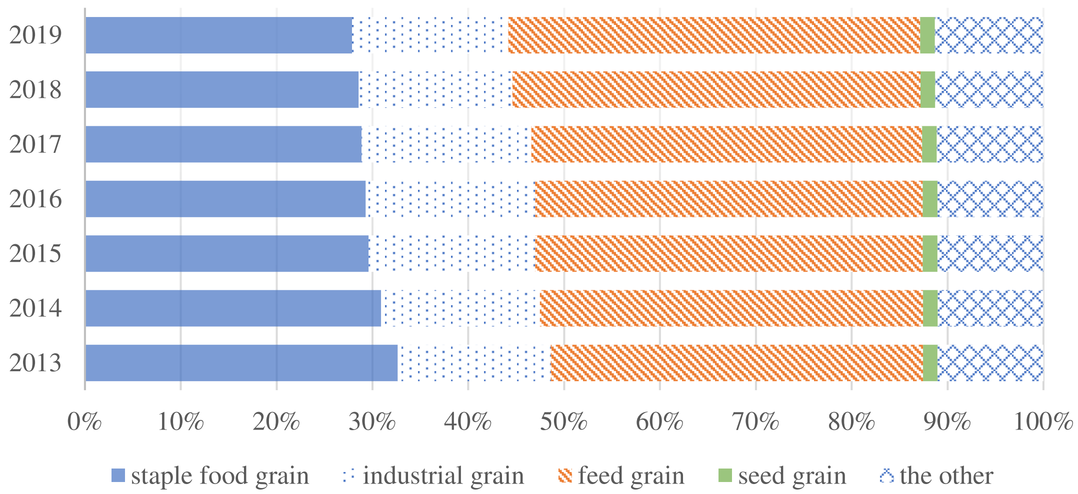
Meeting the demand for foods has always been the core of China's agricultural policy (Sheng and Song, 2019). China has made remarkable progress in achieving rapid growth in grain production since 1978 (Huang et al., 1999; Chen and Lu, 2019). In 2007, China's grain output reached a level of 500 million tons compared to 305 million tons in 1978, and the self-sufficiency percentage was more than 95%. Since 2013, the grain output had always remained above 600 million tons (figure 2). With a rapid increase in the consumption of animal foods and vegetable oils after 2007, grain consumption grew remarkably, and the self-sufficiency continuously declined to 83.7% in 2017 (NBSC, 2018; Anderson and Strutt, 2014). China's import of grain was more than 100 million tons after 2015 (figure 2). From 2010 to 2019, China had always been the largest soybean importing country, and its volume was far more than that of other countries. In 2020, China's soybean import was 1003.3 million tons, increasing 13.3% from 2019.



Data source: FAOSTAT

Figure 2. Grain production, imports and exports in China (unit:10000 tons)

To the structure of China's grain consumption, the proportion of feed grain increased from 38.8% in 2013 to 43.0% in 2019. And the ratio of staple food grain decreased from 32.6% in 2013 to 27.9% in 2019. The proportions of seed grain, industrial grain, and the other were relatively stable during 2013-2019, ranging between 28.5%-30.3% (figure 3).



Data source: FAOSTAT

Figure 3. The consumption structure of grain in China during 2013-2019

Borlaug and Dowswell (1993) called for assessing the feasibility of maintaining global cereal production per capita in the next half-century. Before doing so, the food and feed resources per capita needed to provide a balance diet as a global average need to be estimated (Conway, 1997). Most existing research about food demand has focused on staple foods, such as wheat, rice, soybeans, and maize (e.g., Lobell *et al*., 2008; Müller *et al*., 2009; Rosenzweig *et al*., 2014). Although more recent studies have been concerned with a greater variety of foods (e.g., Ge *et a*l., 2021; Macdiarmid *et al*., 2018; Ruiter *et al*., 2018; Nair *et al*., 2016). This paper focuses on staple food grain and feed grain, referred to as food grain that currently accounts for about 70% of the total grain demand in China.

As one of the main impacting factors of food grain demand, China's population structure is undergoing significant changes due to accelerated urbanization, increased aging, adjusted fertility policies and general increases in disposable income (Liu, 2018; Chen and Lu, 2019; Hovhannisyan *et al*., 2019). By around 2030, China's population is expected to grow to its peak of 1438 million (Liu and Liu, 2018). According to FAO data, the caloric demand of one person aged 17-18 reaches the highest average value and then shows a downward trend with individual age. The caloric demand of one person aged 60-69 is 70.3% of the highest value, and to a person aged 80-89, the ratio further decreases to 49.9% on average. The caloric demand of males is usually more than that of females.

Food consumption and nutrition are closely interlinked and can affect diet quality in different ways, potentially leading to undernutrition as well as overweight and obesity. The change in the dietary patterns of households is progressing at a rapid rate (Vecchia and Majem, 2015; Gouel and Guimbard, 2019; Liu *et al*., 2019). The rising incomes of rural and urban residents are among the main reasons (Vasileska and Rechkoska, 2012; Popkin *et al*., 2012). The Chinese diet has an inadequate intake of dairy products and the excessive intake of staple foods and meats (Han *et al*., 2020). From 1984 to 2017, the demand from Chinese residents for staple foods is decreasing, while the demand for processed foods and supplementary foods is increasing, and it is expected that the consumption of meat and dairy products will continue to rise for a long time (Lv *et al*., 2017; Xin and Li, 2018).

Residents are beginning to pay more attention to the balanced dietary structure (Zheng *et al*., 2016; Zhang *et al*., 2016; Huang, 2018). Chen *et al*. (2018) and Zhang *et al*. (2019) concluded that Chinese citizens' principal and ultimate concern was a high-quality diet. The Chinese Nutrition Society had issued Dietary Guidelines for Chinese Residents to popularize nutrition knowledge and to guide people in achieving a balanced diet. Dietary Guideline for Chinese Residents (2019) (hereafter referred to as DGCR 2019) is the latest nutrition standard in China, which has some adjustments from the last version in 2016 (Li *et al*., 2016). DGCR 2019 is designed to meet the nutritional health and basic needs of Chinese residents; it recommends 250-400g of cereals, potatoes, and beans, 50-100g of fish and shrimp, 50-75g of livestock and poultry meat, 300g of milk and dairy products, and 25-50g of eggs, etc. per day for Chinese aged 15-50. The guide calls on everyone to improve his/her diet and eat more fruits, vegetables, eggs, milk, and less meat or cereals. If the DGCR 2019 is popularized, what will be the impact on China's food grain demand from a macro perspective? Policymakers need this information and can also draw on studies such as Gerbens-Leenes and Nonhebel (2002), (Hovhannisyan and Gould(2014), Hovhannisyan and Devadoss (2017) and Liu *et al*.(2019).

Most existing research on food grain demand focused on energy consumption (calories) (Cheng and Chen, 1998; Ma and Niu, 2009; Xin et al., 2015). However, given data limitations, few of these studies had fully considered the impacts of each age-gender structure of the population on grain demand, essential factors that directly affect food demand (Wu, 2011; Xiang *et al*., 2013; Liu *et al*., 2016). Furthermore, little research has been conducted to provide a detailed analysis of food grain demand from the perspective of the residents' dietary structure and nutrient intake status (Luo, 2008; Tang and Li, 2012).

In fact, at present, a macro estimation that measures the overall national food grain demand according to the latest DGCR is lacking. The provision of this information would enable a better understanding of the general change trend of food grain demand in the whole country, thus bringing scientific suggestions for improving food grain supply and developing appropriate policies to guide residents' diet. For these reasons, we established a multi-factor driven model to forecast China's food grain demand (including staple food grain and feed grain) during 2021-2050, with full consideration of the nutritional health standards of the residents, each age-gender structure, and urban and rural structure of them.

Results

The Standard Person Consumption Coefficient (SPCC)

We applied equations in Table 1 for estimating BMR_{ik} from bodyweight. Then with equations (1)-(2), the values of δ_{ik} for Chinese males and females at different ages were obtained (see Figure 4).

Table 1. Equations for estimating *BMR* from body weight

Age (Years)	BMR_{ik} (MJ/day)
Males	
< 3	0.2550* AW_{ik} -0.14
3-9	0.0937* AW_{ik} +2.15
10-17	0.0769* AW_{ik} +2.43
18-29	0.0669* AW_{ik} +2.28
30-60	0.0592* AW_{ik} +2.48
>60	0.0563* AW_{ik} +2.15
Females	
< 3	0.2460* AW_{ik} -0.0965
3-9	0.0842* AW_{ik} +2.12
10-17	0.0465* AW_{ik} +3.18
18-29	0.0546* AW_{ik} +2.33
30-60	0.0407* AW_{ik} +2.90
>60	0.0424* AW_{ik} +2.38

* Note: AW_{ik} is expressed in kg. *BMR* equations in table 1 were sourced from Henry (2005).

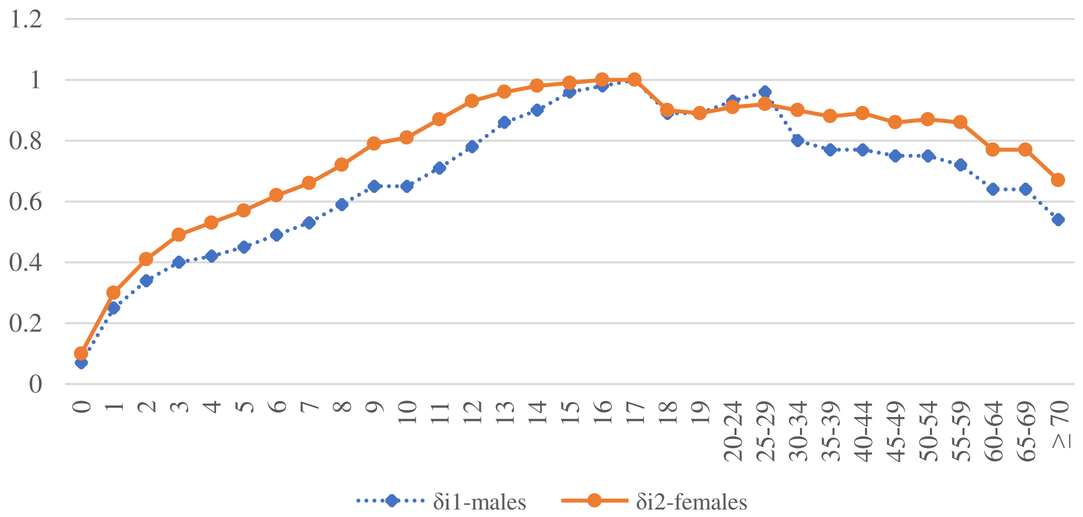
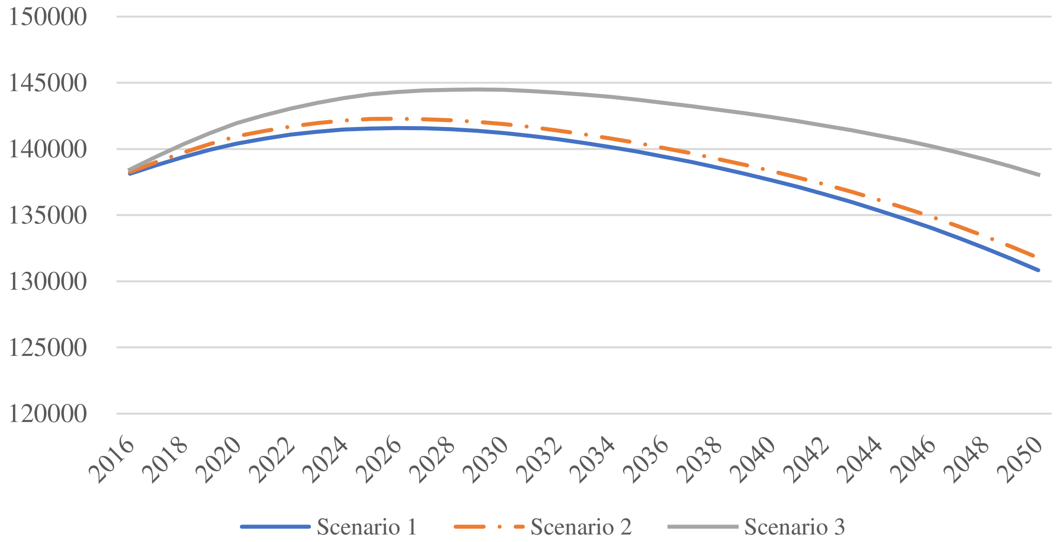


Figure 4. The estimated δ_{ik} for Chinese males and females at different ages

Forecasted Chinese Population by Age-Gender

Liu and Liu (2018) developed by age and gender based population projections for China with the cohort-component method. We used the results in the 3 scenarios. China's three-child policy was announced on 1st June 2021 and is expected to maximize the population's role in driving economic and social growth and address the risks of a downward trend in fertility, according to the country's health authority. Liu and Liu (2020) indicated that even if the two-child policy is further relaxed, it will exert little influence on fertility choice. It can be supposed that scenario 3 will have the most consistent with China's actual population structure and size in the future.

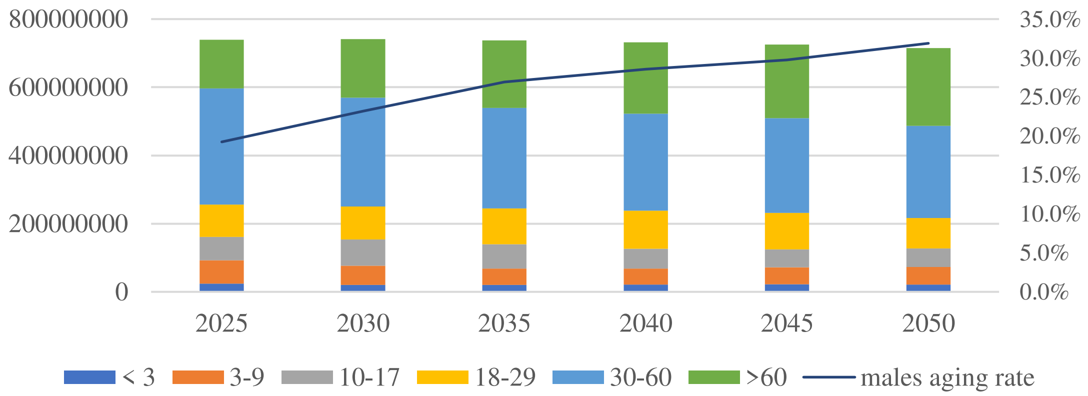
In scenario 3, China's population is expected to grow to its peak of 1457.6 million in 2030; the population size would be 1444.9 million in 2040 and 1413.8 million in 2050(figure 5); the aging rate (which is the proportion of elderly persons aged ⩾60 years accounts for the total size of the population) would reach 26.4% in 2030, 31.7% in 2040 and 36.4% in 2050. Compared with scenario 2, the population peak would increase by about 1.3% in scenario 3, and the aging rate would decrease 0.4 percentage points in 2030, 0.7 percentage points in 2040, and 1.3 percentage points in 2050 in scenario 3.



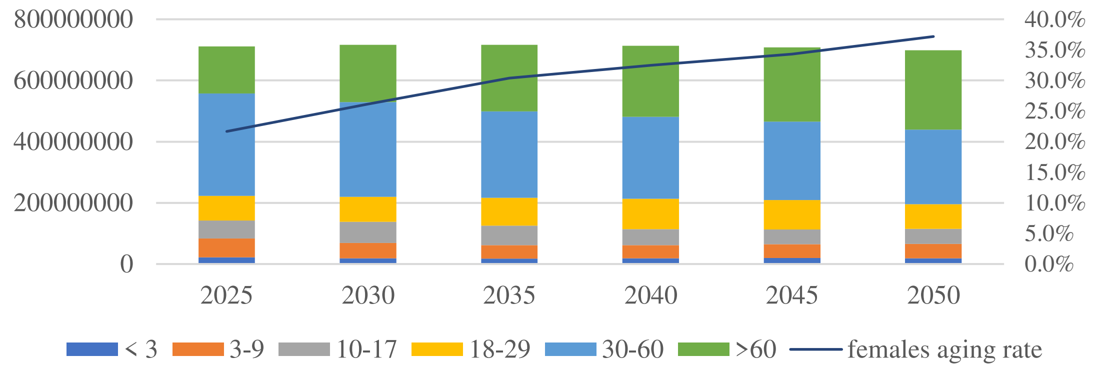
Source: Liu and Liu (2018)

Figure 5. The predicted size of the population in China in 3 scenarios

Furthermore, in scenario 3, the male aging rate would be 23.2% in 2030, 28.6% in 2040, and 31.9% in 2050 (Figure 6.a), while the females aging rate would be 26.1% in 2030, 32.5% in 2040, and 37.2% in 2050 (Figure 6.b). The aging rate of females is most commonly greater than that of males in the same year.



(6.a)



(6.b)

Figure 6. Males (a) and females (b) in different age group and their aging rates in China in Scenario 3

For the population younger than 30 years old, the ratio of males to females would be greater than 1.1 over the period 2025-2050. In particular, for the cohort aged 18-29, the ratio of males to females would be 1.18 in 2030 in scenario 3 (figure 7). The imbalance of males and females will bring many social problems and the gender structure will impact the demand for food grain.

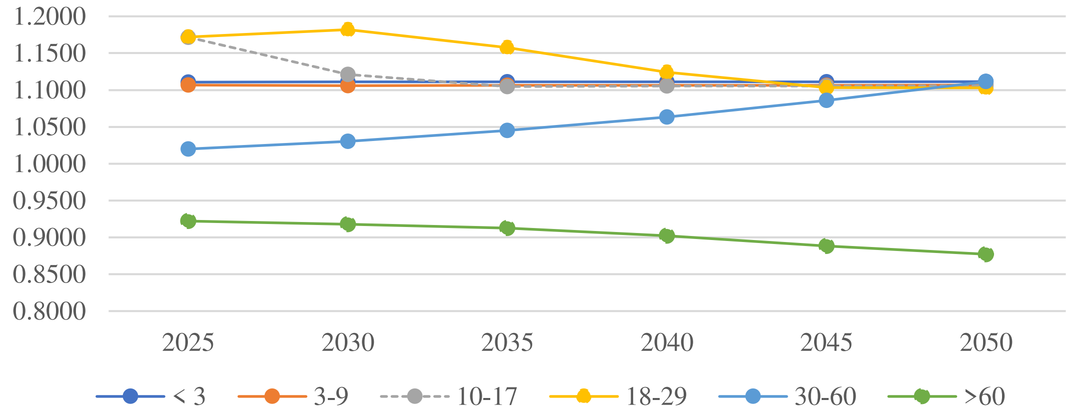


Figure 7. The ratio of males and females in different age groups in scenario 3

Forecasted Urbanization Rate

There are apparent differences in income levels and consumption habits of urban and rural residents. The development experience of Asian high-income countries from the 1970s to 1990s showed that the increase of urban population and livestock consumption meant that more food grain (especially feeding grain) was consumed. Further, addressing the urban and rural structure of the population can improve the forecasting accuracy of food grain demand. China's urbanization rate (means the proportion of urban permanent population in total permanent population) has risen steadily every year, from 17.92% in 1978 to 63.89% in 2020. The development of the urbanization rate in various countries indicates that it presents an elongated S-type curve. The urbanization rate increases rapidly after the first inflection point, slowing down obviously after the second inflection point. Based on Japanese and German experience, China's urbanization process may slow down after reaching 65%-70%; at present, China is still in an accelerated period of urbanization. Drawing on the work of Jian and Huang (2010) to predict China's urbanization rate during the accelerated period suggest that China would reach the second inflection point around 2030; this was estimated with equations (3)-(6).

It is estimated that China's urbanization rate would be 64.11% in 2021 and 73.69% in 2030 (figure 8). With the method proposed by Zeng *et al*. (2013), we assumed an average annual growth rate of 0.5 percentage points from 2030 to 2050. The urbanization rate in 2050 is estimated to be 83.69% (figure 8). The prediction result of China's urbanization rates in this paper is consistent with the judgment of several studies such as RDR (2020) and UDE (2019).

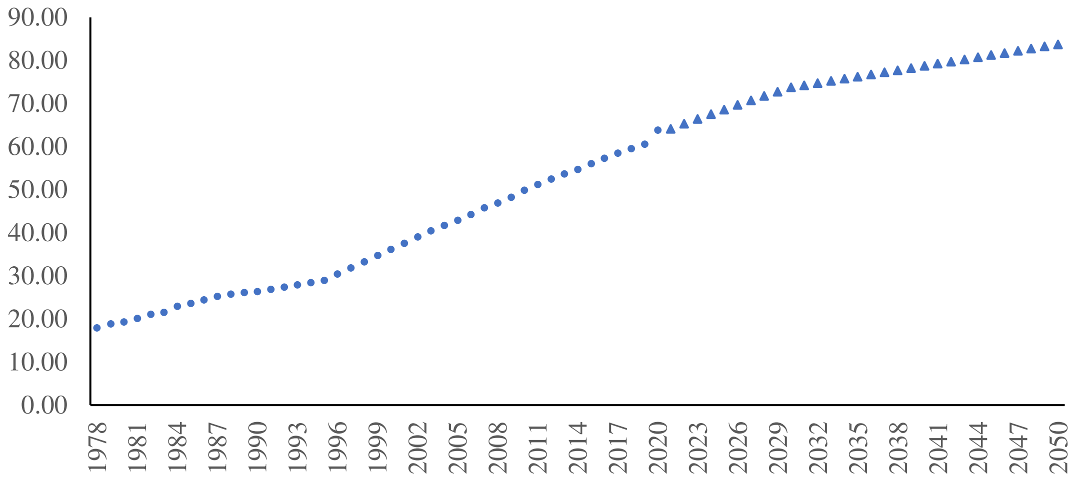


Figure 8. The urbanization rate in China from 1978 to 2050 (%)

(1978-2020 data is sourced from National Bureau of Statistics of China)

4.4 Forecasted per Capita Daily Food Grain Demand by an Adult based on DGCR 2019

Using the DGCR 2019, the per capita food grain demand in the balanced dietary pattern is divided into high, medium, and low levels. The conversion coefficient of livestock products to food grain consumption was estimated according to the method proposed by Chen and Lu (2019), and the results are shown in table 2.

Table 2. The grain consumption conversion coefficient of different kinds of livestock products

Livestock products	The grain consumption conversion coefficient
Pork	2.8
Beef and Mutton	1.0
Poultry	2.0
Eggs	1.7
Milk	0.3
Fish	0.9

Using the method of Tang and Li (2012), the average food consumption structure in China during 2014-2018 was estimated with data from FAOSTAT (2014-2018); the results are shown in table 3.

Table 3. The average food grain consumption structure in China during 2014-2018

Varieties	Food grain items	Average annual food consumption 2014-2018 (1000 tons)	Proportion (%)
Grains	Cereal	271095	81.0
	(Wheat)	92106	34.0
	(Rice)	168651	62.2
	(Maize)	10338	3.8
	Pulses	1991	0.6
	Tubers	61748	18.4
Meats	Pig meat, bovine meat, and mutton	66332	75.3
	(Pig meat)	54176	81.7
	(Bovine meat)	7148	10.8
	(Mutton)	5008	7.5
	Poultry	20249	23.4
	Other	1473	1.7
Aquatic products	Crustaceans	6386	13.4
	Freshwater fish	24985	52.4
	Marine fish	2102	4.4
	Molluscs aquatic products	14178	29.8
Milk	Cow milk	32548	88.1
	Other	4380	11.9
Eggs	Chicken egg	23078	84.4
	Other	4251	15.6
Vegetable	Tomato	48379	9.8
	Other	443234	90.2
Fruit	Apple	30574	22.0
	Other	108375	78.0
Pulse and nut	Pulse	1991	34.6
	Nut	3756	63.4
Oil	Animal fats	11852	79.8
	Vegetable oils	2996	20.2

Using the estimates in tables 2 and 3, we calculated the corresponding food grain conversion coefficients of different foods under the assumption of a balanced diet. These results are shown in table 4. To the food consumption data from FAOSTAT, food waste in household was not accounted for, this will lead to a lower estimation of food consumption. In Southeast Asia, the percentage of food waste in household consumption (Gustavsson *et al.*, 2011) is listed in table 4. We used these data as the percentage of food waste in China's household consumption.

Table 4. The conversion coefficient of different foods to food grain in China and the percentage of food waste in household consumption in Southeast Asia

Foods	The conversion coefficient ($\boldsymbol{V_i}$)	Percentage of foods waste in household consumption($\boldsymbol{C_i}$)
Cereal, tubers and beans-1	1.0	3%
Vegetable-2	0.0	7%
Fruit-3	0.0	7%
Fish and shrimp-4	0.9	2%
Meat and poultry-5	2.3	4%
Eggs-6	1.7	1%
Milk and Dairy-7	0.3	1%
Pulse and Nut-8	1.0	1%
Oil-9	0.15	1%

Using equation (7), with the values of V_i, C_i from table 4 and L_{ij} from table 5, we can estimate G_{ij}; the results are shown in table 5. Equation (8) provides the values of AG_1=215.8kg, AG_2=275.0kg, AG_3 =334.2kg and AG_4 =259.3kg.

Table 5. The per capital daily food grain demand of China's residents (Unit: g)

Items	$\boldsymbol{L_{i1}}$	$\boldsymbol{L_{i2}}$	$\boldsymbol{L_{i3}}$	$\boldsymbol{L_{i4}}$	$\boldsymbol{G_{i1}}$	$\boldsymbol{G_{i2}}$	$\boldsymbol{G_{i3}}$	$\boldsymbol{G_{i4}}$
Cereal, tubers and beans-1	250	325.0	400	358.7	257.7	335.1	412.4	369.7
Vegetable-2	300	400.0	500	260.9	0	0	0	0
Fruit-3	200	300.0	400	125.4	0	0	0	0
Fish and shrimp-4	50	75.0	100	32.4	45.9	68.9	91.8	29.7
Meat and poultry-5	50	62.5	75	99.5	119.8	149.7	179.7	238.4
Eggs-6	25	37.5	50	27.2	42.9	64.4	85.9	46.7
Milk and Dairy-7	300	300.0	300	33.4	90.9	90.9	90.9	10.1
Pulse and Nut-8	30	40.0	50	11.4	30.3	40.4	50.5	11.5
Oil-9	25	27.5	30	27.8	3.8	4.2	4.5	4.2
Sum	-	-	-	-	591.3	915.7	753.6	710.5

In table 5, L_{i4} was estimated with the average per capita daily food consumption of different categories from 2015 to 2019 from the China Statistical Yearbook data. We can see that L_{54} is 1.3 times of L_{53}. L_{14}, L_{94} are in the suggested range (L_{11}, L_{13}) and (L_{91}, L_{93}). While L_{74} is only 0.1 times of L_{71}. L_{84} is 0.4 times of L_{81}. $L_{34}\ and$ L_{44} is 0.6 times of $L_{31}\ and\ L_{41}$ respectively. These indicate that Chinese households consumed more meat and poultry, but their consumption of milk and dairy, pulse and nut, fruit, and vegetables was insufficient to accord with a recommended balanced diet.

Forecasted China's Food Grain Demand in 3 Scenarios

We took the high level of the food grain consumption based on the DGCR 2019, 334.2kg/year, as the volume of food grain consumption of an urban male standard person with a balanced diet. According to the recommended dietary energy intake for Chinese residents, at age 18-50 years old, it is 11.3 MJ/d for males and 9.6 MJ/d for females (Chinese Nutrition Society, 2014), which means the energy demand of a female is 85.1% of that for a male on average. Then, the food grain demand for an urban female standard person was estimated to be 284.4 kg/year. According to Xin *et al*. (2015), the difference between urban and rural residents' per capita food grain consumption was about 45.7kg. Therefore, the food grain demand with a balanced diet of a standard person (male or female) in an urban and rural area can be estimated (table 6).

Table 6. The estimated food grain demand of a standard person in an urban and rural area with a balanced diet (Unit: kg/year)

urban male (u_1)	urban female(u_2)	rural male(r_1)	rural female(r_2)
334.2	284.4	288.5	238.7

Using the estimates provided in table 6, the demand for food grain with a balanced diet in China during 2021-2050 under the three fertility scenarios (*sgds)* can be estimated with equation (9); If the SPCC method was not applied, equation (10) was traditionally used to estimate the food grain demand with a balanced diet. If the actual dietary structure was kept in scenario *s,* the food grain demand agd_s was estimated with equation (11). The results are shown in table 7.

Table 7. The estimation results of China's food grain demand with balanced diet from 2021 to 2050 in three scenarios (unit: million tons)

Year	sgd_1	gd_1	agd_1	sgd_2	gd_2	agd_2	sgd_3	gd_3	agd_3
2021	316.7	413.1	365.1	318.5	417.3	368.7	319.6	420.2	371.3
2025	319.6	418.2	367.1	322.6	420.4	369.0	324.7	428.6	376.2
2030	320.5	420.3	366.2	325.6	422.4	367.9	329.3	434.0	378.1
2035	316.3	417.7	362.6	323.2	419.5	364.1	328.6	434.4	377.0
2040	309.5	412.8	357.0	317.9	414.7	358.6	325.0	433.3	374.7
2045	301.1	405.3	349.3	311.3	407.8	351.4	320.4	431.3	371.6
2050	291.2	395.2	339.3	303.4	397.9	341.5	314.6	427.2	366.7

Analysis of the Results

Table 7 shows that sgd_3 would peak at 329.3 million tons in 2030 and decrease 24.1% compared with gd_3 in 2030. The maximum difference between sgd_3 and gd_3 would be 112.6 million tons in 2050, and the minimum difference would be 100.5 million tons in 2021. For the other two scenarios, the difference between *sgd* and *gd* would be in the range of 94.4-104.3 million tons. Each amount accounts for 14.1% and 15.6% of total China's grain production in 2020, respectively. It means that we may overestimate food grain demand by about 15 percent if we ignore the age-gender and urban-rural structure of the population. Thence, the estimates may lead to an oversupply of grain and accumulation of stocks, which will generate an inventory burden.

From table 7, we know that the value of *agd is* between *sgd* and *gd* each year. In scenario 3, agd_3 is about 50 million tons greater than sgd_3 during 2021-2050, which means that if all Chinese household adopt DGCR 2019 in scenario 3, about 50 million tons of food grain would be saved, which accounts for 7.5% of China's total grain production in 2020. The results indicate that we should promote DGCR 2019, since there would be a double dividend – a healthier population and a saving of about 7.5 percent of food grain consumption, reducing the scarcity pressure of water and land.

In table 7, in each year sgd_3 is greater than sgd_2 and sgd_2 is also larger than sgd_1 because of different fertility policies. Compared with sgd_2, sgd_3 would have increments of 2.1

million tons in 2025, 3.7 million tons in 2030, and 11.2 million tons in 2050. sgd_3 is also greater than sgd_1 each year, with increments of 5.1 million tons in 2025, 8.8 million tons in 2030, and 23.4 million tons in 2050, which accounts for 0.76%, 1.31%, and 3.50% of China's total grain production in 2020 respectively.

About 35% of China's grain production was wasted annually around 2014 (Xinhua Net, 2014). The annual restaurant food waste in China was about 17-18 million tons in 2015 (Cheng et al., 2018), which is much higher than the annual increase in food grain demand due to demographic policy changes over the period 2021-2050. Hence, the shift in population size and structure caused by China's fertility policy adjustment is not the main factor that is influencing food grain demand from 2021 to 2050.

A sensitivity analysis is needed to estimate the impact of some uncertainty in the average weight of the population over 70 years; currently, these estimates are 63.5kg for a male and 55.6kg for a female (Lv and Zhang, 2018). The effect of a 5kg fluctuation of average weight over 70 years old on food grain demand is shown in table 8. In 2030, 2040, and 2050, the proportion of the population over 70 years old would be 11.4%, 17.1%, and 21.3%, respectively. The sensitivity analysis results show that if the fluctuation of average weight over 70 years old is within 5kg, the impact on food grain demand is less than 0.8%. Therefore, we can accept the estimation of the average weight over 70 years old.

Table 8. Effect of average weight fluctuation of people over 70 years old on food grain demand

Average weight over 70 years	2021	2025	2030	2035	2040	2045	2050
±5kg	0.27%	0.34%	0.39%	0.49%	0.62%	0.72%	0.76%

Discussion

There are BMR equations for Chinese people as a whole but not for the different age groups. Equations for estimating BMR of varying age groups in this paper were derived from Henry (2005), which were the latest equations we can find for the world population. But they are not designed especially for the Chinese population. We used the percentage of food waste data in Southeast Asia as the data for China since there have no such detailed data in China. In order to prevent food waste, ensure national food security, save resources, protect the environment, and promote sustainable economic and social development, a law on preventing food waste of the people's Republic of China has been formally implemented from April 29, 2021. Food waste in China should be decreased in recent years and the future. These may generate some uncertainty in the results. So far, we have only considered the average food intake for the different age-gender groups in China's urban and rural areas. We have not considered the preference of foods and different constitutions of the population across different regions in China. Further research will need to be conducted to address the spatial heterogeneity within China.

Although there is a considerable literature that has predicted China's grain demand, most of their results are very crude, e.g., ignoring dynamic change of age-gender composition of its population, not considering the need for a balanced diet and so forth. Table 9 shows the predictions for China's grain demand in 2020 and 2030. As their prediction models and parameters differ from each other, it is not surprising that their results are also different (Lv and Hu 2012; Mi *et al*. 2013). Commonly, if the population's age structure and urban-rural structure were considered in the prediction model, the forecasted grain demand is smaller than those that ignored these factors. Results from this study confirm the need to address demographic differences and geographic location in generating forecasts.

Table 9. Forecasted results of China’s grain demand in some literature

	Methods	Forecasted year	Population age structure	Urban-rural structure	Forecasted China’s grain demand (million tons)
Gao (2004)	Time series	2020	no	no	590
Tang (2012)	Balanced diet	2020	no	no	567
Yuan (2017)	Balanced diet	2020	Yes	Yes	480
Luo (2008)	Nutrition demand	2020	no	yes	576
Zhang (2012)	CEMM	2030	no	yes	610
Tang (2012)	Balanced diet	2030	no	yes	586
Yuan (2017)	Balanced diet	2030	yes	yes	560

Compared with the traditional forecasting methods for food grain demand, this study developed a multi-factor driven model with additional factors such as age-gender structure, dietary nutrition standard, fertility policies, etc., in the forecasting methodology. These factors are common in the real world but difficult to incorporate into existing models. In addition, the adopted model includes a comprehensive list of foods and is linked to a dietary nutrition standard. The model can thus be used to identify which food may be in short supply to meet a balanced diet under different scenarios. Significantly, the model can be applied to evaluate the impacts of fertility policy on food grain demand which arouses the intense attention of the government, residents, and academics.

The multi-factor driven model developed in this paper will be a framework. There are many ways to extend the model in the future. Apart from age-gender, urban-rural structure, some other factors can affect food grain demand, such as COVID-19, climate change (Ye et al., 2013), region-specific inequality, etc. It can be easily adapted to implement additional factors to be built into the model later, which is beyond the scope of this study. Although prices are not explicitly incorporated in this model, the price mechanism to allocate commodities among residents was partially incorporated in the consumption and dietary preferences.

Conclusions and suggestions

First, the change of age-gender structure, especially the increase of the aging rate, will reduce the food grain demand and release the pressure on food grain security. Compared with results provided by more traditional methods, China has about 15 percentage points of slack space in planning its future food grain demand, which can save about 1 billion RMB in grain annual inventory costs. Furthermore, the structure of food grain demand we forecasted is different from that provided by the traditional method, and it will meet with the balanced dietary demand. China's grain production structure can be adjusted according to the forecasted results of food grain demand in the future.

Secondly, the results show that the change of population size and structure caused by the adjustment of China's fertility policies is not the main influencing factor of food grain demand from 2021 to 2050. This finding is in line with Song *et al*. (2021), who suggested that the one-child policy's relaxation is unlikely to significantly affect total grain consumption. Hence, there appears to be a significantly reduced concern about the effect of changes in family planning policy on food grain demand. Liu and Liu (2020) indicated that even if the two-child policy is further relaxed (such as to the three-child policy), it will exert little influence on fertility choice. Thus, pro-birth public policies, such as strengthening China’s infrastructure and public facilities to support child-rearing (Li *et al*., 2019; Qian *et al*., 2020), free universal public schooling from the age of three, improving the average level of compulsory education, etc. should be combined to increase fertility rate.

Thirdly, we should promote the implementation of DGCR 2019. It can make people healthier and save about 7.5 percent of food grain consumption, which will release the scarcity pressure of water and land. Huang and Tian (2019) found that food accessibility contributes to improvements in dietary quality in rural China. While increasing food accessibility might also increase the consumption of some food that is already over-consumed in rural areas, other policies such as promoting dietary knowledge in rural areas should be implemented along with rural development. Trade can promote a healthier and more balanced diet; Nelson *et al*. (2018) and Godfray *et al*. (2010) show that increasing trade always improves the nutrition security of countries. Disputes and conflicts between any two countries can severely disturb global trade and food security. We need to remove obstacles and barriers to facilitate more free trade so that some potential trade opportunities can be used and the demand can be met.

Methods

Figure 9 presents the flowchart of the methodology. Because people in different age-gender groups have different nutritional needs. The population-level nutrient requirement per capita in a country is based on the demographic composition of its population. Countries with a larger aging and female population will have a lower nutrient requirement than those with a younger adult population. The country's demographic composition will change over time, and so will the population-level nutrient and food demand. Based on the dynamic composition of each age-gender population in China, this paper called for the SPCC method (Xiang and Zhong, 2013) to introduce the age-gender structure, urban-rural structure variables to estimate population-weighted average dietary energy requirements. The physical activity level (PAL) and basal metabolic rate (BMR) for different age-gender groups were applied to estimate average dietary energy requirements.

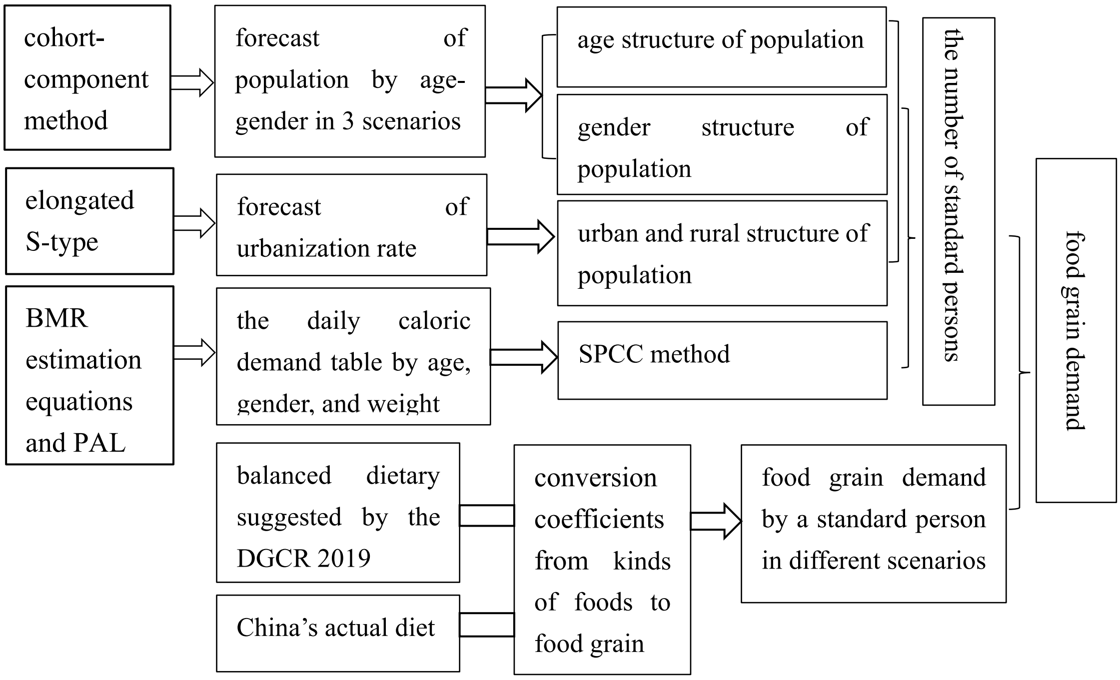


Figure 9. Structural flow diagram of estimating China's food grain demand

The following equations show the details of the model.

$$\alpha_{ik} = BMR_{ik} * PAL_{ik} \tag{1}$$

$$\delta_{ik} = \alpha_{ik}/\alpha_{17,k} \qquad i=1, 2\cdots 30 \tag{2}$$

$$y = \frac{1}{1+\lambda e^{-kt}} \tag{3}$$

With equation (3), we got,

$$ln(\frac{1}{y} - 1) = ln\,\lambda - kt \tag{4}$$

Let $ln\,\lambda = \beta_0$, $-k = \beta_1$, $ln(\frac{1}{y} - 1) = y'$, then equation (4) can be transformed into equation (5).

$$y' = \beta_0 + \beta_1 t \tag{5}$$

With China's urbanization rate data during 1978-2020, the linear result obtained by fitting curve is as follows.

$$y' = 1.568 - 0.048t + \varepsilon \tag{6}$$

To equation (6), at the significance level of 0.05, $R^2 = 0.99$, F=4058.09 and $t_{1.568}$=85.05, $t_{-0.048}$=-63.70.

$$G_{ij} = \frac{L_{ij} * V_i}{1 - C_i} \qquad (i = 1, 2, \cdots 9; j=1, 2, 3, 4) \tag{7}$$

$$AG_j = \sum_{i=1}^{9} G_{ij} * 365/1000 \tag{8}$$

$$sgd_s = \sum_{k=1}^{2}\sum_{i=1}^{6} sp_{iks} * y * u_k + \sum_{k=1}^{2}\sum_{i=1}^{6} sp_{iks} * (1 - y) * r_k \tag{9}$$

s=1, 2, 3; k=1, 2; i=1,2,3…6

$gd_s = AG_2 * p_s$ s=1, 2, 3 (10)

$agd_s = AG_4 * p_s$ s=1, 2, 3 (11)

Since we considered multiple factors that drive the change of food grain demand in the forecasting process, we call the model established in this paper the multi-factor driven model. Definitions of all notations are listed in table 10.

Table 10. Definitions of all notations

α_{ik}	average daily demand for energy of a person at the age *i* with gender *k*
BMR_{ik}	basal metabolic rate of a person at the age *i* with gender *k*
PAL_{ik}	physical activity level of a person at the age *i* with gender *k*
AW_{ik}	Average weight of a person at the age *i* with gender *k*
δ_{ik}	the standard person consumption coefficient of a person at the age *i* with gender *k*
y	urbanization rate
y'	replacement variable of y
t	time, we set t=0 in 1978, t=1 in 1979, t=2 in 1980…
λ, k, β_0, β_1	parameters
L_{ij}	the per capita daily food grain demand of i-th categories of food based on DGCR 2019 in three level of low (j=1), medium(j=2) and high (j=3)
L_{i4}	actual average per capita daily foods consumption
V_i	the conversion coefficient of i-th categories of food
C_i	the percentage of food waste in household consumption of i-th categories of food
G_{ij} (j=1,2,3)	the per capita daily i-th categories of food grain demand by an adult in low, medium, and high level suggested by DGCR 2019 respectively
G_{i4}	the actual average per capita daily i-th categories of food grain consumption
sp_{iks}	the size of standard persons at the age group *i* with gender *k* in scenario *s*
u_k	the estimated food grain demand of a standard person with gender *k* in urban area
r_k	the estimated food grain demand of a standard person with gender *k* in rural area
gd_s	if SPCC method was not applied, the food grain demand in scenario *s*
p_s	the population size in scenario *s*
agd_s	if the actual dietary structure was kept, the food grain demand in scenario *s*

Data Source

The nutrient requirements are from the DGCR 2019. The value of PAL for different age-gender groups is sourced from FAO (2004), which is the latest reference we can found. According to the data available in the FAO database, the period of 1961 to 2018 is chosen to be studied. Typical diet varies across countries and reflects a country’s tradition and culture and natural and land-use conditions. We used the average reported food consumption between 2014 and 2018 (to smooth out fluctuations in any one year) as the baseline for China’s typical diet. The weights of males and females aged 0-69 in China are sourced from The 2014 National Physical Fitness Monitoring Bulletin published by the State Sports General Administration[6]. The average weight of

Chinese males over 70 years old was 63.5kg, and of Chinese females was 55.6kg (Lv and Zhang, 2018). We chose annual time data because it is appropriate for the production cycle and the time scale of the model (2021–2050). And because data on consumption, production, and population are only available annually.

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Author contributions Professor Xiuli Liu designed the model, made the calculation, and drafted the manuscript. Ph.D. candidate Yuxing Dou collected data, some references and forecasted China's urbanization rate. Professor Dabo Guan provided suggestions and edited the manuscript. Professor Geoffrey Hewings reviewed and edited the manuscript. Professor Shouyang Wang explained some results and provided policy implications. All authors contributed to the revisions.

Competing interests The authors declare no competing interests.

Data availability All data used in this study are publicly available from open sources as indicated in the references. Inquiries related to the data should be made to X. L. (xiuli.liu@amss.ac.cn).

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