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Agricultural production and food consumption in China: A long-term projection

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ABSTRACT

This paper uses a multi-country and multi-product partial equilibrium model to forecast food supply and demand in China and its impact on food trade in 2050. The model endogenises shifting consumption preferences due to China's demographic changes and real incomes growth caused by ongoing urbanisation and industrialisation. We show that total food demand in China is to increase by 33% by 2050 and its structure will shift towards more luxurious goods, away from necessities. While improved productivity growth will enable domestic production to rise, imports are still likely to play an important role in reducing the "quality" gap in future Chinese food demand.

1. Introduction

The rapid economic growth in China has lifted the level of its real income per capita over the past four decades (OECD, 2012). This, combined with a steady expansion of its total population, has not only increased total food demand but also changed the structure of food consumption. In 2015, apparent consumption of major agricultural commodities including cereals (mainly rice, wheat and maize), meat, dairy products, vegetables and fruits in China were 455.2 million tons, 91.8 million tons, 51.1 million tons and 553.0 million tons respectively, which were 3.2 times, 8.3 times, 17.1 times and 10.5 times of those in 1978. In particular, per capita consumption of dairy products and vegetables and fruits both increased by more than ten times, which were much higher than that of meat (8.3 times) and cereals (3.2 times). Moreover, since total population and real income per capita in China are still increasing, it is expected that China's food demand will sustainably drive up world market prices in particular for specific commodities such as major cereal products and red meat (Linehan, Thorpe, Andrews, et al., 2012).

To meet domestic food demand, agriculture is treated as one of the key strategic industries in China. Although its contribution to GDP and total employment fell over time, China's gross output of major agricultural commodities continued to rise. Between 1978 and 2015, the production of paddy rice and pig meat (two major food products) increased from 93.4 million tons and 8.8 million tons to 145.8 million tons and 47.5 million tons, respectively (FAO, 2016). This rise in agricultural output occurred with only modest rises in arable land and labour usage (5% and 1.7% increase in arable land and efficient labour usage over the same period, respectively). Productivity growth, partly due to large scale of migration resulting from institutional reforms which lowered labour/land ratios, technological progress and infrastructure investment, has played an important role in contributing to the output increase. Over this period, the annual growth rate of agricultural total factor productivity (TFP) and labour productivity in China were 2.8% and 4.3% respectively, which are much higher than the world average of 1.0% per annum for both total factor productivity and labour

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productivity in agriculture (Fuglie & Rada, 2015).

Given China's growing importance in world food markets, it is of great interest to academics and policy makers to understand future food demand and supply in China and its implications for global food trade. This has led to the development of various partial and general equilibrium models aimed primarily at projecting China's food demand and supply in the near future. The widely used partial equilibrium models include the USDA CPPA and ChinaAg models (Hjort & van Peteghem, 1991), the IFPRI International Model for Policy Analysis of Agricultural Commodity and Trade (IMPACT) model (FAPRI, 1996, IFPRI, 2012), the World Bank Econometric Simulation Model (WBESM) (Fan & Agcaoili-Sombilla, 1997), Overseas Economic Cooperation Funds of Japan (OECF) model and the FAO World Food model (Frohberg & Britz, 1994) and the OECD-FAO AGLINK-COSIMO model (OECD, 2001); while the general equilibrium models include the global trade and agricultural project (GTAP), G-Cubed and global trade and environmental model (GTEM) models.[1]

Results from previous studies, though differing in magnitude, generally demonstrated that China's consumption of cereals and grains will continue to rise in the long run. Furthermore, with resource constraints with respect to both land and labour, this increased food demand was expected to be met increasingly by imports of a large amount of wheat and rice if there is no further breakthrough in production technology (Fan & Agcaoili-Sombilla, 1997). However, this finding is yet to be proved accurate as the past decade witnessed a rough balance between the supply and demand for cereals and grains in China. Surprisingly, China even started to export paddy rice to the international market since 2014. A possible explanation of the poor performance of most existing models in projecting China's food demand is that they did not properly account for the change in 'quality' of aggregate food consumption due to the changing demographic structure and income growth, and substantial structural changes in food consumption due to changing preference and income (Yu & Abler, 2009; Zhou, Yu, Abler, & Chen, 2017 and Zhou, Yu, & Herzfeld, 2015).

This paper developed a multi-country and multi-commodity partial equilibrium model (Linehan, Thorpe, Neil, and Beaini, 2012, ABARES, 2014) to examine Chinese food production, consumption and trade in 2050. Contributing to the literature, it endogenises the shift of aggregate-level consumption preference by considering the interaction of different consumption trends of households with different appetites (namely, urban high income, urban low income and rural groups). Although our projection also inform that significant structural changes in future China food consumption will take place as in Yu and Abler (2009) and Zhou et al. (2017), it attributes these aggregate demand changes to dramatic adjustments in population and economic structure due to economic transformation rather than gradually changed income and price elasticities. As such, it provides information regarding the distributional impact of macroeconomic shocks (i.e. changes in demographic structure and per capita income) between different income groups and across regions on aggregate food consumption between commodities. When combining with the index measuring consumption quality (Clements & Gao, 2012), the estimates can demonstrate "quality" escalation in food demand — a phenomenon related to many transitional economies — and its implication for the long-term projection on agricultural production and trade along with Yu and Abler (2009) and Tian and Yu (2017) which have showed evidence on quality escalation in China's agricultural trade. In addition to the innovation on the demand side, our model also has the flexibility in accessing the commodity-level impact of different industrial and trade policies so as to provide useful insights for policy making.

The results show that total food demand in China will increase by 33% in quantity by 2050 compared with 2015 driven by both population and income growth. At the same time, the consumption patterns will shift from necessities (i.e. cereals, grains and starchy staples) to more luxurious goods, particularly meat and dairy products, reflecting "quality" escalation of food consumption. While the majority of China's future food demand will be met by an increase in domestic production, there are great pressures for China to increase productivity for all agricultural products and to open domestic market for foreign investment and trade to boost high value and high protein products to meet the "quality" gap in demand.

The rest of the paper is organised as follows. Section 2 summaries the characteristics of food production and consumption in China. Section 3 discusses the structure of our model and the related assumptions. Section 4 presents data sources on the demand supply elasticities, the base year for calibration and policy scenarios. Section 5 provides the projection on China's food demand and supply and discusses the implications for the global food market. Section 6 concludes.

2. China's agricultural production and consumption

Agriculture is an important industry in China historically, and its ongoing expansion has made a significant contribution to rural economic development and welfare improvement for the Chinese people. Between 1961 and 2012, the gross value of agricultural production in China increased from US$71 billion to US$594 billion (in 2004–2006 US dollars), representing an annual growth rate of 4.2% a year (FAO 2014). In 2012, Chinese agricultural production accounted for 28% of global agricultural production in value terms, making it the largest agricultural industry in the world. The industry still employed around 405 million people though the rural population continued to fall (as the result of the rapid pace of urbanisation), and used 515 million hectors of arable land (around 10% of world arable land) (FAO 2014).

Compared to agricultural industries of other countries, the Chinese agricultural industry is characterised by limited arable land and large labour force engaged in agricultural production. In 2012, the average arable land under permanent crops per person and per farmer were 0.09 ha and 0.24 ha, respectively, which are much lower than the world average (i.e. 0.2 ha and 0.5 ha). The relative

[1] In addition to the accuracy of projection, another criticism for the CGE model is that it is operating as a black box and would not provide a clear mechanism on how the food demand and supply are balanced. Also, those studies based on the CGE model are not appropriate for commodity-level policy analysis.

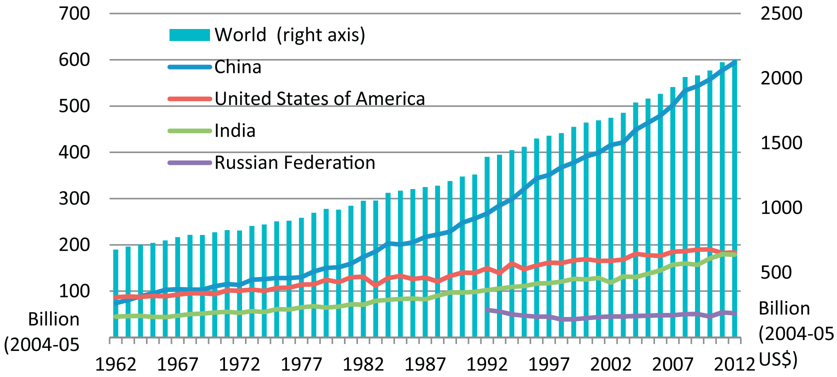

Fig. 1. Gross value of agriculture in China relative to other countries and world.
Source: FAO STAT database.

scarcity of arable land implies that, in general, China tends to have a comparative advantage in the production of labour intensive crops, such as fruits and vegetables, and a disadvantage in the production of land intensive crops, such as grains and oilseeds (FAO 2014). However, the current product structure of the industry does not reflect the underlying comparative advantage, and instead it reflects a pattern of production which was determined by the related government policies that favour cereal and grain production to meet domestic demand. In 2011, grains accounted for around 50% of agricultural output, meat, fat and vegetable oils accounted for 22%, and fruit and vegetables 19%. In particular within the production of grains, paddy rice production was most common in 2012 (206 million tons) followed by maize (200 million tons) and wheat (103 million tons) Figs. 1 and 2.

Government support and subsidies for agricultural production played an important role in facilitating productivity growth, particularly for the grain industry. However, these policies have also created market distortions in terms of their impact on prices. OECD (2011) showed that the Total Support Estimate (TSE) for agriculture in China is relatively high (at 3.7% of GDP) compared to the average level of OECD countries which is 0.4% of GDP, partly reflecting high levels of government intervention in production, consumption and trade of agricultural products. The intervention of government drove a wedge between domestic and world prices, which was believed to bring additional profits to farmers and the incentive for them to invest in advanced production technologies. As an example, yield growth for grains and oil crops was higher than that of vegetables and fruits in the five decades to 2012, given the consistent focus of government support on grain production (Fig. 3).

Although food production and consumption are roughly balanced in China nowadays, the policy makers are facing two main challenges over the medium to long term. First, China's average income per capita is expected to rise continually and the proportions of middle class in total population and that of urban population will continue to increase. These changes will make China's consumption preferences shifting from grains to high protein and high value products such as red meat, milk products and fruits (Fig. 4). However, the current production structure does not reflect this change due to significant policy distortions. Second, there will be limited resources available, particularly land and water, to further increase agricultural output. To increase agricultural output, policymakers will need to consider funding on research and development (R&D) to increase productivity, facilitate internal reallocation of resources to create more efficient farm structures, improve production technology in small-scale farmers who are currently dominant in the production system, and improve transparency in implementing agricultural policies (OECD, 2012).

To address the above two concerns, we believe that the model exercise in this study will provide some useful insights and forecast on how changes in government policies could affect the outcome. In addition, it is to be noted that our model is designed to focus on the equilibrium effect in the long run while leaving the transitional dynamics for future study.

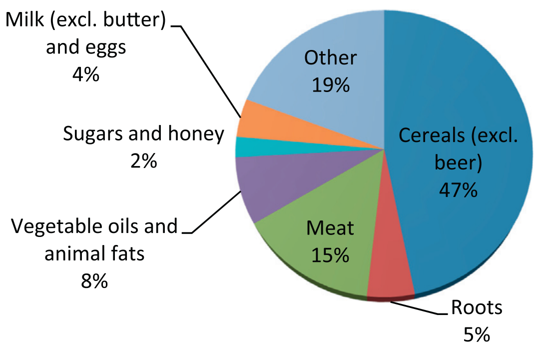

Fig. 2. Food group shares in total food supply in China, 2011.
Source: FAO STAT database.

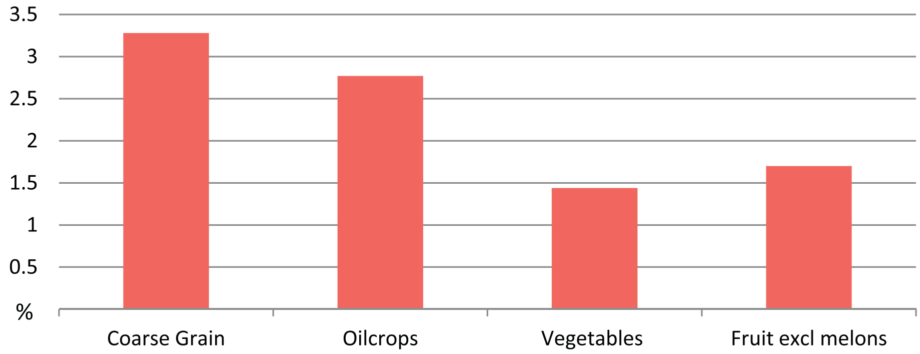

Fig. 3. Comparison of yield growth in major crops per annum: 1961–2012.
Source: FAO STAT database.

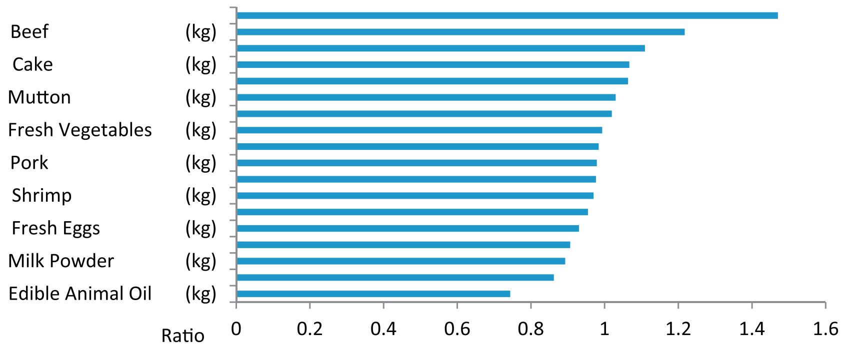

Fig. 4. Change in per capita consumption by commodity in China: 2003–2006 (unit: kg per capita).
Source: Authors' estimates by using data from China Household Survey (SSB, 1996).

3. Methodology: a multi-country and multi-sector agrifood model

The model used in this paper is a multi-region and multi-commodity partial equilibrium model, solved by using the dynamic recursive technique (Linehan, Thorpe, Neil, and Beaini, 2012). It assumes the world consists of many countries and regions, and each region has only one agricultural industry producing groups of commodities substitutable across the region with constant elasticity. Consumption is determined by representative agents through maximising their utility with the externally given income and population growth. Production is determined by technological progress and the supply of various inputs (i.e. land, capital and intermediate inputs). Equilibrium is achieved when the aggregate demand and supply of each commodity are equalised, and the surplus in production (or consumption) exports to (or imports from) the world market. The world price, therefore, adjusts to balance aggregate demand with aggregate supply from each region and for each commodity.

The following will briefly discuss the model structure from the perspectives of the demand, supply and market equilibrium.[2]

3.1. Demand for food, feed and other industrial uses

Aggregate demand for a commodity in a region equals to the sum of food and feed demand and demand for other purposes (e.g. biofuel and other industrial use). Food demand represents the final consumption demand, while production demand represents the intermediate demand for the production of other agricultural commodities such as feed stuffs, vegetable oils/meals, and livestock/seafood related products among others. Demand for other purpose mainly refers to demand of commercial crops used for biofuel production.

Food demand is mainly driven by real income per capita and population growth, and it is modelled in two layers. At the first layer, demand for food commodity groups are chosen by the representative consumer according to a log linear specification in exogenous real income and endogenous own and substitute prices (as in Eq. (1)). Food commodity groups are assumed to include meat and eggs, milk and dairy products, fish and other seafood, cereals, vegetables, fruits, vegetable oils and other food items. The definition of food commodity groups reflects characteristics of various food commodities and their relative substitutability.

[2] For detailed discussion of the ABARES Agri-food Model, please refer to Linehan et al. (2013).

$$\log\left[\frac{qdfoagg}{qdfoagg0}\right] = edfoincagg*\log(ginci) + \sum_{jagg}\left[edfopagg*log\left(\frac{pdfoagg}{pdfoagg0}\right)\right] \quad (1)$$

where *qdfoagg* stands for the food aggregator quantity; *ginci* denotes the real income tax; *edfopagg* is the own and cross-price elasticity of demand for food type; *pdfoagg* indicates food aggregator price. The subscript zero represents the equilibrium at the baseline period. At the second layer, a constant elasticity of substitution (CES) function is employed to allocate demand between commodities within each commodity group, according to their relative price levels (as in Eq. (2)). By assumption, changes in exogenous taste by product are imposed to moderate or amplify outward shifts in demand over time from per capita income and population groups for a particular commodity.

$$\frac{qdfo/qdfo0}{\sum_{iagg} qdfoagg/pdfoagg0} = gtastesubi*\sum_{iagg}\left[\frac{\frac{pdfoagg}{pdfoagg0}}{\frac{pd}{pd0}}\right]^{\sum_{iagg} sigmafo} \quad (2)$$

where food consumption is denoted by *qdfo*; taste shifter index for food demand is represented by *gtastesubi*; *pd* indicates the consumer price; *sigmafo* is the elasticity of substitution between foods of different type. To account for potential structural change in consumption preference at the aggregate level, total consumption is also split into three income strata including urban high, urban low and rural groups. Each income strata have different consumption preferences, determined by their income levels.

Intermediate input demand comes from three industries, including domestic feed production, crop and oilseed meal/fish meal production, and oil concentrate. Demand for individual commodity depends on the output of final consumption product and the related production technologies.

For example, the production of generic feed mix requires using coarse grains as ingredients. To identify such demand for individual coarse grain, we assume that the total volume of feed mix consumed by each livestock type is proportionate to the volume of livestock product output, when the livestock production technology takes the Leontief form (Allen, 1968). A CES function is thus used to split the total volume of feed mix into demand for individual crops, according to their relative prices (as in Eq. (3)).

$$\frac{\left[\frac{qdfdfmx}{qdfdfmx0}\right]}{\left[\frac{qfdmxact}{qfdmxact0}\right]} = \left[\frac{\frac{pdfdmx}{pdfdmx0}}{\frac{pd}{pd0}}\right]^{sigmamx} \quad (3)$$

where *qdfdfmx* symbolises use of feed for production of generic mix; *sigmamx* is the elasticity of substitution between inputs in livestock feed mix; *qfdmxact* indicates generic feed mix produced. Similarly, the production of crushed oil and meal and fish products also requires to use oilseed crops and fishes as intermediate inputs (or throughput) respectively. Assuming there is a Cobb-Douglas transformation function, the growth in demand for those throughputs is thus proportionally to the growth in the total composite crush output, subject to their relative prices (as in Eq. (4)).

$$\frac{\left[\frac{qscrml}{qscrml0}\right]}{\sum_{icruip}\frac{qdcru}{qdcru0}} = \frac{\frac{ps}{ps0}}{\sum_{icruip}\frac{pdcrustar}{pdcrustar0}} \; and \; \frac{\left[\frac{qscrol}{qscrol0}\right]}{\sum_{icruip}\frac{qdcru}{qdcru0}} = \frac{\frac{ps}{ps0}}{\sum_{icruip}\frac{pdcrustar}{pdcrustar0}} \quad (4)$$

where *qscrml* represents the oilseed crush meal output; *icruip* signifies the dummy mapping crush input to output; *qdcru* is oilseed crush throughput; *pdcrustar* denotes the price of Cobb-Douglas complex output; *qscrol* symbolises oilseed crush oil output; *ps* indicates the producer price. Finally, for simplicity, demand for biofuel production is assumed to be an exogenous share of total domestic demand.

3.2. Production of agricultural products

The production of agricultural commodities is modelled separately for individual products, and defined over five production blocks including various crops and livestock products, the crush of oilseed crops to meal and oil, fish catch and the production of generic feed mix and fish products.

The production of crop and livestock products is modelled in a similar way. Both types of products use land and other inputs as common inputs, while livestock products require animal feed as additional input (as in Eq. (5)). Land demand is linking between various crop and livestock production activities, and allocated (through a competitive market) to individual crop or livestock production due to its marginal costs. Land supply is responsive to its real price to account for land conversion from other uses in response to profit opportunities. A finite limit has been imposed as an additional constraint to prevent infinite land expansion. Other inputs are assumed to be sector specific, and its unit costs increase with output of particular products. This limits the unlimited expansion of specific enterprise, allowing competing agricultural land use to expand to some extent, dependent on relevant parameter values. For livestock products, feed use is assumed to take a fixed proportion of output similar as using the Leontief production technology to combine land and feed use. Finally, exogenous technology progress is assumed to improve the efficiency of land, other input and feed usages.

$$plndc*iolndc + uopcc \geq ps \text{ (for crops)}$$

$$plndg*iolndl + pdfdmx*iofdmx + uopcl \geq ps \text{ (for livestock)} \tag{5}$$

where *plndc* and *plndg* stand for the crop and pasture land rental prices; *uopcc* and *uopcl* symbolise the unit operating cost of crop and livestock production; *uopcc* and *uopcl* are designated as the exogenous trend in marginal costs of other inputs for crop and livestock production; *iolndl* is the intermediate input coefficient; *pdfdmx* represents the price of generic feed mix. The production of oilseed crush sectors is modelled by using a Cobb-Douglas transformation function (as in Eq. (6)). Throughout the production process, crushed meal and oil are produced by using oilseed crops and other inputs, where oilseeds are throughputs and other inputs are used to reflect the production efficiency. The unit cost of production is defined to the price of the throughput plus a unit operating cost for crushing, and the zero profit condition ensures that unit revenue from the crush (or the value of output of meal and oil divided by the volume of throughput) equals to operating cost.

$$pd + uopccru = pdcrustar \tag{6}$$

where *uopccru* is the unit operating cost of crush throughout. Given the importance of fish product in agricultural production, the supply of fish and fish product is also endogenously modelled. High and low value capture fisheries are distinguished in the model, which are jointly determined by marginal cost of fish capture, resource availability and government policies (namely, quota) to maintain the sustainability. In particular, we assume that annual production must lie within or on quota. To achieve this goal, the rental price of quota is negligible if the quota is not filled; otherwise, the rental price is found where the level of production equates demand with the quota limit. The rental price is then equal to the price received net of unit operating costs (as in Eq. (7)).

$$pren + pd*iofdaq + uopcf \geq ps \tag{7}$$

where *pren* represents the rental price on fish quota; *iofdaq* is the intermediate input coefficient; *uopcf* is the unit operating cost of fish supply. Similar as the production of crush sectors, the production of fish products (i.e. fish meal and oil) also use the fish capture as the throughput and other inputs for marginal costs (as in Eq. (8)). Both high and low value fish types are assumed to be perfect substitutes in the production process. An endogenous price premium is incorporated in the model to reflect the imperfect substitution between different types of fish in human food consumption.

$$Pd + Uopcfrd \geq opipfrd*ps \tag{8}$$

where *opipfrd* stands for the price premium.

3.3. Price and market equilibrium

In equilibrium, aggregate demand equals to aggregate supply. In other words, domestic production equals to domestic consumption plus export (as in Eq. (9)) while domestic consumption equals to domestic production plus imports (as in Eq. (10)). This condition ensures that: after accounting for various market mark-up (caused by transportation costs, government tax or subsidy or public/private supports such as the import quota, the market support for maize production), there will be a unique market price for each commodity clearing the market. Specifically, the producer price should equal to the domestic market price inflated by the exogenous ad valorem producer support estimate while the consumer price should be equal to the domestic market price deflated by the exogenous ad valorem consumer support estimate, such that.

$$ps = pg*(1 + pse) \tag{9}$$

$$pd = pg*(1 - cse) \tag{10}$$

where *pg* indicates the local price, *pse* denotes the ad valorem producer support estimate (fraction) and *cse* is designated as ad valorem consumer support estimate (fraction). To account for simultaneous exporting to the world market and importing from the world market of the same good at the same time and place, agricultural product is not assumed to be homogeneous following the Armington assumption (Armington, 1969). For each potentially traded good in the model, supply from domestic and foreign source is greater than or equal to demand from domestic and foreign sources (Eqs. (11)–(13)). A constant elasticity of substitution (CES) function form (following the Armington assumption) is used to split demand between domestic production and foreign supply, and a similar procedure is also applied to supply to domestic and foreign market.

$$qstot + impt \geq qdtot + expt \tag{11}$$

$$pexptfob = pw - tc \tag{12}$$

$$pimptcif = pw + tc \tag{13}$$

qstot is the total local production by commodity; *impt* stands for import; *qdtot* represents the total local consumption by commodity; *expt* denotes export; *pexptfob* signifies the export parity price; *pw* is the world price; *tc* indicates the unit transport cost to and from the world market; *pimptcif* symbolises the import parity price. In addition, the model also captures the trade related transportation costs as a feature in the prices and trade block. In particular, a unit transport cost to and from the world market is specified to distinguish export from import parity price in the absence of government price interventions. Producer and consumer support estimates are then used in the model to capture government support policies.

A regional switch between exporter, autarky and importer occurs depending on benefit and cost conditions. The price of domestic produce is bound from above by the import parity price and from below by the export parity price. If the domestic unit cost of

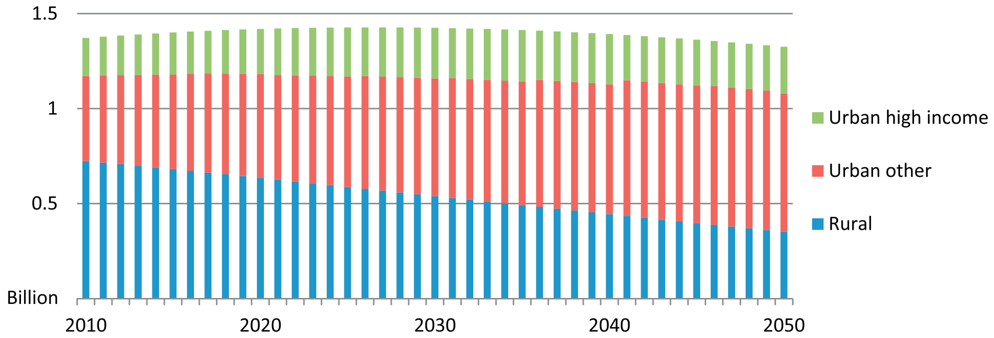

Fig. 5. Assumption on changing population structure.
Source: UN Population Projection.

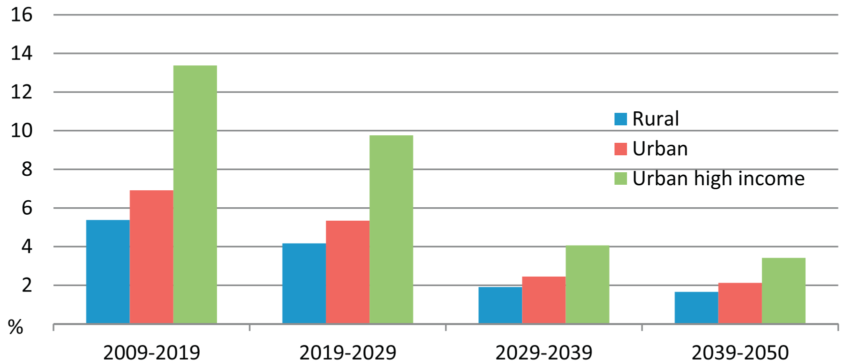

Fig. 6. Assumption on annual average yearly growth rates.
Source: Authors' estimation.

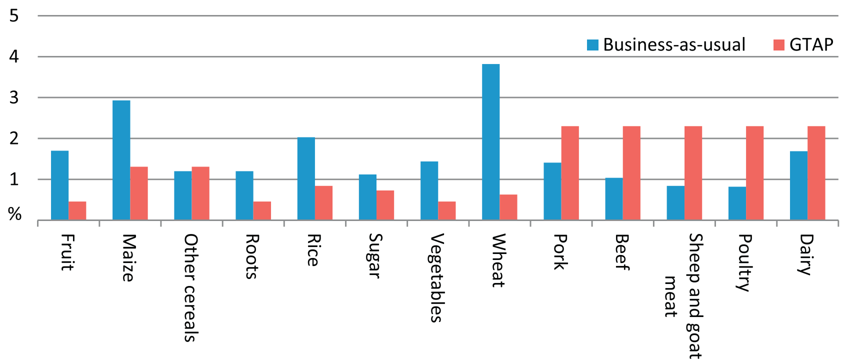

Fig. 7. Comparison of various productivity growth scenarios.
Source: Authors' estimation.

production is lower than the export parity price, then exports increase until marginal net benefits are zero.

In sum, our model has more flexible and transparent settings to capture public policies comparing with other alternative models. For example, as productivity (from the supply side) and income (from the demand side) are exogenously determined, production and consumption subsidies can be easily added up to the marginal cost of production or the consumption price for policy analysis. In addition, the assumption of a unit transportation cost (or trade barriers) to and from the world market can easily be used to distinguish export from import parity price (or a price in the absence of government price interventions) to reflect the potential arrangement in trade policies. Finally, when using the index measuring consumption quality (Clements & Gao, 2012), the estimates from our model can be used to demonstrate the structural change in "quality" of food consumption.

$$y_{\eta w} = \sum_{i=1}^{n} W_i(\eta_i - 1)\widehat{W_i} \tag{14}$$

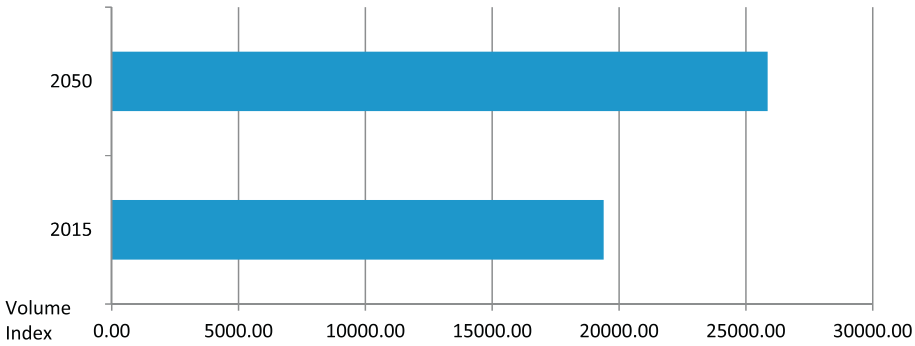

Fig. 8. Total food demand in China. Note: The volume index equals the weighted average of output of each commodity with their prices as weights.
Source: Authors' forecasts.

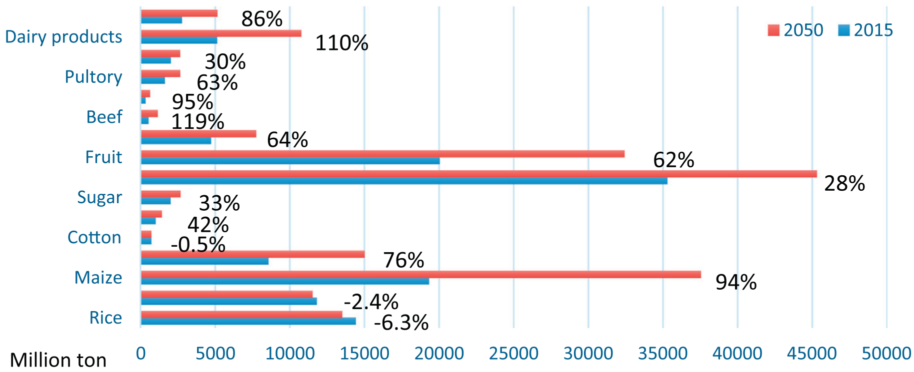

Fig. 9. Consumption of major agricultural commodities.
Source: Authors' estimation.

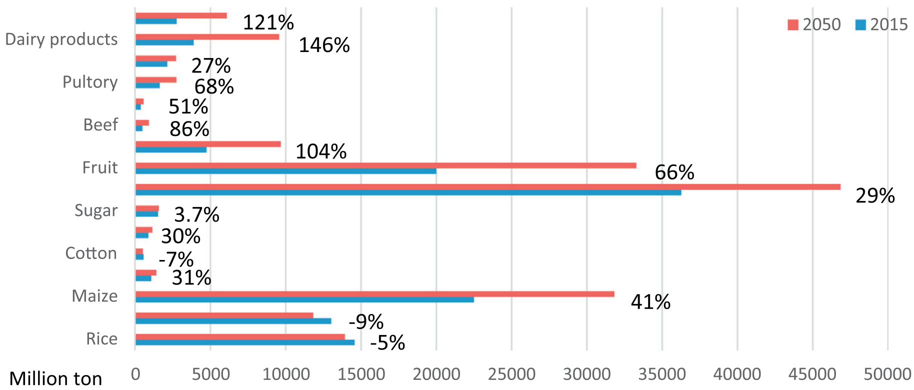

Fig. 10. Production of selected commodities.
Source: Authors' estimation.

where $y_{\eta w}$ is the quality index, W_i is the budget share and η_i is the income elasticity. $y_{\eta w}$ is positive (negative) when, on average, the shares of luxuries increase (decrease) and those of necessities decrease (increase).

4. Data collection and compilation

Three groups of data are used to calibrate the model, which include: parameters used to define the demand and supply functions; the production and consumption data for calibrating the model at the base year (i.e. 2009) and; data used to construct macro-economic shocks. This section briefly discusses the sources of these data.

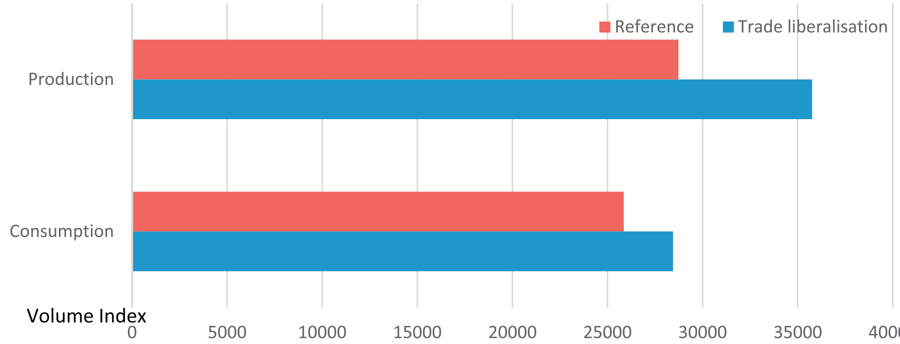

Fig. 11. Production and comparison of food consumption: autarky versus openness. Note: The volume index equals the weighted average of output of each commodity with their prices as weights.
Source: Authors' estimation.

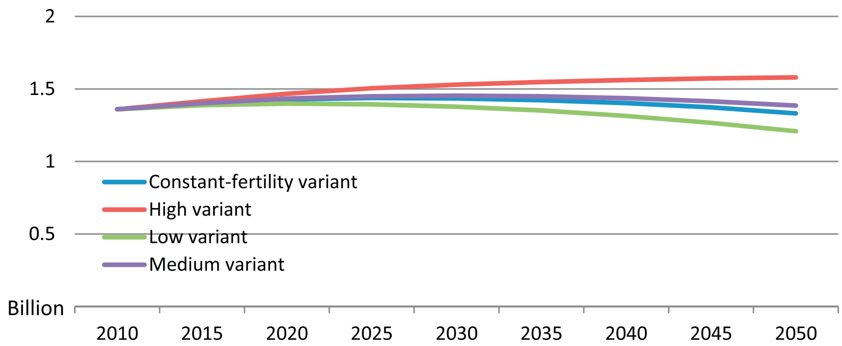

Fig. 12. Alternative population projections.
Source: United Nations (2014).

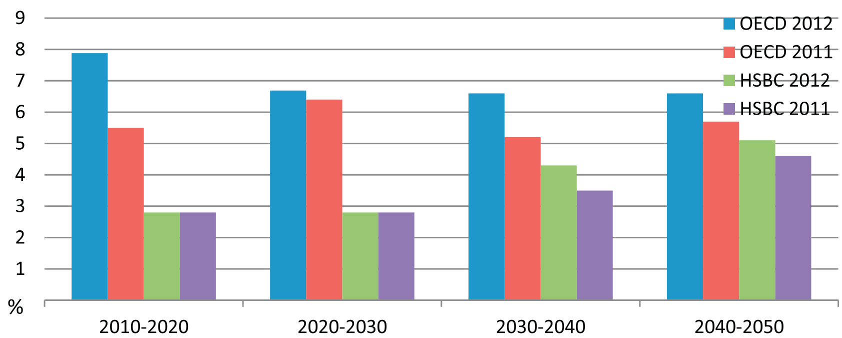

Fig. 13. Alternative income growth projections.
Source: OECD (2012); HSBC (2012).

4.1. Parameters of demand function and baseline data

Parameters used to confine the demand functions of agricultural products in China consist of the income elasticity, own-price elasticity and cross-product price elasticities (Table 1 and Table 2). These elasticities are estimated by using data obtained from Chen, Abler, Zhou, Yu, and Thompson (2016), which conducted a meta-analysis of food and agricultural demand elasticities for China. To capture difference in consumption preference of various income groups, elasticities are estimated for urban high-income, urban low-income and the rural population independently. Specifically, average income and own-price elasticities obtained from Chen et al. (2016) have been used to approximate income and own-price elasticities for urban low-income, while their response to income has been used to adjust average income and own-price elasticities for calculating those for urban high-income and rural groups. Generally, the urban high-income group has relatively higher income and own-price elasticity of high protein and high value goods than

Table 1
Income and own-price elasticities for different income groups by commodity.

	Income Elasticity			Own-price Elasticity		
Commodity	Urban High	Urban Low	Rural	Urban High	Urban Low	Rural
Rice	0.431	0.433	0.435	−0.755	−0.598	−0.466
Grain	0.237	0.239	0.241	−0.969	−0.859	−0.727
Oil and fat	0.284	0.268	0.254	−0.504	−0.481	−0.389
Vegetable	0.516	0.418	0.420	−0.725	−0.568	−0.436
Fruit	0.586	0.517	0.434	−0.759	−0.708	−0.665
Pork	0.560	0.483	0.391	−0.831	−0.738	−0.660
Beef	0.555	0.478	0.386	−0.700	−0.607	−0.529
Mutton	0.403	0.326	0.234	−1.148	−1.055	−0.977
Poultry	0.706	0.669	0.654	−0.824	−0.731	−0.653
Dairy product	0.782	0.654	0.502	−0.615	−0.807	−0.968
Egg	0.434	0.357	0.265	−0.719	−0.626	−0.548
Fish	0.730	0.695	0.653	−0.434	−0.527	−0.605
Fish (High value)	0.853	0.695	0.630	−0.434	−0.527	−0.605

Source: Authors' estimation by using data from Chen et al. (2016). The elasticities for urban low income group is assume to take the average elasticity, while those for urban high income and rural groups are approximated by using the coefficients in front of the interaction terms and those in front of income.

Table 2
Average cross-product price elasticities.

	Rice	Grain others	Oil and fat	Vegetable	Fruit	Beef and Mutton	Pork	Poultry	Dairy product	Egg	Fish	Food away from home
Rice	–	0.463	0.203	0.066	0.027	0.158	−0.004	0.003	0.091	0.283	−0.028	−0.241
Grain others	0.054	–	0.059	0.018	0.015	0.123	0.006	0.043	0.063	0.058	0.035	0.436
Oil and fat	0.138	0.245	–	0.084	0.051	0.213	0.043	0.102	0.106	0.219	0.061	−0.275
Vegetable	0.148	0.266	0.312	–	0.111	−0.096	0.127	0.29	0.168	0.093	0.173	−0.049
Fruit	0.017	0.085	0.108	0.066	–	0.323	0.056	0.145	0.193	0.049	0.227	0.277
Beef and Mutton	0.055	0.078	0.098	−0.015	0.068	–	0.017	0.028	−0.009	0.191	0.124	−0.167
Pork	−0.031	0.091	0.201	0.157	0.116	0.164	–	0.271	0.059	0.222	0.059	−0.515
Poultry	0.011	0.193	0.135	0.11	0.089	0.079	0.084	–	0.098	0.203	0.083	−0.211
Dairy product	0.059	0.237	0.113	0.052	0.097	−0.022	0.013	0.079	–	0.033	0.101	−0.339
Egg	0.139	0.141	0.144	0.015	0.015	0.278	0.032	0.101	0.022	–	0.015	−0.052
Fish (including high valued)	−0.055	0.177	0.095	0.08	0.171	0.452	0.021	0.101	0.152	0.033	–	−0.057
Food away from home	−0.085	0.093	−0.028	0.058	0.043	−0.036	−0.216	−0.043	−0.064	0.025	−0.037	–

Source: The cross-price elasticities are obtained from Chen et al. (2016).

the urban low-income group and rural group. This is consistent with our expectation of the change in food consumption preference as real income increases.

Parameters used to confine the supply side are endogenised in the production function of different types of commodities, where only input usage (i.e. land) and production technologies are exogenously determined. Since different types of products use different inputs and intermediate inputs, there is no unique way to specify these parameters. For simplicity, we use the standard setting obtained from the OECD-FAO ARGLINK model (Piero & Londero, 2001). Since these parameters are essential for our projection, we have compared them with the literature. Generally, they are consistent with those settings in standard model (i.e. GTAP) in literature (GTAP, 2011) which were aggregated from 140 countries and 26 agricultural sectors (GTAP, 2011).

As for the baseline data for calibration, we use the Food Balance Sheets, FAO STAT database (FAO, 2016), to provide the related information on the quantities of production, consumption, stock change, imports, exports and intermediate input usages by country and by commodity. The base year is assumed to be 2009 since it is the latest year when the complete dataset for the whole world is available. Equilibrium world market prices for each commodity are approximated by using the US domestic market price, with the adjustment for transportation costs and other mark-ups for 2009. In addition, data obtained from the Chinese Household Survey 2003–2009 are also used to specify the proportion of consumption by different income groups in China for the base year (Table 3).

4.2. External shocks to the food demand and supply

To predict the food demand and supply of China in 2050, it is crucial to use appropriate macroeconomic shocks from both the demand and supply sides. These shocks mainly include the prediction of population and real income growth (the demand side) and the change in the land supply and agricultural productivity (the supply side).

Table 3
Per capita consumption by commodity (unit: kg/person/per year): 2009.

Commodity	Urban High	Urban Low	Rural
Beef	9.22	3.02	1.37
Pork	43.43	19.07	16.57
Mutton	4.19	1.39	1.65
Poultry	19.13	5.98	5.86
Egg	27.18	9.77	8.25
Dairy products	64.18	18.10	6.61
Wheat	30.39	14.85	69.39
Rice	19.55	48.04	73.27
Maize	3.97	1.45	6.67
Other cereals	0.88	0.32	1.48
Potatoes	5.86	2.07	39.52
Other roots plants	4.82	1.71	32.54
Other plantations	1.51	0.55	2.55
Soybean	6.55	2.28	1.74
Soybean oil	5.31	2.06	1.78
Rape seeds	0.00	0.00	0.00
Rape seeds oil	2.74	1.06	0.92
Sunflower	0.00	0.00	0.00
Sunflower oil	0.24	0.09	0.08
Other vegetable oil	5.61	2.18	1.88
Vegetable	366.55	124.70	175.12
Fruit	108.42	30.31	32.12
Sugar	16.80	4.86	2.63
Aquatic product	21.28	13.68	15.47
Aquatic product (high valued)	7.25	4.66	5.27

Source: China Household Survey, Chinese Bureau of Statistics.

Assumption on population growth for China comes from the medium scenario of the United Nation Population projection. Over the projection period (between 2009 and 2050), the growing trend of total population will take an inverted "U"-shape curve with the average annual growth rate close to zero. Driven by ongoing urbanisation process, urban populations continue to rise and rural populations fall. As a consequence, the proportion of urban population in total population will increase from 46% in 2009 to more than 73% in 2050 (Fig. 5).

Assumption on the growth of real income per capita follows that of OECD (2012), which has two characteristics. First, real income growth has been gradually declining over time. For the period of 2009 to 2015, the real GDP and GDP per capital growth in China, 8.3% and 11.4% per annum have been used (CBS, 2016). For the period of 2015 to 2030, the average GDP growth and GDP per capita growth in China are projected to be 6.6% and 6.4% per annum; for the period of 2030–2050, these two income growth rates will 2.3% and 2.8% per annum. Second, income growth is not evenly distributed across different income groups. When using data from China Household Survey data to decompose real income growth rates by income groups, it shows that urban population generally will have much faster income growth than rural population (Fig. 6). This implies that there tends to be an enlarging income gap between urban and rural population and between high income and low income groups. Both population growth and real income growth are summarised in Table 4.

Assumptions on agricultural productivity growth is estimated by using the historical statistics by commodity (or, based on the business as usual practice). Both yield data at the commodity level obtained from FAO STAT between 1961 and 2012 (FAO 2014) and the total factor productivity and labour productivity at the industry level between 1961 and 2010 estimated by the USDA ERS (Fuglie

Table 4
Projection on population and real income in China (at constant price of 2009): rural vs. urban.

	2009		2020	2030	2040	2050
	RMB Yuan	USD	USD	USD	USD	USD
Expenditure/Income per capita						
Rural Income group	3504.84	513.1	1930.9	2409.1	3708.4	4020.7
Urban Middle Income	8738.79	1279.3	3672.9	4513.4	5674.8	6991.5
Urban High Income	14,964.37	2190.7	12,760.7	21,990.2	32,685.6	45,835.3
Average Income per capita (2009 USD)		1628.9	8729.2	10,854.6	12,993.0	14,652.9
Total Population						
Rural Income group		198,086	253,909	287,295	299,574	300,484
Urban Middle Income		462,200	592,454	670,354	699,007	701,128
Urban High Income		681,049	541,428	435,427	362,325	293,992
Total Population		1,341,335	1,387,791	1,393,076	1,360,906	1,295,604

Source: Authors' estimation.

& Rada, 2015) have been used for this projection. Compared to productivity projections used by other studies, our estimates show relatively higher productivity growth in grain, vegetable and fruit industries while a relatively lower productivity growth in beef, sheep and poultry industries (Fig. 7). For example, Tian and Yu (2012) conducted a meta-analysis of 5308 estimates of total factor productivity growth n China from 150 primary studies and found that the aggregate agricultural productivity had grown at only 2% per year since 1978. Yet, this is a reasonable assumption as Tian and Yu (2012) also pointed out that sector-specific productivity growth are generally larger than aggregate productivity growth. Since the production process for vegetables and fruits involves more labour usage relative to beef, sheep and non-irrigated grains and over time government gave more support to the production of the low value commodities, this pattern in productivity growth between commodities is more likely to reflect the comparative advantage of agricultural production in China and the effects of some supportive policies from the government. As a robustness check, we also use the estimates of 2% of agricultural total factor productivity growth at the national level from Tian and Yu (2012) to re-do the exercise.

Finally, it is assumed that the land supply to agricultural production does not change between 2009 and 2015 and declines by 15% between 2015 and 2050. This assumption is reasonable due to the historical experience in China, as the ongoing urbanisation and industrialisation have reduced the arable land by 15% between 1990 and 2009.

5. China food demand and supply in 2050

Using the model with predicted changes in population, real income and agricultural productivity as external shocks, we update the base period from 2009 to 2015 and forecast food demand and supply in China and its implications on trade of agricultural products by 2050.

5.1. Food consumption

The total food demand in China is projected to increase by 33% by 2050 compared to 2015 (Fig. 8). Such a quantity increase in consumption is accompanied with a mild increase in consumption price. Consumption growth increases more quickly before 2030 than from 2030 to 2050 because of projected higher population and income growth over the earlier period.

While consumption of most commodities is projected to rise, the largest increases are for high value products such as beef, dairy, sheep and goat meat, and aquatic product (Fig. 9). By 2050, beef consumption is projected to rise by 119% to 1139.2 million tons, dairy is projected to rise by 110% to 10,759.9 million tons, sheep and goat meat is projected to rise by 95% to 628.1 million tons and aquatic product consumption is projected to rise by 86% to 5132.3 million tons.

In contrast, consumption of grains and some selected vegetables is projected to grow relatively slow. For most cereals and starchy staples including rice, potatoes, yams and sweet potatoes among others, consumption is projected to either increase more slowly than higher valued products or even decline by 2050. However, there is an exception for maize consumption, which is projected to rise by 94% to 37,526.3 million tons. The increase of maize consumption largely reflects the projected increase in feed demand given the expected rise in livestock production.

The more rapid growth in demand of meat and dairy products than that of grains reflects a dietary shift away from staple foods such as cereals, to high valued products as real per capita incomes increase. In other words, as income per capita increases and demographic structure changes, China's food consumption will experience a rapid escalation in quality in the long run. Using the index of the changing "quality" in food consumption (Clements & Gao, 2012), we further measure the degree to which the consumption basket as a whole moving towards more luxurious goods, away from necessities, and its components. By 2050, there are around 14% increase in expenditure for food quality in China, comparing to 2% increase in the rest of the world. Among this change, more than 85% (i.e. 12%) comes from the change in food quality while only 15% (i.e. 2%) is attributed to the price effects.

To explain the change in China's food demand in 2050, two important factors deserve to be mentioned. On one hand, the increase in income per capita and population will raise the total food demand and shift the food consumption structure towards luxuries (rather than necessities) products. However, these changes only gradually affect the structure of food consumption which have already been captured by existing studies.[3] On the other hand, the changing demographic structure, a result of ongoing urbanisation, will contribute more substantially and more quickly to the shift in dietary structure. As more rural migrants move into cities, urban consumers' preference in food consumption will dominate rural consumers' preference. As such, there will be a rapid increase in the quality of food consumption, such that more consumption of high valued products and its growth, rising urban populations and real incomes over the projection period, will dominate aggregate food consumption.

5.2. Food production and trade

Driven by increased demand (and thus the commodity price in domestic market) and productivity growth, China's production of agrifood products is projected to increase for almost all commodity groups except for rice, wheat and cotton (Fig. 10). However, constrained by limited input growths (mainly land and water), the increased output is generally smaller than that of consumption. As a consequence, there will be a substantial gap between domestic food consumption and production, in particular for high value and

[3] In this paper, the aging problem and its potential negative effects on aggregate food consumption have been taken into account through the reduced demand elasticities for all food products

high protein products. By using the index of the changing "quality" in food consumption, we show that there are only 10% of increase in production value for quality improvement which is made up of 9% increase in quality of volume and 1% increase in quality of price. This implies that domestic food supply is unlikely to satisfy domestic food demand in structure even if the total amount of food production is sufficient enough, and food imports will play an important role in China's food supply towards 2050.

Specifically, China's consumption of rice, wheat, vegetable, fruit, and poultry meat has been mainly met by domestic production, with trade playing a relatively minor role. Towards 2050, the situation for these commodities is not expected to change significantly and most of these commodities may even change to export. In contrast, a significant portion of China's beef, sheep and goat meat, sugar and dairy product consumption as well as the demand for maize and soybean is projected to depend on imports. For these commodities, most of the import growth is projected to occur between 2015 and 2030 because of relatively high population and income growth over this period.

Given the enlarged gap between food demand and supply for high quality products in China, there will be great potential for agricultural trade, though the effects could be unevenly distributed by commodity.

5.3. High-value commodities

The most significant rise in projected imports is for beef. China is projected to remain a net importer of beef in 2050, with the beef imports projected to increase to 225.8 million tons. While this projected increase may be large, it is important to note that, in the four years to 2013, annual average import growth was 132% in value terms. If the projection is achieved, the import share of total Chinese beef consumption would be about 20% in 2050, compared with just 9% in 2015.

In addition to beef, net import high-value commodities also include dairy products and sheep meat. China is projected to remain a net importer of dairy products in 2050 with imports projected to increase by 165% to 63 million tons in 2050. This growth will see the import share of total Chinese dairy consumption increase from around 6% in 2015 to 10% in 2050. China's sheep and goat meat imports is projected to increase significantly to 62.6 million tons by 2050, albeit it from a low base.

5.4. Cereals

Although production of rice and wheat is projected to decline, they are still able to meet the domestic demand. As such, China is projected to be a net exporter of rice and wheat by 2050. Rice and wheat exports are projected to be 432.1 million tons and 316.7 million tons respectively.

To meet domestic demand of feed to support the production of livestock industries, China is projected to remain a net importer of maize and soybean over the projection period. China's maize imports projected to increase to 5701 million tons by 2050. This will see the import share of total Chinese maize consumption increase from 2.4% in 2015 to 15.2% in 2050, which is equivalent to a 6 times increase. Over the same period of time, soybean imports are also projected to increase by 66% to 13,592 million tons.

5.5. Further openness to trade

What would happen if China is willing to reduce government support and subsidies and open its food market? To answer this question, we forecast food production, consumption and trade of China in an alternative scenario in which free-trade is assumed. In this scenario, it is assumed that China will gradually implement three policies between 2015 and 2050. First, it is to relax trade restrictions and market access for agricultural commodities through removing the tariff rate quota (TRQ) control. Second, it is to equalize the domestic prices of major agricultural commodities (i.e. wheat, maize and soybean etc. whose domestic prices are higher than those in international market by a range of 30–50% in 2015) to the international prices. Third, it is to remove the price intervention policy through abolishing both minimum price for rice and wheat and procurement prices for maize, soybean and rapeseed under the temporary storage program (TSP).

Under this free-trade scenario, both the production and consumption of agricultural products will increase due to the decline in the equilibrium consumption price. China's agrifood production is projected to increase by 61% by 2050, a result higher than the reference scenario projection of 49%. This increase in agricultural production, to some extent, reflects the additional benefits that could be obtained from a more efficient reallocation of resource between commodities when market distortions are eliminated. At the same time, agrifood consumption is projected to be 47% higher than in 2015, a result that is 14% higher than the reference scenario (Fig. 11).

However, China's agrifood imports only increases by 15.3% by 2050, which is lower than the projected increase under the reference scenario of 21.9%. The lower level of agrifood imports under this scenario reflects reduced agrifood demand for the high value commodities from international market, as increased imports of feed grains (such as maize and soybean) compared to the reference scenario, decreases the production cost of high value products. Imports of these commodities decline the most relative to the reference scenario. In contrast, the commodities whose imports are relatively higher than in the reference scenario include oilseeds (5%), soybean (7%) and maize (30%).

Finally, market oriented reforms and open to trade also help to improve the welfare of consumers by facilitating the shift of the food consumption basket as a whole towards more luxurious goods, away from necessities, (or the escalation in quality) in China due to population growth and economic transformation towards a more urbanised society. This finding is consistent with the observations of Yu and Abler (2009) and Tian and Yu (2017) which shows that there are price and quality changes in China's vegetable and fruit imports. Comparing between openness to trade scenario and the autarky scenario, the increase in expenditure for food quality (measured by using the index of the changing "quality" in food consumption) under the openness to trade scenario is around 22% which is much higher than that under the autarky scenario (i.e. 14%). Although the price effect partly due to the declining terms of trade for agricultural products (as China is more likely to export the necessities while import the luxuries) has significantly contributed to this increase (say, an increase from 2% to 8%), there is still more than 2% increase in quality of volume under the openness to trade scenario relative to the autarky scenario. This implies that market oriented reforms and openness to trade will bring additional benefits by improving the quality of food consumption in China.

5.6. Robustness check

To check whether our projection is sensitive to different demand shocks, we have redone the simulation using different assumptions on population and real income growth, as well as different assumptions on agricultural productivity growth. Specifically, for population growth, we use the UN population projection under the assumption of high, low and constant-fertility variant (Fig. 12); for real income growth, we use the GDP per capita growth estimated by HSBC and World Bank (Fig. 13). Following Tian and Yu (2012), we also lower the shock of agricultural productivity growth at the aggregate level to 2% per year.

Although there are some differences in magnitude (not reported), the results obtained from those new simulations are generally consistent with those obtained from our reference model in terms of food consumption structure. Although the gap between domestic demand and supply for high-value and high-protein goods is enlarged when agricultural total factor productivity is assumed to grow at 2% per year as in Tian and Yu (2012), the estimates from the new scenario is generally consistent with our initial projection. This suggests that our findings are less sensitive to different assumptions of demand shocks.

Finally, we also compare our projection results with other projections from China (CASIM) for 2025 (Huang, Xie, & Cui, 2017), from the GTAP model by Xie, Tariq, Cui, and Huang (2017) and from AGLINK-COSIMO model by OECD-FAO (OECD-FAO, 2017). Generally, our projection results on China total food production and consumption are similar as those from the literature but there is more rapid increase in high-end demand than necessities. This reflects the core mechanism of our model in predicting that income growth and ongoing urbanisation process in China is more likely to generate more rapid structural change in food consumption, which in turn will drive up the domestic production and imports of high-value and high protein products.

6. Conclusions

Under certain assumptions on supply, demand and macroeconomic policies, food consumption in China is projected to increase by 33% by 2050. Most of this increase will originate from urban middle- and high-income households given their rapid shift to more western-style diets and demand for high-valued commodities like beef, dairy products and sheep and goat meat. The high rate of urbanisation combined with a slowing population growth rate results in structural change in consumption preference and leads to aggregate food demand changing in quality.

Although imports of many agrifood commodities are expected to increase to 2050, China's own agricultural production will largely meet the projected increase in total demand for food, in particular for the necessities. Ongoing investment, technological innovation and further agricultural reforms such as land system, and labour and capital market reform will help to achieve the required rise in food production. Not only must productivity increase, but more modern approaches for contending with the challenges of a deteriorating resource base will need to be adopted. Existing investment rates and initiatives being taken by the Chinese Government would indicate that it is poised to meet these challenges.

Finally, the significant rise in food consumption of more luxuries will be driven by urban middle- and high-income households, which will, to a large extent, be met by both domestic production and imports. In this sense, public policies with the aim to facilitate market-oriented reforms and openness to trade will reduce the costs related to structural adjustment in production and agricultural trade between China and the rest of the world and bring additional benefits to consumers by optimising the distributional impact of changes in the structure of food consumption.

References

ABARES (2014). What China wants: Analysis of China's food demand to 2050. *Conference Paper 14.3. ABARES Outlook Conference Paper, 4-5 March 2014*.

Allen, R. G. D. (1968). *Macro-economic theory: A mathematical treatment.* London: Macmillan35.

Armington, P. (1969). A theory of demand for products distinguished by place of production. *International Monetary Fund Staff Papers, XVI (1969)* (pp. 159–178). .

Chen, D., Abler, D., Zhou, D., Yu, X., & Thompson, W. (2016). A meta-analysis of food demand Elasticities for China. *Applied Economic Perspectives and Policy, 38*(1), 50–72.

China Bureau of Statistics(CBS) (2016). *China statistical yearbook.* China Statistical Press.

Clements, K. W., & Gao, G. (2012). Quality, quantity, spending and prices. *European Economic Review, 56*, 1376–1391.

Fan, S., & Agcaoili-Sombilla, M. (1997). Why do projections on China's future food supply and demand differ? *IFPRI Working Paper*. Washington, D.C.: International Food Policy Research Institute.

FAO (2014). OECD-FAO agricultural outlook 2014-2023. *United Nation Farm and Agricultural Organisation*.

FAO (2016). *FAO STAT.* Rome: Food and Agriculture Organisation of the United Nations. available at faostat.fao.org/site/655/default.aspx.

Food and Agricultural Policy Research Institute (1996). *World Agricultural Outlook, STAFF Paper No. 2–96.* Columbia: Iowa State University and University of Missouri.

Frohberg, H., & Britz, W. (1994). The world food model and an assessment of the impact of the GATT agreement on agriculture. *Research report.* Bonn: FAO.

Fuglie, K., & Rada, N. (2015). ERS data product-international agricultural productivity. Available at the website http://www.ers.usda.gov/amber-waves/2013-November/growth-in-global-agricultural-productivity-an-update.aspx.

GTAP (2011). GTAP 9 database. available on website https://www.gtap.agecon.purdue.edu/databases/v9/default.asp.

Hjort, K., & van Peteghem, P. (1991). *The CPPA Model-Builder: Technical Structure and Programmed Options in Version 1.3.* Economic Research Service, U.S. Dept. of. Agriculture Staff Report No. AGES 9144.

HSBC (2012). *The world in 2050: from the top 30 to top 1000.* HSBC Global Research: Global Economics. January 2012, website http://www.google.com.au/url?url=http://www.hsbc.com/~/media/HSBC-com/about-hsbc/in-the-future/pdfs/030214-2012-report.pdf&rct=j&frm=1&q=&esrc=s&sa=U&ei=nlR2VJ6nNITd8AWz7YHgDQ&ved=0CBsQFjAB&usg=AFQjCNHhkhurWLvuLtViadhb-E3fe-uACA.

Huang, J., Xie, W., & Cui, Q. (2017). The prospects for China's Food Security and Imports: Will China Starve the World via Imports? *Journal of Integrative Agriculture, 16*(60), 345–347.

IFPRI (2012). Global food policy report. Research Report 2012 *International Food Policy Research Institute* Washington D.C.

Linehan, V., Thorpe, S., Neil, A., & Beaini, F. (2012). Food Demand to 2050: Opportunities for Australian Agriculture-Algebraic description of Agrifood Model. *ABARES Research Report, May 2012, Canberra*.

Linehan, V., Thorpe, S., Andrews, N., Kim, Y., & Beaini, F. (2012). *Food Demand to 2050: Opportunities for Australian agriculture, Outlook Conference Paper 12.4, Canberra, 6–7 March*.

OECD (2001). *Measuring Productivity: OECD Manual of Measurement of Aggregate and Industry-level Productivity Growth.* Paris: OECD.

OECD (2011). *Productivity and Competitiveness in Agriculture: the Role of Research and Development.* OECD, Paris: Trade and Agricultural Directorate.

OECD (2012). *Medium and long-term scenarios for global growth.* Paris: OECD.

OECD-FAO. Agricultural Outlook 2017–2026. (2017). available at http://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm OECD, Paris.

Piero, C., & Londero, P. (2001). AGLINK: The OECD Partial Equilibrium Model. *OECD Working Paper No. 8. Paris*.

State Statistical Bureau (1996). *China Statistical Yearbook.* China Statistical Publishing House.

Tian, X., & Yu, X. (2012). The enigmas of TFP in China: A meta-analysis. *China Economic Review, 23*, 396–414.

Tian, X., & Yu, X. (2017). The quality of imported fruits in China. *Emerging Markets Finance and Trade, 53*(7), https://doi.org/10.1080/1540496X.2016.1179627.

United Nations (2014). World Population Prospects: 2012 Revision, United Nation. available at: http://www.un.org/en/development/desa/population/publications/dataset/index.shtml.

Xie, W., Tariq, A., Cui, Q., & Huang, J. (2017). Economic impacts of commercializing insect-resistant GM maize in China'. *China Agricultural Economic Review, 9*(3), 340–354.

Yu, X., & Abler, D. (2009). The demand for food quality in rural China. *American Journal of Agricultural Economics, 91*(1), 57–69.

Zhou, D., Yu, X., & Herzfeld, T. (2015). Dynamic food demand in urban China. *China Agricultural Economic Review, 7*(1), 27–44.

Zhou, D., Yu, X., Abler, D., & Chen, D. (2017). Projecting meat and cereals demand for China based on a meta-analysis of income elasticities. *China Economic Review*. https://doi.org/10.1016/j.chieco.2017.12.002 5 December 2017.