Journal of Integrative Agriculture 2015, 14(6): 1092–1100

Available online at www.sciencedirect.com

ScienceDirect

RESEARCH ARTICLE

Future perspective of China's feed demand and supply during its fast transition period of food consumption

DONG Wan-lu[1, 2], WANG Xiao-bing[1], YANG Jun[3]

[1] *Center for Chinese Agricultural Policy, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, P.R.China*

[2] *University of Chinese Academy of Sciences, Beijing 100049, P.R.China*

[3] *School of International Trade and Economics, University of International Business and Economics, Beijing 100029, P.R.China*

Abstract

China has experienced dramatic changes in food consumption patterns over the last three decades. However, there are different opinions regarding the future trends in consumption. By adopting the well-developed partial equilibrium model—China Agricultural Policy Simulation Model (CAPSiM), the demand for livestock products and the main feed crops over 2011–2030 is predicted and analyzed. It is found that China's per capita consumption of livestock products will continue to rise during this period, even though its growth rate will slow down gradually. Meanwhile, the expansion of livestock production will pose great challenges for feed supply in China. More accurately, China will be confronted with feed security rather than grain security in the future.

Keywords: feed demand, food consumption pattern, partial equilibrium model

1. Introduction

While China has succeeded in maintaining its food security over the past three decades, its widening agricultural trade deficit in recent years has drawn attention across the world. The Chinese market has witnessed a rapid transition in food consumption patterns, with an increasing share of high value-added foods (e.g., vegetable oils, fruits, meat, fishery, and dairy products). This trend is consistent with the processes of urbanization and industrialization—summarized as "the livestock revolution" (Delgado 2003), which has commonly occurred in countries after their economic takeoff (Hartwell 1961; Delgado 2003; Yang *et al.* 2013). China's agricultural production increased dramatically over 1978–2012 with agricultural Gross Domestic Production (GDP) rising by 4.6% annually, more than 4.5 times the rate of population growth. Consequently, China has maintained its status as a net food exporter for more than two decades since 1978 even while undergoing rapid growth in food demand and quick transitions in food consumption patterns. However, the situation seems to have changed completely after 2004, when China was converted into a net agricultural importer for the first time since 1990, and its agricultural trade deficit has continued to rise since then (The agricultural trade deficit reached 49.2 billion USD in 2012 (NBSC 2012)). The large import volume and its rising trend have triggered recurrent concerns around the world over China's food security.

Feed demand plays a vital role in ensuring China's food

Received 7 July, 2014 Accepted 31 December, 2014
Correspondence: WANG Xiao-bing, E-mail: xbwang.ccap@igsnrr.ac.cn

doi: 10.1016/S2095-3119(14)60992-8

security. The increase in consumption of livestock products is manifested through this sector indicating the highest growth among all agricultural products in China. In contrast to many other countries like Japan and Korea, China's rising demand for livestock products depends heavily on its domestic production, which means that more feed is required to raise animals. Whether China can create a balance between supply and demand in feed crops appears to be the key component in its grain security and food security strategy for the future (Chen 2012; Huang *et al.* 2012).

Researchers do not reach consensus on the perspectives of China's feed balance. Many experts believe China's feed supply deficit will become exacerbated over the next decades (Huang 2004; Xu *et al.* 2011; Chen and Yang 2013). On the demand side, China's food consumption pattern will continue to change significantly in favor of high value-added foods such as meat and dairy products rather than cheaper and less nutrient-dense foods like grain crops (Huang and Rozelle 1998; Yen *et al.* 2004; Yu and Abler 2009). This, in turn, will lead to fast growth of feed demand and more grain crops will be used as feed rather than for direct consumption (Yu *et al.* 2012). On the supply side, China confronts stricter constraints on the resources required to increase agricultural production, as more land, water, and rural labor will be reallocated to the profitable non-agricultural sectors in the process of fast urbanization and industrialization (Pingali *et al.* 1997; Zhao *et al.* 2006; Wang *et al.* 2011). Therefore, many studies indicate that the gap between feed demand and domestic supply in China will be enlarged. Taking maize as an example, the most important feed crop in China, Huang (2004) projects that China's net imports of maize will increase sharply to 57 000 thousand tons in 2020. Chen and Yang (2013) predict that China's net maize imports will lie in a range between 29 500 and 53 600 thousand tons in 2020 and between 72 000 and 160 000 thousand tons in 2030.

On the contrary, some experts believe that China can maintain the balance of feed demand and supply. There exist three main reasons to justify this perspective. First, China's per capita meat consumption has become stable and may even be close to its peak, according to the national statistical record (Jiang *et al.* 2002). This process will accelerate as China turns into an aging society (Yu and Sun 2012; Zhong and Xiang 2012). Therefore, feed demand will increase quite moderately in the future. Second, the balance of feed demand and supply can be reached through efficiency improvements in feed usage (Cui 2012). China's livestock production has changed remarkably from a style dominated by backyard production to that of industrialized production, which has proved to use feed more efficiently (Ma *et al.* 2011; 2012). Last but not least, the yield of feed crops, especially maize and soybean, can be promoted remarkably by the adoption of advanced technologies (e.g., genetic modification technology and mechanization) and improvements in infrastructure (Jin *et al.* 2002).

A careful analysis of the future perspective of China's feed demand and supply is needed particularly in terms of the importance of the issue and the notable variation in conclusions. Currently, most studies focus on China's changing food consumption patterns or the demand for specific feed crops. However, to our best knowledge, few studies have explored systematically the dynamic evolution and main characteristics of China's consumption and production of livestock products, as well as their impact on feed demands. The overall goal of this paper is to improve the better understanding of the changing processes in China's feed demand and supply over the two decades (2011–2030). To meet this goal, the paper is organized as follows. Section 2 presents China's historical changes in the production of livestock products and feed demand. Section 3 describes our methodology and key assumptions for future projections. The results are analyzed and discussed in section 4. The final section provides concluding remarks and a discussion of policy implications.

2. Evolution of livestock production and demand for feed crops

The production of livestock in China increased dramatically in 1980–2012. As shown in Table 1, the production of poultry, beef, and dairy products grew the fastest. Their production increased remarkably by 18.5, 23.6, and 27.3 times respectively, from 936, 269, and 1 367 thousand tons in 1980 to 18 230, 6 623, and 38 754 thousand tons in 2012, with average annual growth rates of 9.7, 10.5, and 11.0%. The production of mutton, eggs, and fishery products rose relatively moderately by 8.0, 11.6, and 12.1 times, from 445, 2 266, and 4 497 thousand tons in 1980 to 4 010, 28 612, and 59 077 thousand tons in 2012, with annual growth rates of 7.1, 8.4, and 8.2%, respectively. The production of pork grew the least among livestock products. Its production rose by 3.7 times from 11 341 thousand tons in 1980 to 53 427 thousand tons, with an annual growth rate of 5.1%. As a whole, China's meat production (including pork, poultry, beef, and mutton) rose significantly by 595.8% from 12 054 to 83 872 thousand tons, with an annual growth rate of 6.2%. While China's meat production is dominated by pork, its share in total meat production decreased continuously from 94.1% in 1980 to 63.7% in 2012, as its growth rate is much less than that of overall meat production in 1980–2012.

Apart from dairy products, the growth of other livestock products has slowed down since 2000. As shown in Table 1, the average annual growth rates of production of pork, poultry, beef, and eggs dropped notably from 5.7, 14.0, 15.1,

Table 1 Change of production and annual growth rates of different livestock products during 1980–2012 in China[1)]

	Meat					Fishery products	Dairy products	Eggs
	Total	Pork	Poultry	Beef	Mutton			
Production (thousand tons)								
1980	12 054	11 341	936	269	445	4 497	1 367	2 266
1990	28 570	22 811	3 435	1 256	1 068	12 370	4 751	7 946
2000	60 139	39 660	12 707	5 131	2 641	27 062	9 191	21 820
2012	83 872	53 427	18 230	6 623	4 010	59 077	38 754	28 612
Annual growth rate (%)								
1980–1990	9.0	7.2	13.9	16.7	9.1	10.6	13.3	13.4
1991–2000	7.7	5.7	14.0	15.1	9.5	8.1	6.8	10.6
2000–2012	2.8	2.5	3.1	2.1	3.5	6.7	12.7	2.3
Total growth (1980–2012, %)	595.8	371.1	1 847.6	2 362.1	801.1	1 213.7	2 735.0	1 162.7
Annual growth rate (1980–2012, %)	6.2	5.0	9.7	10.5	7.1	8.4	11.0	8.2

[1)] Source: *China's Agricultural Statistical Yearbook* (NSBC 1981–2013).

9.5, and 10.6%, respectively, in 1991–2000 to 2.5, 3.1, 2.1, 3.5, and 2.3% in 2001–2012. Although fishery products still kept a relatively high growth rate, the annual growth rate decreased from 8.1% in 1991–2000 to 6.7% in 2001–2012. Only dairy products show a different trend in growth. Their average annual growth rate rose tremendously from 6.8% in 1991–2000 to 12.7% in 2001–2012. The fast growth of the production of dairy products is mainly driven by rapidly rising demand (Fuller 2006; Gale and Huang 2007).

All the existing analyses of China's feed supply and demand are carried out under certain assumptions, as no authoritative statistical data are publicly available. Currently, there are two types of quantitative approach used to estimate feed demand. The first is the implied demand approach, through which the feed demand is calculated by multiplying the outputs of animal products and the feed-meat conversion ratios. The second is the residual supply approach. The feed demand is derived by deducting the grain used for human consumption, seeds, and industry usage from total grain output. In this paper, we adopt a method that combines the two approaches, which means the feed demand estimated from the first approach must equal the one derived from the second approach. There is no doubt that the quantity and quality of the data required by the new method is more convincing than those used in the above two approaches. Meanwhile, it also facilitates us to check the reasonableness and consistency of the data. China's feed demand is estimated based on the long-term historical database of agricultural demand and supply of the China Agricultural Policy Simulation Model (CAPSiM), constructed by the Center for Chinese Agricultural Policy (CCAP), Chinese Academy of Sciences (CAS). The estimated feed

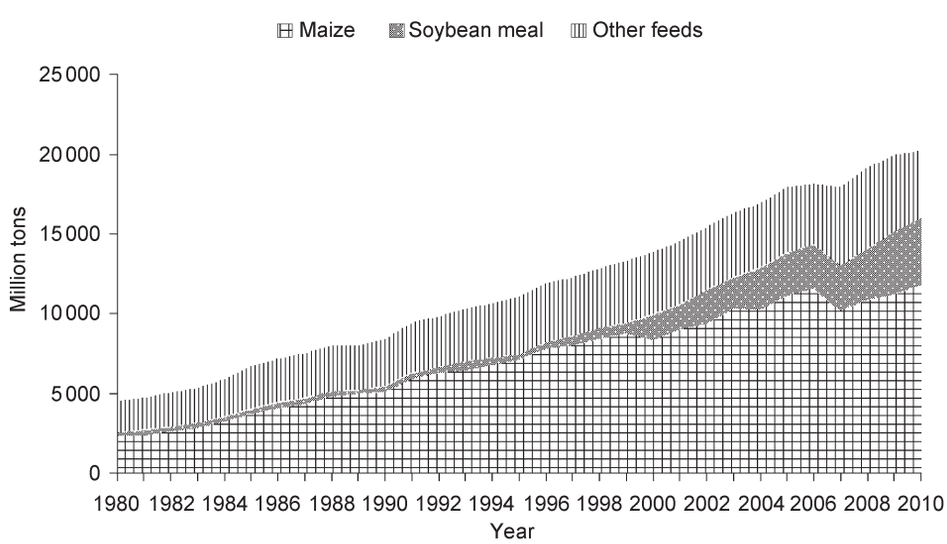

Fig. 1 Change of China's feed demand by categories (thousand tons) in 1980–2012. Source: estimated by authors based on *China's Agricultural Statistical Yearbook* (NSBC 1981–2013).

demand over 1980–2012 is shown in Fig. 1.

China's feed consumption increased dramatically over the past three decades, accompanied by a rapid growth in livestock production. As shown in Fig. 1, the demand for commercial feed (excluding forage grass) increased by 385.8% in 1980–2012 from 44 900 to 218 100 thousand tons, with an annual growth rate of 5.1%. Paralleled with the trend in animal production, the average yearly growth rate of feed demand slows down gradually. The annual growth rate of feed consumption dropped from 6.4% in 1981–1990 to 5.2% in 1991–2000 and further to 3.8% in 2001–2012. Such a trend is consistent with the declining growth rate of livestock production and the rising efficiency of feed usage (Ma *et al.* 2011). It is interesting to note that feed demand dropped slightly in 2007 because lots of hogs and poultry were slaughtered due to the outbreak of porcine reproductive and respiratory syndrome (PRRS) and avian influenza in that year. However, feed demand recovered and resumed its trajectory of growth afterward.

Maize and soybean meal, the two dominant feed components, play a critical role in China's feed supply. Maize is the most important feed crop and its share in total feed demand ranges between 50–65%. In contrast to maize, the use of soybean meal as feed increased dramatically after China liberalized its soybean market in 1996. China's soybean imports rose dramatically from nearly zero in 1995 to 58 400 thousand tons in 2012. Meanwhile, the use of soybean meal as feed increased significantly by more than 10 times from 3 800 thousand tons in 1996 to 43 600 thousand tons in 2012. Correspondingly, its share in total feed consumption rose more than six times from 3.2 to 20.0% during 1996–2012.

The evolution in feed demand is critical to China's grain and food security. The rapid expansion of the livestock sector boosts the demand for feed, which is the main driving factor leading to the imbalance in grain trade (Tuan *et al.* 2004). For example, imports of maize and soybeans reached 1.7 and 34.9 billion USD in 2012, respectively, accounting for 32.6% of China's total agricultural imports and 92.3% of grain imports. The combined trade deficit of the two commodities was 36.3 billion USD in 2012, accounting for nearly three quarters (73.8%) of the total agricultural trade deficit.

3. Methodology and scenario design

CAPSiM is adopted here to analyze China's demand for livestock products and feed in the future. CAPSiM is an agricultural partial equilibrium model designed to analyze the impacts of policies and external forces on the production, consumption, prices, markets, and trade of Chinese agricultural products, and to forecast the future supply, demand, trade, and price of agricultural products. The theoretical framework of CAPSiM is shown in Fig. 1. For a detailed explanation of the model, see the researche of Huang and Li (2003) and Huang *et al.* (2007). CAPSiM has been used widely to assess the impacts of trade policy, technological innovation, urbanization, and climate change on China's agricultural development (Huang *et al.* 2007; Yang *et al.* 2011; Huang *et al.* 2012).

There are two main reasons for us to select CAPSiM for this study. First, CAPSiM develops a comprehensive analytical framework to reflect the complicated interaction among factors including income, meat consumption, animal raising styles[1], production of livestock, and feed demand. Second, official statistics are believed to be questionable by many researchers (Cheng and Zhou 1997; Zhong 1997; Fuller *et al.* 2000; Jiang 2002; Yu and Alber 2014). Findings based on the official statistical data may lead to serious bias and misleading conclusions (Yu and Alber 2014). The database of CAPSiM is constructed using the balance-sheet approach and many survey data on agricultural production and consumption by CCAP, CAS. Moreover, continuous efforts have been devoted to building up the long-term serial balance sheets of the major agricultural commodities from 1980 to 2012; this ensures the consistency and reliability of the database.

There are thirteen crops covered by the CAPSiM production model, including rice, wheat, corn, sweet potato, potato, other coarse grains, soybean, cotton, oil crops, sugar crops, vegetable, fruit, and other crops. Meanwhile, the production model also covers nine categories of livestock products and fishery products, namely pork, beef, mutton, poultry, egg, milk, fish, shrimp, and other fishery products. In the consumption model, there are 23 categories of products, namely rice, wheat, corn, sweet potato, potato, other coarse grains, soybean, edible oil, sugar, vegetable, fruit, squash, pork, beef, mutton, poultry, egg, milk, fish, shrimp, other fishery products, other foods, and all the non-foods. In this study, we select data from 2010 as the benchmark, and the forecast period is the following two decades (i.e., 2011–2030).

To meet the objective of this analysis, a series of assumptions is made according to the findings of various previous studies. These assumptions cover economic growth, population growth, urbanization, wage growth, rural/urban income, and technological improvements, etc. The values under different assumptions are mainly estimated according to the results from Huang *et al.* (2010, 2014) and Han (2014), as well as various forecasting data from the World

[1] The feed-meat ratios by animals and feeding styles in 2010 are shown in Appendix A.

Bank, the International Monetary Foundation (IMF) and the United Nations (UN). The detailed assumptions on each key variable are as follows:

• Growth rate of GDP: It is supposed that China's economic growth will slow down in the future but still maintain growth at a fast speed. The annual average growth rate is assumed at 7.5% in 2011–2015, 7.0% in 2016–2020, 5.9% in 2021–2025, and 5.0% in 2026–2030.

• Population growth rate: The growth rate of China's population tends to descend. The estimated annual average growth rate is 0.6% in 2011–2015, 0.44% in 2016–2020, 0.22% in 2021–2025, and 0.06% in 2026–2030.

• Rural/urban income gap: It is expected that the income gap between rural and urban residents will narrow gradually. During the period of 2011–2030, rural income will keep an average annual growth of 8.33% and urban income will grow relatively slower at an average annual rate of 6.83%.

• Urbanization rate (defined as ratio of urban residents to total population): The urbanization rate in China will continue to ascend. It is supposed that the urbanization rate will rise from 49.8% in 2010 to 60% in 2020 and 67% in 2030.

• Changes in rural labor wage and land rent: The average annual growth of the actual wage of rural labor from 2011 to 2030 is estimated at 6.1% and that of land rent at 2.5%[2].

• Progress in agricultural technology: It is assumed that the Chinese government will continue to increase investment in agricultural technology and infrastructure. However, rising marginal costs in production mean lower contribution rates of technological innovations. The future contribution rates of technological progress to the average annual growth of one unit production of different agricultural products are listed in Appendix B.

4. Analysis of supply and demand in livestock products and feed

4.1 Change of supply and demand in livestock

With rising incomes and fast urbanization, the consumption of livestock products will maintain a high growth rate over the next two decades, even though the growth rate decreases gradually and varies remarkably across commodities. As shown in Table 2, commodity-wise growth rates will slow down generally in the future. For example, the increase of per capita consumption of beef, mutton, and dairy products will decrease from 50.0, 45.5, and 64.1%, respectively in 2011–2020 to 25.0, 21.9, and 26.5% in 2021–2030. While Chinese meat consumption in average is dominated by the pork and poultry, the much faster growth rate of the per capita consumption of beef, mutton, and dairy products indicates that the meat consumption structure will also experience a remarkable change. The per capita consumption of pork, poultry, and eggs will rise by 19.3, 35.8, and 26.4%, respectively in 2011–2020, much less than that of beef, mutton, and dairy products. The heterogeneous growth of per capita consumption of livestock products will continue and become more explicit over 2021–2030. For example, the increase of per capita consumption of pork, beef, and eggs will drop notably to 7.4, 12.2, and 3.8% in 2021–2030.

Responding to rising consumption, livestock production in China grows very quickly. The increases of production across commodities are consistent with changes in their consumption. For example, the production of beef, mutton, and dairy will rise significantly by 48.6, 43.3, and 62.0%, respectively, in 2011–2020, experiencing the fastest growth among livestock products. However, it is noteworthy that despite this fast growth, the increase in production still falls behind the growth in consumption. As a result, the gap between demand and supply of these commodities expands and the self-sufficiency rate decreases to a certain extent. Table 2 shows that the self-sufficiency rates of beef, mutton, and dairy products drop from 100, 99, and 89%, respectively in 2010 to 98, 93, and 84% in 2020. Such trends will continue through the period 2021–2030. The production of these three commodities will still experience the fastest growth and rise by 22.3, 14.3, and 18.7%, respectively in 2021–2030. However, the gap between demand and supply will be further enlarged. Their self-sufficiency rates will drop notably to 96, 88, and 78%, respectively, in 2030.

While the production of pork, poultry, and eggs is projected to grow much slower than that of beef, mutton, and milk, the self-sufficiency rates will maintain at high levels or even improve in the future. As shown in Table 2, the production of pork, poultry, and eggs will rise by 23.1, 42.4, and 30.9%, respectively, in 2011–2020 and 8.6, 14.3, and 5.0% in 2021–2030. As their production grows at rates either similar to or even faster than the demand, China will maintain the balance of demand and supply of these three products, and may even be a net exporter of poultry and eggs. For example, the self-sufficiency rates of pork, poultry, and eggs will be 99, 101, and 100% till 2030, respectively.

Similarly, the consumption of fishery products will also increase significantly over the next two decades. Table 2 also shows that the consumption of fishery products will increase from 18.9 kg per capita in 2010, to 28.3 kg per capita in 2020 and further to 33.5 kg per capita in 2030. Its growth rate of

[2] Urbanization and industrialization will lead to more labor and land shifting away from agricultural sector. One of the direct effects of the economic transition is to induce the price of those primary inputs rising. Therefore, it is assumed the wage of labor and land rent increasing in the future as response to the rising scarcity of these resources. Please refer to Huang *et al*. (2014) for the details.

Table 2 China's supply and demand of livestock products and main feed crops in 2010, 2020 and 2030 (thousand tons)[1)]

	Livestock products							Main feed crops	
	Pork	Beef	Mutton	Poultry	Eggs	Dairy products	Fishery	Soybean	Maize
2010									
Output	43877	4742	3097	15374	17658	34006	27781	15083	177245
Import	201	24	57	542	0	4408	2308	61450	1570
Export	110	22	13	435	78	73	2486	509	130
Net import	91	2	43	107	–78	4335	–177	60941	1440
Total demand	43968	4744	3140	15481	17580	38341	27604	66114	197430
Food consumption	42327	4330	2907	14588	16778	37593	25232	63887	17991
Per capita demand (kg person^{-1})	31.6	3.2	2.2	10.9	12.5	28.1	18.9	47.8	13.5
Self-sufficient (%)	100	100	99	99	100	89	101	20	99
2020									
Output	54947	7048	4436	21889	23120	55076	42960	14816	223050
Import	667	126	350	62	0	10593	2770	76428	18992
Export	71	5	0	197	49	57	3528	340	143
Net import	597	121	350	–135	-49	10536	–758	76089	18849
Total demand	55544	7170	4786	21754	23071	65612	42202	90905	241899
Food consumption	52975	6756	4553	20861	22269	64864	39830	88541	11517
Per capita demand (kg person^{-1})	37.7	4.8	3.2	14.8	15.8	46.1	28.3	63.0	8.2
Self-sufficient (%)	99	98	93	101	100	84	102	16	92
2030									
Output	59603	8617	5069	24611	24282	65362	49976	14722	241572
Import	782	344	667	76	0	18492	3246	84577	39847
Export	60	2	0	159	41	30	3021	307	100
Net import	722	342	667	–83	–41	18462	224	84270	39748
Total demand	60325	8959	5736	24529	24241	83824	50201	98992	281319
Food consumption	57757	8545	5503	23636	23440	83076	47829	96472	7620
Per capita demand (kg person^{-1})	40.5	6.0	3.9	16.6	16.4	58.3	33.5	67.6	5.3
Self-sufficient (%)	99	96	88	100	100	78	100	15	86

[1)] Source: CAPSiM simulation results.

54.6% in 2011–2020, and 16.3% in 2021–2030, is ranked as the second highest, following dairy products.

Unlike dariy products, however, the demand for fishery products is characterized as mainly depending on domestic supply. The production of fishery products will grow from 27 800 thousand tons in 2010 to 42 960 thousand tons in 2020 and then to 49 970 thousand tons in 2030. The other distinguishing characteristics of fishery products is that both imports and exports will increase quickly and in large volumes. Table 2 indicates that the import of fishery products will increase from 2 310 thousand tons in 2010 to 2 770 thousand tons in 2020 and 3 250 thousand tons in 2030. Meanwhile, its exports will increase from 2 490 thousand tons in 2010 to 3 530 thousand tons in 2020 but decrease slightly to 3 020 thousand tons in 2030. Decomposing the imported fishery products in detail, we found that a large proportion of China's aquatic imports is fishmeal, which is mainly used for high-protein feed. That the export value is larger than that of imports explicitly indicates that China will maintain its status as a net exporter of fishery products in term of value in the future.

4.2 Change in China's feed demand in the future

There is no doubt that driven by rising animal production, China's feed demand will keep growing over the coming decades. Table 3 presents the total demand for commercial feed will increase by 30.0% from 202 600 thousand tons in 2010 to 259 300 thousand tons in 2020 and further by 7.9% to 279 700 thousand tons in 2030. The average annual growth of feed demand will decrease notably from 2.5% in 2011–2020 to 0.8% in 2021–2030. This slowdown could be explained as follows. First, the above analysis show that the growth rate of China's livestock production will drop over time. For example, as the largest sector of feed demand, the growth of pork production will drop from 19.3% in 2011–2020 to only 7.4% in 2021–2030. Second, the production structure of livestock will experience remarkable changes, shifting from pork and poultry towards beef, mutton, dairy, and fishery products. The feed required by ruminant animals (e.g., cattle, sheep, and goats) is much less than that for swine and poultry (Rae and Hertel 2000; Zhou *et al.* 2008). Consequently, the change in structure

will further dampen the demand for commercial feed.

The two dominant components of commercial feed, maize and soybean meal play an increasingly important role in China's feed supply. The commercial feed can be classified into two categories: energy feed (various grains) and protein feed (bean pulp). As shown in Table 3, maize and soybean meal take the overwhelming share of energy feed and protein feed, respectively. Moreover, their shares keep rising in the future. For example, the share of soybean meal in protein feed will increase from 70.6% in 2010 to 88.8% in 2020 and further to 89.2% in 2030. Meanwhile, the share of maize in energy feed will rise from 83.0% in 2010 to 84.9% in 2020 and further to 90.4% in 2030. In sum, the total share of maize and soybean meal in China's feed consumption increases sharply from 79.3% in 2010 to 86.1% in 2020 and further to 90.0% in 2030.

The rising feed demand on maize and soybean meal has major implications for the production and supply of maize and soybeans. Table 3 also indicates that the maize used for feed will increase from 118 100 thousand tons in 2010 to 153 400 thousand tons in 2020 and further to 173 800 thousand tons in 2030. Such a rapid growth in feed demand will definitely generate great opportunities for maize production. As shown in Table 2, maize production will grow the fastest among all grains, from 177 200 thousand tons in 2010 to 223 000 thousand tons in 2020 and 241 800 thousand tons in 2030 (column 8 of Table 2). However, this rising maize supply is still far behind the increase in demand and the gap between demand and supply will gradually grow larger. China's imports of maize will increase dramatically from 1 600 thousand tons in 2010 to 19 000 thousand tons in 2020 and 39 800 thousand tons in 2030. Correspondingly, the self-sufficiency level will drop from 99% in 2010 to 92% in 2020 and 86% in 2030. Grain security is always among the top priorities in China. However, our result depicts that the grain security confronted by China in the future is more accurately defined as feed security. As the grain (soybean is not included) used for feed grows much faster than that for food, the share of grain used for feed to total grain demand will keep rising from 31.6% in 2010, to 35.0% in 2020 and further to 41.8% in 2030 (last row of Table 3).

The soybean market is the most representative to show the vital role of imports in ensuring China's feed supply. The demand for protein feed rises dramatically and grows much faster than other feed types. Its share in total feed demand increases steadily from 29.8% in 2010 to 30.4% in 2020 and further to 31.3% in 2030 (row 6 of Table 3). The demand for the dominant component of protein feed-soybean meal will grow significantly from 42 600 thousand tons in 2010 to 69 900 thousand tons in 2020 and 78 100 thousand tons in 2030 (row 3 of Table 3), which will generate heavy pressure on soybean supply. Nowadays, China's soybean supply depends heavily on global markets to meet its huge demand. However, this situation will become more pronounced. China's soybean imports (including equivalents converted from imported soybean oil) will increase from 61 500 thousand tons in 2010 to 76 400 thousand tons in 2020 and 84 600 thousand tons in 2030. This huge volume of import will provide a great opportunity for soybean exporting countries (e.g., Brazil, Argentina, and USA) to increase their production. As imports are much larger than domestic production, China's soybean self-sufficiency level is quite low and decreases steadily from 20% in 2010 to 16% in 2020 and 15% in 2030 (Table 2).

5. Main conclusion and policy implications

China's per capita consumption of livestock products will continue to increase over 2011–2030, even though its growth will slow down gradually. Accompanying the rapid industrialization and urbanization of the past three decades, China's food consumption pattern is characterized as increasing demand for more high-value agricultural products. This process is far from over. While the growth of food consumption of high value-added foods will slow down, this evolution will be maintained and will continue for the next two decades. One of the distinguishing characteristics of the evolution is that the consumption of the products of ruminant animals (e.g., beef, mutton, and dairy products) increases much faster than other livestock products (e.g.,

Table 3 China's feed demand in 2010, 2020 and 2030 (thousand tons)[1)]

	2010	2020	2030
Total commercial feed	202 630	259 323	279 740
Protein feed[2)]	60 346	78 722	87 544
Soybean meal	42 580	69 906	78 104
Energy feed	142 326	180 600	192 197
Maize	118 100	153 412	173 800
Ratio of protein feed in feed demand (%)	29.8	30.4	31.3
Ratio of feed demand in total grain demand (%)[2)]	28.4	30.4	35.6

[1)] Source: authors' calculation based on CAPSiM simulation results.
[2)] The soybean is not included in grain for this calculation.

pork, poultry, and eggs). No doubt, the continuously rising production of livestock will pose great challenges on China's feed supply. Meanwhile, the fast growth of ruminant animals indicates that it is a good strategy to promote the production of forage grass oriented to alleviate the pressure of feed supply in China.

China confronts severe challenges of feed security rather than of grain security in the future. The demand for commercial feed is estimated to rise dramatically from 202 600 thousand tons in 2010 to 259 300 thousand tons in 2020 and 280 000 thousand tons in 2030. It means that feed demand will increase annually by about 6 000 thousand tons in 2011–2020, and 2 000 thousand tons in 2021–2030. While China's feed crop production (e.g., of maize and soybeans) will keep rising, the gap between demand and supply will be greater in the future. It is estimated that China's imports of maize and soybeans will reach 19 000 and 76 400 thousand tons, respectively in 2020, and 39 800 and 84 600 thousand tons in 2030. It is vital for China to better utilize global resources to ensure its feed supply, considering its limited agricultural resources and serious environmental constraints.

China should set up feasible policies to promote feed production and to ensure the availability of feed crops from global markets. China still owns great potential to increase the production of forage grass (Xu and Zhang 2004). Therefore, necessary support policies should be provided to enhance research and development in the efficient utilization of forage grass. Second, technological improvement is critical for China to increase production of key feed crops and secure its feed supply. Last but not the least, since WTO accession, China has become one of the world's most liberalized agricultural markets, and its agricultural imports have risen dramatically. China is currently the world's largest importer of soybeans, and this will also be the case for maize according to our predictions. Therefore, China should actively take part in the negotiation of global and regional policy portfolios of agricultural trade liberalization, aiming at securing the sustainable increase of global agricultural trade and reducing trade risks within the framework of a fair global market.

Acknowledgements

The authors would like to acknowledge the funding support from the National Natural Science Foundation of China (71373255), the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (2012RC102) and the National Maize Industrial Technical System, China (nycytx-02).

Appendix associated with this paper can be available on http://www.ChinaAgriSci.com/V2/En/appendix.htm

References

Chen G J. 2012. Changes in supply and demand of Chinese feed grain and its effects on future grain self-sufficiency. *Chinese Journal of Animal Science*, **48**, 23–26. (in Chinese)

Chen Y F, Yang L. 2013. *China's Grain Supply and Demand Forecasts. Report of the Conference "China's Food Security Strategy and Policy Research Towards High-Income Countries"*. Development Research Center of the State Council, China. (in Chinese)

Cheng G Q, Zhou Y H. 1997. Estimates of supply and demand of China feed. *Problems of Agricultural Economy*, **18**, 25–29. (in Chinese)

Cui X L. 2012. Substantial growth in Chinese imports of corn will not repeat the mistakes of soybeans fall. *China's Foreign Trade*, **4**, 64–65. (in Chinese)

Delgado C L. 2003. Rising consumption of meat and milk in developing countries has created a new food revolution. *The Journal of Nutrition*, **133**, 3907S–3910S.

Fuller F, Hayes D, Smith D. 2000. Reconciling Chinese meat production and consumption data. *Economic Development and Cultural Change*, **49**, 23–43.

Fuller F, Huang J, Ma H, Rozelle S. 2006. Got milk? The rapid rise of China's dairy sector and its future prospects. *Food Policy*, **31**, 201–215.

Fuller F, Tuan F, Wailes E. 2002. Rising demand for meat: Who will feed china's hogs? In: Gale F, Tuan F, Lohmar B, Hsu H H, Gilmour B, eds., *China's Food and Agricultural: Issues for the 21st Century*. pp. 17–19.

Gale F, Huang K S. 2007. *Demand for Food Quantity and Quality in China*. Ecomomic Research Service, United States Department of Agriculture.

Han J. 2014. *China: Food Security and Agricultural Going Out Strategy Research*. China Development Press, Beijing, China. (in Chinese)

Hartwell R M. 1961. The rising standard of living in England, 1800–1850. *The Economic History Review*, **13**, 397–416.

Huang J, Rozelle S. 1998. Market development and food demand in rural China. *China Economic Review*, **9**, 25–45.

Huang J K. 2004. Past and future of Chinese agriculture. *Management World*, **3**, 95–104. (in Chinese)

Huang J K, Yang J, Qiu H G. 2012. Thoughts on national food security strategies and policies in the new era. *Issues in Agricultural Economy*, **3**, 4–8. (in Chinese)

Jiang N H. 2002. Theories and methods of national and provincial meat products statistics adjustment. *Journal of Agrotechnical Economics*, **6**, 12–20. (in Chinese)

Jiang N H, Xin X, Yin J. 2002. Analysis on factors affecting Chinese urban and rural livestock consumption. *Chinese Rural Economy*, **12**, 48–54. (in Chinese)

Jin S, Huang J, Hu R, Rozelle S. 2002. The creation and spread of technology and total factor productivity in China's agriculture. *American Journal of Agricultural Economics*, **84**, 916–930.

Ma H Y, Hu Q L, Li W, Allen R, Guo S M, Tang H C, Ren X J. 2011. Hog production in China: Technological bias and

factor demand. *Agricultural Sciences in China*, **10**, 468–479.

Ma H Y, Huang J K, Rozelle S. 2004. Reassessing China's livestock statistics: An analysis of discrepancies and the creation of new data series. *Economic Development and Cultural Change*, **52**, 445–473.

Pingali P L. 2001. Environmental consequences of agricultural commercialization in Asia. *Environment and Development Economics*, **6**, 483–502.

Rae A N, Hertel T W. 2000. Future developments in global livestock and grains markets: The impacts of livestock productivity convergence in Asia-Pacific. *Australian Journal of Agricultural and Resource Economics*, **44**, 393-422.

Wang X B, Huang J K, Zhang L X, Rozelle S. 2011. The rise of migration and the fall of self employment in rural China's labor market. *China Economic Review*, **22**, 573–584.

Xu X, Zhang W Q. 2004. Consideration on mechanization condition of forage grass production and its development opportunities in China. *Chinese Agriculture Mechanization*, **3**, 14-16. (in Chinese)

Yang J, Cheng S, Yang B Q, Wang X B. 2013. Changing of food consumption structure in Japan and Korea and their implication for China's future food demand. *China Soft Science*, **265**, 24-31. (in Chinese)

Yang J, Huang J K, Li N H, Rozelle S, Martin W. 2011. The impact of the Doha trade proposals on farmers' incomes in China. *Journal of Policy Modeling*, **33**, 439-452.

Yen S T, Fang C, Su S J. 2004. Household food demand in urban China: A censored system approach. *Journal of Comparative Economics*, **32**, 564–585.

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

Yu X, Sun M. 2012. A study of the impact of the aging of population in China on consumption. *Jilin University Journal* (Social Sciences Edition), **52**, 141–160. (in Chinese)

Zhao Q G, Zhou S L, Wu S H, Ren K. 2006. Cultivated land resources and strategies for its sustainable utilization and pritection in China. *Acta Pedologica Sinica*, **43**, 662–672. (in Chinese)

Zhong F N. 1997. Bias on meat production statistical data and their causes. *Chinese Rural Economy*, **10**, 63–66. (in Chinese)

Zhong F N, Xiang J. 2012. Impacts of demographic dynamics and professional structure on food demand. *Issues in Agricultural Economy*, **9**, 12–16. (in Chinese)

Zhou Z Y, Tian W M, Malcolm B. 2008. Supply and demand estimates for feed grains in China. *Agricultural Economics*, **39**, 111–122.

(Managing editor WENG Ling-yun)