ESTIMATING THE NON-COMMERCIAL-COMMERCIAL FEED GAP IN CHINA AND ITS IMPACT ON FUTURE WORLD DEMAND FOR SOYBEANS

BY

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THESIS

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ABSTRACT

Two effects simultaneously shape the future soybean meal (SBM) demand in China: the income effect on meat consumption and the transition effect on feed usage in animal production. The income effect has been studied intensively by previous researchers, and more animal products are believed to be consumed. The transition effect, however, has yet received enough attention. This study shows that transition effect is more important in determining China's future derived demand for SBM than income effect. Future soybean demand in China is predicted based on both effects till 2030.

To my beloved wife and parents

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CHAPTER ONE: INTRODUCTION

World annual consumption of meat, eggs, and aquatic products increased from 115 million metric tons (MMT) in 1961-1963 to 391 MMT in 2001-2003 with a compound annual growth rate of 3.1% (Figure 1). This increase in meat, egg, and fish consumption mainly came from China and other developing countries. China consumed 124 MMT of meat, eggs, and fish annually over the 2001-2003 period, or 31.6% the world total. Europe and the US consumed 19.4% and11.8%, respectively. China's per capita consumption of meat, eggs, milk, and aquatic products increased from 11 kg per year in 1961-1963 to more than 120 kg per year over the 2005-2007 period due to fast income growth and urbanization. China's per capita income grew from $76 (constant USD in 2000) to $1625, and the urban population share grew from 16% to 41% from the 1961-1963 period to the 2005-2007 period.

The growth in China's livestock industry has so far prevented domestic supply-demand imbalances despite of the significant growth of its meat consumption. Only 1.1% of China's total meat demand was annually imported during the 2005-2007 period. China's overall animal production keeps expanding at a fast rate although different meat, egg, and aquatic products compete as substitutes on the dinner table. China's annual meat, egg, and aquaculture production increased from 6 MMT to 134 MMT at a compound annual growth rate of 7.5% from the 1961-1963 period to the 2005-2007 period. Shares of pork and eggs in total animal production dropped to 34.3% and 18.6%, while those of poultry and aquaculture increased to 10.8% and 29.3%, respectively in 2005-2007 (Figure 2). China is the largest pork, egg, and aquatic producer and the second largest poultry producer in the world.

Indirect demand for feed-grains increases rapidly as animal protein replaces food-grain in people's diet. Consuming meat is a much less efficient way of utilizing grain energy than consuming grains directly. Soybean meal (SBM) is the most widely used feed protein source. It has long been considered the best protein supplement in swine and poultry diet due to its high protein content (44% - 48%) and almost ideal amino acid composition (Cromwell, 1999). SBM on average accounts for about 20% of the animal feed ration. Producing 95 MMT of meat & eggs, 20 MMT of aquatic products, and 36 MMT of milk annually in 2005-2007 requires about 80 MMT of SBM, assuming four pounds of feed-grains are required to produce one pound of meat product (Hayes, 1999). However, only 28 MMT of SBM were actually fed. China would require another 52 MMT of SBM or 64 MMT of soybeans either from expanding domestic soybean production, importing raw beans, or SBM.

Two factors simultaneously influence China's derived SBM demand. The first one is implied from the income effect. High income elasticity of demand for animal protein plus rising incomes increase Chinese households' demand for meat, eggs, seafood, and milk. The second effect, which has not been given enough attention by previous research, comes from the diffusion of modern commercial feeding technologies (Figure 3). As large-scale animal production entities replace small rural household production, SBM usage could increase by 4-6-fold (Somwaru, 2003). The accelerating effect of the transition to commercial feeding rations that include SBM needs to be taken into account when forecasting future demand for soybeans and land area dedicated to soybean farming (Figure 4). Soybeans compete with other feed & food crops for limited land and water resources. Understanding the structure, timing, and the magnitude of future derived soybean demand in China benefits both policy makers and private investors as they analyze the dynamics of the global agri-food system.

The goal of the thesis is to address the gap in the literature by considering the diffusion path of commercial feeding technology when forecasting China's future soybean demand. I empirically address the following five objectives to meet the research goal:

- Objective 1: estimate income elasticity of demands for meat quantity and quality;
- Objective 2: estimate the current commercial feeding gap;
- Objective 3: analyze the reasons for low SBM feeding ratios;
- Objective 4: predict future SBM feeding ratios;
- Objective 5: forecast future soybean demand in China.

The rest of the thesis is organized as follows: Chapter II, Literature Review, which outlines the literature on income elasticity estimation of meat, China's current animal production situation, forecasts of future feed-grain / SBM demand, and the agricultural technology diffusion process. Chapter III, Methods, illustrates different methodologies used by this study to address the five objectives. Chapter IV, Data Construction, outlines the data used in this study and how the data set is constructed; Chapter V, Results and Discussion, provides the results of the study, and presents predictions on future derived SBM demand in China. Chapter VI, Summary and Conclusion, summarizes the study and concludes with future research directions.

CHAPTER TWO: LITERATURE REVIEW

Estimating Income Elasticity

Various attempts have been made to uncover the true income elasticity of demand for various food items in China. Estimation results differ due to different models, different data periods, and different levels of geographical coverage (Table 1).

Meat consumption increases as household income grows, while coarse-grain consumption drops. Halbrendt, Tuan, Gempesaw, and Dolk-Etz (1994) are pioneers studying food demand in rural China using the Almost Ideal Demand System (AIDS). Their research discovered that meat, poultry and other food items other than grains had expenditure elasticities of over one in rural Guangdong Province using 1990 household survey data. Guangdong Province is one of the most developed provinces in China. Large income elasticities reflect the fact that rural households' demand for meat & poultry was highly sensitive to their income growth in the remainder of China in the 1990s (Jiang & Davis, 2006). Fan, Wailes, and Cramer (1995) applied a two-stage LES (Linear Expenditure System)-AIDS model to provincial aggregate 1982-1990 time series data in rural China. They reached a similar conclusion of a near unity unconditional expenditure elasticity for meat but a much lower estimate for coarse-grains. They predicted that as indirect feed-grain consumption further replaced food-grain consumption, China would need to import large amount of feed-grains due to limited arable land available.

Urban and rural China need to be treated separately when one analyzes the food consumption pattern in China (Zhou et al., 2008). Huang and Bouis (1996) found that urbanization could increase meat product consumption and decrease grain consumption by 20%, holding income and price constant. They reported different income elasticities for large cities, small cities, and rural areas. Income distribution is extremely unequal between urban and rural

China. Average urban and rural per capita income was 13786 *yuan* ($552) and 4140 *yuan* ($1838), respectively in 2007. Average urban and rural per capita consumption of meat, eggs, aquatic product, and milk at home was 74 kg and 34 kg, respectively in 2007. Disparate household income levels, food marketing systems and people' life styles cause significant differences in meat consumption patterns between urban and rural China (Huang & Bouis, 1996).

Different demographic factors affect food consumption patterns in China, too. Liu and Chern (2003) suggested that China should be treated as separated markets based on different demographic factors. The same argument was made by Ma, Rae, Huang, and Rozelle (2004). They introduced regional dummy variables in their AIDS model and found biased expenditure and price parameters when omitting them. Firstly, households' income disparity among east, central, and west China is significant. Per capita disposable income in the east was 51% higher than the rest of China in 2007. Secondly, animal production characteristics are different among regions. Central & west China tend to consume more cattle meat and eastern & southern coastal regions consume more aquatic products due to their relative abundance of the corresponding animal products (Ma et al., 2004).

Income elasticity estimates are biased if food-away-from-home (FAFH) quantities are ignored (Ma et al, 2004). Ma, Huang, Fuller, and Rozelle (2006) looked at Chinese urban households' FAFH consumption behavior using a multivariate Tobit model. Their derived FAFH total expenditure elasticities for grains and meats were 0.4430 and 0.9788, respectively. Meat demand from FAFH is highly income elastic. They proposed a revised food consumption series adjusted for FAFH. The new series closed up the gap between official supply-demand series (Ma et al., 2004b). Min, Fang, and Li (2004) found that income elasticity of FAFH was not only large, but also increasing from time to time by applying a nonparametric model to 1992-1998 household survey data. Gould and Villarreal (2004) applied a fractional Logit analysis to analyze the relative allocation of FAFH and Food-At-Home (FAH). They found that wealthier households tend to consume more FAFH.

Pork, poultry, eggs, beef & mutton, seafood, and milk each displays distinct income responsiveness in Chinese households' diet choices. Shono, Suzuki, and Kaiser (2000) applied the Principal Component Analysis to show that Chinese people's diet pattern would follow Asian developed countries or districts, such as Japan, Republic of Korea, Hong Kong, and Taiwan where aquatic products are preferred over regular meats. Yen and Lin (2006) extended the multivariate sample selection model to a nonlinear equation system with partial selection, and applied to household meat consumption in urban China in 2000. They found that the total expenditure elasticities for poultry & fish were above unity, and beef & pork were below. They argued that their results were robust by finding similar output when excluding alternative equation from the system. Similar results were obtained by Gale & Huang (2007). Income elasticities for poultry, seafood, and milk are generally higher than those for pork and eggs. Marginal expenditure shares of poultry, seafood, and milk increase with income and urbanization, while those of pork and eggs decline (Ma et al., 2004).

Marginal income elasticity changes as income level increases. Guo, Mroz, Popkin, and Zhai (2000) found that income elasticities for pork and fat were actually increasing through 1989 – 1993. They argued that in transitional economies like China, people's preferences & tastes change during the course of modernization. Researchers using static income elasticity will easily fail to accurately predict future consumption over time. Gale and Huang (2007) applied a log-log-inverse (LLI) Engle demand equation to estimate income elasticity using 2002-2003 aggregate household survey data. They allow income elasticity to change across different households' income levels for both rural and urban China. Their estimates were smaller than most of other studies due to not incorporating FAFH since higher income households tend to consume more FAFH. The relationship between income and meat consumption is not static for different household income levels. The relationship can be divided into three stages. The income elasticity of demand for meat will hardly increase in the first stage, then they rise steeply and finally they decline (Keyzer & Merbis, 2002).

Demand for food quality and safety is another important dimension of explaining Chinese households' future demand pattern for animal products. As household income grows, demand for food quantity slows down and demand for quality emerges (Gale & Huang, 2007). Yu and Abler (2009) proposed a theoretical framework of assessing the income and price elasticity of demand for food quality. By applying a hedonic model to a panel data of 10 (years) by 26 (provinces) in rural China, they reported income elasticities for food quality were: grain-0.31; seafood-0.17; dairy products-0.18; fats and oil-0.19; vegetables-0.35. They argued that income elasticities derived for rural China without correcting for quality would be overestimated by more than 30% for grain, but less for other food items.

To sum up, income elasticity estimates from previous studies vary under different estimating models and dissimilar time & geographical coverage. Recovering the true income elasticity to predict future food demand is not an easy task. Urbanization, FAFH, demand for food quality, and changes in preferences & tastes further complicate the empirical estimation process (Huang & Bouis, 1996; Guo et al., 2000; Ma et al., 2004; Dong & Fuller, 2007; Gale & Huang, 2007; Yu & Abler, 2009). However, appropriate estimates are crucial to predict future food consumption. Simple averages of previous estimations are selected as benchmarks due to widely spread estimates. The averages are believed to better represent the truth since they do not tend to be severely biased towards one source of the problems.

Pork elasticity estimates range from 0.24 to 1.07 for rural households with an average of 0.78, and from 0.13 to 1.20 for urban households with average of 0.71. Poultry elasticity estimates range from 0.66 to 1.69 for rural households with an average of 1.20, and from 0.38 to 1.95 for urban households with an average of 1.18. Beef & mutton elasticity estimates range from 0.39 to 1.12 for rural households with an average of 0.76, and from 0.19 to 1.68 for urban households with an average of 0.86. Egg elasticity estimates range from 0.46 to 1.93 for rural households with an average of 1.00, and from 0.10 to 1.25 for urban households with an average of 0.58. Aquatic product elasticity estimates range from 0.50 to 1.39 for rural households with an average of 0.99, and from 0.52 to 1.80 for urban households with an average of 1.00. Milk product elasticity estimates range from 0.70 to 2.06 for rural households with an average of 1.38, and from 0.64 to 2.20 for urban households with an average of 1.30.

Animal Production Practices in China

In order to get a better idea for the future feed-grain demand, especially SBM demand, understanding the animal production systems in China is crucial (Tina & Chudleigh, 1999). Before discussing China’s animal production system, the situation of SBM feeding is sketched. The world fed 121 MMT of SBM or 10% of total feed ingredients on 2001-2003 annual average. Other major ingredients include corn (33%), starchy roots (12%), bran (11%), wheat (8%), barley (7%), sorghum (2%), oats (2%), and rapeseed meal (2%). Rapeseed meal and other oilseed meals cannot be considered as perfect substitutes for SBM due to their inferior quality (Fenwick, 1982). Fishmeal cannot be viewed as perfect substitutes for SBM due to the higher price and less availability. The growth of demand for SBM keeps strong while other major feedstuffs remain moderate from 1961 to 2003 (Figure 5).

China started to import soybeans after 1999. The US, Brazil, and Argentina exported 32.7 MMT of soybeans or 15% of world's total production to fill up China's giant soybean deficiency in 2007 (Figure 6). Those soybeans are crushed domestically into SBM for animal feed and vegetable oil for human consumption. Various kinds of inferior feed ingredients are fed in China (Figure 7). Starchy roots, i.e. potatoes & sweet potatoes, and wheat and rice bran are the major starches used, which are not popular in a modern corn-SBM-based feeding practice. Small producers also feed significant amount of table scraps and food wastes to their animals (Gale, 2008). The modern feeding technology, on the other hand, suggests intense feed-grain usage to maintain short production cycle and high quality products. For example, China fed 18.7 MMT of SBM to produce 87.6 MMT of meat & eggs in 2001-2003. The US, Thailand, Korea (Republic of), and Malaysia fed 29.0 MMT, 2.6 MMT, 2.4 MMT, and 1.0 MMT of SBM to produce 43.6 MMT, 3.1 MMT, 2.2 MMT, and 1.4 MMT of meat & eggs, respectively in the same time period. The ratios of SBM fed and meat & egg production for China, the US, Thailand, Korea (Republic of), and Malaysia are 0.21, 0.67, 0.83, 1.1, and 0.67, respectively (Table 2). China requires at least 3 times more SBM in the future to match other more developed countries' SBM feeding level. Different animal production systems in China are illustrated below to help understand the non-commercial-commercial feed utilization.

According to Somwaru, Zhao, and Tuan (2003), hog production is traditionally the most important part of animal husbandry in China and it has the most diversified characteristics. There are primarily three types of hog producing operations in China: backyard hog farms, specialized hog-producing households, and commercialized hog-producing enterprises. Backyard farms are those rural households who keep about 2-3 pigs per year in their backyards. These households usually produce other farm products on site as well, such as chicken, eggs, and crops. Raising pigs is an important and traditional way of generating extra income. Majority of the pork produced by backyard farms are consumed by the producers themselves, and only small portion of them flow into the markets nearby. These hogs are fed with traditional or informal feed, such as vegetables, table scraps, raw grains and starchy roots. Pork quality varies farm by farm.

Specialized hog-producing households are those farms that involve family members and focus solely on hog production throughout the year. They feed 30 hogs annually on average, but the range is very broad from less than 10 to more than seven hundred. They are usually found near feed-grain producing areas, i.e. northeast, north and east-central China. Their feeding practice varies, but generally they choose more commercial feed mix in their ration. Large commercialized hog production enterprises consist of old state-owned farms and modern hog-raising companies. The breeding & feeding technology and management skills are similar to those seen in the developed countries, and these farms are often located near large pork consuming areas. They feed 100% commercial feed mix (Somwaru et al., 2003; Fabiosa et al., 2005).

Around 95% of hog production was from farmers' backyard in 1985. The ratio dropped to 81% in 1996 (Zhang et al., 1998). About 40% of hogs were raised in farmers' backyards, 52% were from specialized households, and the rest 8% were from large commercial enterprises in 2006 (Figure 8). The backyard production is being crowded out, and specialized & commercial production is gaining more market share at a compound rate of 8% annually. Poultry production is more integrated than hog. 36% of poultry were produced from household farms with less than 100 chicks & ducks in 2006. Large animals are distributed even more scattered than hogs. Only

13% and 4% of the dairy cows and beef cattle were kept in commercial farms in 2006. Rural residents tend to raise only one cow per household for its milk and labor.

Fang and Fuller (1998) showed that as hog production of scale increases, producers would reply more on market for feed inputs. Therefore, China would demand more formal feedstuff directly from market instead of from households' own crop residuals and wastes. According to Somwaru, Zhang, and Tuan (2003), specialized hog farms and large-scale commercial firms were argued to be most profitable and most efficient among the three production systems. According to Fang and Fabiosa (2003), the hog production in the US Midwest has a lower feed cost and higher labor productivity than in China. However, this US Midwest advantage is more than offset by the cost advantage in labor, feeder pigs, and capital replacement of China. Therefore, China's hog production industry is generally competitive in the world pork market. The question then relies on how fast large feeder operations replace backyard producing farms in China.

Rae, Ma, Huang, and Rozelle (2005) called for best production techniques and diffusion of existing technology as high priority for the Chinese livestock management team by decomposing the total factor productivity (TFP) for pork and milk producing sector. They argued that TFP would be higher if China revives its rural extension system. Fabiosa, Hu, and Fang (2005) argued in their case study that commercialized hog producers in China have overall similar production costs as the US producers. The labor-insensitive nature of processing and distributing meat products may allow China to remain competitive duo to its cheap labor. They also stated that rising cost of adopting new technologies, rising wages, and increasing demand for food quality and safety by supermarkets and end-consumers will keep driving the pork producing industry towards more commercialized.

All in all, the transition pace of livestock & poultry production from the backyards of rural households to specialized & commercial operations greatly affects China's future demand pattern of feed-grains. Specialized & commercial operations purchase more feed-grains or commercial feed mix in their feed ration choices (Somwaru et al., 2003; Fabiosa et al., 2005). This transition of animal production system further boosts China's derived demand for SBM in addition to the income effect on meat demand alone. It should not be neglected when determining both the timing and magnitude of China's future SBM demand.

Feed-Grain Demand Estimations

China's feed-grain demand receives more attention by researchers since the late 1980s. However, projections using different methods showed widely distributed results. Hard-to-find credible data resource, fragmented market information, and distinct animal production systems across regions further complicate the research (Zhou et al., 2008). But correctly forecasting the future China's feed-grain demand would provide valuable insight to future world agricultural trade flow and global utilization of limited nonrenewable resources. This undiscovered information would greatly benefit both of private investors and governmental policy makers.

According to Zhou, Tian, and Malcolm (2008), there are two ways to estimate future feed demand. One way to predict feed-grain consumption is to multiply the demand estimations for meat, eggs, milk, and aquatic products by the corresponding feed conversion ratios (FCR's), which is also called the implied demand approach. Unfortunately, even if estimations for income elasticity of meat demand are flawless and reflect the true response of meat demand from income growth, correct feed-grain estimations are not guaranteed. First of all, the FCR's are not constant across time and locations. It tends to get smaller as animal genetics and feeding technology improves and different regions have widely-different FCR's due to different animal feeding practices and feed ingredients. Secondly, the actual feed demand quantity might be significantly lagged behind the theoretical amount because the usage of unusual feed ingredients i.e. starchy roots and bran, etc., is very popular in developing countries like China (Gale, 2008).

The other way to estimate feed-grain consumption is to use the so-called residual supply approach, or balance-sheet approach. It deducts the human consumption, industry usage, storage, seeds, and other usage quantities from the total grain supply amount to impute the grains available to livestock. Nonetheless, this approach has an unavoidable theoretical limitation: it cannot be used to forecast feed-grain demand in subsequent years because total grain supply is hard to predict without knowing the feed-grain demand in the first place. In order to forecast future feed-grain or SBM demand, the implied demand approach is appropriate. Major uncertainties of applying the implied demand approach come from inaccurate income elasticity, lack of knowledge about animal feeding practices, and unknown feed conversion ratios. Huang & Rozelle (1998), Findlay (1998), Zhu (2000), and Guo et al. (2001) all tried to forecast China's feed-grain demand in 2010. However, the projections vary from as low as 158 million metric tons to as high as 346 million metric tons. Although variations in quantitative forecasting should not be surprising, more effort and attention should be devoted by researchers in order to narrow down the interval.

The latest published attempt to forecast SBM demand in China is made by Sun, Knerr, and Kuhn (2009). They built a supply-demand system on protein feed (SBM) and argued that 10% increase in pork, poultry & egg output raises SBM consumption by 8.7%. They forecast that China will import 28.68 MMT of soybeans to meet the protein feed shortage in 2010. However, USDA-FAS estimated that 40 MMT of soybeans was imported by China in 2008/09 marketing year. Their forecast for 2010 underestimates the actual SBM import quantity by at least 30%.

Another attempt of making projection on China's SBM demand is made by Masuda and Goldsmith (2009). They propose a long-term elasticity of 1.3 between meat & egg production and SBM consumption using a co-integrating equation between the two with an error-correction mechanism from 1961 to 2003. They predict that 27.1 MMT of SBM will be needed in 2010 and 29.7 MMT in 2020. However, USDA-FAS estimated that 34 MMT of SBM were consumed in China in 2008/09 marketing year. China is expected to increase its SBM consumption in 2010 than 2008/09. Therefore, Masuda and Goldsmith's forecasts underestimate the reality by at least 20% for 2010.

It seems that studies are prone to underestimate China's future SBM demand. One of the main reasons is that they did not incorporate the feeding technology diffusion process from informal feed to commercial feed (SBM) by China's livestock & poultry producers. In fact, the commercial feed diffusion process significantly accelerates China's rising demand for SBM. The equilibrium relationship between animal production and SBM consumption changes through time. SBM feeding level in China gradually approaches to those found in other economies with more developed animal production systems. This transition effect may outpace the income effect and become a dominant role in determining future SBM demand in China.

SBM Feed Diffusion Process

SBM utilization level can be viewed as a proxy of feeding practice improvement from small to large-scale operations (Tuan et al., 2004). Commercial feed comprises about 20% SBM as primary source of crude protein. Regarding the increase of SBM feeding level as a technology diffusion process could possibly improve our understanding of the transition pace from informal feed to commercial feed, and help adjust future SBM and feed-grain demand projections. Suggested by Rogers (1962), the technology diffusion rates are most likely an S-Shaped function of time. The use of S-Shaped diffusion curves has been applied to depict the diffusion patterns of different new products and technologies.

However, researchers have argued that by fitting simple theoretical diffusion curves to the actual diffusion patterns, the true adoption behavior would not be discovered (Sunding & Zilberman, 2001). The threshold model was introduced by David (1969) to explain adoption of grain harvesting machineries in the US. He established a diffusion model that had a threshold effect on minimum farm size of purchasing combines. Later other economists applied the threshold model to other heterogeneities, i.e. land quality and human capital, among farmers' technology adoption behavior (Caswell & Zilberman, 1986; Akerlof, 1976). More emphasize was then placed on studying the adoption behavior to answer the question "what factors trigger the adoption behavior?", and to predict the future adoption decision by farmers. A large body of literatures thrived using Logit or Probit models, which have discrete choices variable as dependant variables (Wale et al., 2005; Moser & Barrett, 2006; Ward et al., 2008). Other derived adoption models were also developed, which incorporate considerations such as geography, performance and risk, institutional policies, credit availability, and other factors maybe having effects on farmers' adoption behavior.

Griliches (1957) studied hybrid corn adoption by American farmers and established guidance and foundations for further technology adoption research. He adopted the logistic S-shaped curve and found a few potential factors that influenced adoption "origins, slopes and ceilings" by showing the correlation coefficients between market density, farm size, and "corn beltlines" and "origins, slopes and ceilings". Lekvall and Wahlbin (1973) suggested different functional forms of innovation diffusion, i.e. logistic function, modified exponential function, and Gompertz' curve. They argued that the communication process, i.e. internal or external, influenced the diffusion pattern by shifting the inflection point up or down. A universal functional form was proposed with extreme cases being logistic and modified exponential. They also stated that if the specific market was dominated by internal communications such as “discussing with neighbors”, the diffusion process would tend to be logistic, and vice versa. Feder, Just, and Zilberman (1985) wrote a thorough review on analyzing technology adoption and diffusion behaviors under different scenarios, and addressed various factors affecting the adoption and diffusion process – farm size, risk and uncertainty, human capital, etc.

In brief, an S-shape technology diffusion curve is appropriate for empirical analysis. Three phases are involved in the diffusion process: a slowly adjusted learning period by innovators, followed by massive adoption behavior, then the pace slow down till reach a saturation point. Many factors influence farmers’ technology adoption behavior. These factors can have different effects for a specific type of technology and market system. Farmers’ adoption behavior of feeding SBM can be described by the three phases. In the initial stage, only innovators feed SBM. Farmers then realize the benefits of feeding SBM from observing others. The profit from feeding SBM pays off the higher cost. As more farmers feed SBM, marginal increase of SBM feeding ratio increases. At last, the marginal rate declines until saturation. This hypothetic process may not represent the whole story. The establishment of large-scale new animal farms adopts modern feeding technology immediately, which accelerates the whole process further.

CHAPTER THREE: METHODS

Estimating Income Elasticity

Previous studies made numerous attempts to estimate income elasticity of demand for various meat items. However, results vary widely based on different models, time periods, and geographical locations. This study aims to estimate the income elasticity of demand for animal products of higher income households, and investigate the emergence of consumers' demand for food quality and safety. Both of these factors affect China's future derived SBM demand. High income households' diet choices indicate the future diet preferences of an average Chinese household. Demand for food quality and safety calls for more integrated meat production system. Modern feeding technology employed by large production units requires more SBM.

Followed by the procedures proposed by Gale and Huang (2007), the Log-Log-Inverse (LLI) Engel equation is chosen to estimate income elasticity, which is shown as equation (1). This functional form is relatively flexible to capture different shapes of consumption-income relationship. It has two other functional forms embedded implicitly. When $\beta = 0$, it becomes the Log-Inverse form. Elasticity η is just γ / Y. The elasticity will never change sign but varies with income. When $\gamma = 0$, the Log-Log-Inverse becomes the Log-Log, from which income elasticity η is a constant value, i.e. β. When both β and γ are not zero, elasticity η is given by $-\gamma / Y + \beta$. Plus, the Log-Log-Inverse form is also recommended as one of the best Engel functional forms based on various specification tests (Haque, 2005). Since the complete demand system is not considered here, adding-up criteria is not a problem.

Log-Log-Inverse:

$$log\, Cons_i = \alpha + \beta * log\, Y + \frac{\gamma}{Y} + \varepsilon_i \qquad (1)$$

The income elasticity of the above equation gives the response of food consumption quantity by change in income. In order to estimate income elasticity of demand for food quality and safety, the left-hand-side regressand is replaced by food expenditure in the above equation, which is shown as equation (2). The elasticity θ derived from the expenditure-income equation is the income elasticity regarding food expenditure. θ is believed to be larger than η based on people's preferences on better food quality. The income elasticity for food quality ρ is calculated by differencing θ and η.

$$log\,Exp_i = \alpha + \beta * log\,Y + \frac{\gamma}{Y} + \varepsilon_i \qquad (2)$$

Ordinary least squares (OLS) estimation will not give biased estimations using group means to estimate Engel functions (Kmenta, 1971). However, the variance for each group mean tends to be proportional to the group sample size. As a consequence, residuals are heteroskedastic and parameter estimates are inefficient. Therefore, weighted least squares are used here, and the different sample sizes (household numbers in each group) are considered as weights.

SBM Feed Diffusion Process

The second part of this study is designed to answer how fast the Chinese livestock, poultry, and aquaculture producers transform from traditional household farms to specialized farms or concentrated enterprises. The question is relevant in terms of predicting future derived demand for SBM in China due to the transformation process underway in China from small-scaled backyards to large commercialized enterprises. Three different technology diffusion pathway scenarios are proposed to explore the switching rate from non-commercial feed to SBM-based feed mix in China.

Scenario 1: Linear Projection

A simple linear regression is fitted to project the future SBM feeding level. The linear equation is:

$$Y(t) = a + b * t \qquad (3)$$

Y(t) is the SBM feeding ratio at year t calculated using US-standard FCR's and SBM content in animal feed rations. *a* is the starting SBM feeding ratio at time zero. *b* is the speed of increasing SBM feed ratio by year. This naïve linear fit is selected to serve the purpose of showing how fast commercial feed diffuses in China.

Scenario 2: Logistic Curve

One of the most well-known technology diffusion curves is depicted by logistic function, which is shown below. It is commonly believed that logistic function represents the empirical technology diffusion data very well. It assumes that the diffusion rate of a certain technology or product at a given time point is proportional to both the remaining distance to some predetermined saturation level and the instantaneously attained diffusion level (Lekvall & Wahlbin, 1973).

Logistic Function:

$$Y_i(t) = K * (1 + e^{-(a+b_i*t)})^{-1} \qquad (4)$$

It can be easily linearized to the following form:

$$ln(\frac{Y_i(t)}{K-Y_i(t)}) = a + b_i * t \qquad (5)$$

In this equation, both *a* and *b* represent the same meanings as before, i.e., *a*: starting diffusion level; *b*: diffusion rate. *i* means individual countries. *K* is a predetermined saturation point, i.e. 99.99% in this case. China's SBM feeding ratios from 1991 to 2007 were fitted to the above equation in order to estimate the pace of diffusion, i.e. *b*, under the assumption of a logistic diffusion process.

Scenario 3: Modified Exponential Curve

Another well-known diffusion function is the so-called modified exponential function (MEF) which is listed below. Unlike the logistic function, the modified exponential function assumes the instantaneous diffusion rate is only related to its remaining distance to the saturation point. This function form is also widely accepted by empirical researchers (Lekvall and Wahlbin, 1973).

Modified Exponential Function:

$$Y(t) = K * (1 - e^{(-a-b_i*t)}) \qquad (6)$$

Linearized Form:

$$ln(\frac{K}{K-Y_i(t)}) = a + b_i * t \qquad (7)$$

Other right-hand skewed functions such as Gompertz' curve and integral of the lognormal density function, whose inflexion points are below half of the saturation level, are also recommended by other empirical economists. However, these functional forms are not selected because they have more parameters which cannot be estimated sufficiently under the small dataset (17 years). Plus, the time length of the diffusion process would in theory lie in between what logistic function and modified exponential function predict. Logistic function assumes decreasing rate after 50% of the saturation level and modified exponential function assumes decreasing rate from the time zero. The diffusion level in China in 2007 is 39%, so the logistic function represents the shortest time frame to reach saturation and modified exponential function the longest.

China's Low SBM Feeding Ratio

The third question relates to what factors cause the low SBM feeding levels in China. A simple OLS regression is applied to address the question using SBM feeding levels in 30 provinces. Education level is widely believed to have positive impact on technology adoption behaviors (Alene & Manyong, 2007). Especially in rural China, there is still a significant portion of citizens under literacy. Another possible factor influencing the diffusion in China is the infrastructure development status (Fan & Zhang, 2004). Transportation is important because the mismatch of SBM production-consumption centers. Soybeans are processed in China's east coastal provinces and the demand for SBM is high in the central and western inland areas. Availability of roads and the ease of delivery are supposed to influence farmers' use of SBM in a positive way.

Another consideration is the availability of cheap substitutes. This may negatively influence the farmers' feeding decision. Low-priced rapeseed meal, groundnut meal, and cottonseed meal are usually preferred by farmers over SBM although they are inferior in quality. Proportions of commercialized farms & specialized households are also believed to have a positive effect on overall SBM feeding level. The OLS regression equation is listed below:

$$FR^{SBM} = Constant + \alpha * Edu + \beta * Subs + \gamma * Tran + \delta * Farm + \mu \quad (8)$$

FR is the feeding ratios calculated by dividing the actual SBM consumption by the theoretical feed requirement by province. The theoretical feed requirement is calculated by multiplying meat, egg, fish, and milk production by corresponding FCR's. Education (*Edu*) level is measured by percentage of citizens older than 6 who completed elementary school (6 years of education). Substitution (*Subs*) effect is measured by the provincial production share of national total oilseed production. Transportation (*Tran*) development level is measured by relative road length in each province. Proportions of animals (hogs and poultry) produced by larger farms in each province (*Farm*) are also included in the explanatory variable.

CHAPTER FOUR: DATA CONSTRUCTION

Available data of China's meat and feed sector is far from perfect. Meat production and consumption statistics obtained from China's official data source suffers great discrepancy due to the flawed statistical system (Hansen et al., 2004; Ma et al., 2004). There is no official statistics on grain or feed consumption. Consumption level is estimated by market analysts and government agencies, i.e. National Feed Office. However, these data are hard to get access to. Feed rations used by various producing systems are limited and not easy to aggregate. Official industry-average FCR's are not reported and survey results are spare (Zhou et al., 2008; Gale, 2008). The statistics used in this study are listed below by compiling segmented data sources.

Pork, poultry, egg, beef, mutton, and milk production data for 142 countries from 1961 to 2007 was downloaded from the database of United Nation- Food and Agriculture Organization (FAOSTAT). Freshwater fish, brackishwater fish, and marine fish production (excluding the wild-caught) was archived with an FAO software *Fishstat Plus* for the same countries and time period. SBM consumption data was downloaded from FAOSTAT for the same countries but only available from 1961 to 2003. The SBM consumption data for 2004-2007 was constructed by multiplying the soybean oil production data with the crushing ratio then plus the net imported SBM. FAOSTAT deals with food production & consumption balance, stock variations, and explicit uses for commodities. The problem of FAOSTAT data for China is believed to be less severe (Masuda & Goldsmith, 2009). Feed conversion ratios (FCR's) in 2007 are proposed for each commodity group by incorporating various sources based on US industry standard (Table 3). 1% decrease in FCR's for all commodity groups is assumed to capture the genetic improvement of animals in feed efficiency (Fuller, 1997). SBM contents in feed ratios by US standard for each type of animals are proposed as well. FCR's for Chinese livestock production are collected from USDA Economics Research Service (ERS) unpublished estimations.

Theoretical SBM consumption levels for all countries in 1961-2007 is recovered using the meat, egg, fish, and milk production quantities and the proposed US standard SBM-output conversion ratios. SBM feeding ratios for each country each year are calculated by dividing the corresponding actual SBM feeding levels by the theoretical SBM consumption levels. 56 countries are deleted due to either the unnoticeable market shares or segmented data observations. Provincial SBM consumption data is archived from American Soybean Association Beijing Office. However, the data is only available in 2006. Several attempts were made to get other years' observations but failed. The SBM feeding ratios are constructed as the ratios of actual SBM consumption and the theoretical feed requirement which is calculated using the proposed FCR's for China (Table 4). Oilseed and cotton production data, the percentage of citizens who completed elementary school education, and the total length of roads and railways are obtained from China National Bureau of Statistics (CNBS) by province in 2006. Animal units by farm size in 2006 are from China's 2006 rural survey, and retrieved from USDA-ERS unpublished source. Data are complied and prepared using Excel 2007.

CHAPTER FIVE: RESULTS AND DISCUSSION

Income Elasticity of Demand for Food Quantity and Quality

The Log-Log-Inverse function form fits the data very well as expected. The coefficients for most of the equations are statistically significant. The Log-Inverse is used for pork because of the insignificance of the log coefficient. Adjusted R^2 values are very high due to the use of group means (Table 5). Individual household effects are neutralized within each group, and the effects among groups stand out statistically (see Cramer, 1964).

Pork as a traditional meat choice for Chinese households has a high consumption level relative to other meat products. The income elasticity of pork ranges from 0.52 to 0.04 for various income levels (Table 6). Eggs, as the cheapest animal protein source, have a similar role as pork in traditional Chinese diet choices. However, the elasticity is negative for higher income households (-0.06) and higher for low income households (0.65). The high cholesterol level in egg yolk might be a health concern by richer consumers.

Beef and mutton have similar income elasticities, ranging from over unity (1.04 and 1.02) to slightly negative (-0.03 and -0.07). The negative income elasticities for beef and mutton are spurious. They can be explained by the omission of food-away-from-home (FAFH) statistics in the design of China's urban household survey (Ma et al., 2004). Higher income households mostly consume beef and mutton at restaurants, i.e., hotpots. High consumption levels at restaurants dampen consumption curves for beef and mutton when surveys exclude FAFH activities.

Poultry, fish, shrimp, and milk all have high income elasticities, which are consistent with previous studies (Shono et al., 2000; Yen & Lin, 2006). Income elasticity of demand for poultry ranges from 0.81 to 0.17. Income elasticities of demand for fish and shrimp range from

0.62 and 1.70 to 0.27 and 0.66, respectively. Income elasticity of milk ranges from 1.49 to 0.24 from lower to higher income households.

These findings are informative in terms of examining Chinese urban households' diet composition and future trends. These estimations are within normal sense and consistent with the wide range of previous estimations: pork: 0.13 – 1.20; poultry: 0.22-1.95; beef/mutton: 0.19 – 1.68; eggs: 0.10 – 1.70; fish: 0.64 – 2.20; milk: 0.64 – 2.20. The estimates of low income households appear to be in the general range of previous studies' estimation results. China has a skewed income distribution. Rural households and low income urban households account for more than 60% of the total population in China. The income elasticity estimates for low income households may reflect an average income elasticity value for all Chinese people. The estimates of medium income households appear to be lower than previous studies probably due to not incorporating the change in consumers' preferences over time or capturing the effects of FAFH. The estimates of high income households tend to be smaller than reality due to similar reasons for the low estimates of medium income urban households. However, these estimates can still review part of the story in describing China's future demand for animal protein.

Income elasticities of pork, eggs, beef, and mutton are lower than 0.1 for urban households of income over 15000 *yuan*, or less than $2000 using average USD-RMB exchange rate of 8 in 2004-2006. The consumption of pork, eggs, beef, and mutton appears to have reached saturation for the top 20% of the urban households. Urban population counted slightly less than 50% of the total population in China. That is to say, about 10% of the Chinese citizens have already stopped expanding their year-on-year consumption of red meat and some other animal products, i.e. pork, beef, and mutton, and eggs. A majority of Chinese will cease eating more red meat and eggs by the time China's average per capita GDP reaching the World Bank forecast of

$3600 in 2020 or $4600 in 2030. The slowing of red meat product consumption will also be affected by the income distribution. The large under class in china is expected to continue to increase its consumption of red meat products even though average income may risen to levels sufficient o reduce the rate of animal product consumption per capita to close to zero. Pork, beef, mutton, and egg production though will increase at a slower rate due to the income effect over the next two decades.

On the other hand, the consumption of poultry, aquatic products, dairy products remain moderately responsive even for the top 20% of China's urban households. The income elasticities for poultry, fish, shrimp, and milk are 0.23, 0.31, 0.76, and 0.36, respectively for households of income at $1875. Future demand of these food items will continue to increase at a higher rate than red meat and eggs in the next two decades. The expenditure shares of poultry, seafood, and milk will continue to increase due to the same reason.

Poultry, fish, shrimp, and milk are more efficient in providing protein than beef, mutton, and pork in terms of feed-grain utilization. Growth of broilers, fish, and shrimp requires less total feed-grains. However, these small animals require higher quality and more concentrated protein-based feed than ruminant animals and hogs. SBM as an excellent renewable and cost-effective protein source continues to be the most desired feed ingredients in their feed rations. The future derived demand for SBM in China will continue to rise at a fast rate despite the pork consumption rate is slowing down.

Expenditure elasticity is estimated using the same method and data source. The expenditure data is more aggregated in terms of meat types. Similar to the quantity elasticity estimations, high R^2 are obtained and most coefficients in expenditure elasticity estimation are statistically significant (Table 7). Log-inverse are used for eggs due the statistical insignificance of the *ln* coefficient. Expenditure elasticity is reported in Table 8.

Income elasticity of demand for food quality and safety is derived by differencing the expenditure elasticity and quantity elasticity (Table 9). For all commodity groups, demand for quality and safety increases as household income rises. People are willing to pay price premiums for better food quality and safety. This finding is consistent with other previous studies (Lin et al., 2006; Gale & Huang, 2007; Wang et al., 2008).

Meat quality demand elasticity is relatively constant at 0.15-0.16 indicating that consumers are paying 15% more for good meat quality. Demand for egg quality is low at 0.1. Demand for aquatic product quality varies from low income level (0.32) to higher ones (0.43). It might reflect the fact that aquatic products differ widely in terms of species, freshness, and scarcity. Higher income households tend to purchase fresher (preferably live) aquatic products and those having better textures. Demand for milk quality is lower than expected: the high income households only pay 17% more for good milk products. This may be due to the fact of overall homogenous low milk product quality in the market and lack of awareness of various milk qualities by Chinese consumers. Lower income households pay little for better and safer milk.

Chinese urban consumers with higher income pay price premiums for better food quality and safety. Demand for food quality and safety grows as people gets wealthier. This phenomenon calls for the demand of a more integrated animal production system and better quality and safety control management in China's livestock, poultry, and aquaculture industry. Small-scaled backyard production cannot guarantee the same product quality and safety standards. Large investments in capital and human resources are required for adopting modern animal production technologies. As a result, large-scale commercialized enterprises will ultimately replace small scaled production entities. Better feeding technology requires intense feed-grain usage. The process of this feeding technology diffusion fuels the future derived demand for SBM.

In short, pork demand will still be large due to its current high level of consumption, whereas the future demand for animal products will cumulate on poultry, aquatic products, and milk. Top 20% of Chinese households already seem to reach saturation of red meat consumption. The future demand of meat products will mainly come from low income urban residents and rural households. Demand for poultry, aquatic products, and milk will grow faster than red meat as household income rises. Demand for food quality and safety emerges. It may further accelerate the reform of China's animal production industry from small-scaled backyard production to large modern commercial farms. Feed-grain feeding intensity is significantly higher in modern commercial farms' production practices. Another 44.8 MMT of SBM was required in addition to its realized usage level of 29.1 MMT in 2007 if China fully adopts the modern feeding technology.

SBM Feed Diffusion Process

In order to assess the speed of the feeding technology diffusion in China, different diffusion scenarios are estimated. Estimation result of the simple linear regression is shown below as equation (9) (Figure 9). The SBM feeding ratio dropped from 0.33 to 0.07 during the 1961-1991 period because the animal production, mainly hog production, was growing at a faster rate than the commercial feed sector in China before 1991. China relaxed its policy on importing soybeans in the 1990s. China' demand for imported soybeans grows in a linear fashion at a rate of 2%. The commercial feed diffusion process starts in 1991.

$$Y(t) = 0.0197 * t - 0.0495 \qquad R^2 = 95\% \qquad (9)$$

The diffusion rate of feeding technology approximated by SBM feeding ratio is 1.97% in China from 1991 to 2007. It will take China 33 years from 2009 to reach the SBM feeding ratio of 98% under current pace. This result only sheds little light on the possible pace of SBM feed diffusion process. Convincing results can only be implied after comparing the linear scenario with logistic and modified exponential function scenarios.

Estimation result of the logistic curve is listed below (Figure 10).

$$ln(\frac{0.98}{0.9999-0.98}) = -2.4245 + 0.122 * t \qquad R^2 = 93\% \qquad (10)$$

The estimated b is 0.122, which represents a long-term average speed of SBM feed diffusion. China needs 33 years from to achieve the SBM feeding ratio of 98% after solving the above equation for time t. This provides the same conclusion as the simple linear projection method does.

However, the logistic function has its limitations. One of them is that an inflexion point at a diffusion rate of 50% is pre-determined by its mathematic expression. This drawback will be considered later on with a different function. The other limitation of logistic curve is that it only has one parameter needs to be estimated, which is somewhat restricted in the real-world applications. But this can also be considered as an advantage for sake of degrees of freedom since the data observations are relatively constrained.

Below is the estimation result of the modified exponential function (Figure 11).

$$ln(\frac{0.9999}{0.9999-0.98}) = 0.0316 + 0.0261 * t \qquad R^2 = 94\% \qquad (11)$$

The estimated b is 0.0538. Duration t was calculated base on the above equation. The SBM feeding ratio of 98% would only be achieved not early than 132 years later from 2009 under this scenario. This result may seem shocking at the first glance, but it is because the model basically assumes the speed of diffusion is getting slower and slower from time to time. To illustrate, 43 years are required in order to reach 80% of the saturated soybean meal feeding ration.

The projection results from all three scenarios are shown in Figure 12. The slowest process is shown by modified exponential function and the fastest process is shown by logistic function. The earliest year to realize 80% of the SBM feeding rate would be 2023 and the latest would be 2052. However, horizontal comparisons across countries suggest that logistic function empirically fits the actual process better. United States, Brazil, Spain, Japan, Italy, Argentina, Netherlands, Thailand, Korea (Republic of), Denmark, Chile, and Malaysia have finished their SBM feeding technology diffusion process among the top 26 largest SBM utilization countries. Their highest SBM feeding levels are all over 85%, some of them are over 100%. Logistic functions have higher R^2 values than modified exponential function's for all of these countries completing the diffusion process (Table 10).

Indonesia, Thailand, Korea (Republic of), Philippines, and Malaysia are the five Asian countries which had comparable animal production systems with China. Their SBM feeding levels are all above China's. China's future SBM feeding diffusion pattern could be inferred from theirs. The SBM feeding ratios starting from 7% - 8% are plotted regardless of the year (Figure 13). SBM feeding ratios in Thailand, Korea (Republic of), and Malaysia are over 100%. These countries' animal production industry may have higher feed conversion ratio's (FCR's) and SBM content in their feed rations than the US. Large commercialized animal farms in China have similar FCR's and SBM content in feed rations as those in the US. Therefore, China's future SBM feeding ratios are predicted using logistic functions with a saturation point of 99.99% (Table 11). The SBM feeding curve will be steeper, and more SBM will be consumed if higher saturation point is considered. Multinational agricultural companies and investment banks have been investing in China's animal production and feed industry for years (Goldsmith et al., 2004; Gale, 2008). China's SBM feeding diffusion process may be even faster than what logistic curve predicts since these foreign direct investments adopt new feeding technology instantly. Therefore, the logistic curve only serves the slower side of the process.

China's Low SBM Feeding Ratio

Provinces in China exhibit widely different SBM feeding ratios (Figure 14). The regression result on the original proposed equation is not satisfying. Variables of relative road length (*Trans*) and farm size (*Farm*) are not statistically significant, and *Tran* has an unexpected negative sign. The model also suffers multi-colinearity. These problems might be solved by incorporating more observations and/or select different measures for the same variables which are not available at this point. After dropping *Tran* and *Farm*, the model displays a clean result. The modified model is listed below.

$$FR^{SBM} = Constant + \alpha * Edu + \beta * Subs + \mu \qquad (12)$$

Estimated result is $\alpha = 0.47$ (p=0.000), $\beta = -0.44$ (p=0.005) and the adjusted R^2=65%. The model is reasonably explanatory to the puzzle why Chinese farmers do not feed SBM to animals at the theoretical level. Some OLS assumptions are tested. Normality assumption of residuals by Skewness/Kurtosis tests (p=0.5621) is not rejected. There is no evidence of missing variables suggested by Ramsey RESET test (p=0.2672). Correlation between *Edu* and *Subs* is -0.05 which shows the model does not exhibit multi-colinearity. Breush-Pagan/Cook-Weisberg test for heteroskedasticity shows no evidence against the hypothesis of homoskedasticity (p=0.1796).

The overall model significance and the reasonable parameter estimates reveal at least the bulk part of the story although only two explanatory variables are left in the final regression. Proportion of people who completed elementary school plays an important role in determining the provincial SBM feeding level in China. Every 1% increase in the population who completed elementary education will give rise to an increase of 0.47% in SBM feeding rate or 2.3 MMT of SBM. Availability of cheap substitutes of SBM, i.e. rapeseed meal, groundnut meal, and cottonseed meal, is another deterministic factor for Chinese farmers not feeding SBM. Every 1% increase or 0.37 MMT more, in the rapeseed, groundnut, and cottonseed production will drop the SBM feeding rate by 0.44% or 2.1 MMT. Regression residuals are random across provinces by virtual inspection, and they are believed to represent the distinct characteristics by each province. These individual characteristics cannot be explored further based on current information available.

With the moderate gap in education level between east and west China, the feeding technology diffusion or the acknowledgement of feeding SBM will be lower in West China. The situation may persist until large animal producing enterprises take over the majority of production. The demand for cheaper vegetable cooking oils, cotton and sesame oil will keep rapeseed meal, groundnut meal, cottonseed meal, and sesame meal active in China’s protein feed market. Other than these two factors, the unbelievably low rate of feeding SBM could be partially explained by farmers’ choice of feeding wheat and rice bran, and other unusual feed ingredients, such as table scraps, potatoes, and vegetables. In 2001-2003, 30% and 13% of the total feed ingredients came from starchy roots and crop bran, respectively. The other possible reason might be the household income level. With higher income, households have tendency to purchase higher quality feed (Dey, 2005). Although the trend of feeding these irregular feedstuff is sliding down, but replacing them for SBM and corn is not a fast process.

Predicting Future Derived Demand for Soybeans

In order to predict future derived demand for soybeans, the first step is to propose income elasticity for various commodities. The estimates from previous sections are not used due to the shortcomings discussed before, i.e., FAFH effect. Average income elasticities are selected based on previous research. These averages are thought to better represent the national urban & rural income elasticity because they suffer less regional effects and neutralize the biases of each individual estimating model. However, as household income rises, income elasticity tends to drop. An average decline of 40% in income elasticity is assumed for the next two decades. Pork has an income elasticity of 0.42 for both urban and 0.47 for rural households, respectively (Table 12). Beef & mutton has an income elasticity of 0.52 and 0.46 for urban and rural households, respectively. Poultry has an income elasticity of 0.71 and 0.72 for urban and rural households, respectively. Eggs have an income elasticity of 0.35 and 0.60 for urban and rural households, respectively. Aquatic products have an income elasticity of 0.6 for both urban and rural households. Milk has an income elasticity of 0.78 and 0.83 for urban and rural households, respectively. Equation Below is used to predict future meat consumption for both urban and rural households.

$$Cons_{t,i} = Cons_{t0,i} * (1 + InGr_t * InEl_i)^t * Pop_t \quad (13)$$

$Cons_{t,i}$ is the per capita consumption level of commodity *i,* at time *t*. Base year consumption level is adjusted for FAFH. The center for Chinese Agricultural Policy (CCAP) survey of 1999 indicates that 34% of the meat consumed by urban and 12% of that consumed by rural households had been eaten outside the home. Almost 20% of rural residents migrated to urban areas between 1980s and 2000, which is also indicated by the survey. $InGr_t$ and Pop_t are the income growth and population at time *t*, respectively. $InEl_i$ is the proposed income elasticity for each food item *i*. Consumption of different animal protein types are then converted to theoretical SBM demand using China standard FCR's, *FCR*. Predicted SBM feeding ratios, *SBM_FR*, are multiplied by the theoretical amount of SBM consumption for different time periods, *t*. Predicted SBM demand, *SBM*, can be calculated as below.

$$SBM_t = (\textstyle\sum_i Cons_{t,i} * FCR_i) * SBM\_FR_t \qquad (14)$$

SBM yield from crushing soybeans is assumed to be 79% (USDA). Forecast results are listed in Table 13. China's derived SBM demand is predicted to be 32.3, 69.6, and 102.9 MMT in 2010, 2020, and 2030, respectively. The prediction for 2010 is similar to those by Masuda & Goldsmith (2009). However, the difference between the two gets wider for distant future, i.e, Masuda & Goldsmith (2009) forecast China will consume 46.3 MMT of SBM in 2030, while in this study, the projection is 102.9 MMT. The difference in future derived demand for SBM mainly comes from the effect of commercial feed adoption in China. The income effect only contributes averagely 2.1% in determining the theoretical SBM consumption quantity for the next 20 years (Figure 15). The feeding technology diffusion effect, however, fuels another 3.6% annual compound growth rate on the demand increase for SBM in the same time periods. The transition effect is roughly equivalent to 1.5 times of the income effect. One could seriously underestimate China's future derived demand for SBM or feed-grains if ignoring the unique feature of this feeding technology diffusion in animal production industry. Projections from other available sources are listed for comparison (Table 14).

World soybean production is 211 MMT in 2008/09. China today consumes about 18% of the world soybeans available. Soybean demand in China is predicted at163 MMT in 2030. The world soybean production quantity was forecasted at 359.7 MMT in 2030 (Masuda & Goldsmith, 2008). China will consume about 45% of world soybean supply in 2030. China's soybean demand will rely more on soybean import based on the fact that it only has about 10% of world arable land. However, total arable land on the globe is limited and the competition from other crops restricts the expansion in planting soybeans in more land area. Therefore, yield improvement appears to be the key to meet the additional 100 MMT of soybean demand from China. Yield can be improved in two ways. First, yields can be raised by substantial R&D investment in developing new soybean genetic traits world-wide. But this approach requires large amount of capital and takes years to accomplish. Second, high yield soybean breeds can be transferred to low yield producing districts. This approach can greatly improve the average yield of soybeans around the world in a relatively short period of time. China's giant future derived demand for soybeans calls for more research on R&D on raising soybean yield and international intellectual property issues on technology transfers.

Sensitivity Analysis on SBM Forecast

A lower income growth rate is proposed to analyze the effect of the income growth projection on future demand for SBM in China. The low income growth scenario assumes China's income will grow 20% slower than the World Bank's projection based on the current world-wide economic downturn. The assumed growth rates are 7%, 4%, 3%, 2%, and 2% for 2006-2010, 2011-2015, 2016-2020, 2021-2025, 2026-2030, respectively. Different SBM saturation levels, *K*, are also selected in order to check the sensitivity of China's future demand for SBM responding to the change in *K* from 0.8 to 1.2 (Table 15). If income growth slows down by 20% in China from 2006 to 2030, the derived demand for SBM will decrease by 14% in 6% in 2010, 14% in 2020, and 18% in 2030. If China's saturated SBM feeding level is 1.2

instead of 1, the derived demand for SBM will increase by 4% in 2010, 12% in 2020, and 17% in 2030. If China's saturated SBM feeding level is 0.8, the derived demand for SBM will drop by 4% in 2010, 10% in 2020, and 15% in 2030.

The lowest forecast on SBM demand is 69.7 MMT in 2030 under the scenario of both low income growth and low saturation level. The highest forecast on SBM demand is 118.6 MMT in 2030 under the scenario of both high income growth and high saturation level. China will demand at least another 36 MMT by 2030, which is twice the size of the current consumption level. Nonetheless, China might consume another 85 MMT of SBM in 2030 under the scenario of high income growth and saturation level, which is 2.5 times of the current size. The implication discussed above still holds although the band between the two extreme cases is relatively wide. The dramatic increase of China's SBM demand places tremendous pressure on world arable land. Improving soybean yield world-wide is critical to release the stress.

CHAPTER SIX: SUMMARY AND CONCLUSION

In light of the Engel's law and Bennett's law, China's fast growth in income and urbanization fuels the consumption of animal products for their high protein content over other low cost starch-based calories. Income elasticity is estimated using Engel log-log-inverse functional form. Income elasticities of poultry, aquatic products and milk are higher than those of pork, beef and mutton. Food consumption in lower income households is more sensitive to their income levels. Top 10% households with income of $2000 reached saturation in consuming pork, beef, mutton, and eggs. Marginal increase in demand for animal protein slows down and will gradually diminish to zero by 2030. Demand for food quality emerges in China's food market which calls for more production from commercialized firms. It triggers further growth in derived feed-grain demand because large commercialized farms employ feed-grain-intense feeding technology compared with traditional backyard farms.

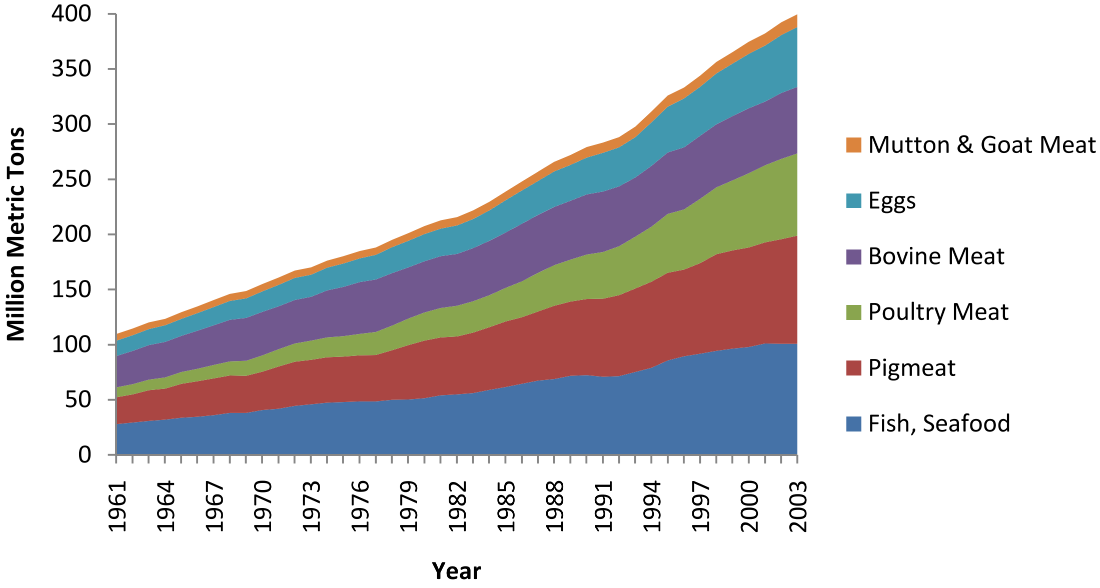
Soybean meal (SBM) as a cheap protein source for livestock, poultry, and aquatic animals is hard to substitute (Cromwell, 1999). More SBM will be fed due to its cost effectiveness and high quality. Implied demand for SBM from raising animals will increase at a faster rate than animal production does due to the diffusion of feed-grain-intense feeding technology. Logistic function is used to predict future SBM feeding ratios in China. The SBM feeding level will increase from 50% in 2010 to 92% in 2030.

The reasons for low SBM feeding ratio are examined. Education level and inferior substitutes are the most important factors. More educated people in one province, more SBM is fed. Educated people tend to use better feed ingredients instead of table scraps, etc. Cheap substitutes, such as rapeseed meal and cottonseed meal, restrict the acceptance of SBM as a better feedstuff. This is caused by farmers' lack of knowledge on the advantages of SBM over other oilseed meals and the local abundance of these low cost substitutes.

The effect of SBM feeding technology diffusion determines the future SBM demand trend. This effect is 1.5 times larger than the income effect. Derived soybean consumption in China is predicted at 142 MMT in 2030, which shares about 45% of the world soybean production. The giant soybean demand in China will create huge opportunities for soybean exporters as well as private commodity traders. Future research on China's feed market may focus on estimating the marginal change in income elasticity of demand for animal products through time as well as isolating the effect of world feed price and government policy change on China's feed consumption. It might also worth the effort to further examine the international intellectual property issues on transferring high-yield seeds from developed countries to developing countries.

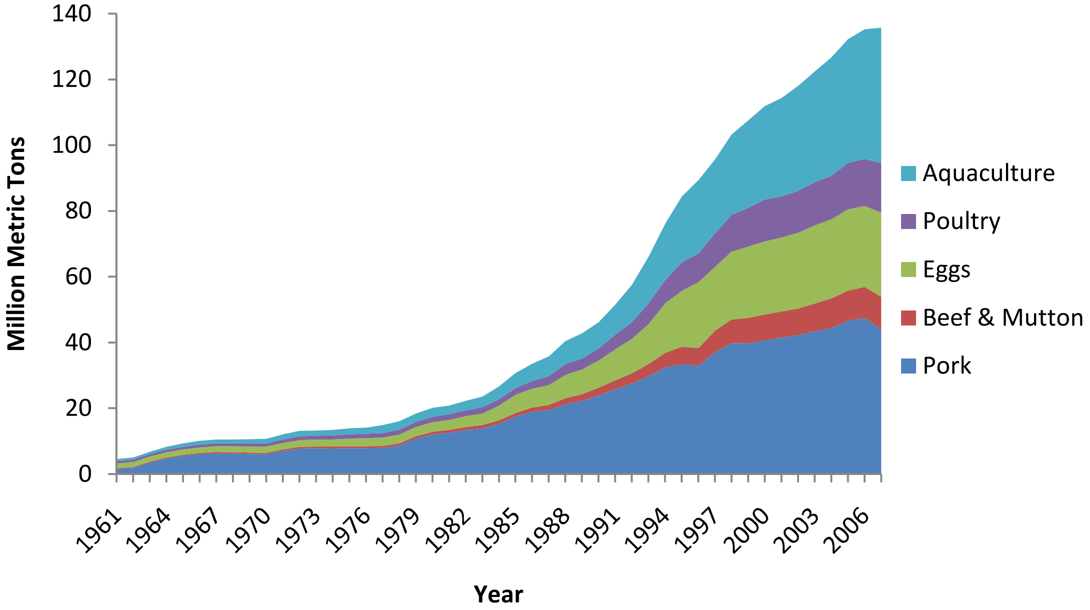
FIGURES AND TABLES

Figure 1 World Animal Product Consumption by Category 1961-2003



Source: Compiled by author from FAOSTAT data.

Figure 2 China Animal Productions by Category 1961-2007



Source: Compiled by author from FAOSTAT data.

Figure 3 Determinants for China's Future Derived SBM Demand

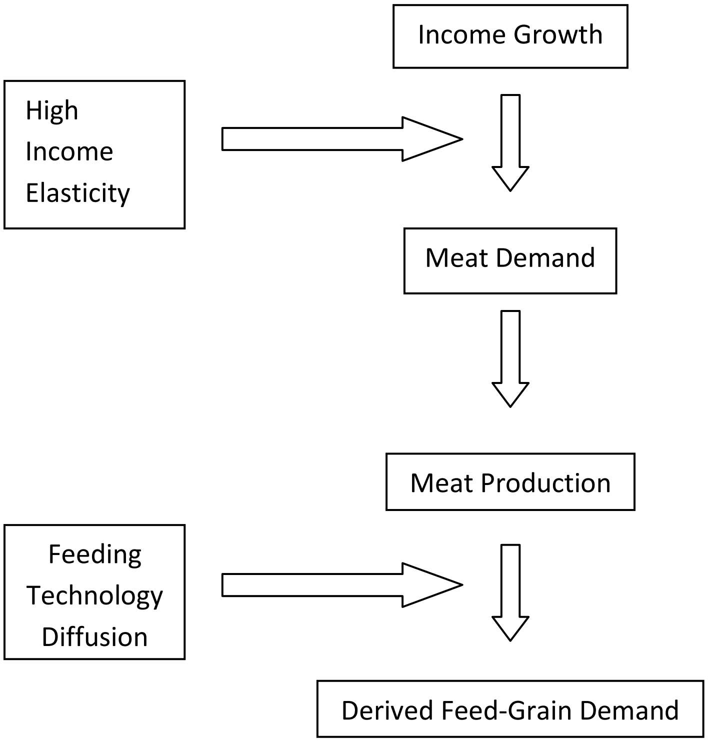
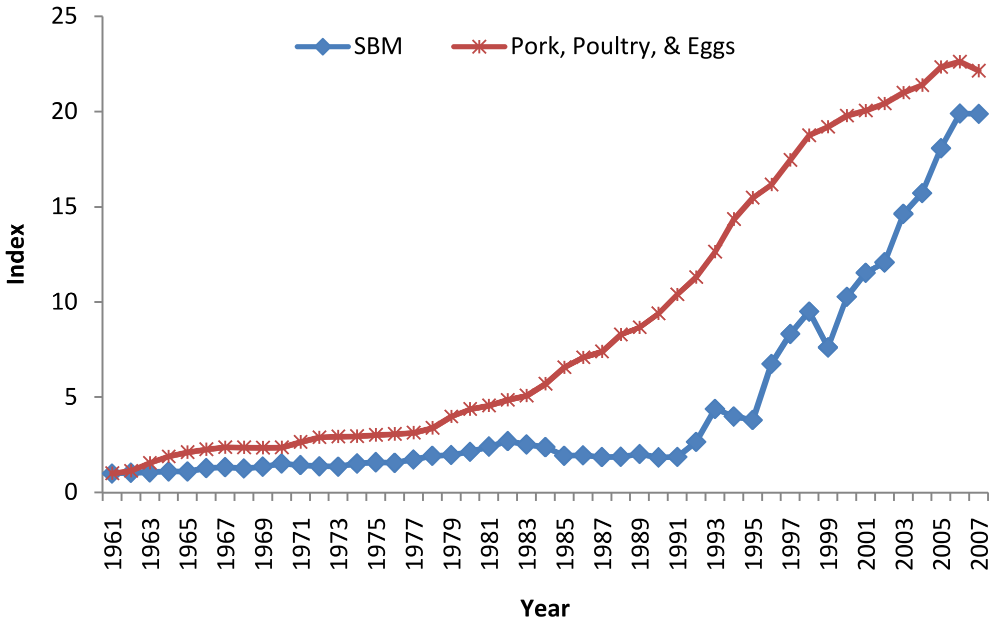
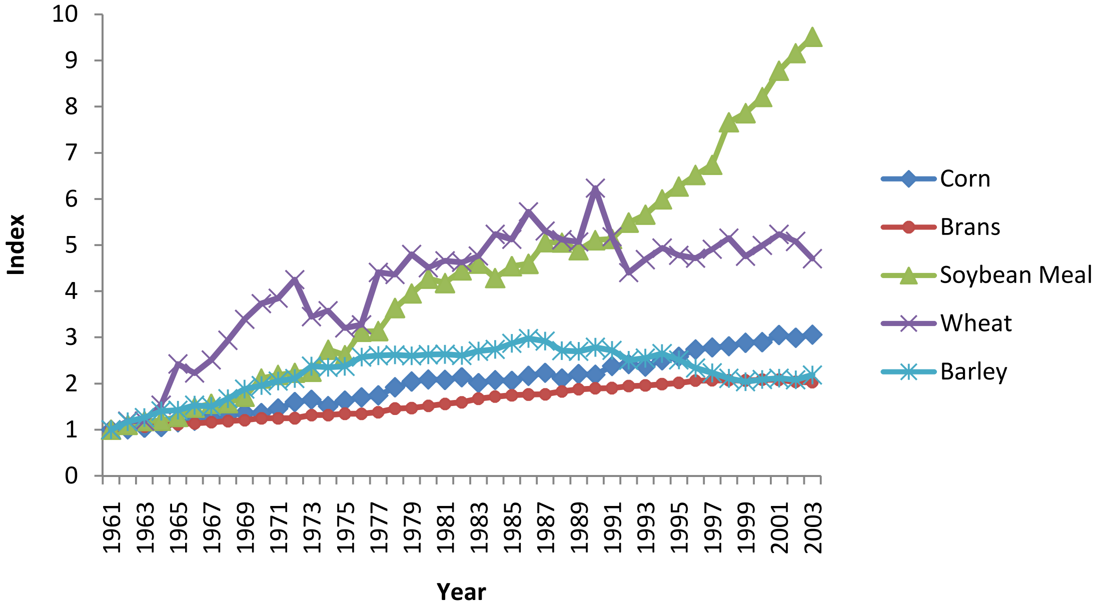


Figure 4 China's Pork, Poultry & Egg Production and SBM Consumption Index 1961-2007



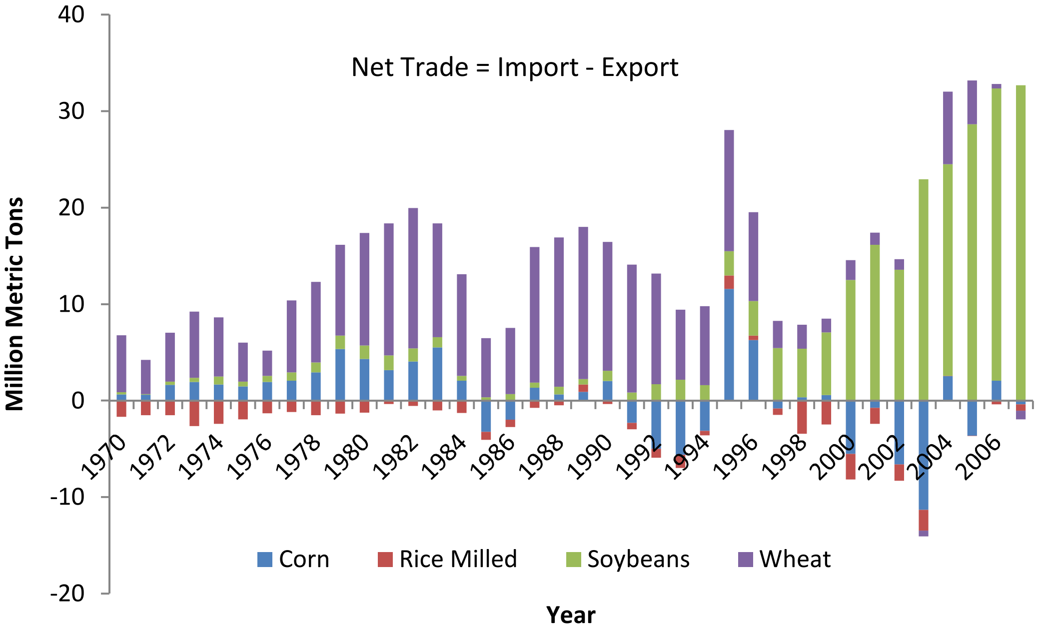
Source: Compiled by author from FAOSTAT data.

Figure 5 World Demand for Major Feed Ingredients 1961-2003



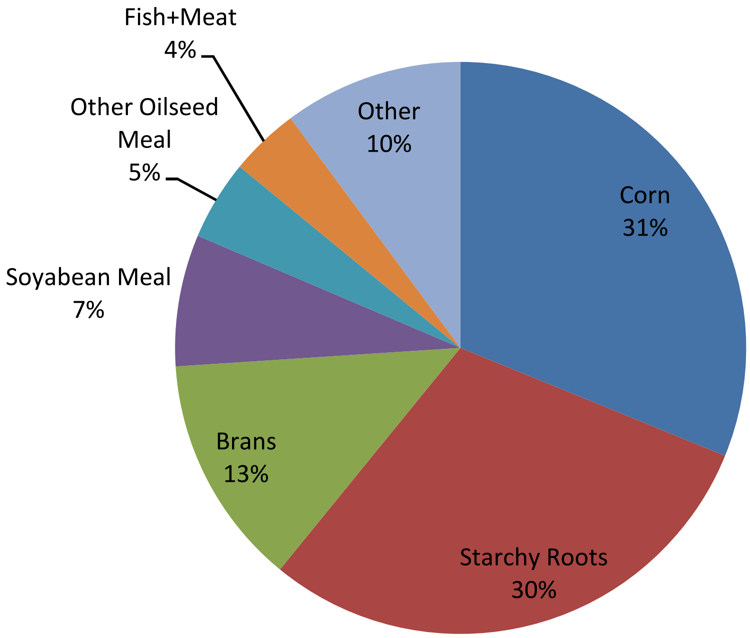
Source: Compiled by author from FAOSTAT data.

Figure 6 Major Grain Net Trades in China 1970-2007



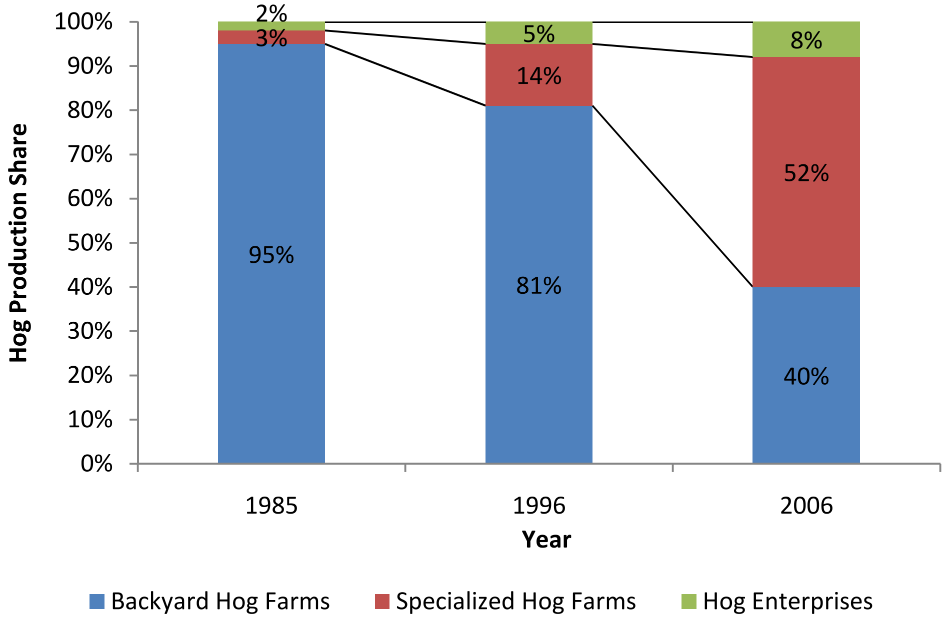
Source: Compiled by author from FAOSTAT data.

Figure 7 China's Feed Ingredient Share 2001-2003



Source: Calculated by author from FAOSTAT data.

Figure 8 Changes in Hog Farm Size in China 1985, 1996 & 2006



Source: Adapted from ERS unpublished source and Zhang et al., 1998.

Figure 9 SBM Feeding Ratios in China 1961-2007

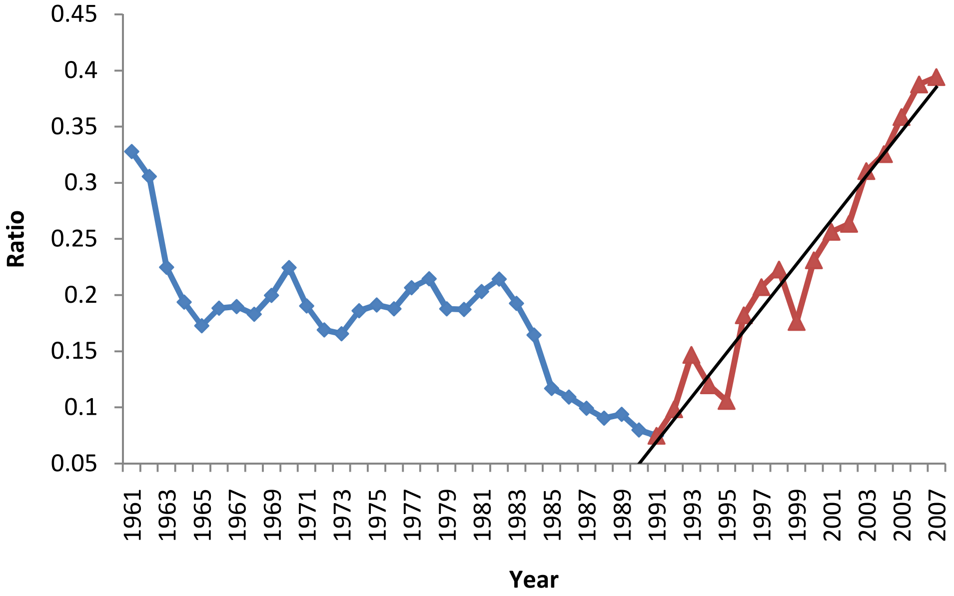


Figure 10 SBM Linearized Logistic Diffusion Curve 1991-2007

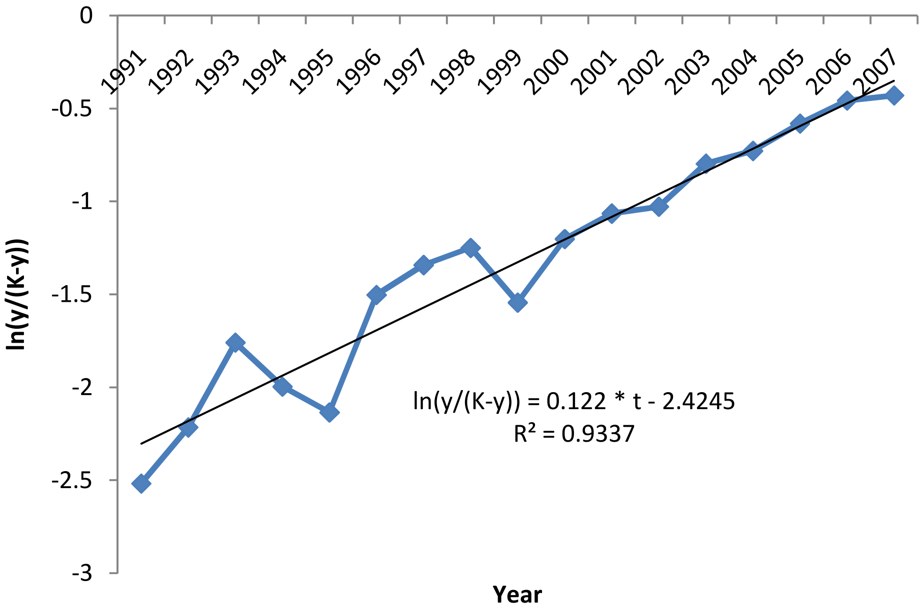


Figure 11 SBM Linearized Modified Exponential Diffusion Curve 1991-2007

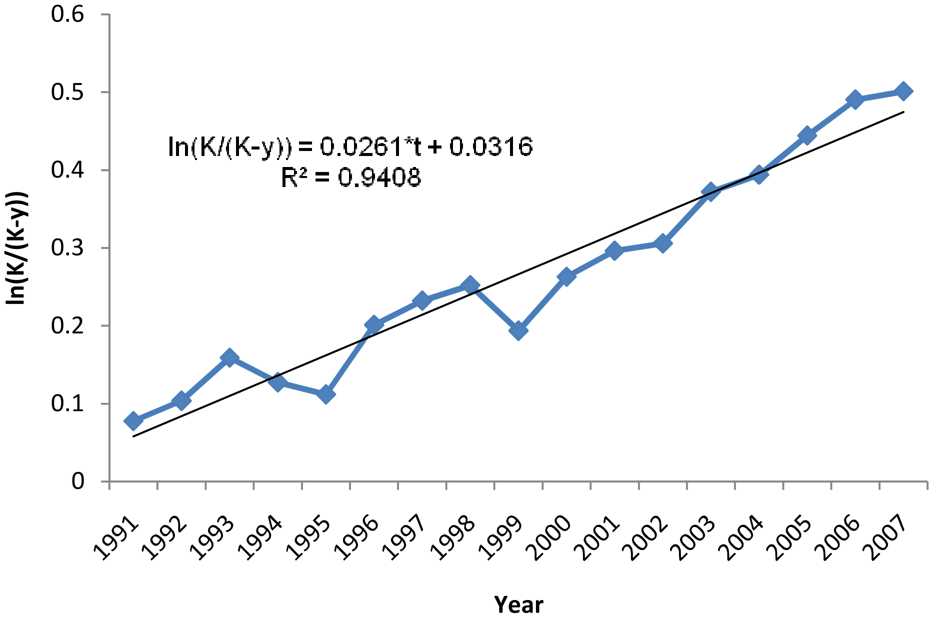


Figure 12 Projected SBM Feeding Ratios 1991-2020

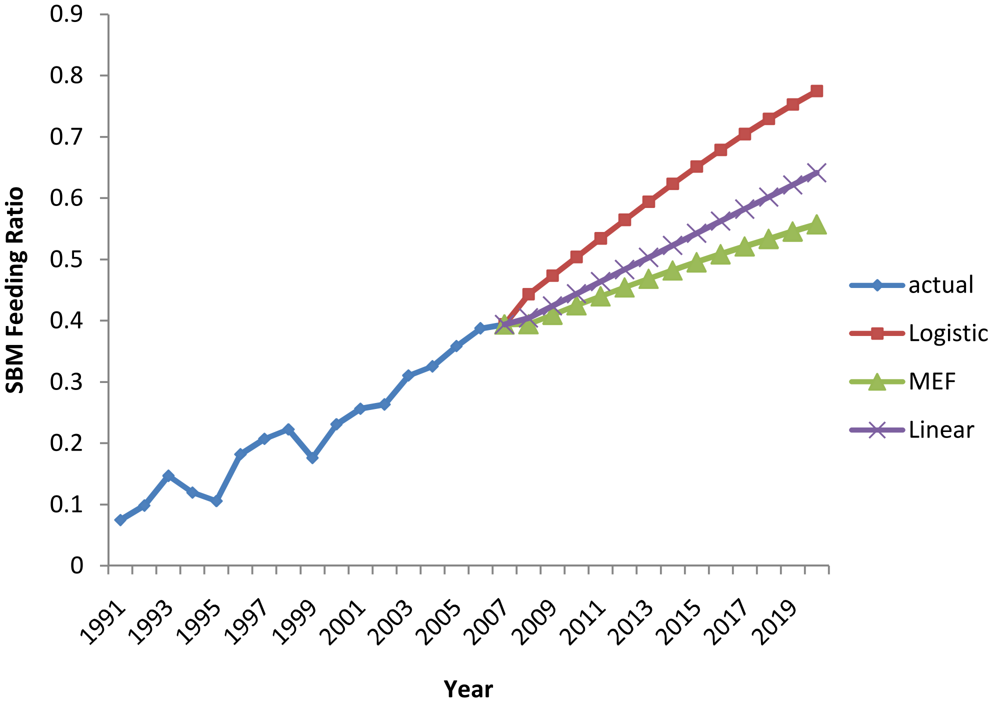
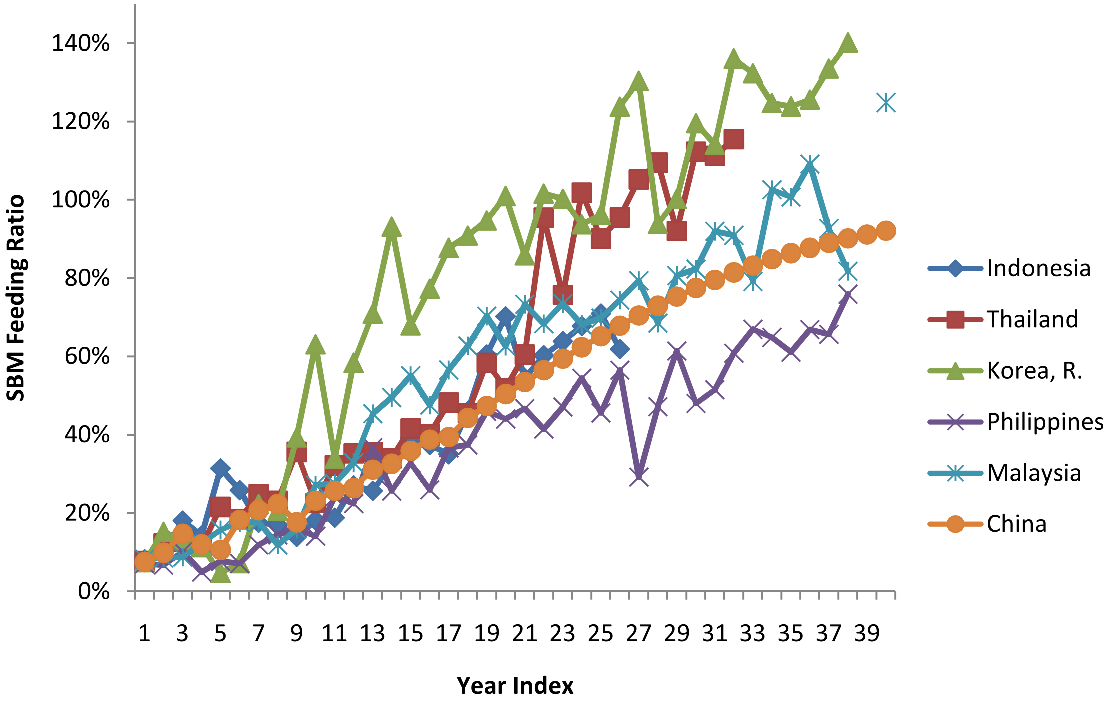
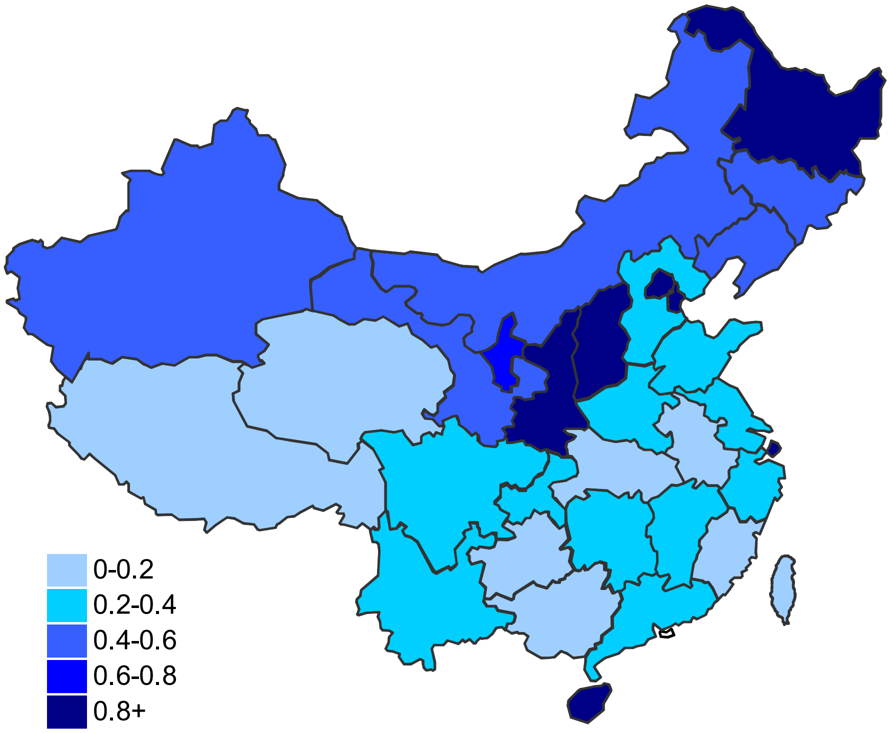


Figure 13 SBM Feeding Ratios in Selected Asian Countries



Source: Author calculations.

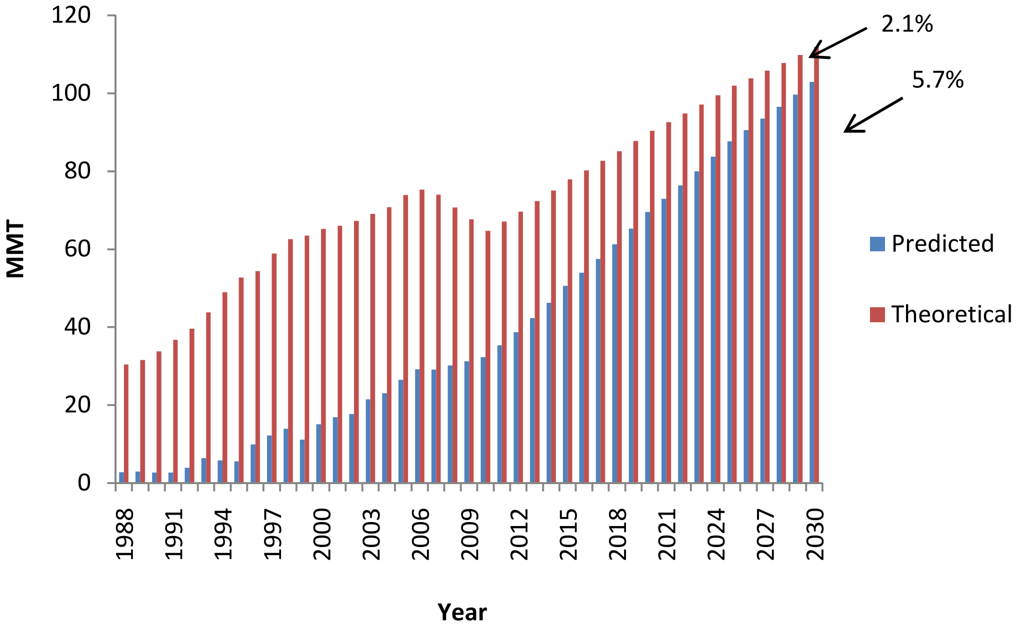
Figure 14 SBM Feeding Ratios by Province in China 2006



Source: CNBS and excelpro.blog.sohu.com.

Note: Data excludes Tibet and Taiwan.

Figure 15 Future Derived Demand for SBM in China



Source: Author forecasts.

Note: Data before 2007 is from FAOSTAT, but the forecasts from 2008 are based on CNBS data.

Table 1 Income (Total Expenditure) Elasticity Estimations for Animal Products from Previous Studies

R/U	Reference	Method	Data Type	Notes	Meat	Pork	Poultry	Bf/Mn	Eggs	Fish	Milk
All	Zhuang & Abbott, 2006	LA/AIDS	79-01 AG	Insignificant		0.14	0.23				
Rural	Fan et al., 1995	2SLES-AIDS	1982-90 AG	28 provinces	0.90						
Rural	Ma et al., 2004	AIDS	1980s HS	29 provinces		0.80	1.69	1.09^{+}	1.64		
Rural	Halbrendt et al., 1994	LA/AIDS	1990 HS	Guangdong	1.09		1.27				
Rural	Huang & Bouis 1996	LA/AIDS	1991 AG	National		1.01	1.13	0.45	0.68	1.39	2.06
Rural	Jiang & Davis, 2007	3SLA/AIDS	1991-95 HS	Jilin	0.88				0.61	0.50	
Rural	Yan & Chern, 2005	QAIDS	1995 HS	Henan		1.07	1.08		0.93	1.14	
Rural	Ma et al., 2004	AIDS	1990s HS	29 provinces		0.76	1.39	1.12^{+}	1.70		
Rural	Gale & Huang, 2007	LLI	2002-03 HS	National		0.24	0.66	0.39	0.46	0.93	0.70
Urban	Dong & Fuller	Rotterdam	1981-04 AG	National	1.51				0.16	1.80	
Urban	Ma et al., 2004	AIDS	1980s HS	29 provinces		0.68	1.95	1.68^{+}	1.25		1.59
Urban	Wu et al., 1995	2SLA/AIDS	1990 AG	33 cities		0.44			0.21	0.08	
Urban	Huang & Bouis 1996	LA/AIDS	1991 AG	Small cities		0.94	1.18	0.82	0.55	1.49	1.96
Urban	Huang & Bouis 1996	LA/AIDS	1992 AG	Large cities		0.92	1.22	0.79	0.56	1.48	2.20
Urban	Shono et al., 2000	Log-Log	1995 AG	National	0.88	0.46		0.50	0.45	0.81	1.05
Urban	Liu & Chern 2003	QAIDS	1998 HS	3 Provinces		0.78	0.86	0.53	0.37	0.94	1.03
Urban	Liu & Chern, 2003	QAIDS*	1998 HS	3 Provinces		0.72	0.76	0.77	0.59	0.82	0.66
Urban	Ma et al., 2004	AIDS	1990s HS	29 provinces		0.66	1.95	1.41^{+}	1.25		1.59
Urban	Yen & Lin, 2006	PSDS	2000 HS	East		0.85	1.08	0.77		1.16	
Urban	Gould et al, 2006	QAIDS	2001 HS	5 provinces		1.20	1.20	1.18	0.92	1.40	1.00
Urban	Gale & Huang, 2007	LLI	2002-03 HS	National		0.13	0.38	0.19	0.10	0.52	0.64

Note: AG - Aggregated Data; HS – Household Survey Data; Bf/Mn – Beef and/or Mutton; * - Demographic factors were added to the model in the original study. $^{+}$: The elasticities are reported for beef. Those for mutton are slightly lower for urban and much lower for rural households.
Source: Compiled by author from previous studies.

Table 2 SBM Feeding Ratio Comparison across Countries 2001-2003

Countries	Meat & Egg (MMT)	SBM Fed (MMT)	Ratio
China	87.57	18.69	0.21
US	43.57	29.02	0.67
Thailand	3.07	2.56	0.83
Korea	2.24	2.36	1.06
Malaysia	1.44	0.97	0.67

Source: Author calculations from FAOSTAT.

Table 3 US Standard Feed Conversion Ratios in 2007

Species	FCR	SBM content	Carcass Ratio	SBM/Gain
Pork	3	19%	75%	0.77
Poultry	2	27%	75%	0.73
Egg	2	22%	100%	0.44
Beef	7	2%	63%	0.22
Mutton	7	2%	52%	0.27
Milk				0.10
Freshwater Fish	1	50%	100%	0.50
Brackishwater Fish	1.5	50%	100%	0.75
Marine Fish	2	50%	100%	1.00

Source: Compiled by author from USDA-ERS, FAOSTAT, and *Grow IN Agriculture.*

Table 4 Feed Conversion Ratios in China in 2006

	FCR (live weight)	FCR (Meat)
Pork	3	4.3
Poultry	2.6	2.6
Eggs	2.5	2.5
Mutton	1.1	1.6
Beef	1.6	2.7
Fish	1.8	1.8
Milk	0.6	0.6

Source: Adapted from ERS unpublished report.

Table 5 Quantity Elasticity Model Estimates for Urban Households

Coef	ln	inv	cons	d5	d6	adj.R^2
Pork*		**-1297**	**3.152**			96%
Beef	**-0.125**	**-2917**	**2.362**	-0.042	0.005	90%
Mutton	**-0.160**	**-2978**	**2.193**	-0.008	-0.062	77%
Poultry	**0.110**	**-1752**	**1.104**	**0.280**	**0.196**	98%
Eggs	**-0.123**	**-1944**	**3.726**	-0.017	-0.022	90%
Fish	**0.246**	**-940**	0.119	**-0.036**	**-0.030**	99%
Shrimp	**0.566**	**-2841**	**-4.498**	**-0.280**	**-0.251**	99%
Milk	**0.130**	**-3397**	**2.219**	**-0.147**	**-0.139**	98%

Note: Estimation results of equation (1) using weighted least squares. Coefficients in bold typeface are statistically significant at 5%. ln, inv, cons, d5, and d6 are coefficients for log, inverse, constant, dummy for 2005 and 2006, respectively.
*: Pork is estimated using log-inv.

Source: Estimated by author from China National Bureau of Statistics data.

Table 6 Quantity Elasticity Estimates by Food Item and Income Level for Urban Households, 2004-2006

Income (yuan)	2500	5000	10000	15000	20000	30000
Pork	0.519	0.259	0.130	0.086	0.065	0.043
Beef	1.041	0.457	0.166	0.068	0.020	-0.029
Mutton	1.024	0.430	0.133	0.034	-0.015	-0.065
Poultry	0.811	0.461	0.286	0.227	0.198	0.169
Eggs	0.651	0.263	0.069	0.004	-0.028	-0.060
Fish	0.622	0.434	0.340	0.309	0.293	0.277
Shrimp	1.703	1.134	0.850	0.756	0.708	0.661
Milk	1.489	0.809	0.470	0.356	0.300	0.243

Source: Estimated by author from China National Bureau of Statistics data.

Table 7 Expenditure Elasticity Model Estimates for Urban Households

Coef	ln	inv	cons	d5	d6	Adj.R^2
Meat	**0.160**	**-1630.9**	**5.054**	0.005	**-0.044**	99%
Eggs*		**-1611.4**	**4.456**	0.010	**-0.054**	95%
Aquatic	**0.739**	**-659**	**-1.469**	**-0.084**	-0.041	99%
Milk	**0.318**	**-3171.8**	**2.414**	**-0.078**	-0.018	100%

Note: Estimation results of equation (2) using weighted least squares. Coefficients in bold typeface are statistically significant at 5%. ln, inv, cons, d5, and d6 are coefficients for log, inverse, constant, dummy for 2005 and 2006, respectively.
*: Eggs are estimated using log-inv.

Source: Estimated by author from China National Bureau of Statistics data.

Table 8 Expenditure Elasticity Estimates by Food Group and Income Level for Urban Households, 2004-2006

Income (yuan)	2500	5000	10000	15000	20000	30000
Meat	0.812	0.486	0.323	0.268	0.241	0.214
Eggs	0.645	0.322	0.161	0.107	0.081	0.054
Aquatic	1.002	0.870	0.804	0.782	0.771	0.760
Milk	1.587	0.952	0.635	0.529	0.477	0.424

Source: Estimated by author from China National Bureau of Statistics data.

Table 9 Quality Elasticity Estimates by Food Group and Income Level for Urban Households, 2004-2006

Income (yuan)	2500	5000	10000	15000	20000	30000
Meat	0.146	0.153	0.156	0.157	0.158	0.159
Eggs	-0.007	0.059	0.092	0.103	0.109	0.114
Aquatic	0.318	0.377	0.406	0.415	0.420	0.425
Milk	0.062	0.119	0.148	0.157	0.162	0.167

Source: Estimated by author from China National Bureau of Statistics data.

Table 10 Selected Countries’ SBM Feeding Ratio Diffusion Curves

Countries	Curve	R -sq	K	Max Y
United States	logistic	86%	0.9999	99%
Brazil	logistic	84%	0.9999	86%
Spain	logistic	83%	1.3	120%
Japan	logistic	76%	0.9999	98%
Italy	logistic	88%	1.1	110%
Argentina	logistic	72%	0.9999	95%
Netherlands	logistic	80%	0.9999	96%
Thailand	logistic	96%	1.2	120%
Korea, R.	logistic	84%	1.5	140%
Denmark	logistic	89%	0.9999	92%
Chile	logistic	77%	0.9999	95%
Malaysia	logistic	89%	1.3	93%

Table 11 Predicted SBM Feeding Ratio in China 2005-2030

Year	SBM Feeding Rate	Year	SBM Feeding Rate
2005	36%	2020	77%
2010	50%	2025	86%
2015	65%	2030	92%

Table 12 Assumed Income Elasticities of Demand for Animal Protein in China

	Pork	Beef & Mutton	Poultry	Eggs	Aquatic	milk
Urban	0.42	0.52	0.71	0.35	0.60	0.78
Rural	0.47	0.46	0.72	0.60	0.60	0.83

Source: Assumed by author based on previous studies.

Table 13 Predicted Meat and SBM Consumption in China 2010-2030

Year	2010	2015	2020	2025	2030
Population (million)	1340	1376	1407	1430	1440
Per Capita Real Income Growth	8.2%	4.9%	3.6%	2.8%	2.2%
Urban Population Ratio	50%	55%	60%	65%	70%
Urban Consumption (kg/yr)					
Pork	35.0	39.2	42.7	45.4	47.5
Beef & Mutton	6.8	7.9	8.7	9.4	9.9
Poultry	16.1	19.5	22.4	24.9	26.8
Eggs	17.7	19.5	20.9	22.0	22.8
Aquatic	20.2	23.8	26.7	29.2	31.1
Milk	36.3	44.7	52.2	58.6	63.6
Rural Consumption (kg/yr)					
Pork	26.5	29.1	31.2	33.0	34.9
Beef & Mutton	2.7	2.9	3.2	3.3	3.5
Poultry	6.4	7.5	8.3	9.1	9.9
Eggs	8.9	10.1	11.0	11.8	12.7
Aquatic	8.9	10.0	11.0	11.8	12.6
Milk	6.0	7.1	8.0	8.8	9.7
Theoretical SBM Demand (MMT)	64.7	77.9	90.4	101.9	111.8
SBM Feeding Ratio	50%	65%	77%	86%	92%
Predicted SBM Demand (MMT)	32.3	50.6	69.6	87.7	102.9
Predicted Soybean Demand (MMT)*	51.1	80.1	110.1	138.8	162.8

Source: *Global food 3D* and author calculations. Note: * food consumption of soybeans is assumed to be 20% of the total consumption.

Table 14 SBM Projection Results Comparisons with Previous Literature

	2010	2015	2020	2025	2030
Masuda & Goldsmith, 2009 (SBM)	29.5	34.6	39	42.9	46.3
Derived SBM Demand Projection	**32.3**	**50.6**	**69.6**	**87.7**	**102.9**
USDA-FAS (SBM)	>34				
Derived SB Demand Projection	**40.9**	**64.1**	**88.1**	**111**	**130.3**
SB Demand Projection	**51.1**	**80.1**	**110.1**	**138.8**	**162.8**
Sun et al., 2009 (SB import)	26.6	37.1	50.6		
SB Import (low*)	**33.6**	**61.5**	**90.4**	**118**	**140.9**
SB Import (high*)	**36.6**	**65.6**	**95.6**	**124.3**	**148.3**
USDA-FAS	>40				

Note: Bold letters are estimates from this study. *: Under low scenario, yield growth of soybean domestic production is assumed to be linear. Under high scenario, domestic soybean production is assumed to be flat. SB import is calculated by differencing domestic consumption and production.

Table 15 Demand Forecasts for SBM under Different Income Growths and Saturation Levels 2010-2030 (MMT)

Year	K	2010	2015	2020	2025	2030
Lower Income Growth	1.0	30.4	45.4	60.1	73.6	84.4
	1.2	31.6	48.2	66.4	83.8	97.3
	0.8	29.2	41.9	53.1	62.4	69.7
Baseline Income Growth	1.0	32.3	50.6	69.6	87.7	102.9
	1.2	33.6	53.8	76.8	99.9	118.6
	0.8	31.0	46.7	61.5	74.4	85.0

Source: Author forecasts.

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