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Who Will Feed China in the 21st Century?

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Who Will Feed China in the 21st Century?

Income Growth and Food Demand and Supply in China

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Abstract

This paper uses resource-based cereal equivalent measures to explore the evolution of China's demand and supply for food. Although demand for food calories is probably close to its peak level in China, the ongoing dietary shift to animal-based foods, induced by income growth, is likely to impose considerable pressure on agricultural resources. Estimating the relationship between income growth and food demand with data from a wide range of countries, China's demand growth appears to have been broadly similar to the global trend. On the supply side, output of food depends strongly on the productivity growth associated with income growth and on the country's agricultural land endowment, with China appearing to be an out-performer. The analyses of income-consumption-production dynamics suggest that China's current income level falls in the range where consumption growth outstrips production growth, but that the gap is likely to begin to decline as China's population growth and dietary transition slow down. Continued agricultural productivity growth through further investment in research and development, and expansion in farm size and increased mechanization, as well as sustainable management of agricultural resources, are vital for ensuring that it is primarily China that will feed China in the 21st century.

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Who Will Feed China in the 21st Century? Income Growth and Food Demand and Supply in China[1]

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Who Will Feed China in the 21st Century? Income Growth and Food Demand and Supply in China

1. Introduction

The balance between domestic supply and demand for food in China is extremely important both for China and for the world. Since China embarked on its economic reforms in 1978, it has had dramatic increases in income, achieving an 8.5 percent average annual per capita Gross Domestic Product (GDP) growth rate in purchasing power parity (PPP) terms (the World Development Indicators (WDI), the World Bank).

This rapid economic growth has contributed greatly to changes in Chinese diets both in quantity and in composition. Since China's overall per capita calorie consumption levels already appear to be well above world average levels, and to be approaching the level in the Republic of Korea, China's per capita food consumption in caloric terms seems unlikely to rise dramatically. However, diets in China are likely to change in composition, as consumers shift their diets increasingly from crop based to animal based products and away from basic staples. The shift to the diets of more affluent consumers imposes greater burdens on the agricultural sector since the production of animal based food takes much greater amounts of agricultural resources and generates more environmental externalities than production of a vegetable-based diet (Steinfeld, Gerber, Wassenaar, Castel, Rosales and De Haan, 2006; Rask and Rask, 2011).

Since the commencement of its reforms, China has experienced an impressive agricultural output growth, with its agricultural GDP at constant prices growing at an annual rate of 4.6 percent between 1978 and 2011, four times faster than the rate of population growth (Huang, Rozelle and Yang, 2013). The introduction of the Household Responsibility System (HRS) (1978), in which farmers were allowed to lease land from the collectives and to exercise autonomy in their production decisions, gave incentives to farmers to increase their productivity

and created a foundation for family-based farming. Since then, China has sustained its output growth, largely benefiting from growing agricultural Research and Development (R&D) investment and high use of key inputs such as fertilizer and irrigation systems.[2] However, in recent years, China's demand for food appears to have been growing more quickly than its supply. As a result, China's trade position for food has turned from surplus to deficit, and this gap has been widening (Fukase and Martin, forthcoming). Some concerns about China's food self-sufficiency have arisen among Chinese policy makers and other stakeholders, especially since China is relatively poorly endowed with agricultural land and water supplies compared to its population base.[3]

A World Bank project on urbanization and food security has recently devoted a great deal of research to the question of China's food demand and supply. This research looks in detail at key issues such as the impact of urbanization on China's food self-sufficiency and food security (Huang et al., 2013), on land availability (Deng, Huang and Rozelle, 2013) and on water availability (Wang, Huang and Rozelle, 2013). Using detailed structural models built up from estimated parameters of demand systems and production structures for China, Huang et al.'s study (2013) predicts that China will need to import feed grains and some other foods for some time but that its overall food self-sufficiency is likely to remain at above 90 percent level through 2030. Their results are consistent with those obtained from other studies, for instance, the forecast for China by 2022 prepared by OECD/FAO (2013) and a recent study using a multi-country multi-sector applied general equilibrium model (Anderson and Strutt, 2013).[4]

[2] Since the economic reforms, China has sustained an impressive annual growth rate in agricultural total factor productivity (TFP) of over 2 percent (Huang et al., 2013).

[3] China has about 20 percent of the world's population and 35 percent of its agricultural labor force, but has only 11 percent of the world's agricultural land and less than 6 percent of its water resources (Christiaensen, 2012).

[4] Using the Global Trade Analysis Project (GTAP) model, Anderson and Strutt (2013) project that China's agricultural self-sufficiency rate may fall about ten percentage points from the baseline level of 97 percent by 2030.

The purpose of this paper is to analyze China's income-consumption-production dynamics for food using an entirely different approach to those used in the studies cited above—econometric techniques based on data for 154 countries during the period 1980-2009. The paper aggregates both the demand for and the supply of food into resource based cereal equivalents (Yotopoulos, 1985; Rask and Rask, 2004, 2011). This approach takes into account one of the central features of food demand behavior—the shift from reliance on direct consumption of grains and other sources of basic carbohydrates into a more diversified diet including edible oils and protein-rich animal products as incomes grow. On the supply side, agricultural output is specified as a function of income and land endowment, with agricultural output growing in response to the productivity growth that is associated with national output growth per person. The econometric approach used relies on the experiences of a wide range of countries and is intended to complement, rather than replace, more detailed country-specific structural approaches.

Section 2 analyzes the changes that have occurred in dietary patterns in China. Section 3 presents the methodology used for the analysis and implements regression analyses. We first discuss the construction of the cereal equivalent measure of food output and demand. Next, we replicate and extend the income-consumption analysis of Rask and Rask (2004, 2011) to the period 1980-2009. Then, we modify Rask and Rask's approach on the production side, specifying a regression model relating both income and land endowment to production. Finally, we suggest the implications of these trends for China's likely net import demands in the future. Section 4 presents conclusions.

2. Changing Patterns of Chinese Diets

Since China embarked on its market-oriented reforms in 1978, it has achieved dramatic economic growth. China's per capita GDP in PPP 2005 prices, which was $524 in 1980, grew at an average annual growth rate of 8.5 percent to reach $7,958 in 2012 (the WDI, the World Bank). This rapid economic growth appears to have contributed greatly to changes in Chinese diets both in quantity and in composition.

Figures 1a-c show estimated average daily calorie, protein and fat intake per capita for China and selected countries for the period 1980-2009. Total calorie, protein and fat intakes are further decomposed into those sourced from crop and animal products. Figure 1a shows that total calorie intake per person per day in China grew substantially, from 2,163 kcal in 1980 to 3,036 kcal in 2009. The decomposition of the source of this change reveals that a majority of the increase comes from a rise in the consumption of animal products, while the calorie intake from crops grew slowly and stabilized at around 2,300 kcal in recent years. China's increase in per capita calorie intake has been much faster than the world average, which grew 2,490 kcal in 1980 to 2,831 kcal in 2009. As of 2009, China's calorie intake was approaching the level in the Republic of Korea, although it remained lower than levels observed in the United States and the European Union (EU) countries. Figure 1a also shows that the total average individual annual calorie intake among high income countries, namely, the United States, Japan and EU countries, declined somewhat in the most recent years.

Figure 1b shows that protein intake in China nearly doubled from 54 g per capita in 1980 to 94 g per capita in 2009 and that about three quarters of this growth came from consumption of animal products. Figure 1c shows that fat intake in China nearly tripled from 34 g per capita in

1980 to 96 g per capita in 2009, and that about two thirds of this growth came from increases in animal product consumption.

The changing dynamics of food consumption shown above affect supply and demand balances for food directly and indirectly. In particular, whereas *direct* demand for food grains such as wheat and rice, tends to decrease as income rises, the same driving force (the rise in per capita income) is likely to lead to an increase in *indirect* demand for feed grains as more grain and other feeds are needed for animal production. Figure 2a shows the self-sufficiency ratios for the key staple foods (rice, wheat, maize and soybeans combined) for the period 1960-2012 for Asian countries. Most strikingly, the self-sufficiency ratios declined sharply in higher income Asian countries, from around 75 to 27 percent for Japan, from about 88 to 21 percent for the Republic of Korea and from about 86 to 13 percent for Taiwan, China, during the period 1960/1961-2012/2013 (Production, Supply and Distribution (PSD) data, the United States Department of Agriculture (USDA)).[5] Figure 2a also shows that whereas China tended to achieve self-sufficiency for grains for the 1960s, 1970s, 1980s and most of the 1990s, its self-sufficiency ratio has been declining in recent years.

Figure 2b reports the evolution of the demand and supply gap by major grains for China. It is clear that China's recent declining self-sufficiency ratio for grains is predominantly attributable to a large increase in soybean imports. The expansion of the livestock sector which increased the demand for protein meal, along with the rise in consumers' demand for vegetable oils, was a major factor leading to the growing demand.[6] The Chinese government appears to

[5] However, further disaggregation of the data reveals that the self-sufficiency ratios for Japan, the Republic of Korea and Taiwan, China, vary by grain: whereas imports of corn contributed most to the widening gap for three countries, they have been relatively self-sufficient in terms of rice.

[6] In 2009, out of 59 million tons of domestic soybean consumption, about 9 million tons was consumed as food. 49 million tons of soybean was crushed and made into 9 million tons of vegetable oil and 39 million tons of soymeal (PSD, USDA).

have responded to the rising demand by liberalizing soybean imports gradually (Weiming and Ying, 2013).[7]

Some scholars view China's increasing imports of soybeans as a rational response to the rising resource constraints in China, especially because soybean is a crop which requires a large amount of land and water (Christiansen, 2012; Qiang, Liu, Cheng, Kastner and Xie, 2013; Weiming and Ying, 2013). For instance, calculating the "virtual" land use embodied in China's imports and exports of crops, Qiang et al. (2013) find that China has become a massive net importer in terms of virtual land during the period 1986-2009 and that the increase in virtual land imports was mainly driven by the rise in imports of soybean. By effectively freeing land, the soybean imports appear to have saved China's domestic cropland area for food grains such as wheat and rice which tend to be regarded as more important for food security objectives (OECD and FAO, 2013; Qiang et al., 2013). In terms of virtual water trade, Chapagain, Hoekstra and Savenije (2006) and Hoekstra and Hung (2005) find that China conserved its national water resources by importing water-intensive agricultural products.

3. Methodology and Regression Analyses

As incomes grow, consumers diversify their food consumption away from basic food staples. This process includes a move to include more edible oils, vegetables, fruit and animal products. Per capita consumption of staple foods declines during this process. Historically, the urbanization process that is inextricably linked with income growth appears to have reduced per capita food consumption slightly by reducing energy needs (Clark, Huberman and Lindert, 1995). In Asia, it also appears to have increased demand for wheat relative to rice (Huang and

[7] China adopted a more liberal trade scheme for soybeans in 1996 which was locked in through negotiations to access the World Trade Organization (WTO) (Weiming and Ying, 2013). China became a full member of the WTO in 2001.

David, 1993). However, it now appears that the key driving force behind changes in per capita food consumption is changes in real incomes—the same increases in real incomes that drive the urbanization process (Satterthwaite, McGranahan and Tacoli, 2010).

3.1. Cereal Equivalent (CE) Measures of Food

Some scholars argue that the dietary shift from crop based to animal based products may increase total food demand sharply relative to supply, due to the inefficient conversion of plant based feeds (typically cereals[8]) into animal based foods.[9] Yotopoulos (1985) argues that the supply of cereals available for food may decline as developed and middle-income countries consume cereals disproportionately as feed, raising world prices of cereals. He suggested that this "Food-Feed Competition" may have contributed to the world food crisis of 1972-74. More recently, a number of scholars have explored the implications of this dietary shift on agricultural resources and the environment (e.g., Elferink and Nonhebel, 2007; Garnet, 2009; Gerbens-Leenes, Nonhebel and Ivens, 2002ab; Gerber, Steinfeld, Henderson, Mottet, Opio, Dijkman, Falcucci and Tempio, 2013; Steinfeld et al. 2006; Williams, Audsley and Sandars, 2006; Wirsenius, 2003; Wirsenius, Azar and Berndes, 2010). For instance, Wirsenius (2003) argues that the idea of competition for grains between animals and humans does not capture fully the resource implications of dietary change, since the core issue is the competition for land rather than competition for consumption of cereals. Analyzing comprehensively total feed[10] and land requirements in their land-minimizing model, Wirsenius et al. (2010) suggest that greater feed-

[8] About 34 percent of cereals were consumed indirectly in the form of animal feed in 2009 (FAOSTAT).
[9] Yotopoulos (1985) suggests calorie-equivalent grain-meat conversion ratios vary from 2:1 for poultry to 7:1 for grain-fed beef, estimates that do not appear to take into account indirect use, such as for breeding animals, considered by Rask and Rask (2011).
[10] In addition to the edible-type crops (e.g., cereals, starchy roots, sugar crops and oil crops), Wirsenius (2003) considers other types of feeds such as the use of forage crops, pastures, and by-products/residues.

to-food efficiency in animal production, decreased food wastage and dietary changes towards less land-demanding foods would help to reduce agricultural land use.

Animal production competes for land directly, for instance, for grazing and fattening, and indirectly through the need to produce animal feeds.[11] Gerbens-Leenes et al. (2002ab) show that foods associated with affluent lifestyles, especially animal products, oils and fats, and beverages, tend to require more land for their production than foods associated with less affluent lifestyles. For China, following Gerbens-Leenes et al. (2002ab)'s methodology, Li et al. (2013) find that China's urbanization appears to have increased pressure on limited arable land resources, since urban residents consume more animal based and other land-demanding food than their rural counterparts.

The approach adopted in this paper is based on the methodology developed by Rask and Rask (2004, 2011) which converts crop and animal products into cereal equivalents. The CE coefficients for crop-based products are computed very simply by matching their caloric content to those of an equal weight of cereals, assuming broadly similar efficiencies across commodities but taking into account the greater resource use associated with producing foods that contain more calories per unit of weight (e.g., vegetable oils) relative to those that have, for instance, a higher water content (e.g., starchy roots). For animal products, the CE coefficients reflect the feedstuff used to produce one unit of animal products in terms of the dietary energy equivalent of a unit of corn, considering not only grains consumed but also other types of feed such as protein supplements, forages (including pasture) and other feeds.[12]

[11] Livestock is the world's largest user of land resources, with grazing land and cropland dedicated to the production of feed crops and fodder representing about 70 percent of all agricultural land. About 33 percent of arable land is used to produce livestock feed (Steinfeld et al., 2006).

[12] The CE coefficients developed by Rask and Rask (2004, 2011) are based on a study published by the USDA (1975). The USDA study is unique in covering all types of feeds including forage crops and pasture in calorie equivalents of corn over the period 1964-1973. Wirsenius (2003) challenges the view that the use of non-edible feeds is "free" arguing that it involves opportunity costs such as production of feedstock for biofuels, preservation of

Table 1 shows the CE coefficients used to convert crop and animal products into cereal equivalents.

Table 1. Sample Cereal Equivalent (CE) Coefficients

Crop products		Animal products[a]	
Products	Coefficients	Products	Coefficients
Cereals	1.00	Bovine meat	19.8
Fruits	0.14	Pig meat	8.5
Pulses	1.06	Poultry meat	4.7
Starchy roots	0.25	Mutton & Goat meat	19.8
Sugar, sweeteners	1.08	Eggs	3.8
Tree nuts	0.74	Milk	1.2
Vegetable oils	2.73		
Vegetables	0.07		

Source: Rask and Rask (2011) and authors' calculation.
[a]Meat coefficients represent animal carcass weight to conform with FAOSTAT definition of meat consumption.

The coefficients in Table 1 reflect the high resource costs of producing animal products relative to cereals, and illustrate the great differences among animal products. The CE coefficient of 19.8 for carcass beef, for instance, takes into account the large amount of feed used directly to produce beef; the relatively low dressing weight percentage for live cattle (0.59); and feed for breeding cows and young calves needed to supply production animals and replacement breeding stock.[13] Pork, poultry and fish are more efficient both because of generally higher feeding efficiencies and the lower costs involved in maintaining their breeding stock. Within crop products, CE coefficients range from 2.7 for vegetable oils to 0.07 for vegetables.

The magnitudes of the CE coefficients appear to be broadly consistent with other estimates of land requirements in the literature (e.g., Gerbens-Leenes et al., 2002ab; Williams et

favorable soil condition and restoration of ecosystems and habitats. Wirsenius et al. (2010) show that the global use of the non-edible type feeds is substantial.

[13] Using beef as an example, Rask and Rask (2011) use a feed conversion ratio of 11.7 for producing live cattle, taking into account feed for both animals slaughtered and for breeding animals. This figure is converted to carcass weight using a dressing weight percentage of 59 percent, which gives rise to the final value of 19.8 (11.7/0.59). Carcass weight is used in order to conform to FAOSTAT meat consumption coefficients which are presented in carcass weight format (e-mail communication with Norman Rask).

al., 2006; Wirsenius, 2003, 2010). For instance, using data for the Netherlands in 1990, Gerbens-Leenes et al. (2002a) estimate the land requirement for beef to be 20.9 m^2 year per kilogram of meat which is more than twice that for pork (8.9 m^2 year per kilogram of meat) whereas their land requirement estimate for cereals turns out to be relatively small (1.4 m^2 year per kilogram). For China, land requirement estimates obtained by Li et al. (2013) and Zhen et al. (2010) are broadly comparable with those from other studies.[14] The implications for environmental burdens implied by the CE coefficients[15] are also generally in line with the findings of other studies.[16] Researchers tend to find that beef production has the most severe GHG impact per kilogram of meat, followed by pork and chicken production (e.g., Fiala, 2008; Gerber et al., 2013; Steinfeld et al., 2006).

Finally, the cereal equivalent measure used in this study does not consider varying feed requirements for animal production depending on technology (e.g., feed mix and efficiencies), production systems (Robinson, Thornton, Franceschini, Kruska, Chiozza, Notenbaert and You, 2011) and local resource availabilities. Differentiating CE coefficients by regions and by production systems would be a potential subject of future research. Further, our analytical technique in the empirical section does not take into account distortions from agricultural incentives, food price policy, or farm gate pricing differences related to product self-sufficiency.

[14] For instance, the arable land requirement for beef of 2.5 m^2 per kilogram of meat estimated by Li et al. (2013) is much smaller than that of Zhen et al. (2010) of 16.7 m^2 per kilogram, largely reflecting the fact that the former study considers only the arable land area for growing "refined" livestock feed (e.g., maize etc.) whereas the latter study includes grassland used to grow grass fodder.

[15] For instance, Williams et al. (2006) find the global warming potential to be about 20 times higher for beef production than for wheat production (Rask and Rask, 2011; Williams et al., 2006).

[16] Livestock production is believed to be one of the largest sources of greenhouse gases (GHG), contributing about 18 percent of the environmental pressures that are believed to be causing global warming (Gerber et al., 2013; Steinfeld et al., 2006). Feed production and processing, and enteric fermentation from ruminants are reported to be the two main sources of emissions, representing 45 and 39 percent of the sector emissions respectively, followed by manure storage and processing (10 percent) (Gerber et al., 2013). For instance, it is reported that, in the Brazilian Amazonian region, a significant amount of carbon dioxide is released when forest is converted into grazing for cattle ranching or into arable land for soy production (Garnett, 2009; Steinfeld et al., 2006). Brazil has committed to a range of mitigation targets to reduce deforestation in the Amazon and in the Cerrado (Gerber et al., 2013).

It would be desirable to do this in future work, but we believe that the impacts on the aggregate measures that we consider are likely to be less than protection rates might suggest. Countries with high average rates of agricultural protection typically provide high rates of protection on traditional staple foods such as rice. But political economy pressures generally keep the rate of protection on feedgrains quite low and hence keep the prices of domestically-produced livestock products like pork and poultry low relative to staple grains. This structure of protection results in an incentive for consumers to increase their consumption of livestock products, thus accelerating the dietary transition that is the focus of this study.

3.2. Estimating Consumption Demand

Cereal Equivalent (CE) Consumption in China

Figure 3a shows that China's CE consumption expanded nearly four times from 407 million tons in 1980 to 1,479 million tons in 2009 (a 264 percent increase). Figure 3a also shows that the rise is mainly driven by the increase in consumption of animal products (which accounts for 87 percent of the change in consumption), while CE consumption of crops remains relatively steady, contributing the remaining 13 percent of CE food consumption increases since 1980.

The increase in China's food consumption at the national level is attributable to both population growth and diet upgrading. Figure 3b shows that China's population increased from 1.0 billion in 1980 to 1.4 billion in 2009 and that its population growth is expected to taper off gradually. Figure 3c decomposes the change in CE consumption into the components of population growth[17] and of diet changes since 1980. The figure shows that about one-third of the increase in food consumption is attributable to China's population growth, and the remaining

[17] The population growth component reflects both the increase in population and the share of dietary changes imputed to the added population.

two-thirds can be explained by the change in diets. As China's population growth is slowing and its total population is projected to peak around the year 2025 (at a level about 2.3 percent higher than in 2014) (FAOSTAT), the primary driver of food consumption increases is likely to be change in diet, and therefore change in *per capita* consumption.

Income-Consumption Relationship: Regression Analyses

While we can observe the rapid growth in China's consumption of food over the period since 1980, this gives us little insight into the way this growth is likely to play out in the future. To gain some insights into this, we turned to econometric analysis using a large sample of countries. This allows us to view a much larger range of real incomes and to obtain a better idea of the extent to which the growth of food consumption in cereal equivalents begins to decelerate. This relationship includes most importantly the effects of income growth on the demand for basic food staples and for foods with relatively high income elasticities but also other influences on demand such as changes in the rate of assistance to agriculture with income growth (Anderson, 1995).

We estimate the CE consumption-income relationship using the functional form used in Rask and Rask (2004, 2011). Specifically,

$$y = f(x) = A_1 - A_2 e^{-kx}, \quad f' > 0, \quad f'' < 0 \qquad (1)$$

where y is CE consumption per capita and x is PPP GDP per capita in 2005 constant prices. As $f' > 0$, $f'' < 0$, this functional form captures the observed pattern of the change in CE consumption, which rises more rapidly at early stages of development and tapers off at higher levels of income. It implies that, as incomes continue to increase, consumption asymptotically approaches a limit given by A_1. Historical figures for CE consumption per capita are calculated using food supply, food demand and population data extracted from FAOSTAT. The GDP data at PPP are obtained

from the World Development Indicators (the World Bank). We use the data for the period 1980-2009 since the GDP data are available only after 1980 and the latest data available in FAOSTAT are for 2009.

The first column in Table 2 reports a cross-section regression result using a 5-year average of CE consumption and GDP for the period 2005-2009. The fitted CE consumption curve based on the regression result is shown in Figure 4 along with actual CE consumptions for the sample countries, including data for China in red. The second column in Table 2 reports an alternative regression using all the available data points for each year during the period 1980-2009. In this regression, the standard errors are adjusted for within-country correlation (clustering). The results turn out to be similar between the two regressions.

Table 2: Regression Results for Cereal Equivalent Consumption

	(1)[a]	(2)[b]
A_1	2.2***	2.2***
	(0.17)	(0.16)
A_2	1.7***	1.7***
	(0.16)	(0.15)
k	4.6×10^{-5}***	5.8×10^{-5}***
	(9.5×10^{-6})	(1.1×10^{-5})
R^2	0.74	0.71
Observations	154	4100

Source: Authors' regression results
Notes: *** indicates that the coefficients are significant at the one percent level.
[a] Regression (1) is based on 2005-2009 averages of CE consumption and real GDP for 154 countries. Robust standard errors are given in parentheses.
[b] Regression (2) shows the results using all the available data points for each year during the period 1980-2009. The standard errors in parentheses are based on heteroskedasticity-consistent estimates of the variance-covariance matrix and corrected for within country correlation (clustering).

The graph presented in Figure 4 shows a concave relationship between food consumption in cereal equivalents and real income levels (Rask and Rask, 2004, 2011). This curve is steep in the early stage of economic development since consumers are likely to spend a large proportion of increases in their incomes on food. This CE consumption continues to increase, albeit at a

slower rate, as incomes grow further and consumers substitute higher-order foods (such as animal products) for cereals and tubers. Only at higher levels of income such as $40,000 does per capita CE consumption growth slow down as the diet shift is nearing completion. This graph also shows the income-consumption pairs for a large range of countries, making clear that there is considerable variation around this broad trend. This is to be expected with such a simple measure, given the differences in food consumption patterns among nations, some of which may be due to inherent cultural features, with others perhaps related to habit formation patterns of the type analyzed by Atkin (2013), or to food price differences related to policy and product self-sufficiency.

Based on the FAO statistics that we use, China's consumption pattern is close to the average demand pattern for our global sample. Not surprisingly, consumption levels are particularly high in countries such as Australia and Brazil, where beef and sheepmeats are produced largely using pasture whose price is determined—given the available technology—by the prices of these beef and sheep products, rather than by arbitrage between pasture and grain. Japan is a negative outlier, probably because of the importance of seafood in its historical animal-product diet with the price of fish determined—at least until recently—by costs of catching from the wild, rather than by the costs associated with fish-farming. Only recently has arbitrage between wild-caught and farm-raised seafood justified the use of our approach to aggregation on the assumption that fish can be produced using cereal products.

In order to gain historical perspective, Figure 5 shows the changes in CE consumption between the beginning of the sample period (the year 1980) and the end (the year 2009). This shows that most countries where per capita income grew substantially observed a sizeable increase in consumption levels, with the slope of the resulting ray being very broadly similar to

that of the estimated equation in the range relevant to the income growth of that country. Contrasting cases, such as the decline in observed consumption levels in Australia, appear to reflect structural shifts in demand away from meats such as beef and sheepmeats that rely on relatively inefficient conversion processes into more efficiently-produced livestock products like poultry (Martin and Porter, 1985). The drop of CE consumption for Hungary appears to reflect the transition from a high level diet, which was induced by low food prices and production subsidies under a centrally planned low food price system, to a food price level more consistent with market economies (Rask and Rask, 2004).

Figure 6 compares the estimated growth of demand for cereal equivalents and for calories on a comparable scale. We use the same functional form (1) to estimate the relationship between income growth and calorie consumption. China's CE and calorie consumption points for each year during the period 1980-2009 are also shown in the same figure. Figure 6 shows two results that are significant for our analysis. First, consumption of calories tends to level off much earlier and at a much lower level than consumption of cereal equivalents. Second, China's per capita consumption levels for both calories and cereal equivalents have been closely consistent with global trends.

3.3 Production

Income, Productivity and Land Endowments

Agricultural output tends to rise as real income rises (see Figure 9 below). The primary driving force for this relationship is the increase in productivity that contributes to increases in national incomes. This relationship is, however, influenced by several other factors, including: (i) the shift in demand away from staple foods, as discussed in the demand section, that influences the

prices of non-traded or incompletely-traded foods and hence the incentives for their production, (ii) differentials in the rates of productivity growth between agriculture and other sectors (Martin and Mitra, 2001), and (iii) Rybczynski effects when high (or low) rates of capital accumulation change factor endowments (Martin and Warr, 1993) or when land use changes alter agricultural land endowments. Since the growth rate of the agricultural sector is almost invariably slower than that of the economy as a whole for most countries, we would generally expect a given percentage change in GDP to result in a less-than-proportional increase in agricultural output.

In order to see if the data support a positive association between income and agricultural productivity, Figures 7a and 7b plot the relationship between GDP and proxies for land and labor productivity. The income-productivity pairs for China are shown in red. Figure 7a shows the relationship between GDP PPP per capita and the average cereal yield per hectare as a proxy of land productivity. Figure 7a confirms that income level and land productivity are positively associated and that China achieved high land productivity relative to its current level of income, almost approaching the productivity level reached by high performing Organization for Economic Cooperation and Development (OECD) countries. This impressive achievement is likely to reflect a number of factors, for instance, a high degree of fertilizer use, expansion of irrigated land,[18] widespread use of multiple-cropping and the introduction of new seed varieties and other technology improvements (Huang and Rozelle, 1996).

Figure 7b plots the relationship between real GDP per capita and agricultural value added per worker as an indicator of labor productivity. Not surprisingly, higher income is generally associated with higher agricultural labor productivity. However, in contrast to China's high land productivity, its labor productivity is found to be very low given its level of development.

[18] Christiaensen (2012) reports that fertilizer use intensity in China is amongst the highest in the world (Figure 6, p.17) and that yields were further boosted through expansion of irrigation (Figure 7, p.18).

China's low labor productivity may possibly be attributable to small farm size (0.6 hectare on average), land fragmentation (Jia and Petrick, 2013), and to the labor-intensive nature of family based farming. In addition, several scholars report that the labor productivity gap between farm and non-farm sectors remains high in China (e.g., Fan, Zhang and Robinson, 2003; Kujis and Wang, 2006). Labor is likely to move out of agriculture and this shift is an inherent part of the process of economic development (World Bank and the Development Research Centre (DRC) of State Council, 2014).

Figure 8 and its attached table show the evolution of agricultural land endowments for selected countries. Following Rask and Rask (2011), hectares of land per capita are computed as a summation of arable land, land in permanent crops, and one-third of land in permanent pastures using FAOSTAT data. Since 1980, the worldwide per capita amount of agricultural land has decreased by about one third from 0.54 ha in 1980 to 0.39 ha in 2009, revealing a trend that agricultural land per capita has been becoming increasingly scarce worldwide. China appears to be a relatively land-scarce country, with its land endowment only about half the world average. Not surprisingly, relatively large net exporters of food, such as Brazil and the United States, are much better-endowed with agricultural land, having agricultural land endowments that are roughly four and five times China's. However, the United States has reduced its per capita agricultural land by about a third over the same period. In comparison with neighboring net food importing countries such as the Republic of Korea and Japan, China has nearly four times the agricultural land endowment per person as the Republic of Korea and almost five times as much as Japan.

Relating Income, Land Endowment and Production: Regression Analyses

We use a regression model to explain agricultural output using land endowment and GDP per capita. The particular specification that we use is:

$$z = B_0 + B_1 x^{B2} l^{B3} \quad (2)$$

where z is CE production per capita, x is PPP GDP per capita in 2005 constant prices, l is hectares of land equivalent per capita. B_0 is intended to capture a subsistence level of agricultural production, assuming that people produce some food from local resources even when their per capita GDP levels are very close to zero. As the purpose of the exercise is to evaluate the demand and supply for "food", CE production per capita reflects "net" production; it is calculated subtracting from (gross) production (FAO, 2001) the use of agricultural output for feed, seed, food manufacture use, other uses and waste. Thus, the difference between food consumption and (net) food production reflects imports, exports and changes in stock.

Column 1 in Table 3 reports a cross-section regression result using a 5-year average of CE production and GDP for the period 2005-2009. Removing some outliers on the production side results in a sample of 140 countries.[19] In parallel with the CE consumption side (Table 2), Column 2 in Table 3 shows the results using the data points available in our sample for the period 1980-2009 (regression (2)). The parameter estimates turn out to be reasonably similar between the two regressions.

[19] It is noted that our results are somewhat sensitive to the exclusion of the outliers on the production side. If, for instance, we run regressions without excluding outliers, the results turn out to be: B_o = 0.27**(0.11), B_1 = 8.9 × 10^{-4}(1.5 × 10^{-3}), B_2 = 0.77***(0.16) and B_3 = 0.33***(0.036) (R^2 = 0.56, Observations = 154) for regression (1); and : B_o = 0.22**(0.10), B_1 = 1.7 × 10^{-3}(2.1 × 10^{-3}), B_2 = 0.71***(0.12) and B_3 = 0.31***(0.030) (R^2 = 0.57, Observations = 4100) for regression (2). However, qualitative results remain essentially unchanged with or without outliers.

Table 3: Regression Results for Cereal Equivalent Production

	(1)[a]	(2)[b]
B_0	0.24**	0.23**
	(0.12)	(0.11)
B_1	4.3×10^{-3}	3.9×10^{-3}
	(5.4×10^{-3})	(4.3×10^{-3})
B_2	0.60***	0.62***
	(0.11)	(0.10)
B_3	0.33***	0.32***
	(0.031)	(0.037)
R^2	0.64	0.65
Observations	140	3762

Source: Authors' regression results
Notes: ** and *** indicate that the coefficients are significant at the five and one percent level respectively.
[a] Regression (1) is based on 2005-2009 averages of CE consumption and real GDP for 140 countries. The robust standard errors are given in parentheses.
[b] Regression (2) shows the results using all the available data points for each year during the period 1980-2009. The standard errors in parentheses are based on heteroskedasticity-consistent estimates of the variance-covariance matrix and corrected for within country correlation (clustering).

Based on the parameter values reported in column 1 in Table 3, Figure 9 shows the estimated relationship between income levels and cereal equivalent production. To allow comparison in two dimensions, the CE production schedule for each country is adjusted so that it has the same land endowment as China (0.21 hectare per capita as an average of the period 1980-2009 per person).[20] The estimated CE production curve is visually close to linear: it rises in line with income, although less rapidly than income because of the secular decline in agriculture's share of national income. From Figure 9, it appears that China has been an out-performer in terms of output. Agricultural output, which is slightly below the consumption level, is substantially above the global trend level. This may reflect the relatively high productivity of much of China's agricultural land and the extraordinary efforts made in China to increase

[20] Both sides of equations (2) are divided by $\left(\frac{l_i}{0.21}\right)^{.33}$ where l_i is the average of land endowment of country i and 0.21 is the average land endowment of China.

productivity in recent decades (International Food Policy Research Institute (IFPRI); 2012; Jin, Huang, Hu and Rozelle, 2002). For instance, a study by the IFPRI (2012) documents that more than one-third of the increase in global public agricultural R&D spending between 2000 and 2008 was attributable to China.[21] However, there have been some concerns expressed about measurement problems with China's livestock production, an issue that is discussed in more detail in the Appendix.

3.4. Supply and Demand Balance for Food

Figures 10a-c compare how the historical patterns of CE production and consumption differ depending on land endowments, translating the differences in endowments into differences in the income response curves based on the parameter results reported in Table 3 (regression (2)). Figure 10a plots actual CE production and consumption points for China for the period 1980-2009 along with estimated global CE production and consumption trend curves. The global production schedule is evaluated at China's land endowment (0.21 hectare per person on average). Figure 10a demonstrates the differing growth patterns of CE production and consumption. At early stages of development, demand for food tends to grow faster than production, widening the gap between supply and demand. As incomes grow, the growth of consumption will slow down relative to growth of production and the gap will begin to close.

Figure 10a demonstrates that, at the onset of the reform, China's CE food production and consumption grew together, albeit from a very low level, at a much faster rate than the global trend, most likely reflecting the impacts of institutional reforms (Rozelle and Swinnen, 2004). China's production fell slightly below its consumption from around 2000, even though China's

[21] During the period 2000-2008, global public agricultural R & D spending increased by $5.6 billion from $26.1 to $31.7 billion in 2005 PPP prices. 38 percent of the increase ($2.1 billion) was accounted for by China (IFPRI, 2012).

CE production of food remained steadily above the global trend level. For comparison purposes, we plot CE consumption and production points for India since it has a similar land endowment to China's (0.19 hectare per person on average). India appears to have attained self-sufficiency for food throughout the period, but at a much lower level of output and consumption than in China, perhaps partly reflecting India's low meat consumption (Alexandratos and Bruinsma, 2012) and its slower growth in agricultural TFP relative to China (Nin-Pratt, Yu and Fan, 2010).

Figures 10b and 10c contrast the evolution of CE consumption and production patterns for relatively land abundant and land scarce countries respectively. In Figure 10b, their estimated CE production schedules are evaluated at the United States' and Brazil's land endowment levels (0.99 hectare and 0.79 hectare per person as averages during the period 1980-2009 respectively). Figure 10b demonstrates that relatively land abundant countries such as Brazil and the United States tend to be exporters over a wide range of income levels, as their estimated CE production lines are almost always above the CE consumption line and the surplus tends to rise with income growth. There is an underlying dynamic favoring growth of exports from the United States, where the growth of CE consumption has stabilized, although production growth seems to have been below what might have been expected. While productivity growth contributed to output growth in the United States, a shift of resources out of agriculture may have offset output growth, making the United States a relatively stable leading exporter.[22] In Brazil, production growth has been substantially greater than might have been expected—a factor that appears to be increasing Brazil's exports. Figure 10c reports estimated CE production lines evaluated at the Republic of Korea's and Japan's land endowment levels, 0.05 hectare and 0.04 hectare per person respectively, along with those two countries' actual CE consumption and production points for

[22] Fuglie, MacDonald and Ball (2007) report that, whereas agricultural input, especially cropland and labor, fell after 1980 in the United States, increased TFP growth outweighed the effects from the declining resource base keeping output from falling.

the period 1980-2009. In contrast to Figure 10b, their estimated CE production lines are below the CE consumption line throughout the period, showing that countries with scarce land endowments tend to be food importers throughout all income levels. In Japan and the Republic of Korea, both demand and supply growth appear to be relatively slow, with the slow growth rate of supply relative to overall income growth contributing to strong net import demand (Figure 10c).

In order to gain insight into how China's consumption and production gap is likely to evolve in the future, we conduct some simulations with hypothetical scenarios. In scenario 1, we start with Figure 10a in which China's actual CE consumption and production as well as estimated CE consumption and production (adjusted to reflect China's average land endowment of 0.21 hectare) trends are shown. Then, we assume that the small gap between China's food consumption and the production from the model is due to factors—such as acquired tastes—that are likely to be time-invariant, and treat the residual from current levels as sustained and so shift the curve accordingly. In the same way, we assume that China's outperformance on the production side is sustained, and correspondingly shift the supply curve to remove this residual. The resulting diagram is shown in Figure 11a. This figure shows that the slope of CE consumption and that of CE production evaluated at China's land endowment are comparable at around $16,350 PPP GDP. Thus, the gap between China's supply and demand for food may continue to grow slightly as China's income per capita rises from its current level to around $16,350. Above that level, it seems likely, according to this scenario, that the growth of consumption will slow down relative to production growth and the gap begins to decline.

The results of scenario 11a depend on an assumption that China's agricultural resource endowment remains the same. However, as China's economy develops and urbanization

proceeds, it is likely that China would experience some loss in its cultivated land both in terms of quantity and quality (Deang et al., 2013; World Bank and DRC, 2014). Figure 11b shows the result of a scenario in which we assume that China's agricultural land areas and land bio-productivity (agricultural production potential) continues to decline at the rate found by Deng et al. (2013), 0.47 percent and 1.68 percent over the period 2000-2008, respectively (scenario 2).[23] Specifically, it is assumed that China loses its "effective" land at 0.27 percent annually (combination of land area and bio-productivity loss), given projected population growth and economic growth rates taken from Huang et al. (2013). In this scenario, as the CE production at each GDP level is evaluated at the projected level of China's land endowment, the estimated CE production line in Figure 11b becomes flatter than that in Figure 11a. As a result, the changes in China's CE consumption and production turn out to be comparable when China's income reaches around $18,500 in PPP terms per person. Until China reaches that point, the gap between supply and demand increases more under scenario 2 than under scenario 1. The results of these scenarios highlight that sustainable land management appears to be a key determinant to ensure reasonable supply and demand balance for food in the future.

These are, of course, only hypothetical scenarios. If, for instance, China's demand for food were to stabilize at a lower level than is assumed in these scenarios, then the gap between supply and demand might start to close at an earlier time. On the supply side, if China were to reduce its investments in agricultural productivity, or if climate change were to decrease its productivity, or if China were to lose agricultural land at a faster rate than that under scenario 2, the gap might increase further. Nevertheless, China is in a very different situation from a country

[23] Between 1988 and 2000, China recorded a net increase in cultivated land of 1.9 percent, which nearly offset the decrease in average potential bio-productivity (-2.2 percent). During the period 2000-2008, area of cultivated land decreased by 0.47 percent while the potential bio-productivity is reduced by 1.68 percent (Deng et al., 2013; World Bank and DRC, 2014).

such as Japan or the Republic of Korea, where the much smaller land endowments almost ensure that continuing large net imports of food will be required.

One important caveat of this study is that the data used for the analyses rely on FAOSTAT data which in turn are based on official statistics. In particular, several scholars point out that the livestock data for China are flawed (Fuller, Hayes and Smith, 2000; Ma, Huang and Rozelle, 2004). Although we are aware of this potential bias in FAOSTAT data, it turns out to be impossible for us to replace FAOSTAT data with revised data due to the lack of comparable data for other countries. We therefore deal with this issue by conducting a sensitivity analysis in the Appendix.

Some Policy Challenges

China's ongoing shift in demand into more affluent, and particularly animal-based, foods is likely to impose substantial pressure on agricultural resources and environment. In particular, animal production puts pressure on land both directly[24] and indirectly through feedstuff production. Cropland area tends to decrease as it competes for space with urban and industrial uses. Since income growth is associated with both dietary upgrading and economic activities which generate income, economic development is likely to intensify the competition for land. In addition, the quality of China's cultivated land is reportedly deteriorating due to soil degradation, pollution and desertification (Chen, 2007; OECD and FAO, 2012; Ye and Ranst, 2009). Climate change adds another challenge, as the overall impact of climate change on agricultural productivity is likely to be negative (Ju, van der Velde, Lin, Xiong and Li, 2013).

Given increasingly tight resource constraints, the evolution of China's net import demand for food depends heavily on its productivity growth in agriculture. This is especially so, as China

[24] About 20 percent of the world's pastures and rangelands are degraded to some extent mainly through overgrazing. In China, the shift of production towards a large-scale grain-based industrial system appears to be leading to nutrient overload of soils and water pollution in some geographically concentrated areas (Steinfeld et al., 2006).

continues to develop from an upper-middle to high income country.[25] The experiences of high income countries reveal that their agricultural output growth tends to rely increasingly on TFP growth rather than input growth (Fuglie, 2012).[26] The increase in productivity would also generally have the desirable effect of increasing the incomes of farmers. In particular, it has very powerful poverty-reducing impacts because so many of the poor—especially in China—live in rural areas and depend on agriculture for their livelihoods (Christiaensen, Demery and Kuhl,2011; Christiaensen, 2012).

Continued investment in R&D is likely to be a key factor for sustained growth of agricultural output in China. However, as China's land productivity has already attained a high level, there is a possibility that further intensification of the use of cropland would result in diminishing returns and environmental degradation (Brown, 1994; Wirsenius, 2010). Technological developments beyond the focus on yield growth, in particular, to explore sustainable management of natural resources and to address environmental concerns, seem likely to become increasingly important. In contrast to China's high land productivity, the labor productivity of farmers in China remains low given China's development level and relative to other sectors of its economy. The shift of labor out of agriculture is likely to continue, imposing challenges on China's current labor-intensive, family based agricultural production system.

Some scholars point out that farm size in China is too small to reap economies of scale necessary for domestic production to satisfy domestic demand (Otsuka, 2013). As China's comparative advantage has been shifting from the farm to the non-farm sector and the

[25] According to the World Bank's income classification, China moved up from "low" to "lower middle income" status in 1996 and further advanced to "upper middle income" status in 2010 (http://data.worldbank.org/about/country-classifications).

[26] Decomposing agricultural output growth into contributions from inputs and TFP for the period 1960-2009, Fuglie (2012) shows that developed countries as a whole have relied increasingly on TFP growth to keep output from falling. Total agricultural inputs for developed countries as a group have been declining since the 1980s (Fuglie, 2012, Table 16.4).

opportunity cost of farm labor is rising, farm sizes need to be expanded, because the substitution of large machines for labor requires scale economies (Otsuka, 2013; Yamauchi, 2014). Promoting scale economies and mechanization is likely to involve a number of changes, including development of land rental markets (Deininger and Jin, 2005; Zhang, Qingguo and Xu, 2004), institutional development such as machine rentals (Takahashi and Otsuka, 2009) as well as removal of restrictions on labor movement from farm to non-farm sectors (Fan et al., 2003). About one-third of the world's farmers are still in China (Christiaensen, 2012). How to promote farm size expansion while ensuring the well-being of smallholders is an important challenge which requires future research. For instance, using farm panel data from Indonesia, Yamauchi (2014) finds that while relatively large farmers tended to increase the scale of operation by substituting machines for labor and by renting more land, such a dynamic change was not observed among relatively small holders.

In principle, a gap between the demand and the supply for food could be diminished by a protection policy that raises the price of all agricultural products relative to non-agricultural products. However, this would have the undesirable effect of reducing the access of some poor people to the staple foods that they need. In any event, as shown in Figures 12a and 12b, it appears that per capita demand for key food staples, such as rice and wheat, is now declining quite sharply in both urban and rural settings. This suggests that it is unlikely that the gap between food demand and supply in China will manifest itself as large net imports of these staples. Given this, there does not seem to be a self-sufficiency argument for increased protection of these staple foods.

Protection for the feedstuffs demanded by China's rapidly growing livestock production sectors could reduce demand for these products, but would do so at the risk of hindering the

development of a modern livestock sector. Given China's land constraints, such a policy, if pursued strongly, could create a demand for imports of staple products by taking land out of staple crops and potentially creating self-sufficiency concerns despite declining consumption of these products.

4. Conclusions

This paper explored the evolution of China's demand and supply for food using resource based cereal equivalent measures of the type proposed by Yotopoulos (1985) and extended by Rask and Rask (2004, 2011). We note that, while demand for food calories has probably come close to its peak level in China, the ongoing shift in demand into high-protein, and particularly animal based, foods induced by income growth, is likely to require a considerably greater agricultural effort than would continuation of past demand patterns. Using the experience of a wide range of countries, we find that China's demand pattern—and the growth of that demand in terms of cereal equivalents—is broadly similar to the international average.

On the supply side, we find that output of agricultural products in terms of their cereal equivalents depends strongly on both the growth of income and on the country's endowment of agricultural land. Countries with much larger land endowments per person than China—that is countries such as Brazil and the United States - tend to be exporters over a wide range of income levels. By contrast, economies with much more limited land endowments than China's – economies such as Japan and the Republic of Korea—tend to become net food importers at a relatively low income level and to remain net importers. China is a relatively land scarce country with a per capita land endowment measured at about one-half of the world average. It appears that China—probably because of the high productivity of much of its agricultural land and its

heavy investments in agricultural research and development—has produced much more food than would be expected given its income level and land endowment.

The analyses of income-consumption-production dynamics suggest that China's current income level appears to fall in the range where consumption growth outstrips production growth, widening its supply and demand gap for food. If China's past outperformance can be maintained, then it seems likely that, although China's net imports of food will rise from current levels for a while, the gap will begin to decline as China's population growth and dietary transition slow down. In the meantime, the quantity of agricultural resources that will be needed to feed the Chinese population is likely to continue to increase. In particular, our simulation exercises show that the evolution of the supply and demand gap for food depends on the changes in China's agricultural land availability both in terms of quantity and quality.

As China progresses from an upper-middle to a high income country, some loss of agricultural land is likely and a large shift of labor out of agriculture is inevitable. The experiences of developed countries reveal that they increasingly rely on agricultural productivity growth in sustaining their agricultural output while their input growth rates tend to decline (Fuglie, 2007; 2012). In conclusion, we suggest that continued agricultural productivity growth through further investment in R&D, and through expansion in farm size and increased mechanization, as well as sustainable management of agricultural resources, appear to be critical for raising farm incomes and increasing food supplies to ensure that it is primarily China that will feed China in the 21st century.

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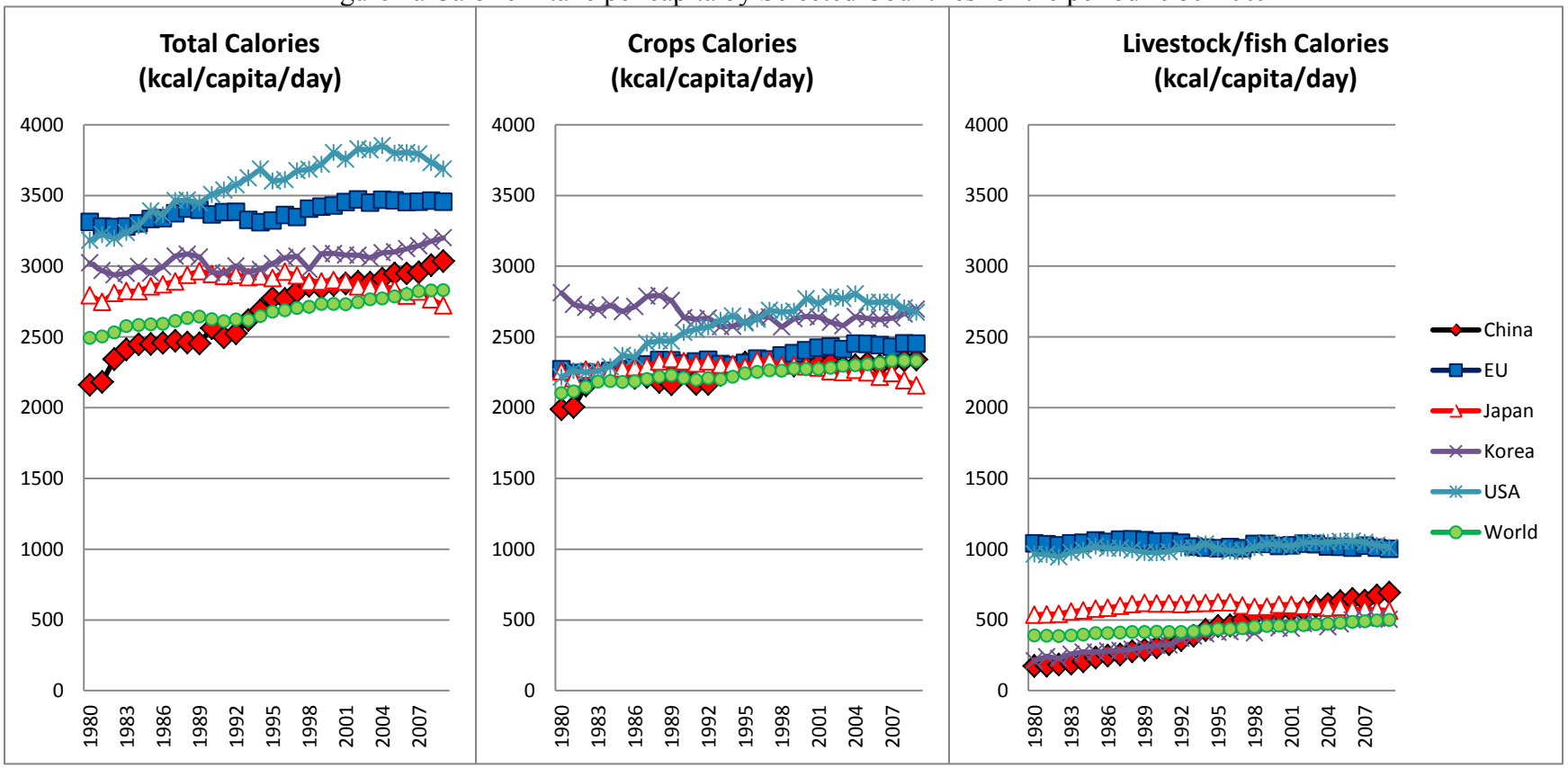
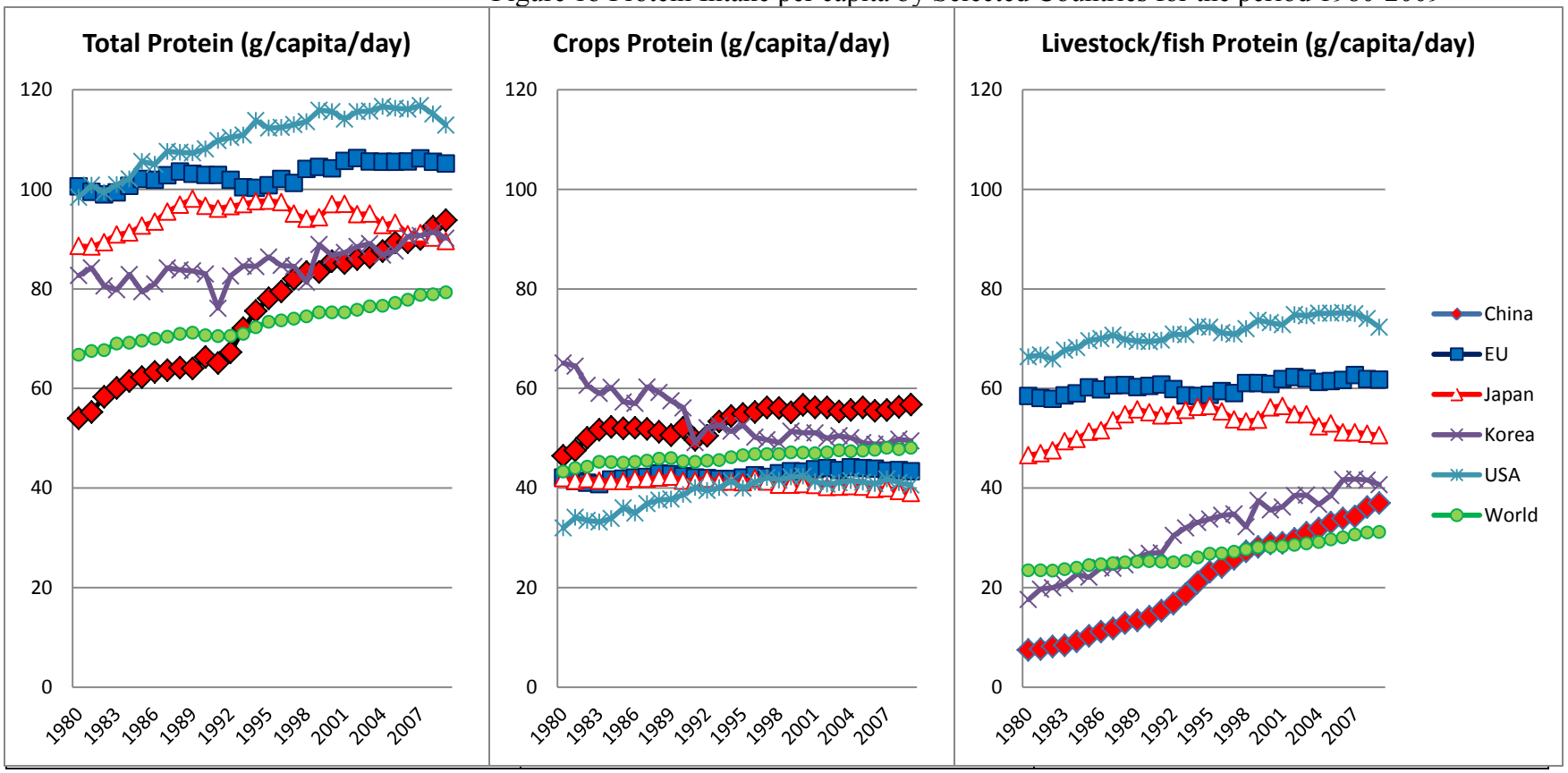
Figure 1a Calorie Intake per capita by Selected Countries for the period 1980-2009



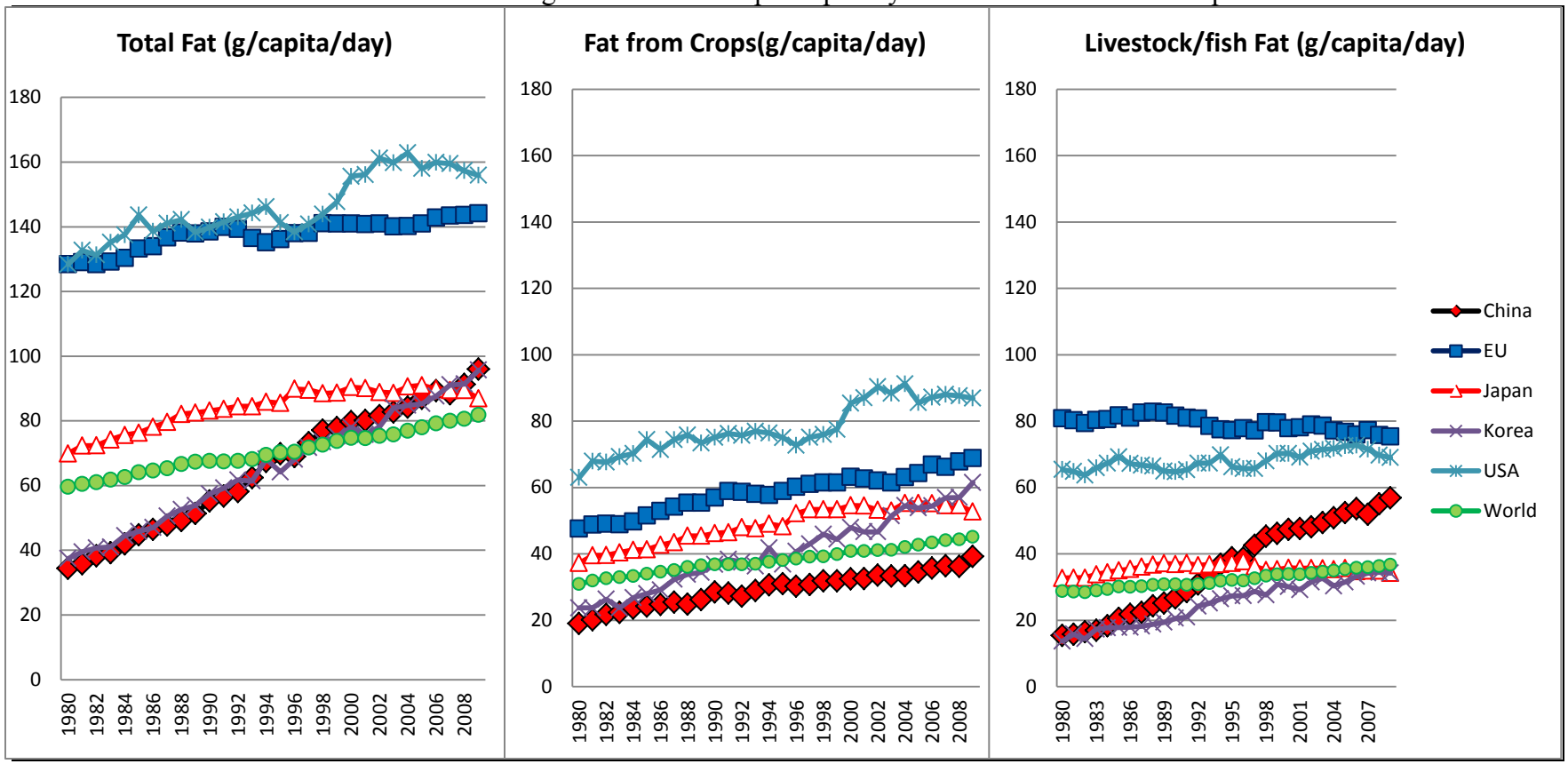
Source: FAOSTAT

Figure 1b Protein Intake per capita by Selected Countries for the period 1980-2009



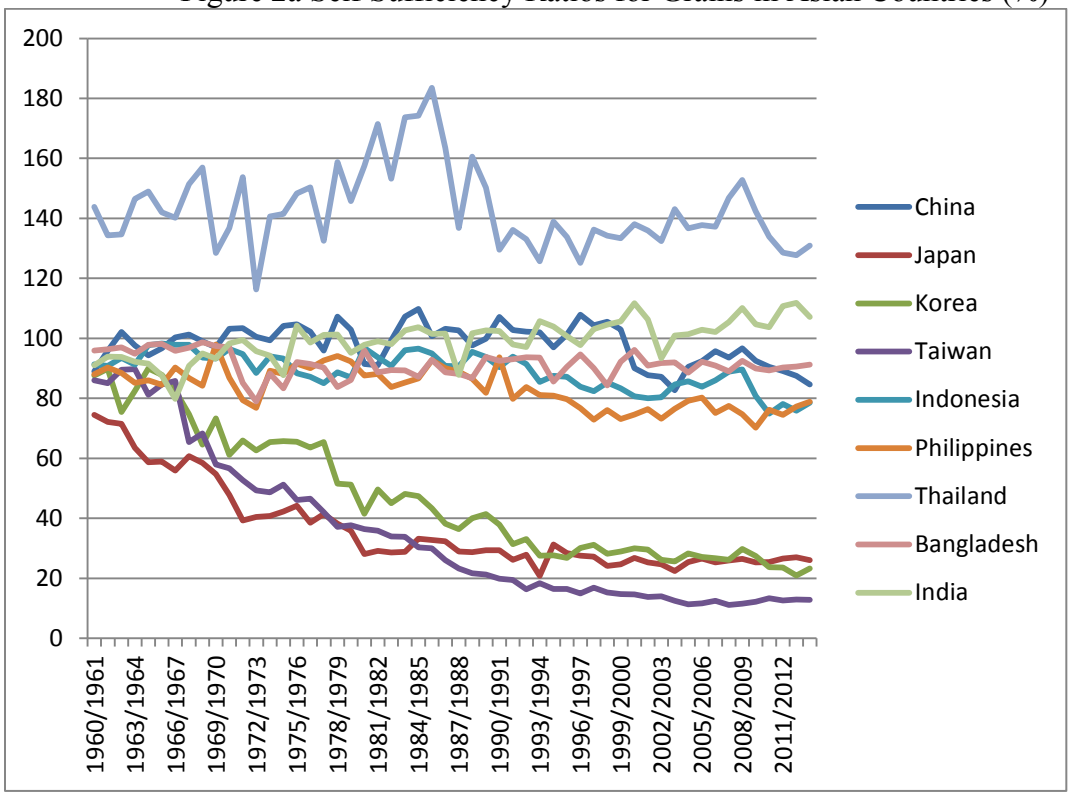
Source: FAOSTAT

Figure 1c Fat Intake per capita by Selected Countries for the period 1980-2009



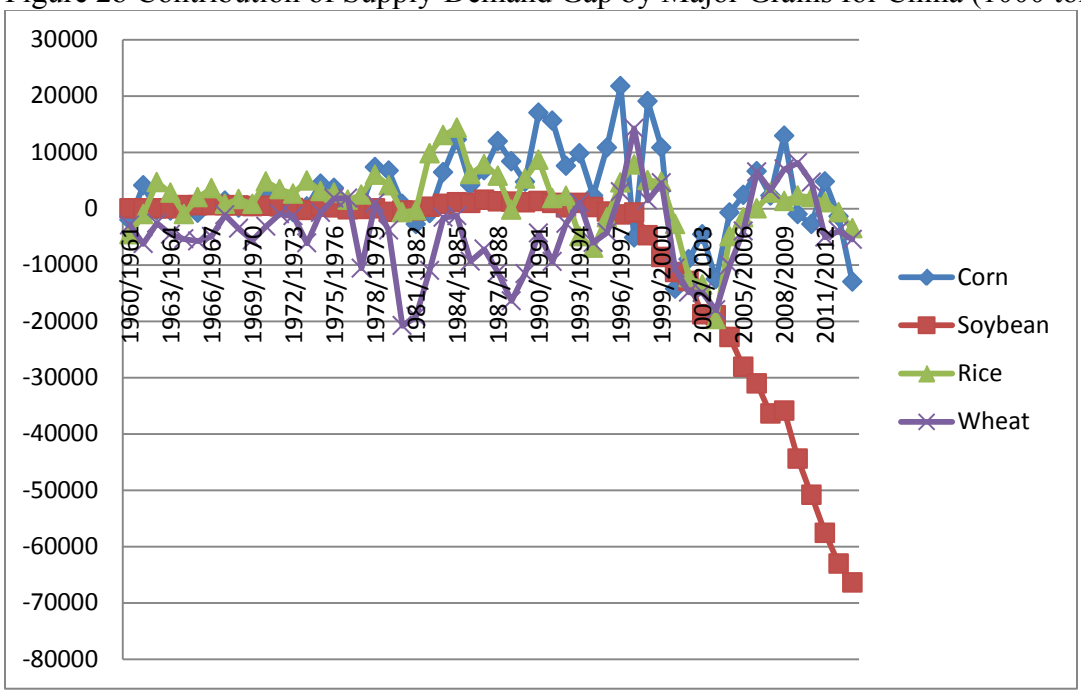
Source: FAOSTAT

Figure 2a Self Sufficiency Ratios for Grains in Asian Countries (%)



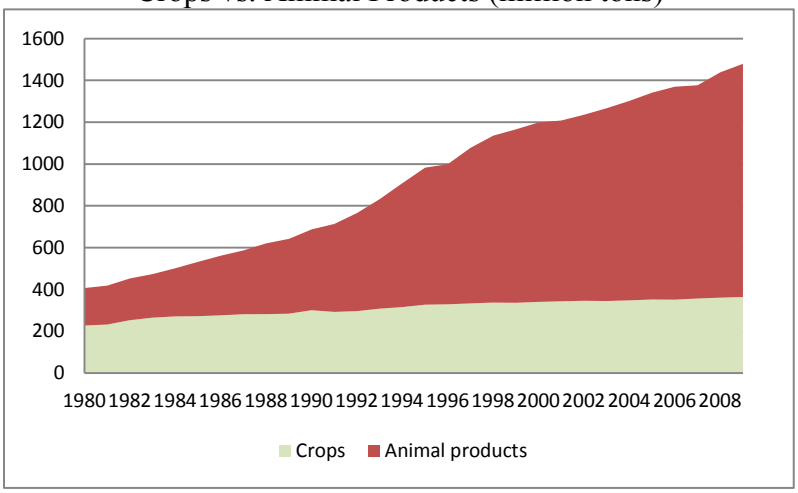
Source: Production, Supply and Distribution (PSD) data, USDA.
Notes: Total for rice, wheat, maize and soybeans.
Self-sufficiency is measured by dividing (gross) production by (gross) domestic consumption excluding stock changes. Gross production and consumption include uses for non-food purposes such as feed use.

Figure 2b Contribution of Supply-Demand Gap by Major Grains for China (1000 tons)



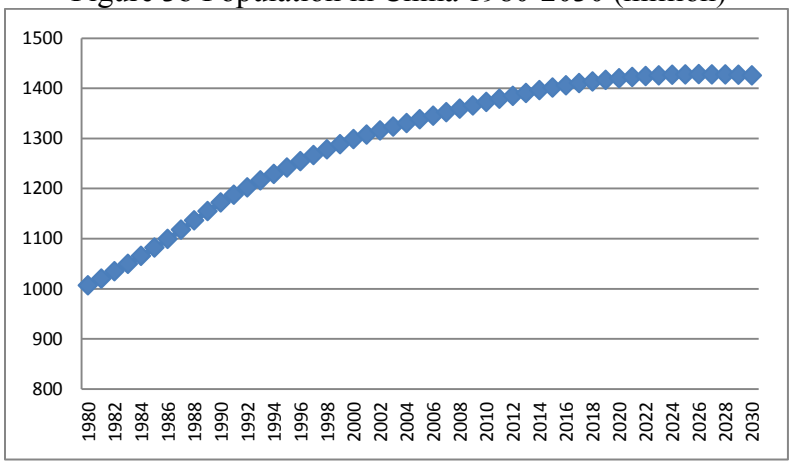
Source: Production, Supply and Distribution (PSD) data, USDA.
Notes: The figures reflect the differences between production and consumption, which are the sum of net imports and the changes in stock (Production – Consumption = Exports – Imports + Changes in stock).

Figure 3a Evolution of CE Consumption in China: Crops vs. Animal Products (million tons)



Source: Authors' calculation

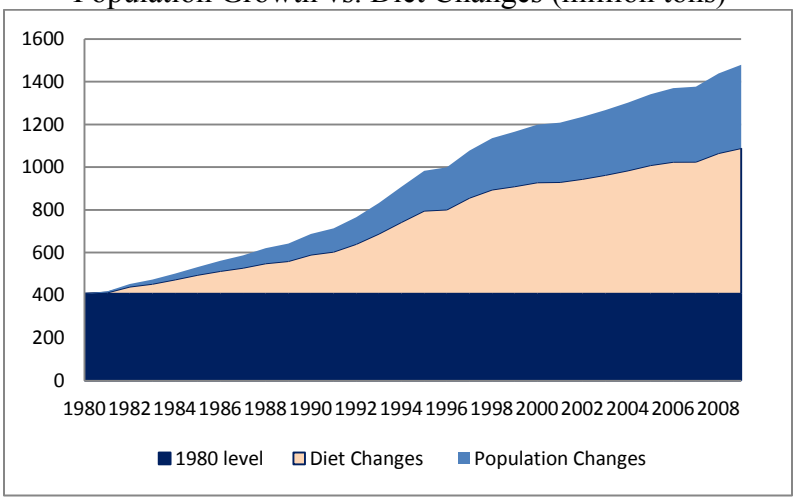
Figure 3b Population in China 1980-2030 (million)



Source: FAOSTAT

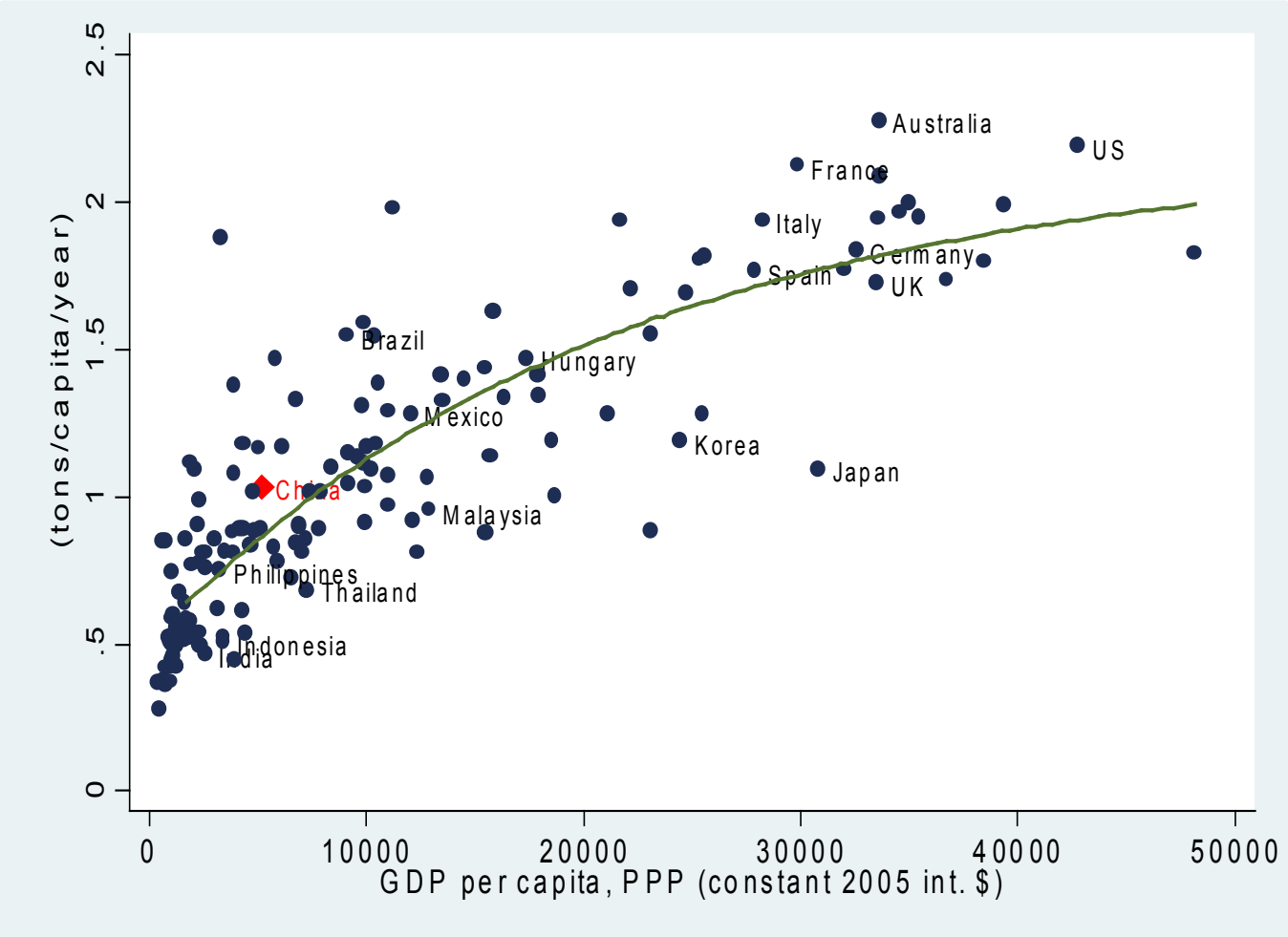
Note: The series consist of both estimates and projections.

Figure 3c Decomposition of Change in CE Consumption: Population Growth vs. Diet Changes (million tons)



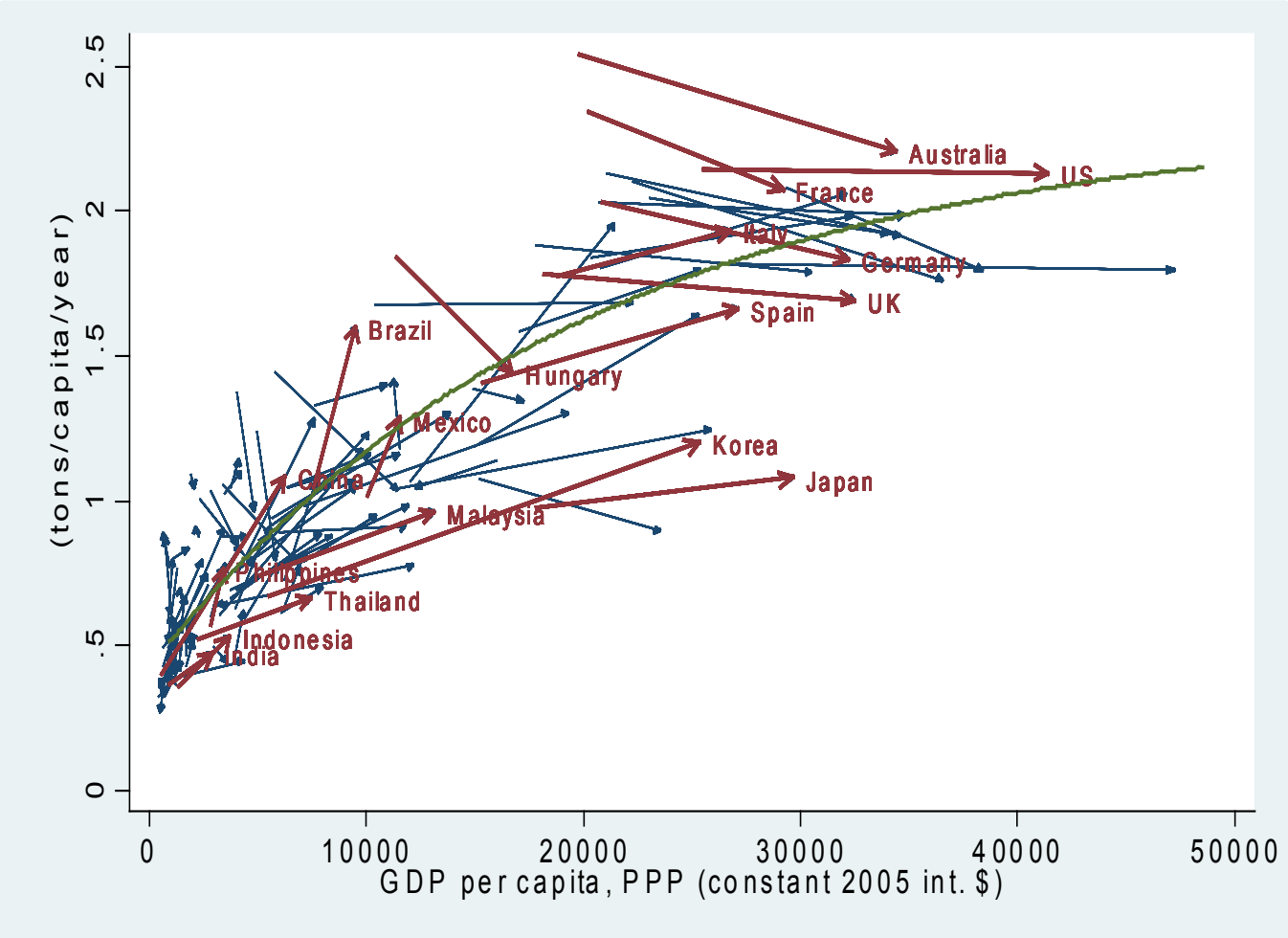
Source: Authors' calculation

Figure 4 Relationship between CE Food Consumption and Income



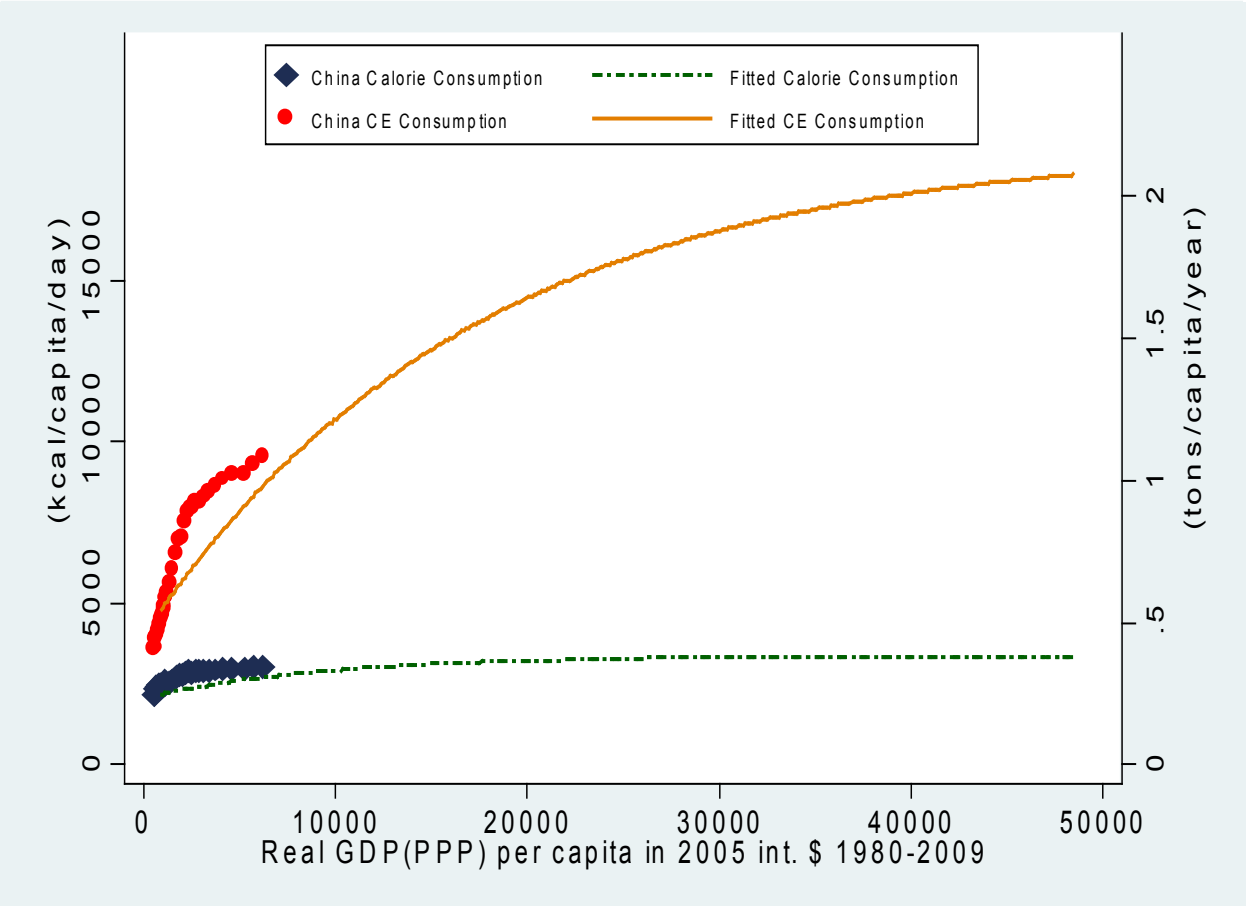
Note: The data are based on 2005-2009 averages.
The fitted CE consumption curve is based on the parameter values obtained by regression (1) in Table 2.

Figure 5 Growth Trend of CE Food Consumption 1980-2009



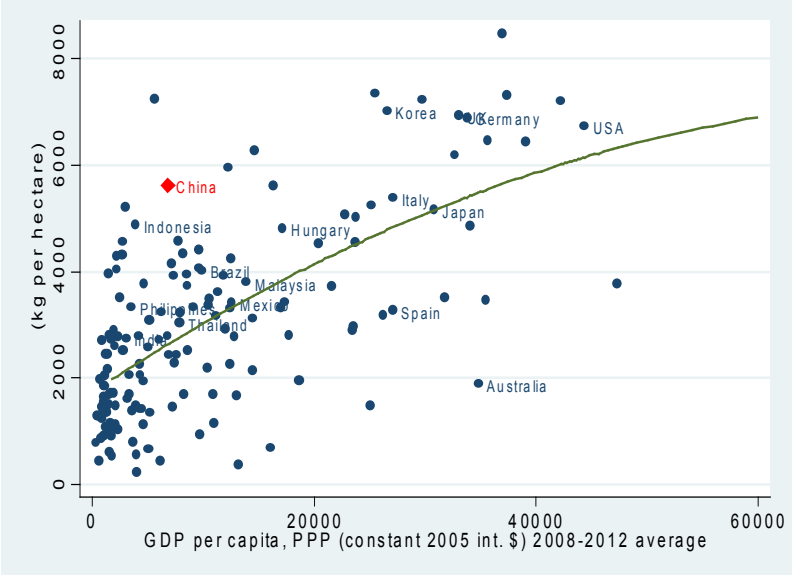
Notes: The starting and ending points of the arrows represent the CE consumptions for the year 1980 and 2009 respectively. The fitted CE consumption curve is based on the parameter values obtained by regression (2) in Table 2.

Figure 6 Calorie vs. CE Consomption 1980-2009



Notes: The fitted CE consumption curve (right-hand side) is based on the parameter values obtained by regression (2) in Table 2. The fitted calorie consumption line (left-hand side) is based on the parameter values obtained using the same functional form as the CE consumption estimate (equation (1)). During the period 2005-2009, the world average per capita cereal consumption was 0.403 kilogram per day (.147 ton per year) which contained 1,296 kcal per day on average. Thus, one ton of CE per capita per year is equivalent to about 8800 kcal per capita per day (1,296/.147≈8800).

Figure 7a Land Productivity (Cereal yield (kg per hectare))

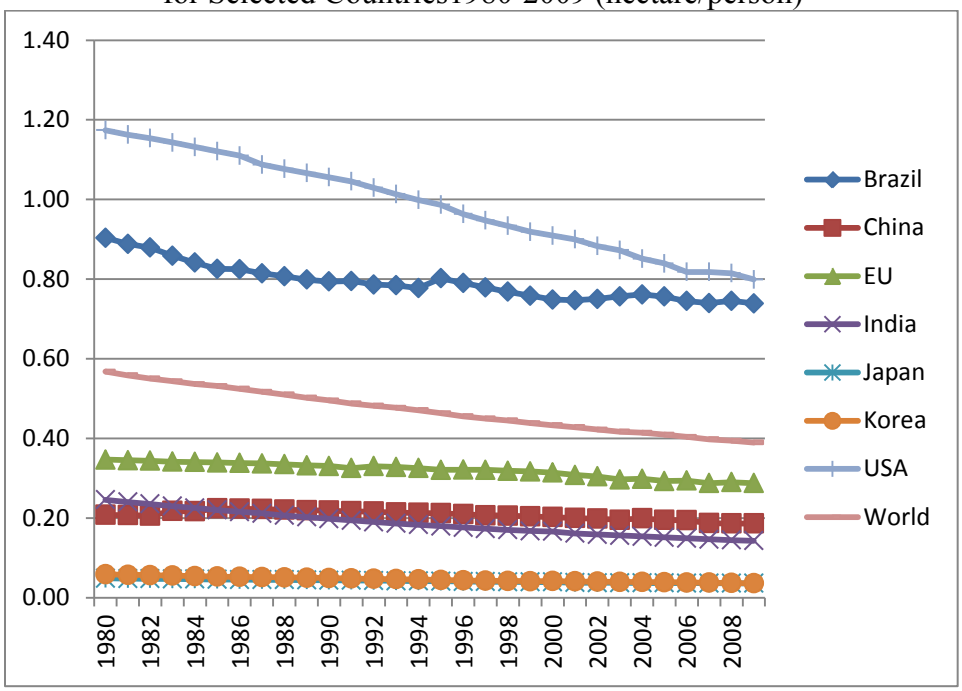


Source: World Development Indicators (WDI), the World Bank
Notes: The fitted line is estimated running a regression $v = C_1 + C_2x + C_3x^2$ where v is cereal yield in kg per hectare (2008-2012 average), x is PPP GDP per capita (2008-2012 average). The results turn out to be: C_1 = 1736.3***(173.3), C_2 = 0.14***(0.034), C_3 = -8.49e-0.7(9.76e-07) (R^2 = 0.43, Observations = 155). The robust standard errors are given in parentheses.

Figure 7b Labor productivity (Agricultural value added per worker)

Source: World Development Indicators (WDI), the World Bank
Notes: The fitted line is estimated running a regression $w = D_1 + D_2x + D3x^2$ where w is agricultural value added per worker in constant 2005 US $ (2008-2012 average), x is PPP GDP per capita (2008-2012 average). The results turn out to be: D_1 = -1461.75(1182.44) + D_2 = 0.76**(0.33), D_3 = 0.000011(0.000010) (R^2 = 0.69, Observations = 147). The robust standard errors are given in parentheses.

Figure 8 Evolution of Agricultural Land Endowment for Selected Countries1980-2009 (hectare/person)



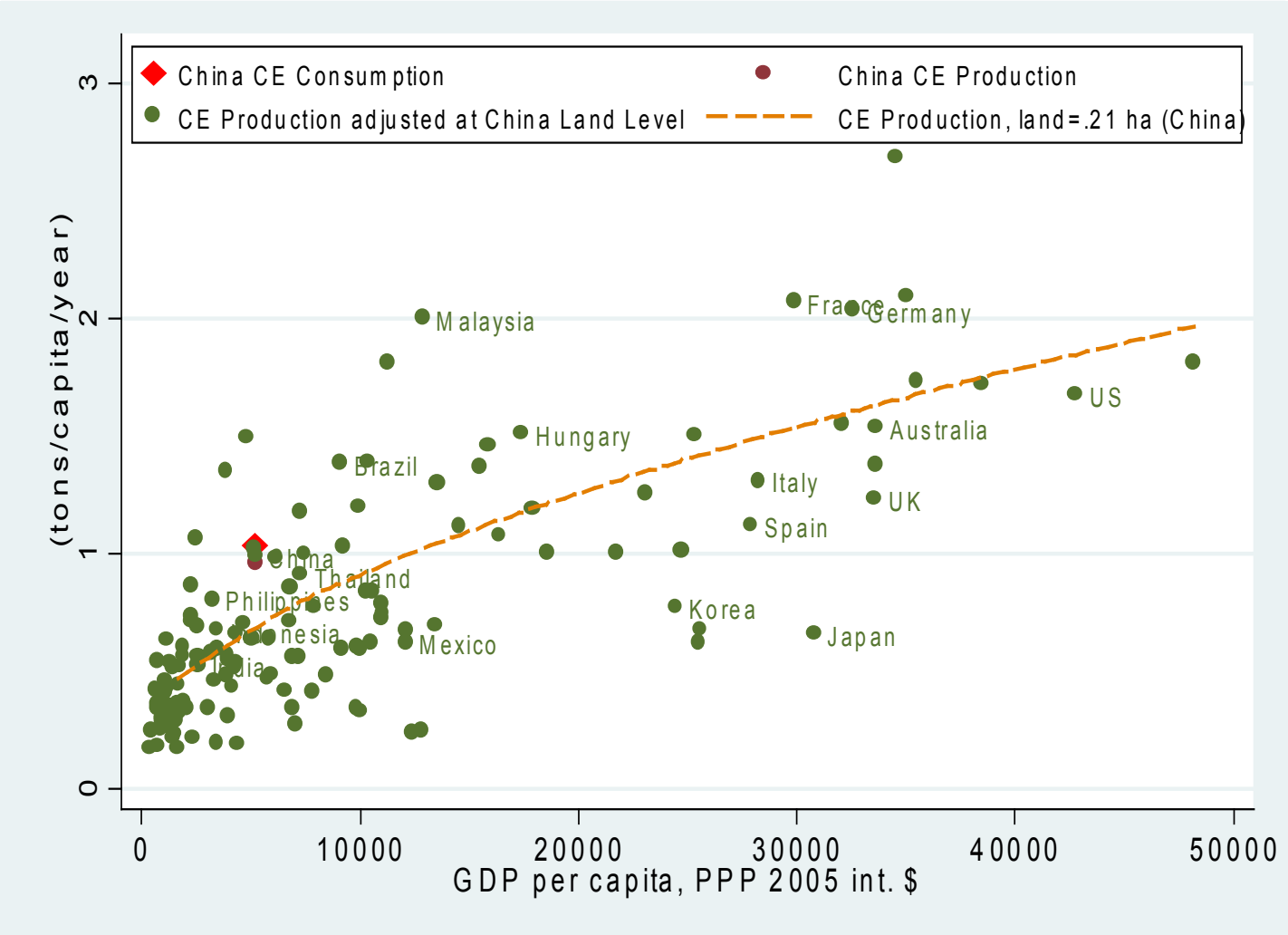
Country	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	1980-2009
Brazil	0.87	0.81	0.79	0.78	0.75	0.75	0.79
China	0.21	0.22	0.22	0.21	0.20	0.19	0.21
EU[*1]	0.34	0.34	0.33	0.32	0.30	0.29	0.32
India	0.24	0.21	0.19	0.17	0.16	0.15	0.19
Japan	0.05	0.05	0.04	0.04	0.04	0.04	0.04
Korea, Rep. of	0.06	0.05	0.05	0.04	0.04	0.04	0.05
USA	1.15	1.09	1.03	0.95	0.88	0.82	0.99
World	0.55	0.52	0.48	0.45	0.42	0.40	0.47

Source: Authors' calculation based on FAOSTAT

Notes: Following Rask and Rask (2011), hectares of agricultural land per capita is computed as a summation of arable land, land in permanent crops, and one-third of land in permanent pasture.

[*1] The data for EU reflect the averages of member countries. Thus, the evolution of EU data reflects partly the composition of member countries.

Figure 9 Relationship between CE Production and Income at China's Land Endowment Level



Note: The data are based on 2005-2009 averages.

Figure 10a CE Consumption and CE Production for China and India 1980-2009

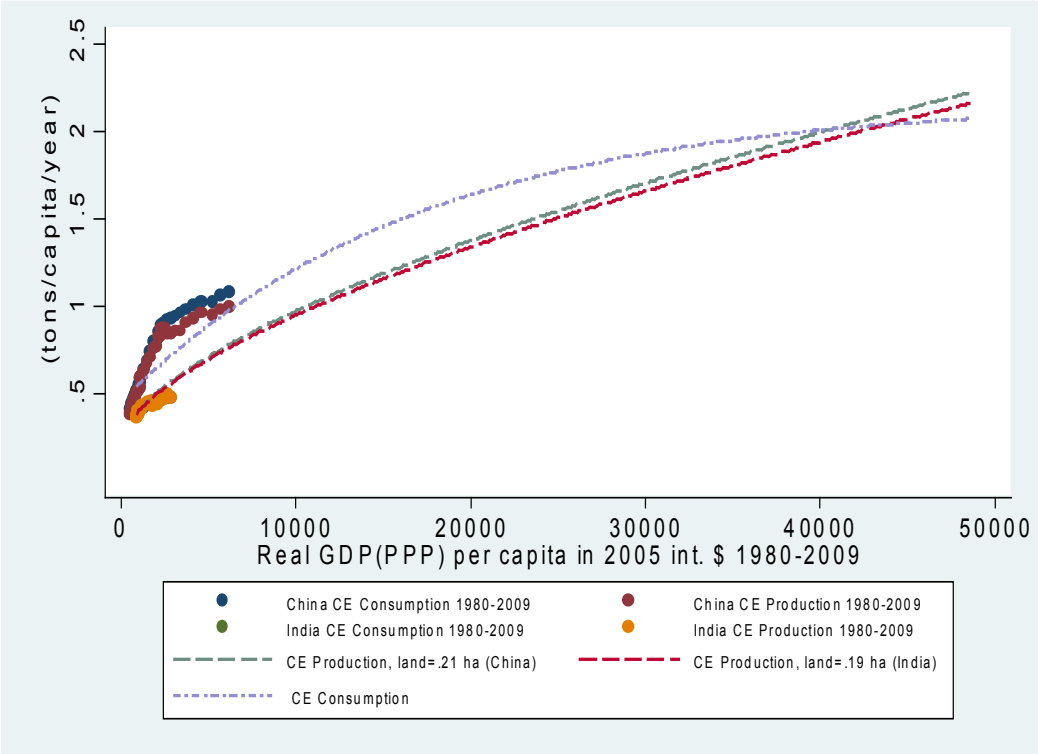


Figure 10b CE Consumption and CE Production 1980-2009
Examples for Relatively Land Abundant Countries: Brazil and the United States

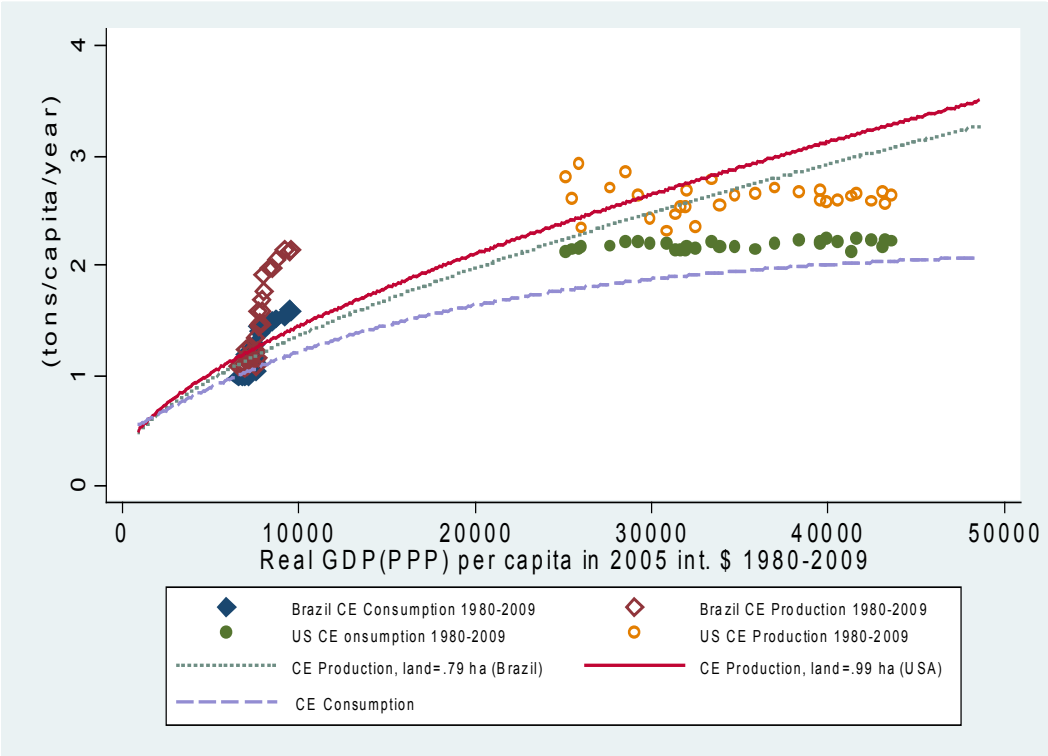


Figure 10c CE Consumption and CE Production 1980-2009:
Examples for Relatively Land Scarce Countries: Japan and Republic of Korea

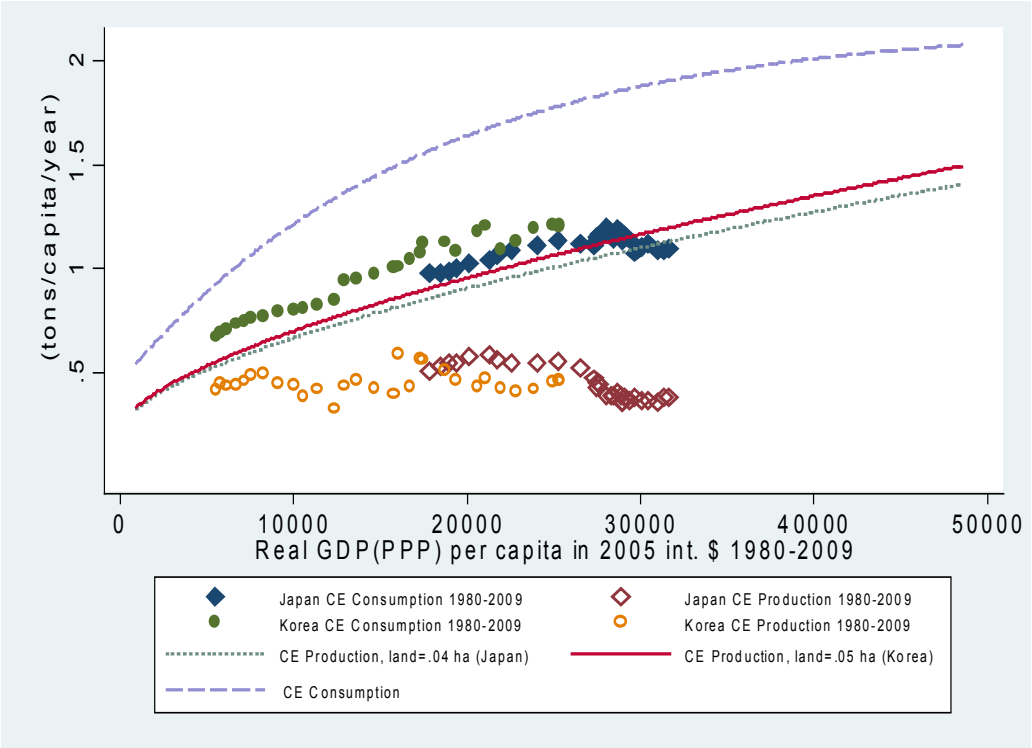


Figure 11a CE Production and CE Consumption
Assuming China's Residuals Reflect a Sustained Difference (Scenario 1)

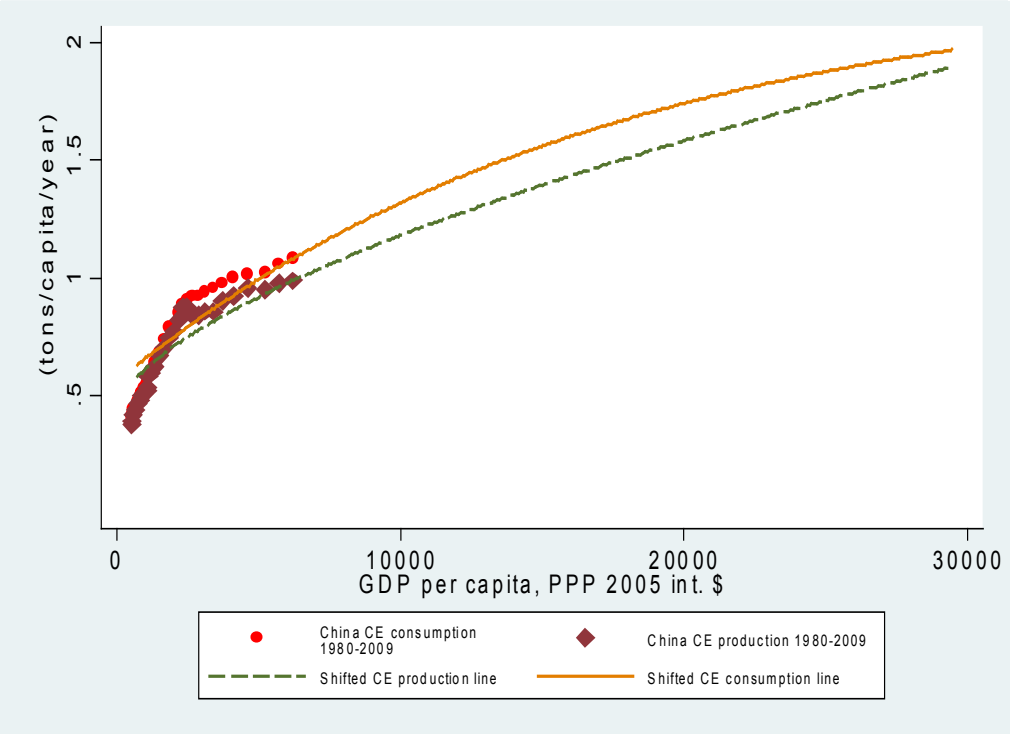


Figure 11b CE Production and CE Consumption
Assuning China's Experiencing Loss of Land Area and Quality (Scenario 2)

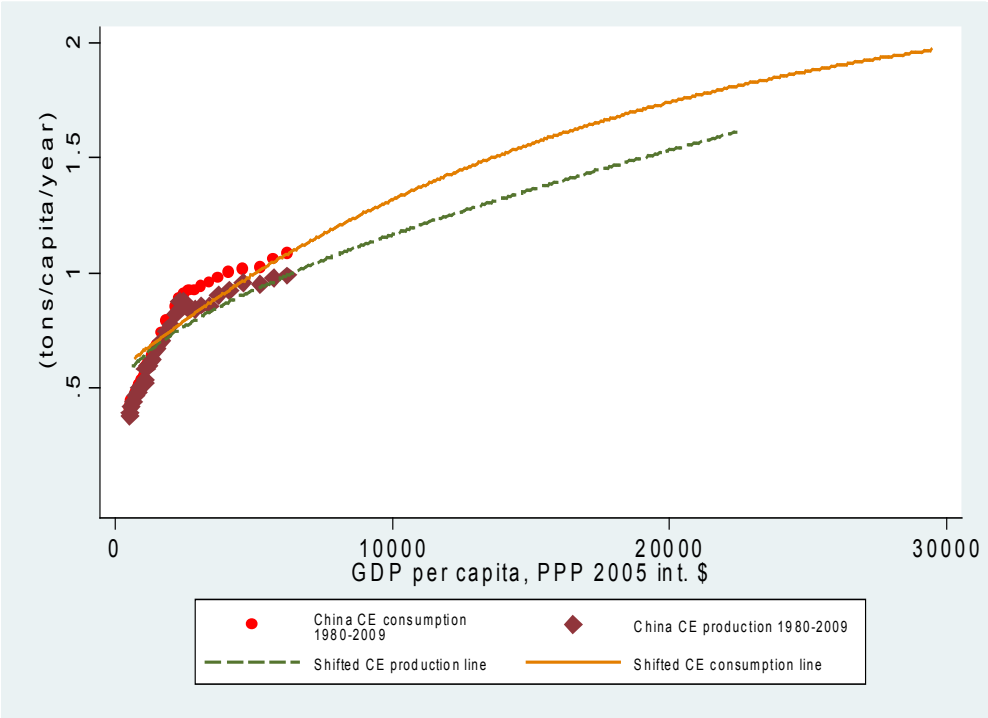
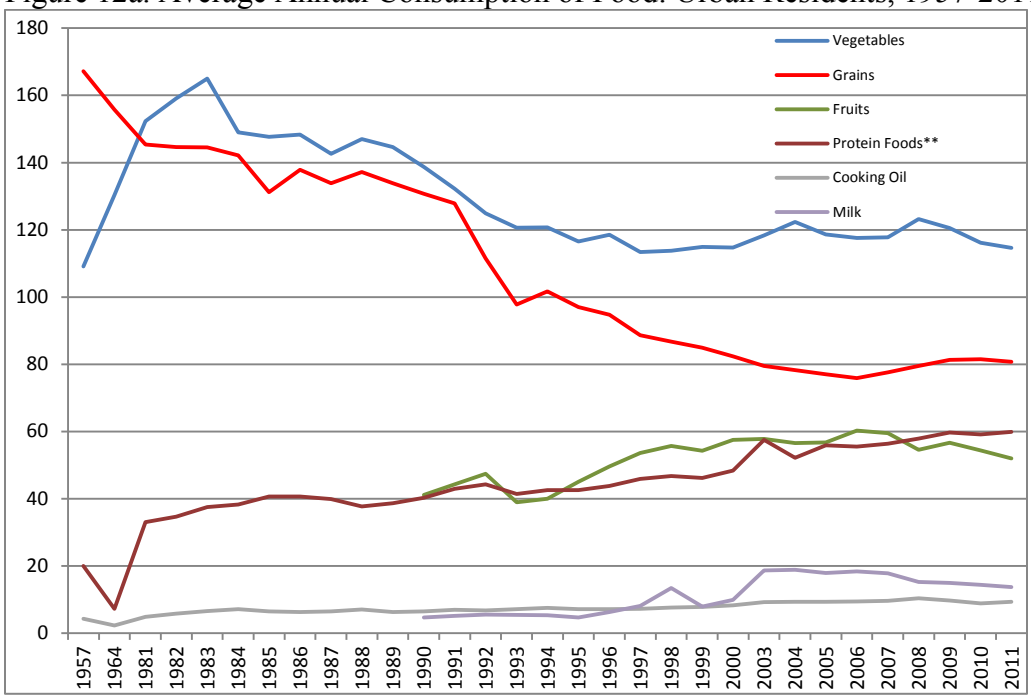
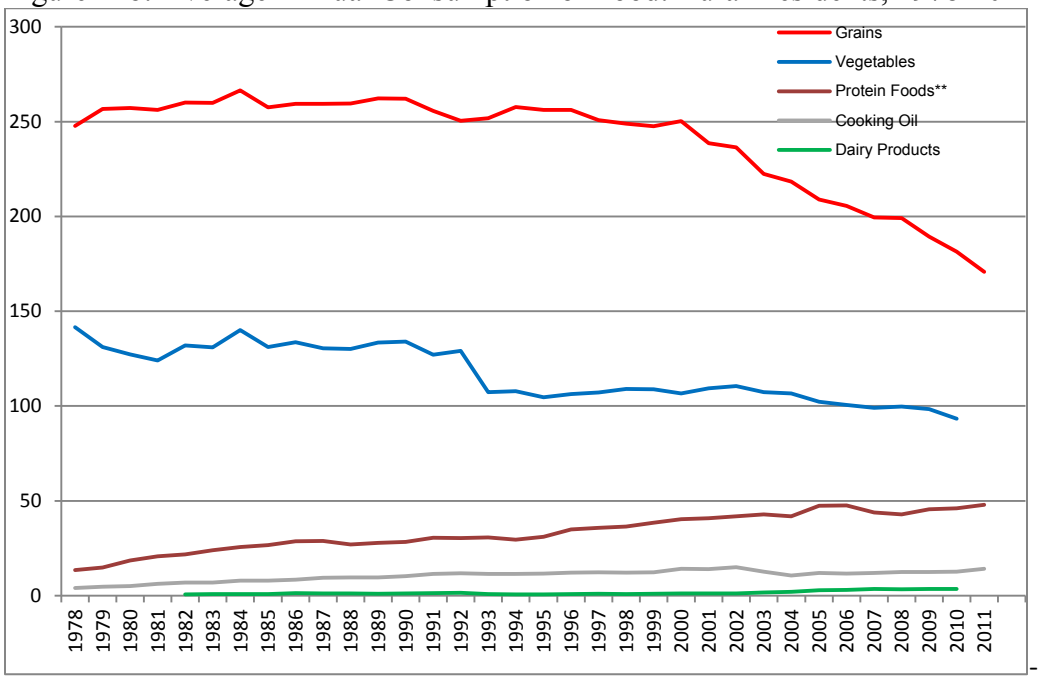


Figure 12a. Average Annual Consumption of Food: Urban Residents, 1957-2011(kg)



Source: World Bank staff calculation based on DRC data
Note: Data unavailable for milk and fruits before 1990; data for milk and fruits from 1996-1998 estimated based on averages of 1995 and 1999.

Figure 12b. Average Annual Consumption of Food: Rural Residents, 1978-2011 (kg)



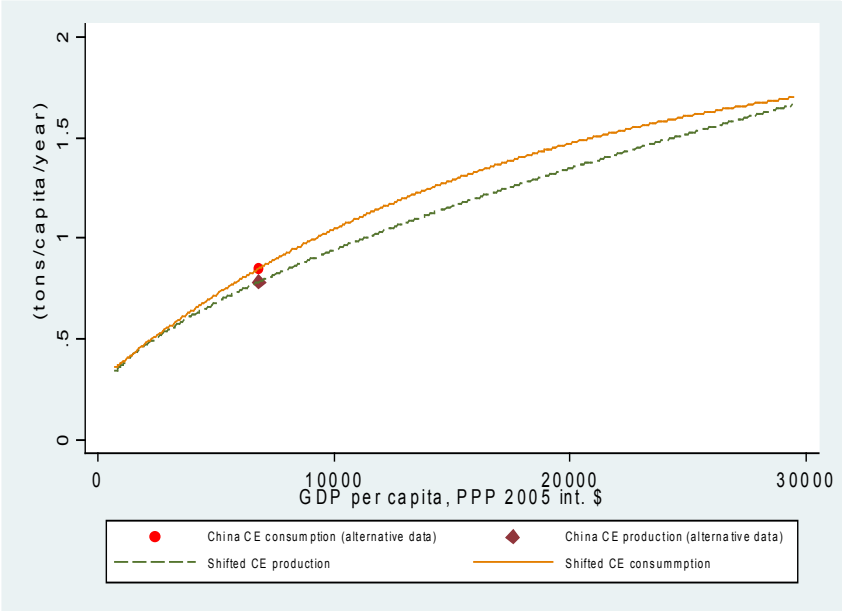
Source: World Bank staff calculation based on DRC data
Note: Protein foods include pork, beef, lamb, poultry, seafood, and egg. Data unavailable for dairy products before 1982, and for vegetables and dairy products in 2011.

Appendix: Some Sensitivity Analysis: CE Production and CE Consumption Using Alternative Livestock Data

Several scholars have argued that the Food Balance Sheets (FBSs) data for China from FAOSTAT, which are based on official Chinese statistics, are biased. In particular, livestock production is widely believed to be over reported introducing potentially serious bias into food supply and demand balance estimates (e.g., Fuller, Hayes and Smith, 2000; Ma, Huang and Rozelle, 2004). Ma et al. (2004) provide revised series on production and consumption for livestock products for China over the period 1980 to 1999. Their results on livestock production are lower than the official numbers up to 1999, although they still show rapid growth with, for instance, a tripling of pork production over the 1980 to 1999 period, rather than an increase of three and a half times. To our knowledge, after 1999, revised livestock production and consumption data are available only for 2000, 2010 and 2012 from the China Agricultural Policy Simulation Model (CAPSiM) (Huang et al., 2013).

To see how sensitive our results might be to the use of alternative data, we repeat scenario 1 (Figure 11a), replacing 2009 livestock data (which is the latest year available in FBSs) with the 2010 livestock production and consumption data from the CAPSiM model (Huang et al., 2013). The results suggest that China's CE production point is close to the global trend, rather than substantially above the trend, while its consumption point turns out to be below the global trend.[27] Following the assumptions in scenario 1, we shift both CE production and consumption curves so that they cross China's alternative CE production and consumption points. The shifted lines suggest that China's current income level lies in the range where consumption growth outpaces production growth, but that the gap will likely start to decrease as China's consumption growth rate declines. However, evaluating the bias of FBSs data is not within the scope of this study and further studies are required to address the data quality issues.

Figure A CE Production and Consumption
With Alternative Livestock data



[27] Since the two datasets are not directly comparable, the difference in the results may be influenced by the differences in characteristics of the datasets. For instance, Kearney (2010) suggests that the FBSs data generally tend to overestimate consumption since they are referring to "available" rather than "actual" food consumption.