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

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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 (World Bank 2013).

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 livestock 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 livestock-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, Yang and Rozelle, 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 addressed 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 security (Huang et al., 2013), on food demand patterns (Wu, 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 near the 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]

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[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 livestock 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 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 the income-consumption dynamics suggested by Rask and Rask (2004, 2011) for 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 $7958 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 livestock products. Figure 1a shows that total calorie intake per person per day in China grew substantially, from 2163 kcal in 1980 to 3036 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 livestock products, while the calorie intake from crops grew slowly and stabilized at around 2300 kcal in recent years. China's increase in per capita calorie intake has been much faster than the world average, which grew at a much slower rate from 2490 kcal in 1980 to 2831 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, somewhat declined 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 livestock 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 livestock product consumption.

The changing dynamics of food consumption shown above certainly affect supply and demand balances for food directly and indirectly. In particular, whereas *direct* demand for food

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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 livestock production. Figures 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 its 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] Chinese government appears to have responded to the rising demand by liberalizing soybean imports gradually (Weiming and Ying, 2013).[7]

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[5] However, further disaggregation of the data reveals that the self-sufficiency ratios for Japan, the Republic of Korea and Taiwan 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).

[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.

Some scholars view China's increasing imports of soybeans 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 livestock 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 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 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 his land-minimizing model, Wirsenius et al. (2010) suggests that greater feed-to-food efficiency in animal production, decreased food wastage and dietary changes towards less land-demanding foods would help to reduce land use.

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[8] In 2009, about 34 percent of cereals were consumed indirectly in the form of animal feed in 2009 (FAOSTAT).

[9] The Feed Conversion Ratios (FCRs), i.e., the amount of feed required to produce one unit of live animal, are typically 5-7 for beef, 3-4 for pork and 2 for poultry (Steinfeld et al., 2006; Yotopoulos, 1985). However, when total enterprise needs are considered (i.e. breeding herd) the FCRs are increased significantly (Rask and Rask, 2004, 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.

Livestock production competes for land directly, for instance, for grazing and fattening, and indirectly through the need to produce animal feeds.[11] Gerbens-Leenes, Nonhebel and Ivens (2002ab) show that foods associated with affluent lifestyles, especially livestock 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 livestock-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, thereby taking into account the greater effort involved in producing foods that contain a large amount of calories per unit of weight (i.e., vegetable oils) relative to those that have, for instance, a higher water content (i.e., starchy roots). For animal products, the CE coefficients reflect the feedstuff used to produce one unit of livestock products relative to the equivalent weight of cereals. The livestock product CE coefficients consider not only grains consumed but also other types of feed such as protein supplements, forages (including pasture) and other feeds and convert them into the dietary energy equivalent of a unit of corn.[12]

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[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 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.

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

Table 1. Sample Cereal Equivalent (CE) Coefficients

Crop Products		Livestock products[a]	
Products	Coefficients	Products	Coefficients
Cereals	1.00	Bovine meat	19.8
Fruits	0.14	Pigment	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 costs of producing livestock products relative to cereals, and 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 (frequently estimated to be 7 kg of feed per kg of live production animal) 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 because of 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.

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[13] Using beef as an example, Rask and Rask (2011) use a feed conversion ratio (FCR) of 11.7 for producing live cattle. This is higher than the widely cited value of seven used to convert feed into live weight, because it reflects the feed used in breeding herds and young calves as well as that fed directly to production 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).

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 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 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). 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 on environmental burdens implied by the CE coefficients are also broadly in line with the findings of other studies.[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).

Our analytical technique does not take into account distortions from agricultural incentives, food price policy, or farm gate pricing differences related to product self-sufficiency. 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 some headline measures 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

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[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 by 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] 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). 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).

keep the rate of protection on feedgrains quite low and hence 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 1479 million tons in 2009 (a 264 percent increase). Figure 3a also shows that the rise is mainly driven by the increase in consumption of livestock 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. Table 3c decomposes the change in CE consumption into the components of population growth[16] 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 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), the primary driver of food consumption is likely to be the change in diet, and therefore the change in *per capita* consumption.

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[16] The population growth reflects both the increase in population and dietary changes of the increased population.

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,

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

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 remarkably similar between the two regressions, highlighting the stability of this relationship across time.

Table 2: Regression Results for Cereal Equivalent Consumption

	(1)[a]	(2)[b]
A_1	2.2***	2.2***
	(.17)	(.16)
A_2	1.7***	1.7***
	(.16)	(.15)
k	4.6×10^{-5}***	5.8×10^{-5}***
	(9.5×10^{-6})	(1.1×10^{-5})
R^2	.74	.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 reveals the dynamics of the income-consumption relationship showing 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 increased income on the procurement of food. This CE consumption continues to increase, albeit at a slower rate, as incomes grow further and consumers substitute higher-order foods (such as

livestock products) for cereals and tubers. Only at higher levels of income such as $40,000 does per capita CE consumption growth slows 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 historical animal-product diets 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 consumption at the beginning of the sample period (the year 1980) relative to consumption at 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

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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 diets, 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. 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 or population growth change factor endowments (Martin and Warr 1993). 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 her 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, the expansion of irrigated land,[17] 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 her level of development, recording merely $684 per capita (in 2005 constant prices, as the average for the period 2008-

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[17] 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).

2012). 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).

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, 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 arable 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:

$$z = B_0 + B_1 x^{B2} l^{B3} \tag{2}$$

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. In parallel with the CE consumption side (Table 2), Column 2 in Table 3 shows the results using all 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.

Table 3: Regression Results for Cereal Equivalent Production

	(1)[a]	(2)[b]
B_0	.27**	.22**
	(.11)	(.10)
B_1	8.9×10^{-4}	1.7×10^{-3}
	(1.5×10^{-3})	(2.1×10^{-3})
B_2	.77***	.71***
	(.16)	(.12)
B_3	.33***	.31***
	(.036)	(.030)
R^2	.56	.57
Observations	154	4100

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 154 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).[18] 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 is clear that—based on the official figures—China has been an out-performer in terms of output. Agricultural output, which is slightly below consumption level, is sizably 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

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[18] 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.

increase 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.[19]

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 differential growth pattern 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. When income reaches about $11150
per capita, the change (slope) in consumption and that in production are comparable, and, after
that point, it seems likely that the growth of consumption will slow down relative to production
and the gap 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).
Whereas China's production fell slightly below its consumption starting in the late 1990s
China's CE production of food remained steadily above the global trend level. For comparison

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[19] 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).

purposes, we plot CE consumption and production points for India since it has a similar land endowment as China (0.19 hectare per person on average). Turning to India's CE consumption and production pattern, 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.[20] 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

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[20] 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 some preliminary insights into how China's consumption and production gap might evolve in the future, we conduct some simulations with hypothetical scenarios. In scenario 1, we assume that the small gap between China's food consumption and the prediction 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 $11150 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 $11150. 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 are based on an assumption that China's resource endowment remains the same. However, China's agricultural land endowment is likely to decline as its economy develops.[21] Figure 11b shows the result of a scenario in which we assume that China

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[21] Between 1988 and 2000, China recorded a net increase of cultivated land by 1.9 percent, which nearly offset the decrease in average potential bioproductivity. During the period 2000-2008, land conversion has had a somewhat

will be losing its land and land bioproductivity at the same rate as found in Deng et al. (2013), 0.47 percent and 1.68 percent respectively during the period 2000-2008 (scenario 2). Specifically, it is assumed that China loses its "effective" land at 0.27% annually (combination of land area and bioproductivity loss), given projected population growth and economic growth rates taken from FAOSTAT and from Huang et al. (2013) respectively. In this scenario, the changes in China's CE consumption and production become comparable when China's income reaches around $14000 in PPP terms per person. Until China reaches that point, the gap between supply and demand widens much more under scenario 2 than under scenario 1.

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, other things being equal, the gap might increase. Nevertheless, China is in a very different situation from a country such as Japan or the Republic of Korea, where the much smaller land endowments almost ensure that continuing large net imports of food are likely to be required.

One limitation 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 their livestock data are flawed (Fuller, Hayes and Smith, 2000; Ma, Huang and Rozelle, 2004). Although we are aware that there may exist bias in FAOSTAT data, [22] we were unable to replace FAOSTAT data with revised data due to the lack of the comparable data for other countries.

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negative effect: area of cultivated land decreased by 0.47 percent while the potential bioproductivity is reduced by 1.68 percent (Deng et al. 2013).

[22] We conducted some preliminary sensitivity analysis regarding the data and the results are available upon request.

Some Policy Challenges

China's ongoing shift in demand into more affluent, and particularly livestock based, foods is likely to impose substantial pressure on agricultural resources and environment. In particular, livestock production puts pressure on land both directly[23] 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 continues to develop from an upper-middle to high income country.[24] 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).[25] The increase in productivity would also generally have the desirable effect of increasing the incomes of farmers. Increases in agricultural productivity have very powerful poverty-reducing impacts because so many of the poor—

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[23] 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).

[24] 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).

[25] 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).

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, further intensification of the use of cropland may 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 and the resulting labor shortage is likely to impose 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 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 livestock 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 her 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, China is likely to experience increasing pressure on its agricultural resources and environment. As China moves on from an upper-middle to high income country,

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 feeds China in the 21st century.

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

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

Total Protein (g/capita/day)

Crops Protein (g/capita/day)

Livestock/fish Protein (g/capita/day)

China
EU
Japan
Korea
USA
World
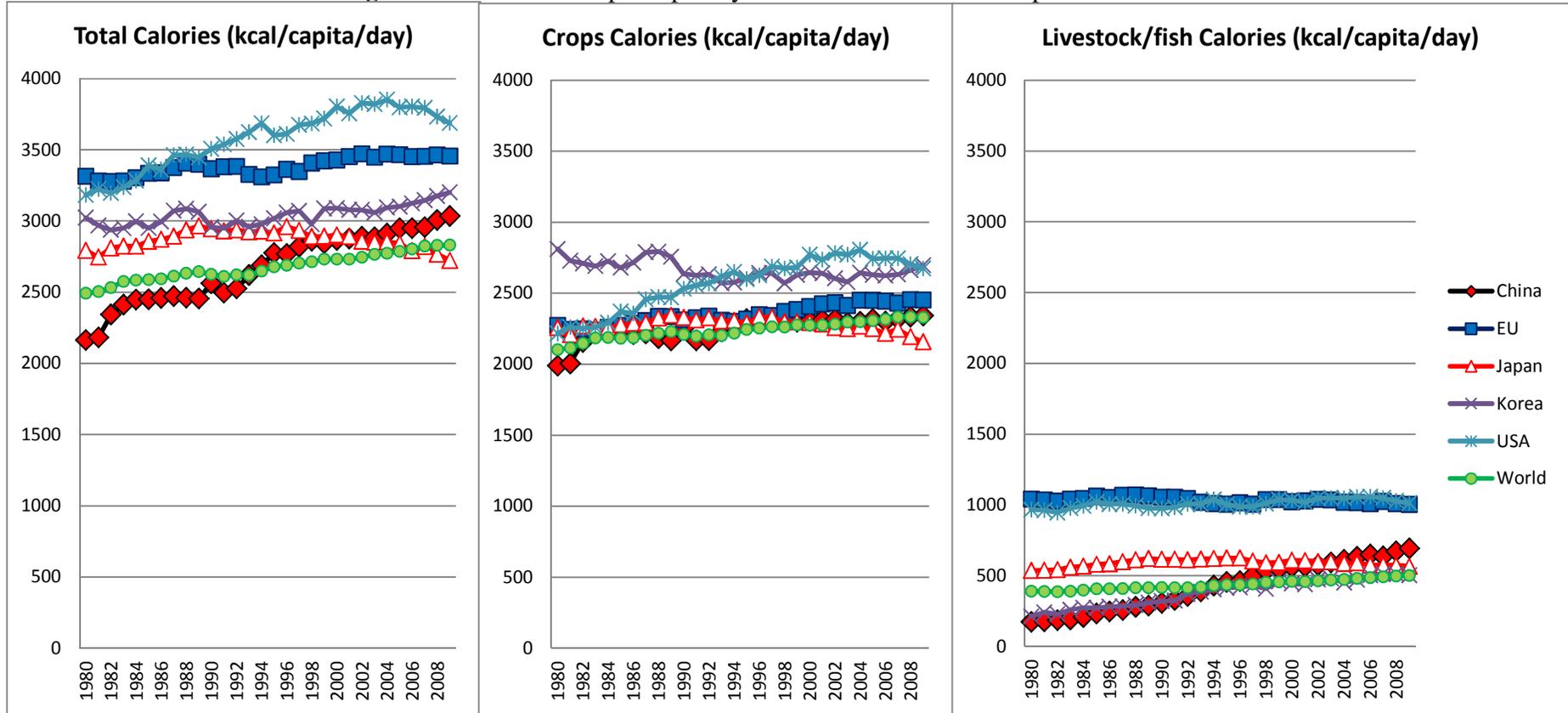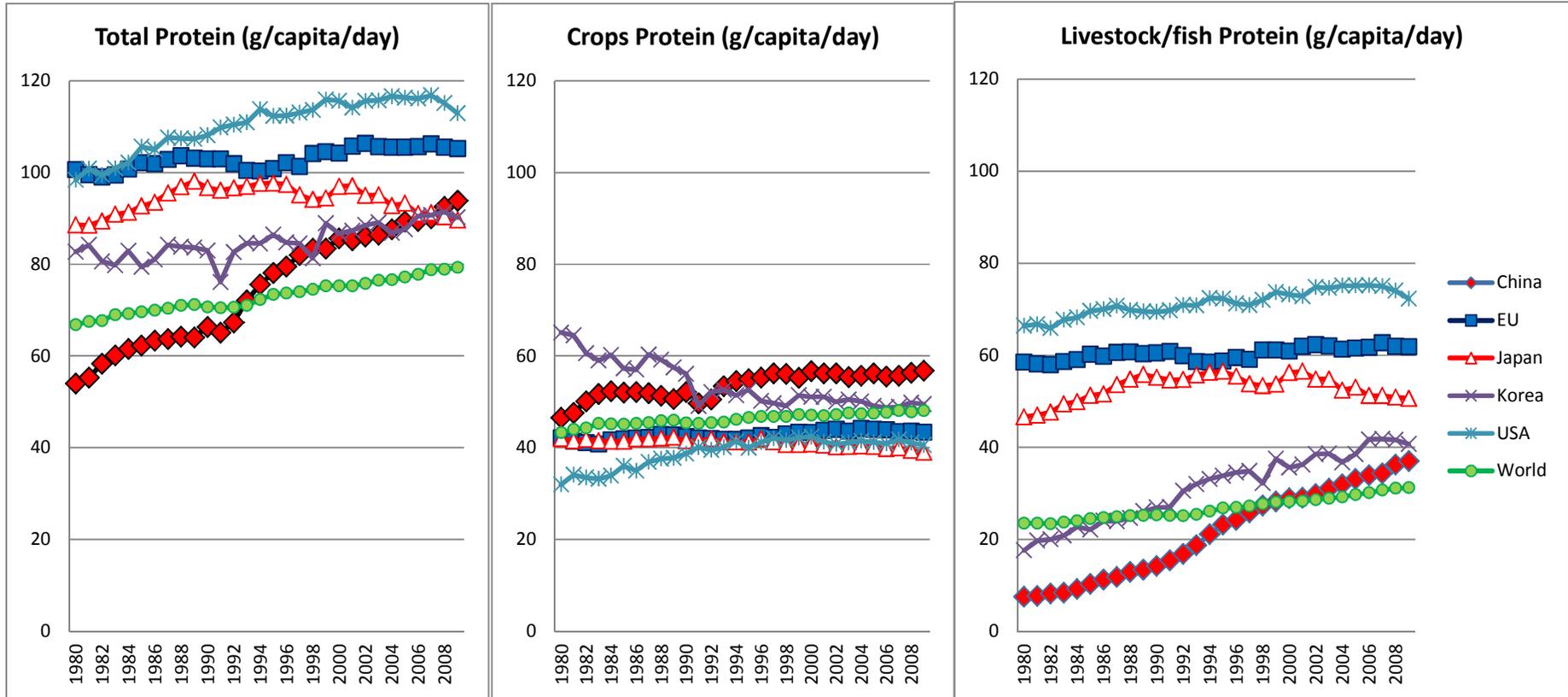
Source: FAOSTAT

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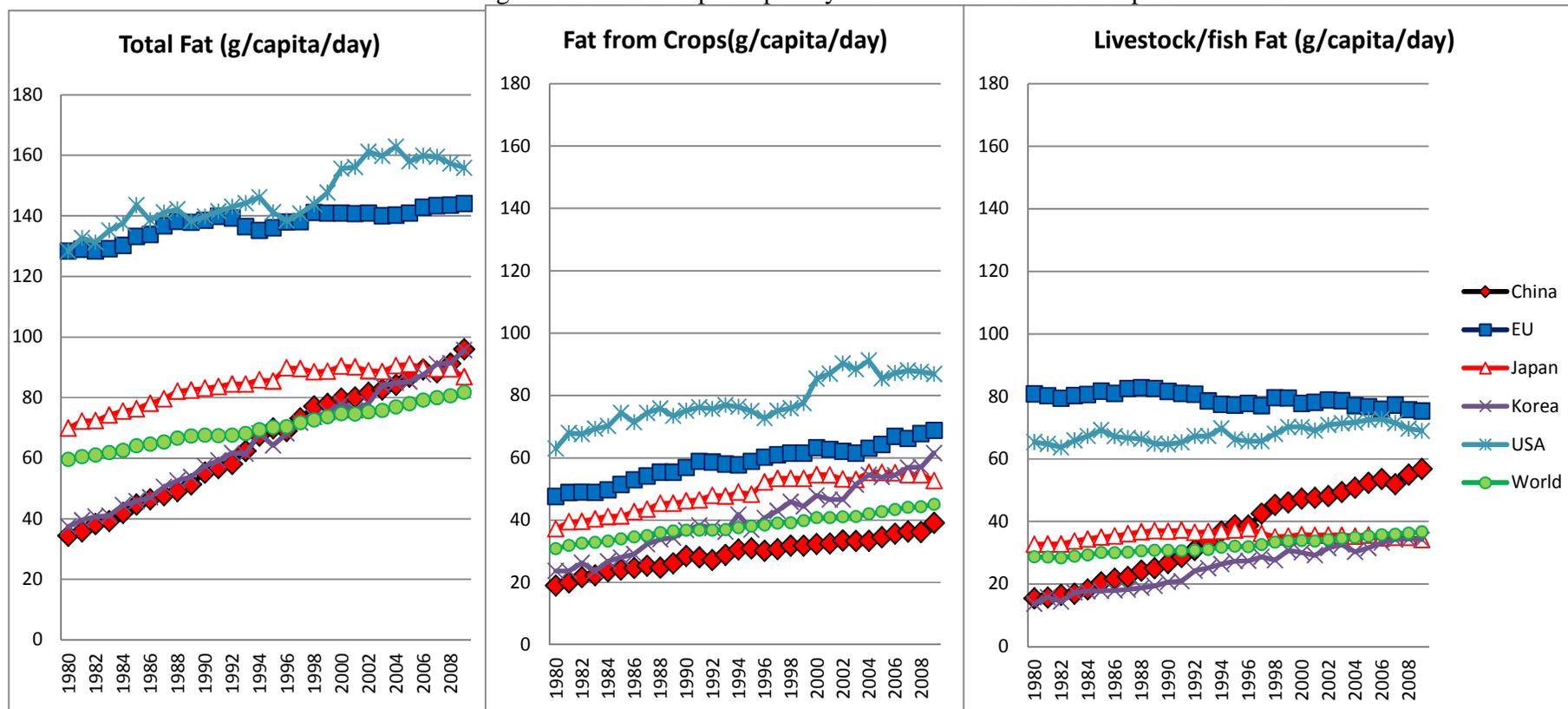
Source: FAOSTAT

Figure 2a Self Sufficiency Ratios for Grains in Asian Countries (%)
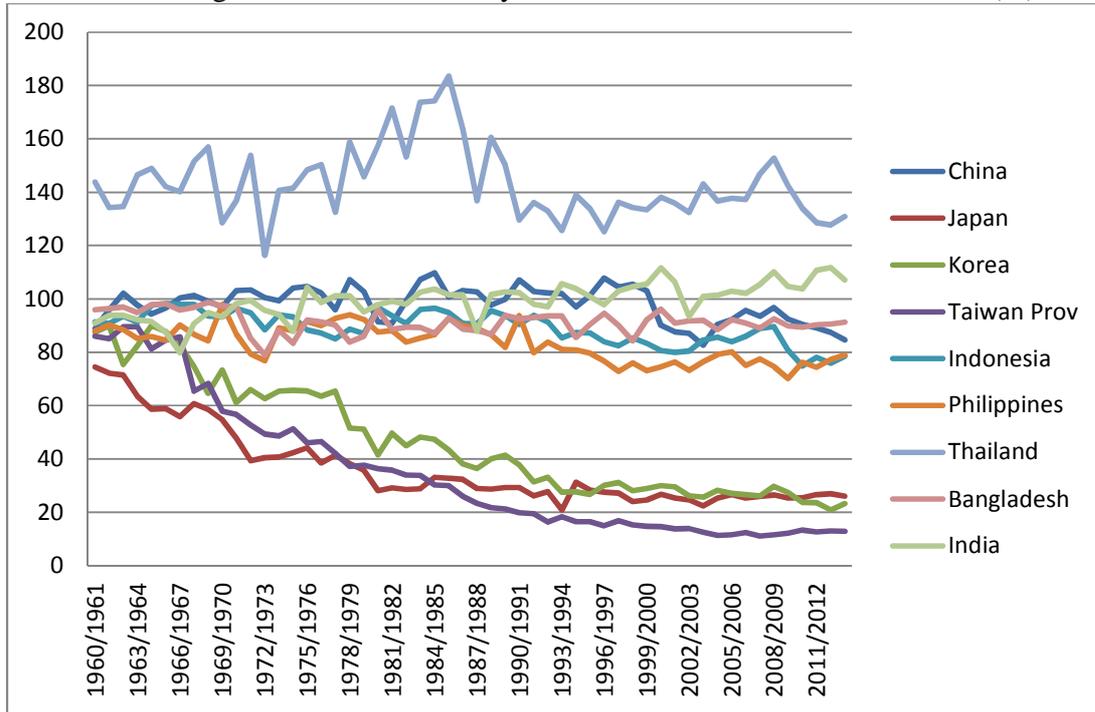
Source: Production, Supply and Distribution (PSD) data, USDA.
Notes: Total for rice, wheat, maize and soybeans.
Self-sufficiency is measured by dividing (gross) production by (gross) domestic consumption excluding stock changes. Gross production and consumption include the use other than food such as feed use.

Figure 2b Contribution of Supply-Demand Gap by Major Grains for China (1000 M tons)
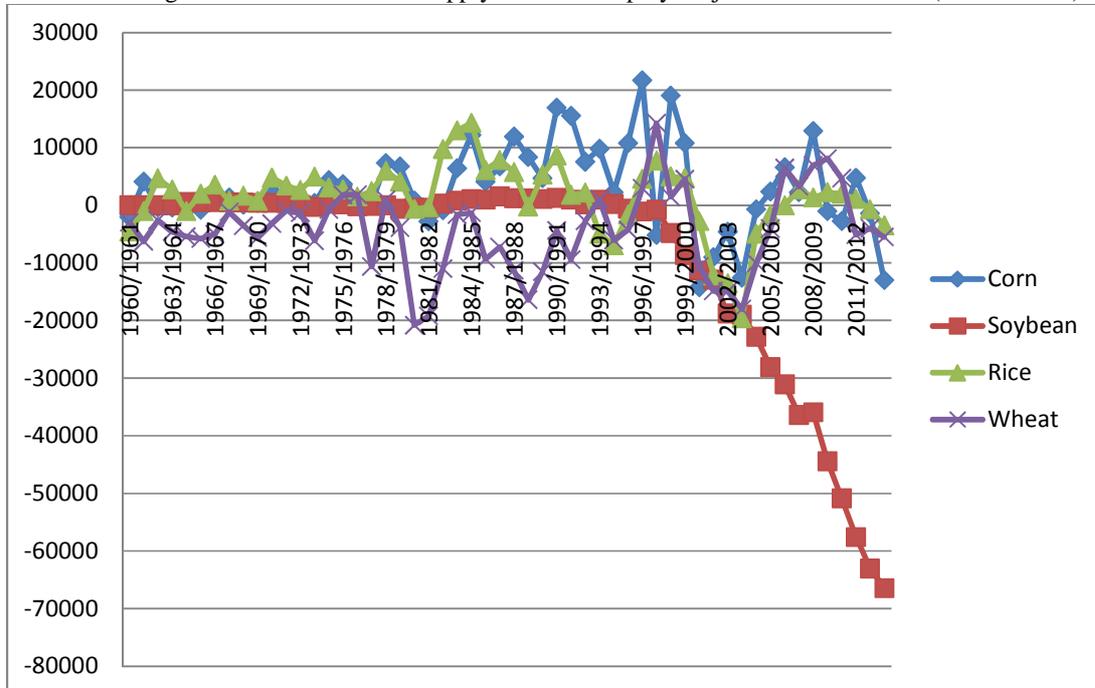
Source: Production, Supply and Distribution (PSD) data, USDA.
Notes: The figures reflect the differences between production and consumption, which are the sum of net imports and the changes in stock (Production – Consumption = Exports – Imports + Changes in stock).

Figure 3a Evolution of CE Consumption in China: Crops vs. Livestock Products (million tons)
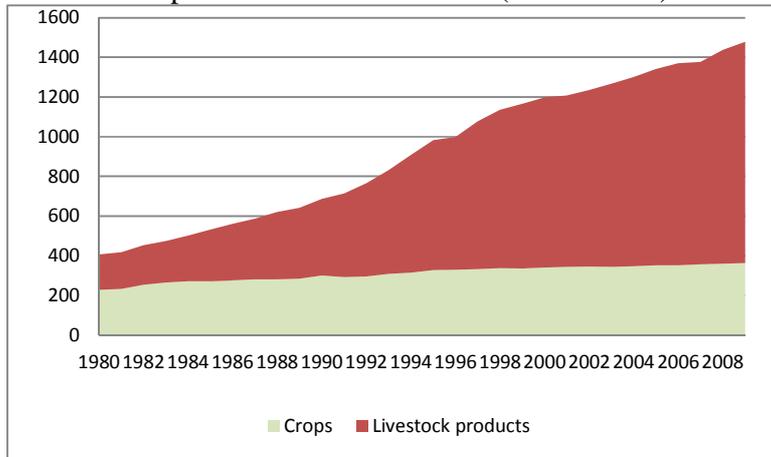
Source: Authors' calculation

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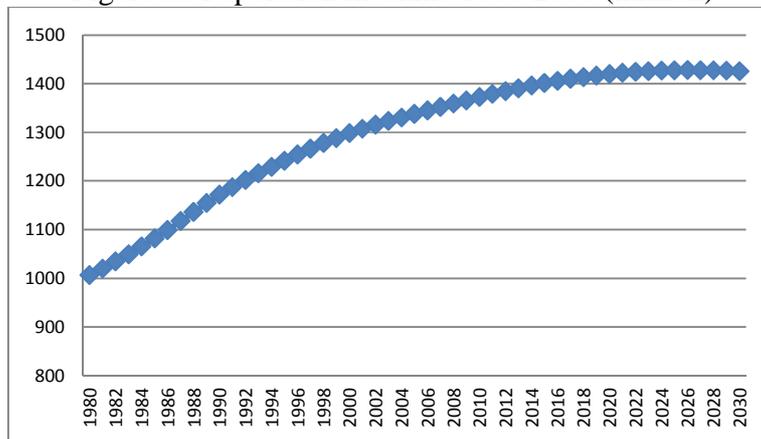
Source: FAOSTAT

Note: The series consist of both estimates and projections

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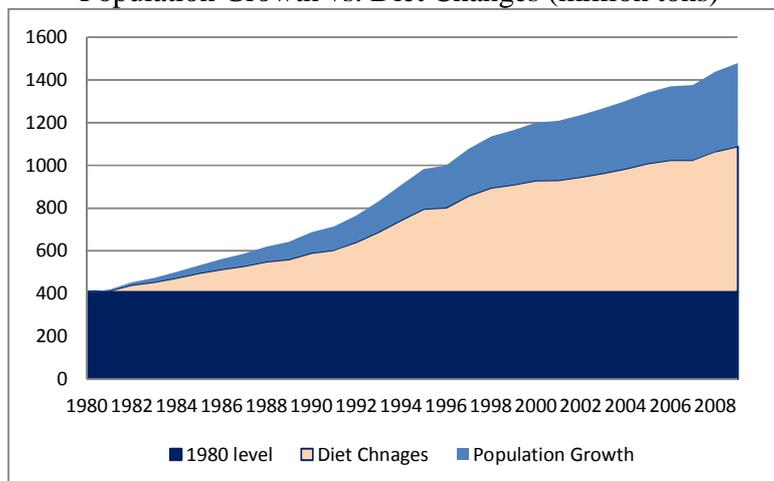
Source: Authors' calculation

Figure 4 Relationship between CE Food Consumption and Income
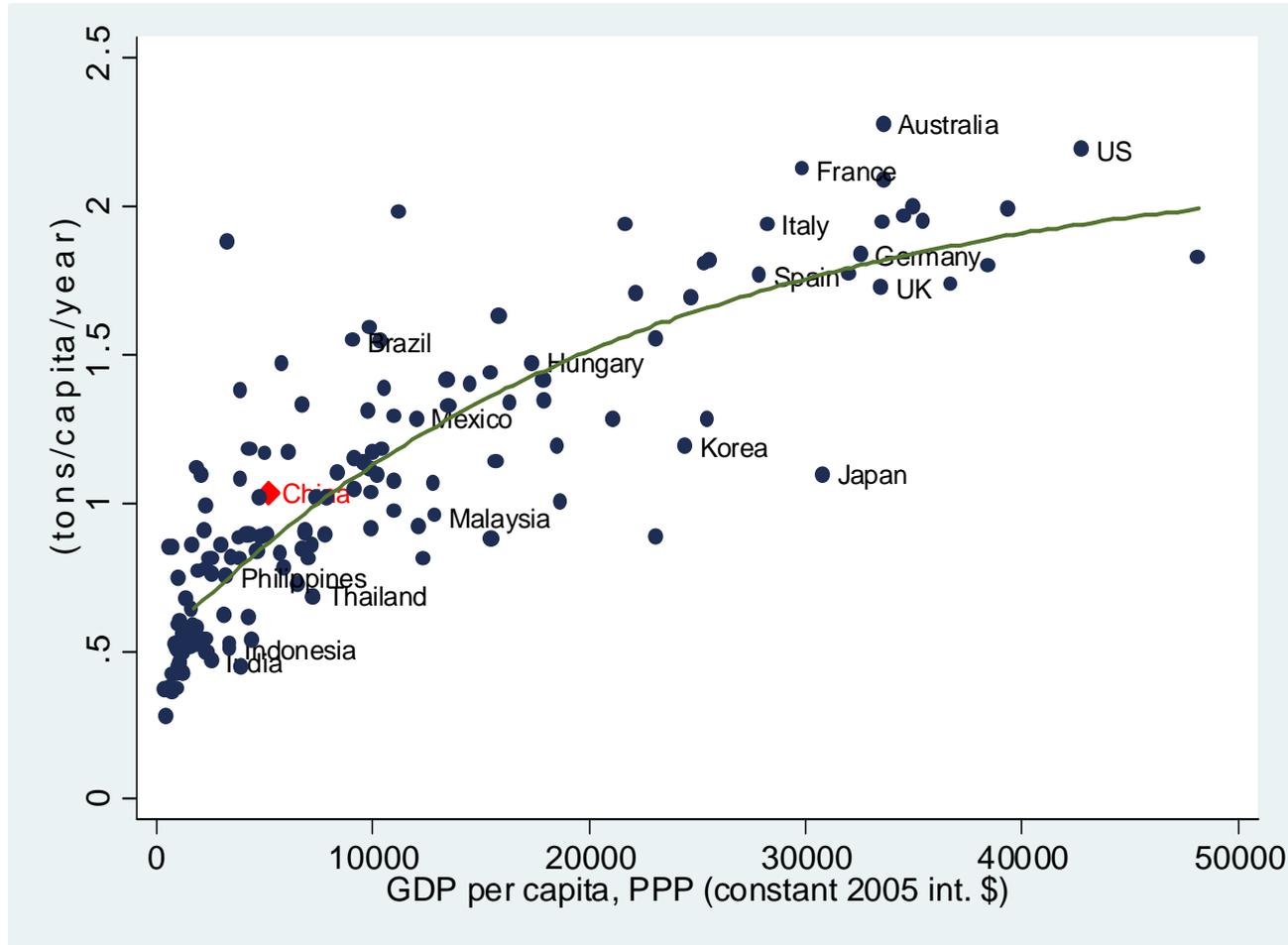
Note: The data are based on 2005-2009 averages.
The fitted CE consumption curve is based on the parameter values obtained by regression (1) in Table 2.

Figure 5 Growth Trend of CE Food Consumption 1980-2009
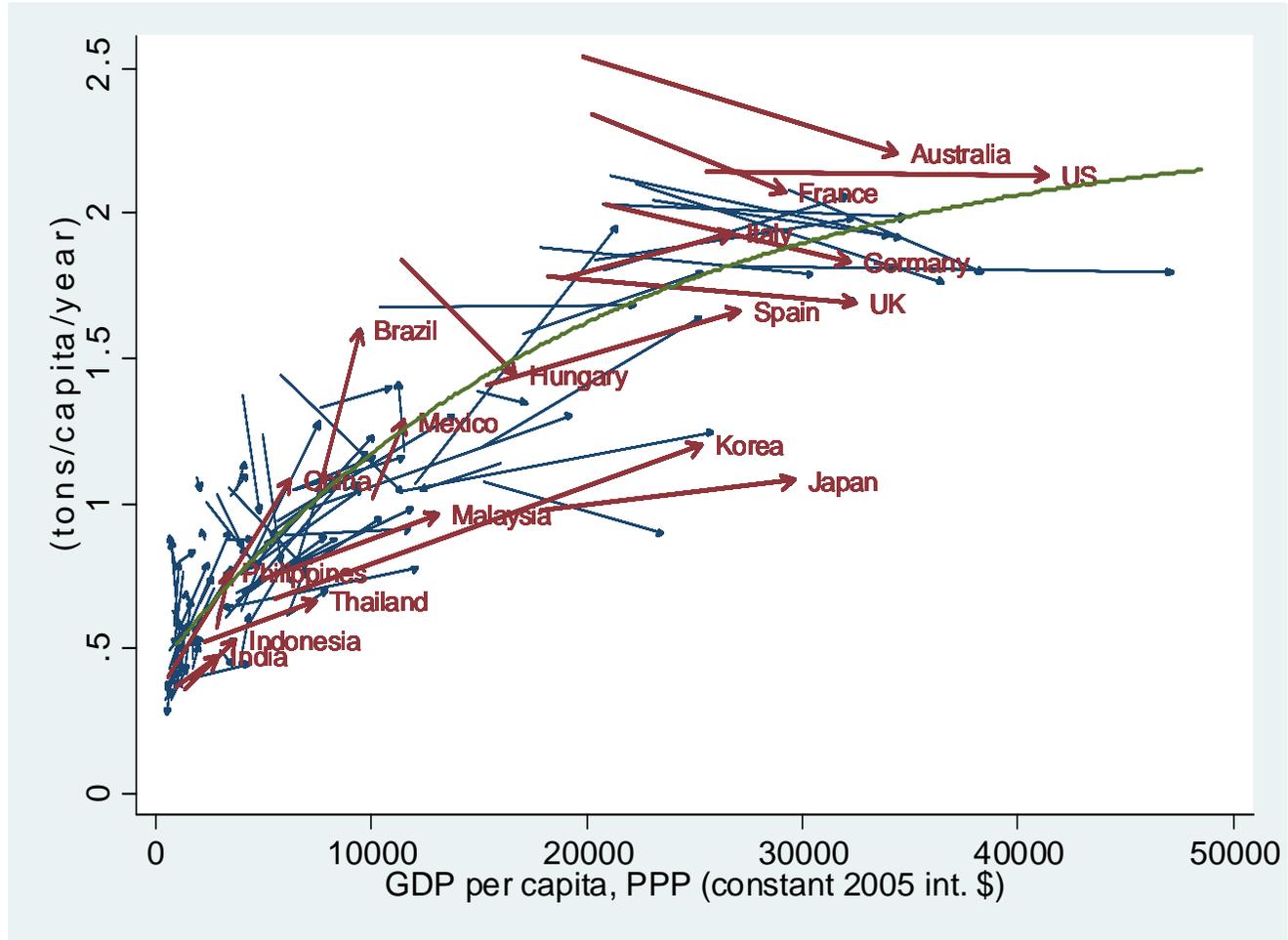
Notes : The starting and ending points of the arrows represent the CE consumptions for the year 1980 and 2009 respectively.
The fitted CE consumption curve is based on the parameter values obtained by regression (2) in Table 2.

Figure 6 Calorie vs. CE Consomption 1980-2009
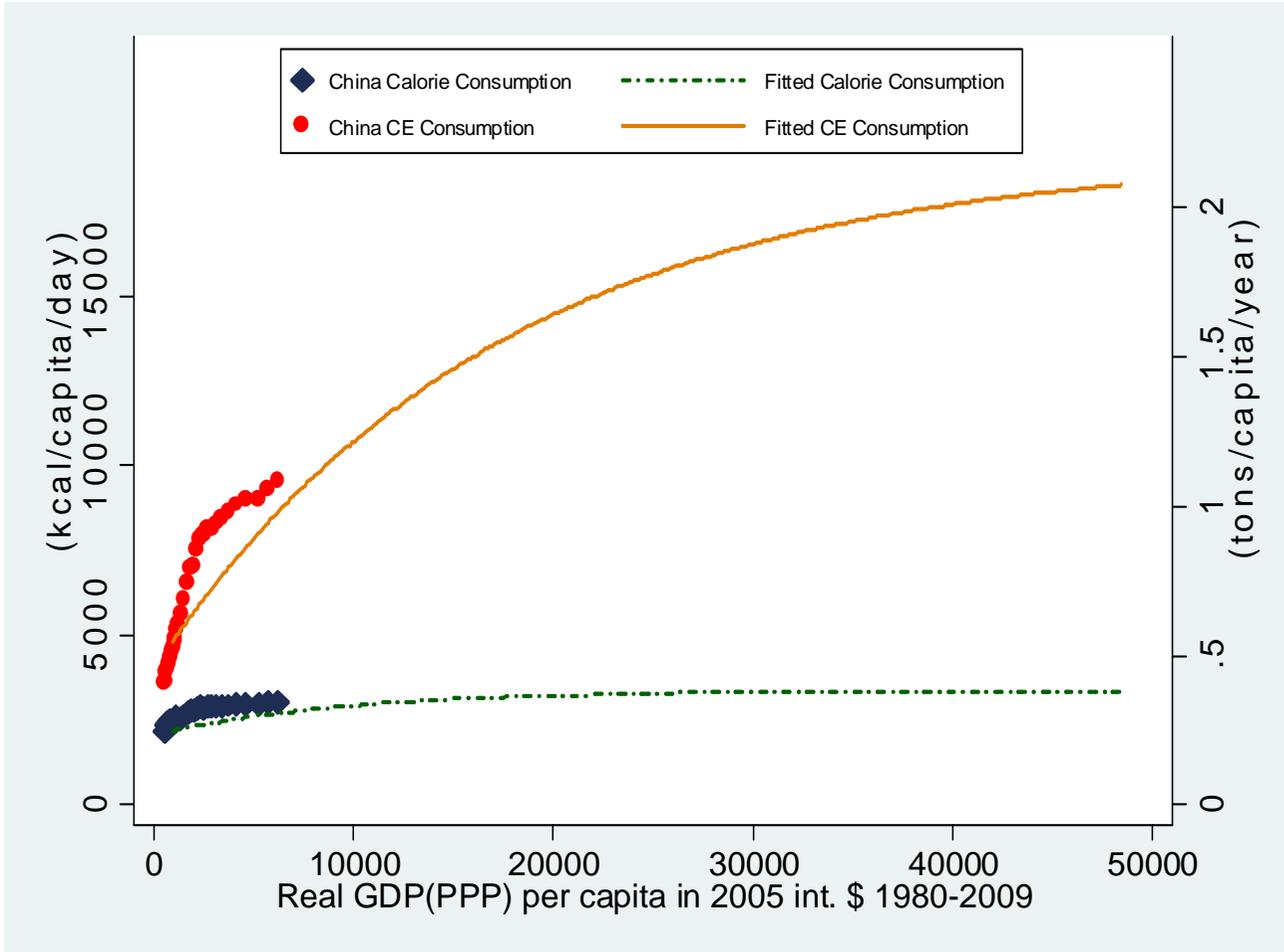
Notes: The fitted CE consumption curve is based on the parameter values obtained by regression (2) in Table 2.
The fitted calorie consumption line is based on the parameter value obtained using the same functional form as the CE consumption estimate (equation (1))

Figure 7a Land Productivity (Cereal yield (kg per hectare))
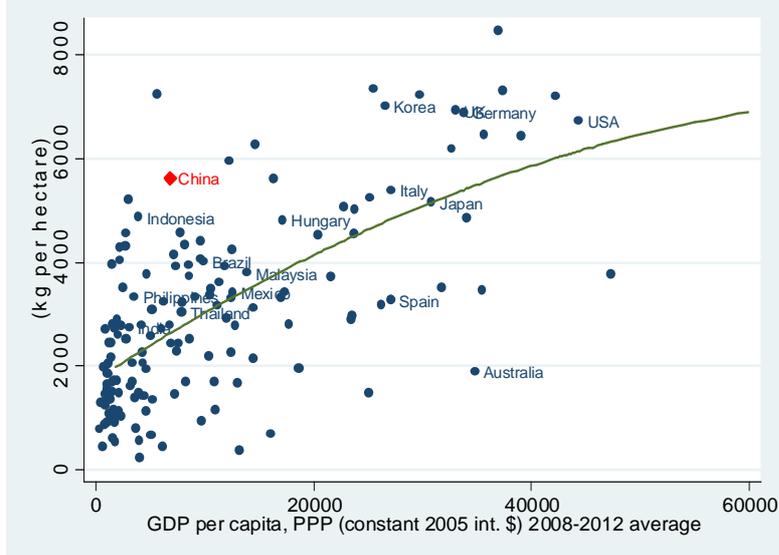
Source: World Development Indicators (WDI), the World Bank
Notes: The fitted line is estimated running a regression $v = C_1 + C_2 x + C_3 x^2$ where v is cereal yield in kg per hectare (2008-2012 average), x is PPP GDP per capita (2008-2012 average). The results turn out to be: $C_1 = 1736.3^{***}(173.3)$, $C_2 = .14^{***}(.034)$, $C_3 = -8.49e-0.7(9.76e-07)$ ($R^2 = .43$, Observations=155). The robust standard errors are given in parentheses.

Figure 7b Labor productivity (Agricultural value added per worker)
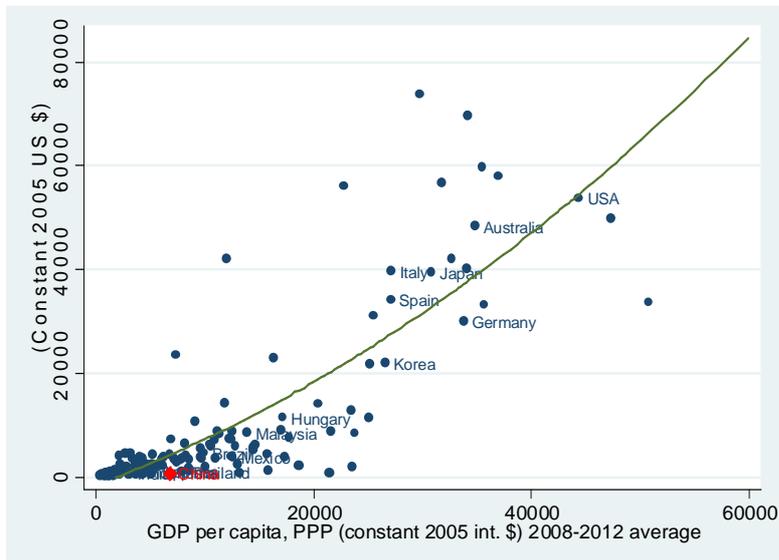
Source: World Development Indicators (WDI), the World Bank
Notes: The fitted line is estimated running a regression $w = D_1 + D_2 x + D3x^2$ where w is agricultural value added per worker in constant 2005 US \$ (2008-2012 average), x is PPP GDP per capita (2008-2012 average). The results turn out to be: $D_1 = -1461.75(1182.44) + D_2 = .76^{**}(.33)$, $D_3 = .000011(.000010)$ ($R^2 = .69$, Observations=147). The robust standard errors are given in parentheses.

Figure 8 Evolution of Land Endowment for Selected Countries
1980-2009 (hectare/person)
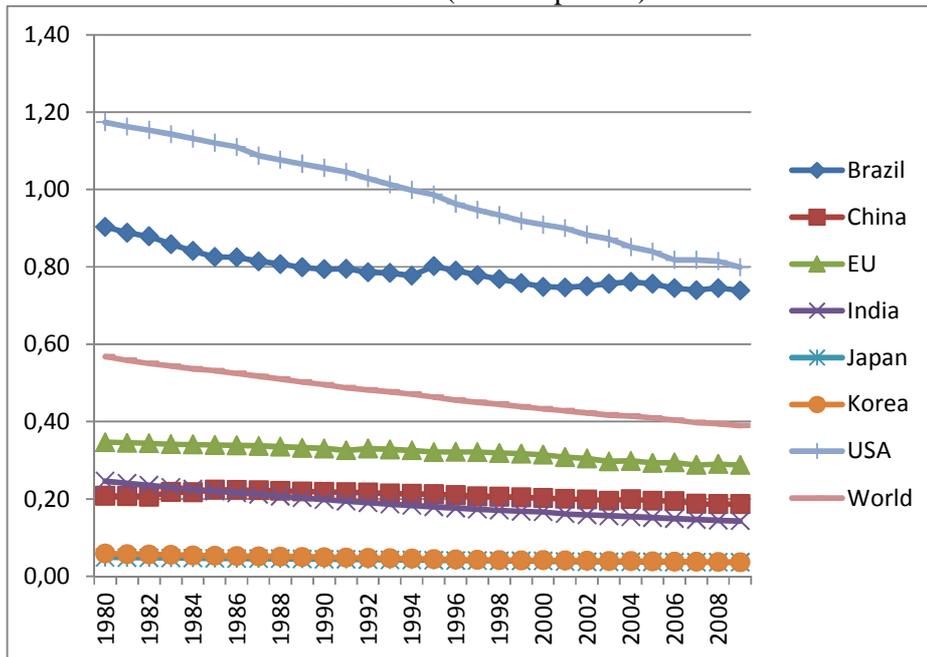
Country	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	1980-2009
Brazil	0.87	0.81	0.79	0.78	0.75	0.75	0.79
China	0.21	0.22	0.22	0.21	0.20	0.19	0.21
EU[*1]	0.34	0.34	0.33	0.32	0.30	0.29	0.32
India	0.24	0.21	0.19	0.17	0.16	0.15	0.19
Japan	0.05	0.05	0.04	0.04	0.04	0.04	0.04
Korea	0.06	0.05	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 land equivalent 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
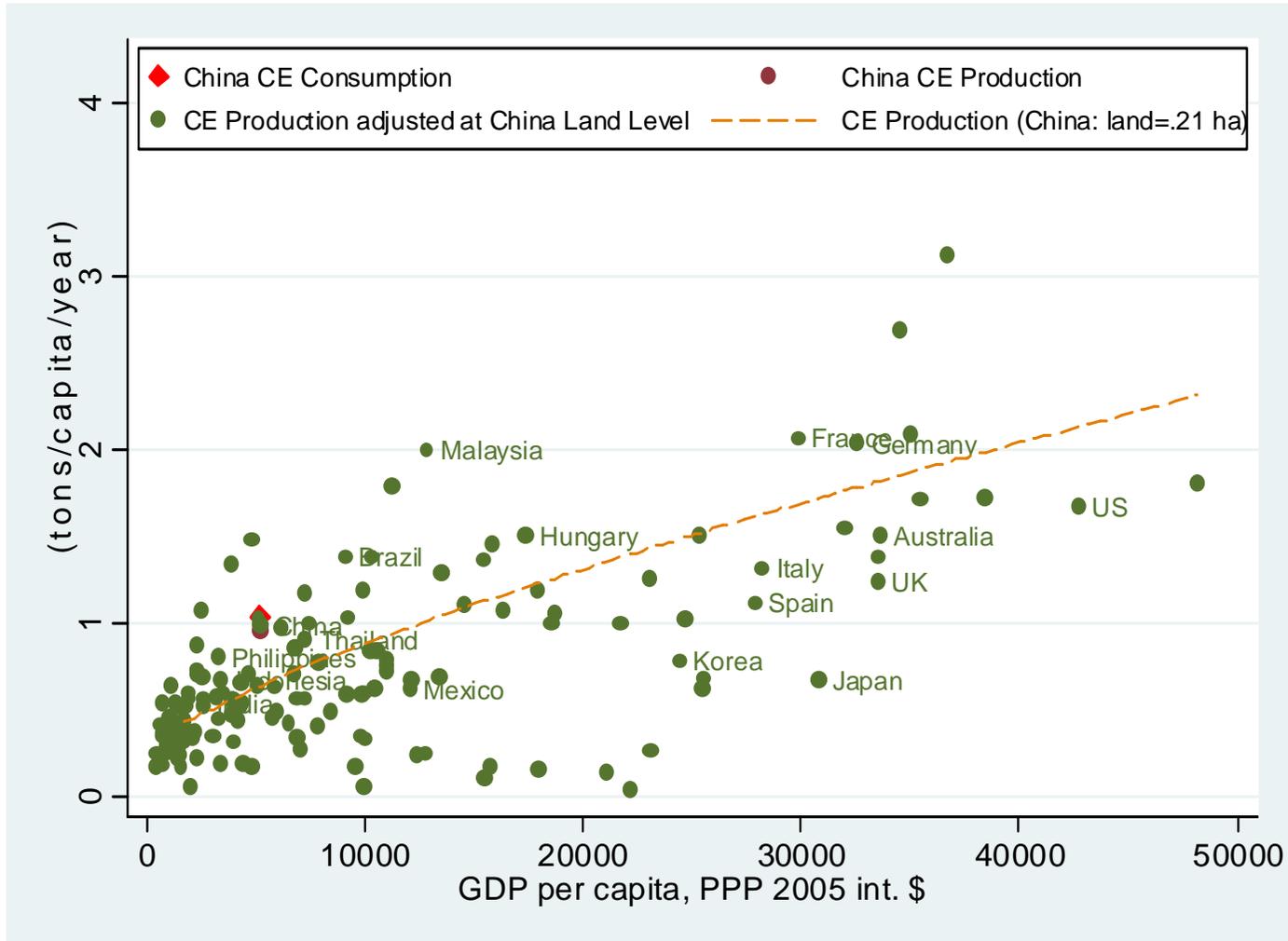
Note: The data are based on 2005-2009 averages.

Figure 10a Cereal Equivalent Consumption and Production for China and India 1980-2009
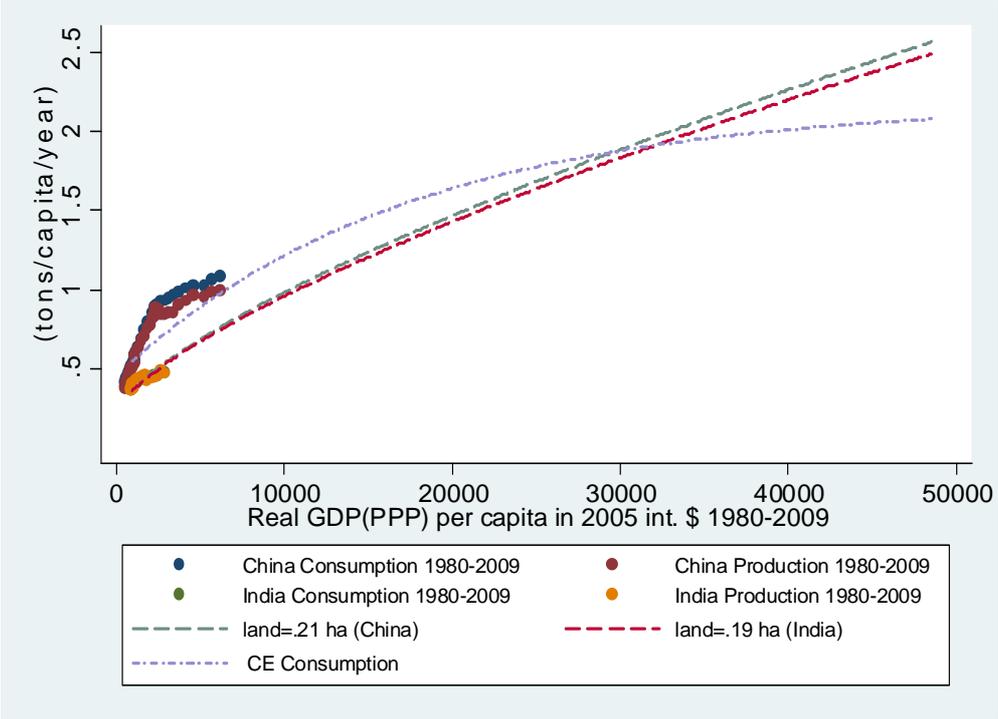
Figure 10b Cereal Equivalent Consumption and Production 1980-2009:
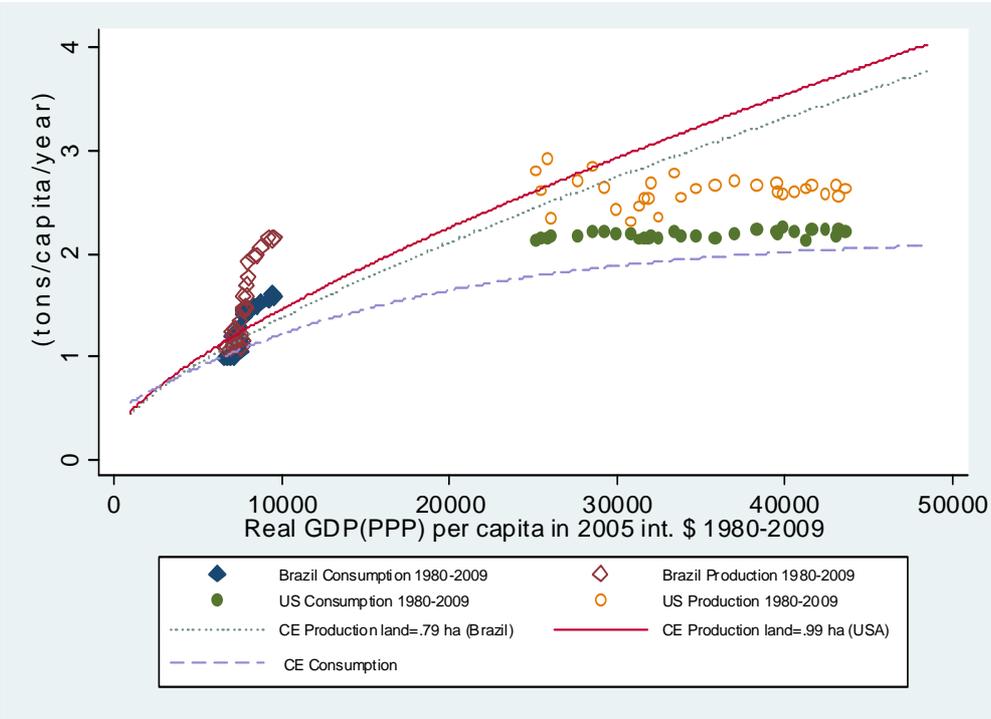Examples for Relatively Land Abundant Countries

Figure 10c Cereal Equivalent Consumption and Production 1980-2009:
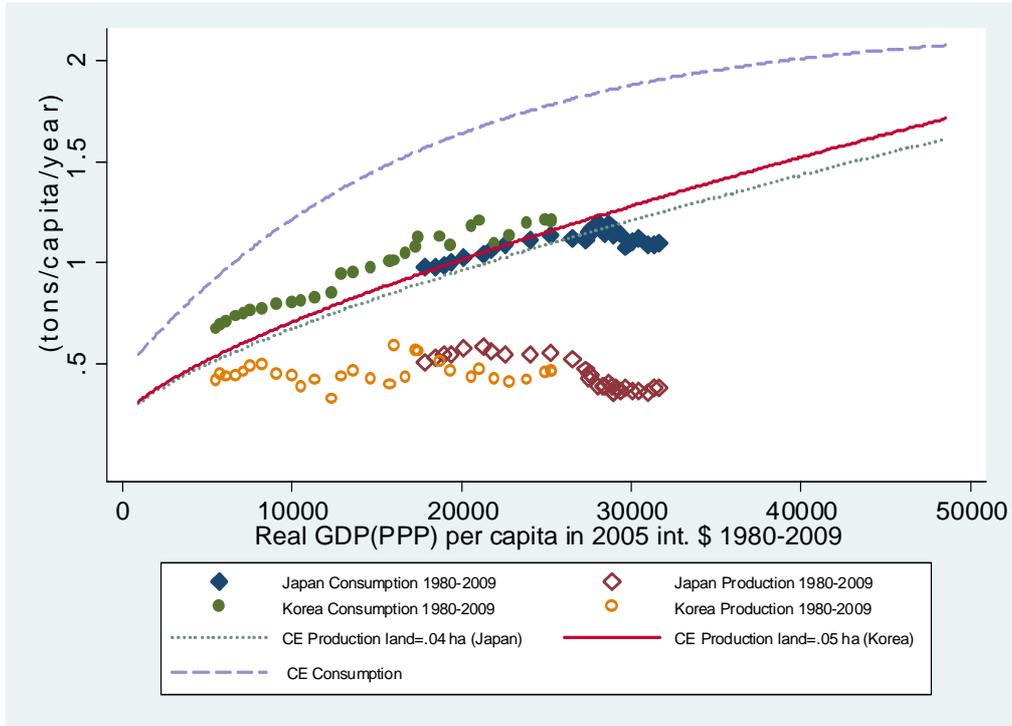Examples for Relatively Land Scarce Countries

Figure 11a CE Production and Consumption
Assuming China's Residuals Reflect a Sustained Difference (Scenario 1)
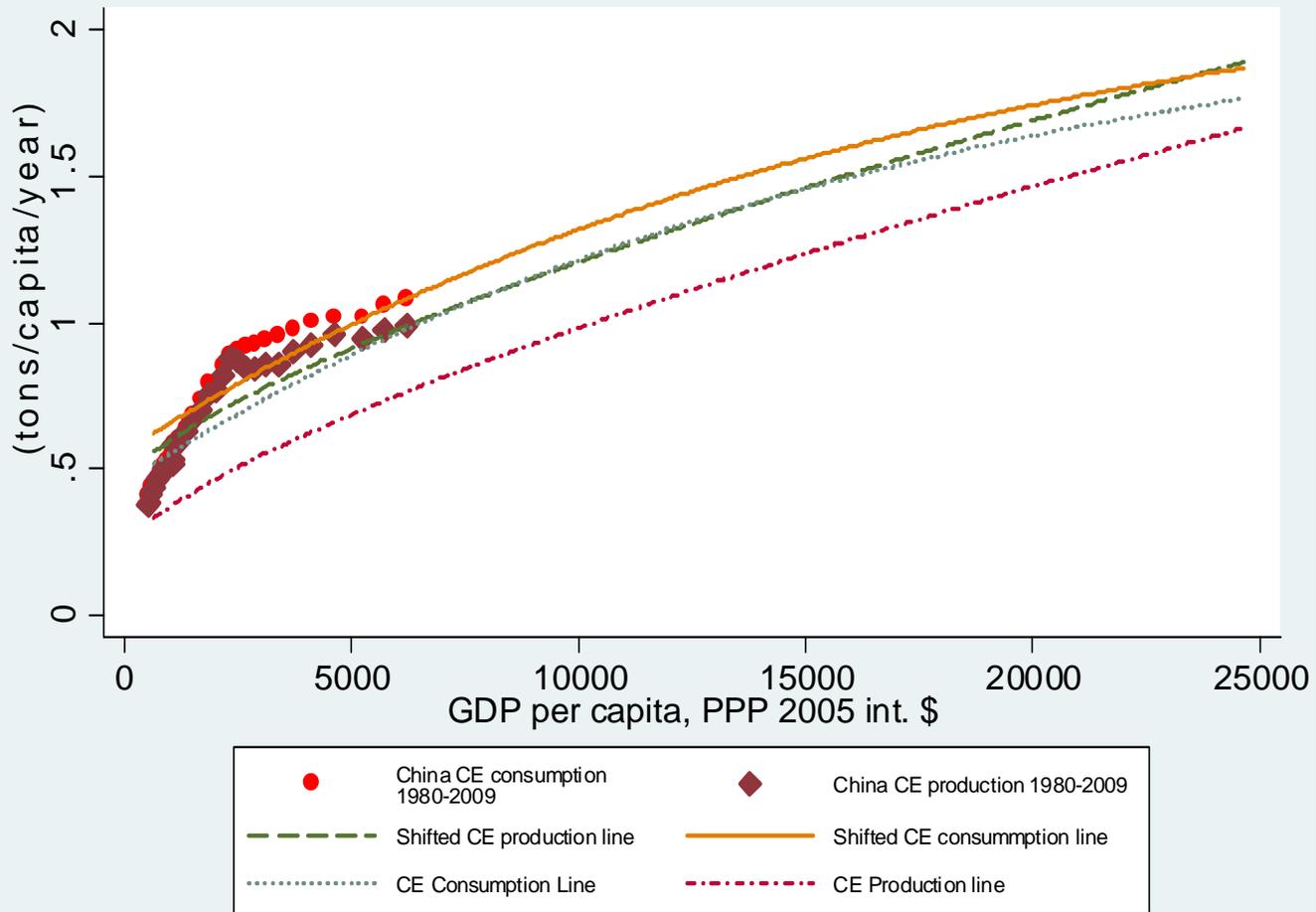
Figure 11b CE Production and Consumption
Assuming China's Experiencing some Loss of Cultivated Land (Scenario 2)
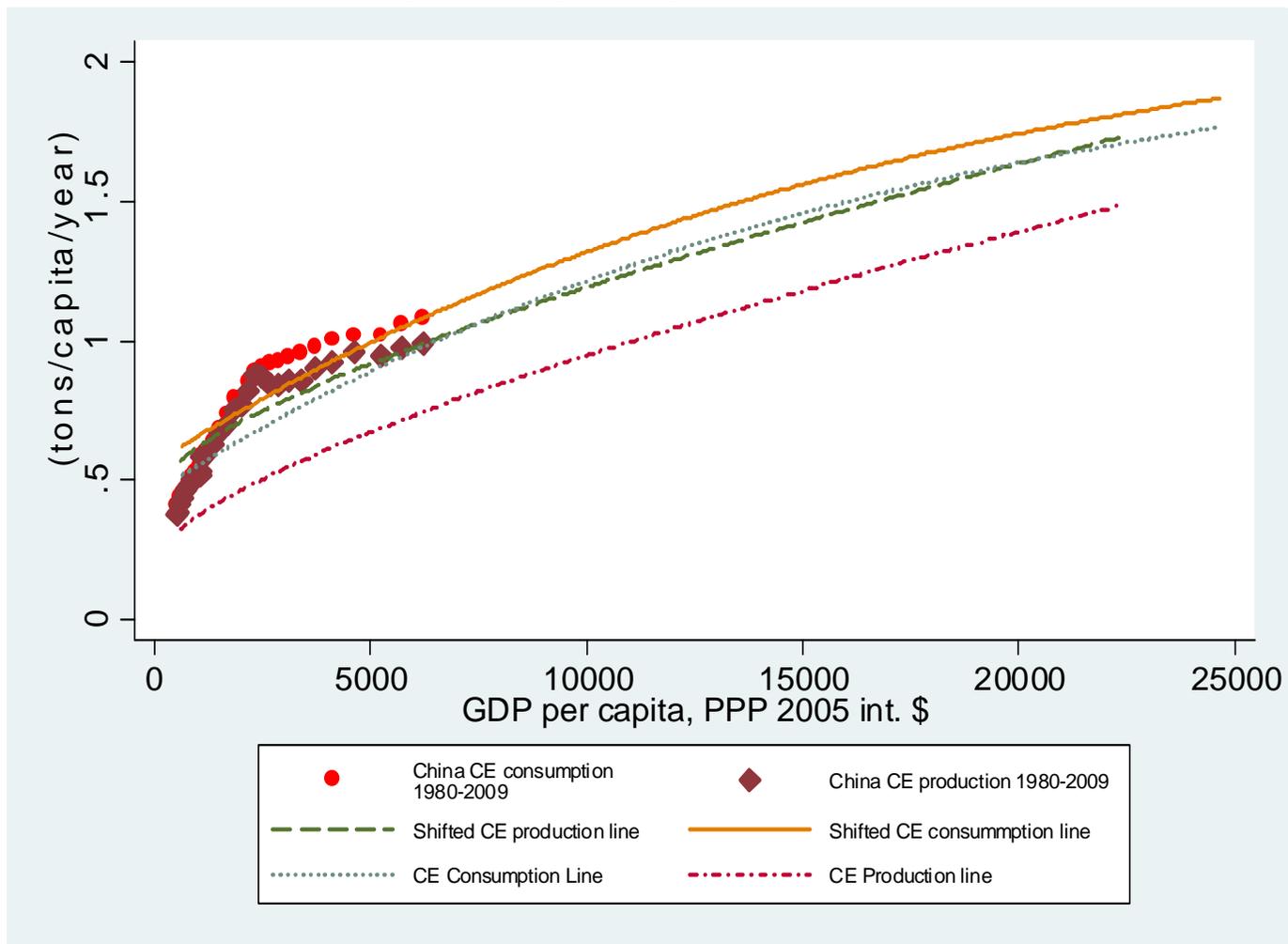
Figure 12a. Average Annual Consumption of Food: Urban Residents, 1957-2011(kg)
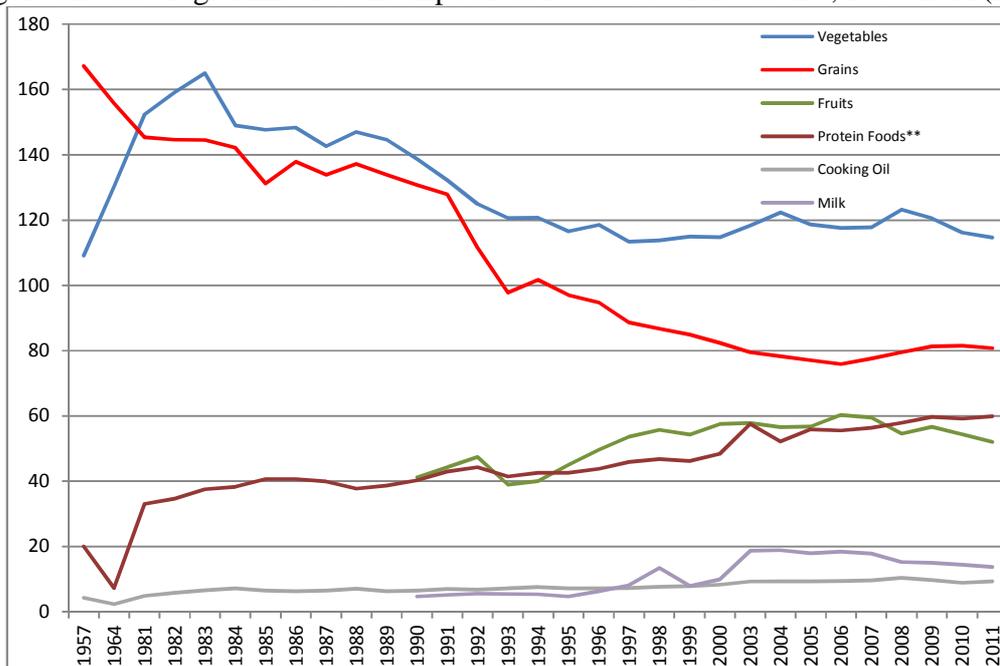
Figure 12b. Average Annual Consumption of Food: Rural Residents, 1978-2011 (kg)