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Future Demand and Supply of Food in China

- A modeling attempt -

by

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Being one of the largest countries in the world as well as having a huge population of 1.3 billion people, China plays an important role in the world economy. A slow transition towards market economy has expanded the markets for a numerous countries worldwide and being a trading partner with China is today of high interest for most industrialised countries. The economic development has grown at a steady pace for the last decades and there are no reasons to believe that this growth is levelling off in the near future. Projections of population trends estimate that the population will continue to expand until 2050 where a levelling off is predicted. The growth of both population and economy drives industrialisation and urbanisation where area for settlement and infrastructure is demanded. Agricultural land is converted into urbanised regions with high water consumption and pollution problems. Population and economic growth not only means that more food is needed, people with a higher income request a more diverse diet, a diet that needs a larger agriculture area to produce the same amount of calories. Higher levels of meat consumption need a large input of grain for feed. Clean water is a major problem today since water has become scarce and polluted in large regions of China.

The fundamental basis for self-subsistence in food production - agricultural land and clean water - is diminishing rapidly. China is densely populated most of the area suitable for food production is already used. The room for agricultural expansion is therefore limited. Soon this may necessitate an extensive grain import from the global market. When one fifth of the world population turns to the global market, it will be noticed all over the world. Unless remedial action is taken, perhaps on a global level, we may experience an increase of international grain prices. This paper aims to study future scenarios of the demand and the supply of food in china. A modelling attempt is made where system analysis and system dynamics is used to model future predictions of the dynamics between human development and food production. To meet the demand of a growing population with an increased living standard, the loss of agricultural land must be halted, new area for production need to be established, water resources should be conserved and re-circulated. The main finding of this study is that even if these conservation measures is carried out China may face an extensive need for future import of grain products. A key issue is how the people in China will change their diet. A rapid change in diet towards meat and diary products will worsen the situation.

Introduction

In 1995, Lester Brown, one of the leading debaters in environmental and sustainability issues, released his book “Who will feed China?” where he elaborates on the issue of China’s possibility for self-sustenance and possible impact on the global food market. His main conclusion is that the current path of development will have a great impact on the world market prices for grain. Since China will be rich enough to import food even with increased grain prices, they will be less affected than others, poorer countries, facing a similar future lack of self-subsistence in food production. If China starts vacuum-cleaning the global market for grain products, poor countries may not afford importing enough food for its people.

The introduction of high-yield crops and energy intensive agriculture during Green revolution has led to an increase in crop production. In 1992, the area used for agricultural production was equivalent with the area used in 1960, in spite of the fact that the world population had grown by 80%. The yield per area unit has increased three fold between during his period (Simonsson, 1996).

With human expansion comes a need for increased food production. China’s future economic growth, urbanisation, diet structure changes and population growth will influence both the demand of and supply for land. An increased affluence will trigger a more diverse diet such as livestock products, which in turn increases the demand for grain for feed. China is such a large nation – in terms of both population and economy – that its successes and failures will affect the entire globe. In an integrated world economy, rising food demand in China will translate into rising food prices everywhere. Land and water scarcity in China will become everyone’s scarcity. The problem is more serious now than ever since most of the land suitable for agriculture is already used (Biswas 1994). Nearly the entire world’s productive land, flat and with water, is already exploited. In Asia, nearly 80% of potentially arable land is now under cultivation. A continuous increase of food demand will put additional pressure on the capacity of agriculture to provide people with food (Biswas, 1994).

Many people argue that since previous models often have proved wrong in predicting future development we should not worry too much about frightening simulations, foreboding starvation and misery. It is true that in many cases these models have proved wrong but we cannot tell if one reason is that they once highlighted a serious problem and thereby gave some room for people to act in a preventive way. Furthermore, in an interconnected world a simulated food scarcity in one country may become realized in another, poorer country, and it is possible that many models may have failed to consider this effect. It is also reasonable to believe that the identified cause is changed during different stages of development (from self subsistence to food deficiency) where religious differences is argued being the root cause for a conflict when in fact this stems from lack of resources.

The purpose of this report is to simulate whether or not China will manage to feed itself while continuing to promote rapid industrialisation. Largely, Lester Browns book have been used as a basic source of information but also other resources are used to develop and parameterise the model. In our model, we will separate the supply from demand that may seem strange from a system dynamics perspective where we aim to “close the loops”, “include the feedbacks” and so forth. The reason for this is that we do not negotiate with the human population. The predicted increase of the population is assumed as if there will be enough food. In one way or another Chine highest priorities must be set to meet this demand. Another reason is that we are interested to know how much increase in food supply (or import) that is needed to meet the demand. A model that closes the loop and where people starts to die from starvation as the food scarcity becomes apparent will fail to capture the gap between demand and supply.

Population growth

China has the largest population in the world and accounts for 1.3 billion people. In 1949, when the People’s Republic of China was founded, the country had a population of about 540 million. Three decades later its population had grown to more than 800 million. This growth is now driving China's population development despite already low fertility levels. Several projections assume that the population will rise to some 1.5 billion people within the next 25 years. This causes a major problem for China's food supply, since an additional 260 million people will have to be supported in just three decades. A massive rural-to-urban migration will also occur during this period, due to a huge excess agricultural population, as well as a growing labour demand of urban industries and service sectors and an income gap between rural and urban employment (Heilig 1999).

Economic growth

With the rapid industrialisation, China has had an economic growth of an average 10% per annum since 1976 (Worldbank 1999). To increase individual welfare, but also avoiding political unrest, a continued economic growth is a major goal in China, as for most nations. The current means to stimulate economic growth is by promoting industrialisation since it generates both employment and combats unemployment. Industrialisation limits possible grain production to some extent since it requires water and occupies land area. Unfortunately, industrialisation takes place where the best land for agriculture is located because this is where most people live. Furthermore, the process of industrialisation consists not merely of building factories, but also the essential development of infrastructure. More roads also result in land lost for agriculture. Brown (1995) states that the Chinese government plans for a transport system based on cars. By promoting the car industry as one of the major growth industries, China thereby follows a known path that will require more land area being converted to roads.

Dietary changes

Furthermore, the fact that China is in the middle of its 'post-Maoist' economic revolution has an additional impact on the future society, including traditional changes. As the people will be more rich they will change their diet. Major trends concerning the diet change show that the overall calorie supply per person has increased and the composition of food has drastically shifted to a richer and more diverse one (Brown 1995). With rising incomes people diversify their diet from the traditional Chinese diet of rice, wheat and starchy roots to pork, poultry, eggs, milk, vegetables and fruits (ibid.). Over the last couple of decades a steady increase in affluence indicates that China's average diet will change towards a higher demand for meat and meat products, dairy products and eggs. Higher meat consumption among the affluent frequently creates problems for the poor, as the share of farmland devoted to feed cultivation expands, reducing production of food staples. An increased demand for feed grain, which cannot be satisfied by the internal production, will lead to increased prices. This is unlikely to occur though, since politicians have had a tendency of buying social stability through subsidising food. In 1993, the government released 2.5 million tonnes of grain from stocks to keep the price rises in check. Grain prices will have to be kept on such levels as to keep the farmers on the land but sufficiently low to prevent urban unrest.

Declining food production

In the early 1960s, most nations were self sufficient in food, now only a few are. Because of high population growth, arable land available per capita has steadily declined with time in nearly all developing countries. By the middle of the next century, Asia will have 50% of the world ´s population but only 31% of the world ´s arable land and 23% of its pastureland. China will be even worse off, with 25% of the world ´s population in a country which has 6% cropland, 18% pasture land and 76% other land uses (The World Guide 1997/98).

China has had an exceptional increase in the per capita grain production, after agricultural reforms in 1978 output rose from nearly 200 million tonnes to 300 million tonnes in six years. The agricultural production level is today comparable with western, highly energy consuming ones. Development leads to a loss in productive cropland due to the conversion into other land uses such as housing, infrastructure and industrial areas; as cropland losses accelerate, they soon exceed increases in the land productivity. While production is falling, rising affluence is driving up the overall demand for grain. Between 1990 and 1994, the grain area in China has dropped 1.4% annually. Rapid industrialisation of an already densely populated country leads to a heavy loss of cropland, which can override any rises in land productivity and, thus, lead to a net decline in total food production. The combination of continually expanding population and a shrinking cropland base will further reduce the already small area of cropland per Chinese citizen. In 1952, there was 0.188 ha of cultivated land area per person. By 1990, this figure had declined more than 50% to 0.086 ha (Biswas, 1994).

Water scarcity and pollution

Water availability can be considered a main issue in China, since the water supply for agriculture is reduced due to expanding urbanisation and growing industrial demand, especially in the northern parts of the country. Agricultural water accounted for 88 percent of the country's total water consumption 20 years ago. However, this proportion has decreased to 72 percent and local experts say population explosion and rapid urbanisation will further cut the rate to 52 percent by mid-21st century (Adhikari 1999). Another problem is that while some 44% of the population and 58% of the cultivated land are in the northern and northeastern provinces, less than 14% of the total water resources can be found in these regions (Heilig 1999). Moreover, about 70% of all cropland is irrigated but estimates show that up to 60% of the water evaporates from open canals and fields with traditional flooding irrigation. In recent decades, several major rivers have actually been dried out before reaching the sea and water shortage is becoming more evident (Brown 1995, Heilig 1999, FAO 2000).

Concerning pollution issues, according to Heilig (1999), about 80% of industrial wastewater is untreated and it accounts for two thirds of the total discharge into rivers, lakes and the sea. UN Food and Agriculture Organisation (FAO) estimates that, as a result of toxic discharge from cities and upstream enterprises, 80% of the 50,000 kilometres of major rivers in China are so degraded that they no longer support fish. The water in the Yellow River (*Huanghe*) is now so contaminated with heavy metals and other toxins that it is in many regions unfit for irrigation (Brown and Halweil 1998).

Conceptual model

A causal loop diagram was created to visualise the main driving forces and the limiting factors in the analysis of the food situation in China (Fig 1).

Population is a key force. Increasing population will lead to increasing demand for grain. Economic growth will translate into an increased demand for meat, leading to increasing demand for grain. The economic growth will depend on industrialisation. Political stability is another reinforcing factor on economic growth, and economic growth leads to increased political stability.

Domestic and industrial water use increase with economic growth, as the general consumption in society will increase. This will translate into a reduction in the amount of water available for irrigation of agricultural land, reducing the amount of available grain.

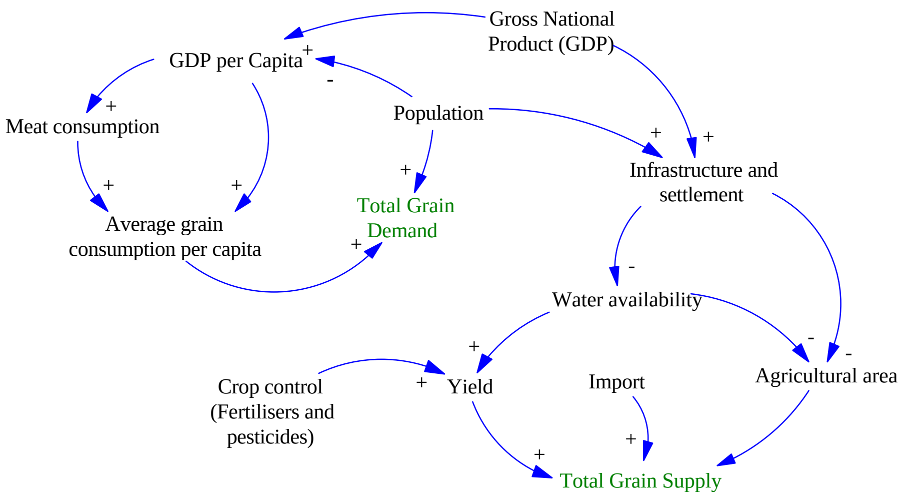

Figure 1. This simplified conceptual model identifies the main factors affecting demand and supply of grain.

The land area used for infrastructure, housing and industrial areas is also influenced by economic growth. When land is used for these purposes the agricultural area will decrease.

The amount of available grain will determine if China needs to import grain from the global market. Grain imports will, in turn, increase the amount of available grain in China. The grain import will, however, decrease the world grain stock, which in turn will result in higher prices and less available grain in China, although this will have a time delay. This is, thus, a fix that fails. World grain supply also influenced the political stability in China in a reinforcing way.

There will be no major increase in the productivity of agriculture in the world that can compensate for the loss of cropland due to land degradation.

Translating into mathematics

The model developed in this paper has the objective to predict the potential gap between demand and supply. We will elaborate the model starting from each of these variables.

Demand

The total grain demand is dependent on the population and the average grain consumption per capita.

$$d = p \cdot c_{G/Cap} \qquad (1)$$

The yearly consumption of grain equivalents per capita is defined as:

$$c_{G/cap} = G + \sum_{i=1}^{n} k_i m_i \qquad (2)$$

where G is the average annual grain consumption, k is a specific conversion factor converting the meat consumption, m, into grain calorie equivalents. Each meat type is denoted *i*. Poultry, pork and bovine are considered in the model.

The average annual calorie intake per capita is dependent of affluence.

$$e_t = f(GDP/Cap) \quad (3)$$

Also, the average annual consumption of meat calories per capita is related to affluence.

$$e_m = f(GDP/Cap) \quad (4)$$

The annual calorie intake is the sum of the grain and meat consumption.

$$\boldsymbol{e_t = e_g + e_m} \quad (5)$$

The equation for calculating demand then becomes;

$$d = p \cdot [\lambda_1(e_t - e_m) + (\lambda_2 \cdot e_m)] \quad (6)$$

where λ_1 and λ_2 are specific constants to convert calories into grain equivalents in kilo. Different crops have different amount of calories per weight unit. The present average consumed grain products (mainly rice and wheat) is used and assumed being constant.

The individual affluence is based on a regression between GDP per capita and the consumption of grain and meat. An estimate of daily calorie intake at a given level of GDP per capita was derived with equation 7.

$$y = \alpha + \beta \ln(x) \quad (7)$$

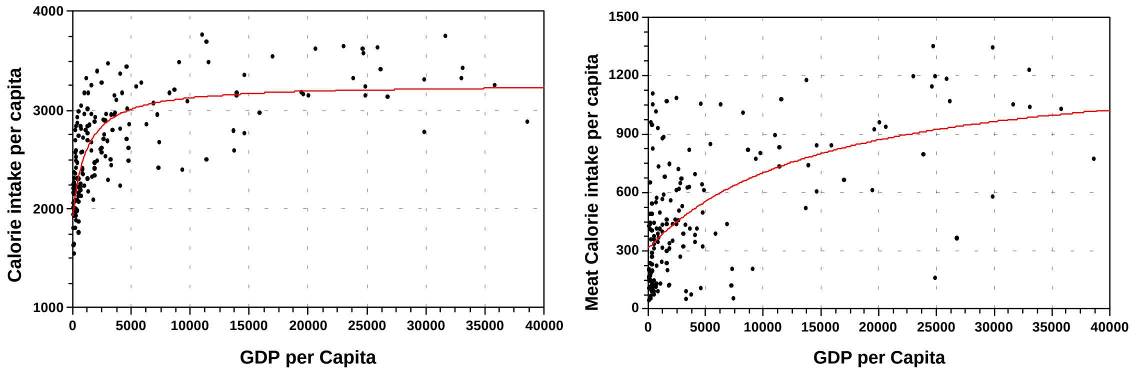

Figure 2. The relationship between GDP per Capita of 171 countries and their (a) total calorie intake per day (r=0.76), and (b) calorie intake per day derived from meat (r=0.6).

The GDP is presently growing at a rate of 8% per year (mean of last 4 years) and is expected to continue to grow at a high rate. The GDP per Capita is derived when dividing the GDP with total population.

Supply

The supply of grain for China can first be divided into domestic production (self produced) and imported grain supply (Equation 8).

$$S = D_p + I \quad (8)$$

The domestic grain supply is a function of yield (Y) (e.g. yearly grain production in kilogram for one hectare) and agricultural area (A) Equation (9).

$$D_p = Y \times A \quad (9)$$

The yield is affected by several factors where the most important are fertilisers and water availability. Also, pesticides, climate, equipment and knowledge are important factors affecting yield. Available area for agriculture is also affected by the availability of water. Furthermore, settlement and infrastructure is today important factors that reduce the land area under agricultural production.

Water is probably the most crucial limitation to a further expansion of the food production. There are however suggested solutions on how to alleviate the problem of water scarcity. These include diverting the pathway of one of the larger rivers in China. We will not model water availability explicitly in this paper. For now, it is enough to state that an increase of water supply would enable the possibility to increase both the annual yield and, since one can irrigate drier land, the area under agriculture.

Model assumptions

- The world grain import, excluding China, was 32 million tonnes in 1995. It is estimated to be 190 million tonnes in 2030 and in 2050 this figure will be 200 million tonnes (Brown, 1995).
- The total produced grain in the world was 1800 million tonnes in 1995 (Wackernagel, 1994 & Biswas, 1994).
- The loss of cropland is 1.4% per year (Biswas, 1994).
- The grain available at the world market will increase with 2% annually (www.WRI.org). This is a rather optimistic increase in global productivity. Another scenario is that the production increase and the loss of arable cropland will be equal and that there will be no increase in the world market.
- Total area used for grain production in China is 80 million ha (The World Guide 1997/98 estimated the area to be 60 million ha, Biswas (1994) estimated this area to be 100 million ha and Wackernagel, 1994, estimates it to be 192 million ha).
- 4.5 tonnes of grain is produced per ha in 1995 (www.WRI.org), and we assume an increase up to 6.0 tonnes in 2050

Parameterisation

The major drivers for the system are population- and economic growth. These two factors sets the foundation for several issues. To estimate the population growth projections made by the UN is used. Three projections (low, medium and high) are used to test the outcome at different future development. Economic growth is more difficult to foresee. The simplest way would be to use the average growth the past years and holding this parameter constant for future scenarios. However, a 10% increase every year produce an exponential growth that seem unlikely to continue. One can argue that we may see a rapid expansion in the economy during the transition towards a more liberated market economy. After some time the economy may decrease to rates more similar to the already industrialised world.

Population estimates

Table 1. Population projection for China (UN Population Information Network, 2001)

Year	*2000*	*2015*	*2025*	*2050*
Population (000)	1 275 133	1 410 217	1 470 787	1 462 058

In order to do sensitivity analysis in a simple way the logistic growth function were used to model the population (Equation 10).

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) \qquad (11)$$

The maximum population is determined by K (usually referred to as Carrying Capacity but in this case it is where the population levels out). N is present population and r is the growth of the population. Values of K and r are parameterised to run different scenarios.

Economic growth

We assumed that the economic growth will continue at a high rate but over time it will land around western rates. Over the 50 years of simulation the rate of economic growth therefore is reduced linearly from a present high level of around 8% to a more moderate level of 2.5%. Both the initial value and the slope of this decline is parameterised according to different scenarios.

Calorie intake

We used the parameter of the regression analysis to estimate how calorie intake changes as the GDP per capita increases (Table 2). The individual confidence interval (95%) for the parameters is used to produce different scenarios.

Table 2. Parameters used for equation 7, estimating daily calorie intake with 95% confidence interval.

	Parameter	95% Confidence interval		Parameter	95% Confidence interval	
	α	Lower	Upper	β	Lower	Upper
Total Calorie Intake	865.66	624.76	1106.54	242.70	211.34	274.07
Meat Calorie Intake	-439.53	-639.59	-239.48	125	99.08	151.17

An efficiency factor was used to convert meat calorie consumption to needed grain production for animal feed (Table 4). 80% of the meat consumption is derived from pig. We assume that the relative distribution of the different animals is constant over the simulation period.

Table 3. The present consumption of meat varieties and their subsequent efficiency factor.

	Calorie intake per capita and day	Per cent	Efficiency factor
Bovine Meat	22.36	5.64	9.1
Mutton & Goat Meat	11.17	2.82	-
Pigmeat	314.53	79.47	5.2
Poultry Meat	45.85	11.58	2.75
Meat, Other	1.88	0.47	-

Simulations –preliminary at this stage

Three scenarios were made; best, medium and worst case. Table 4 show the parameters used for the different simulations. In addition the confidence limits for calorie intake given in table 2 were used.

Table 4. Parameter settings for the three scenarios.

Population growth rate (%)	4	5	6
Maximum population (million people)	1400	1500	1600
Economic growth (%)	6.4→2.0	8→2.5	9.6→3.0

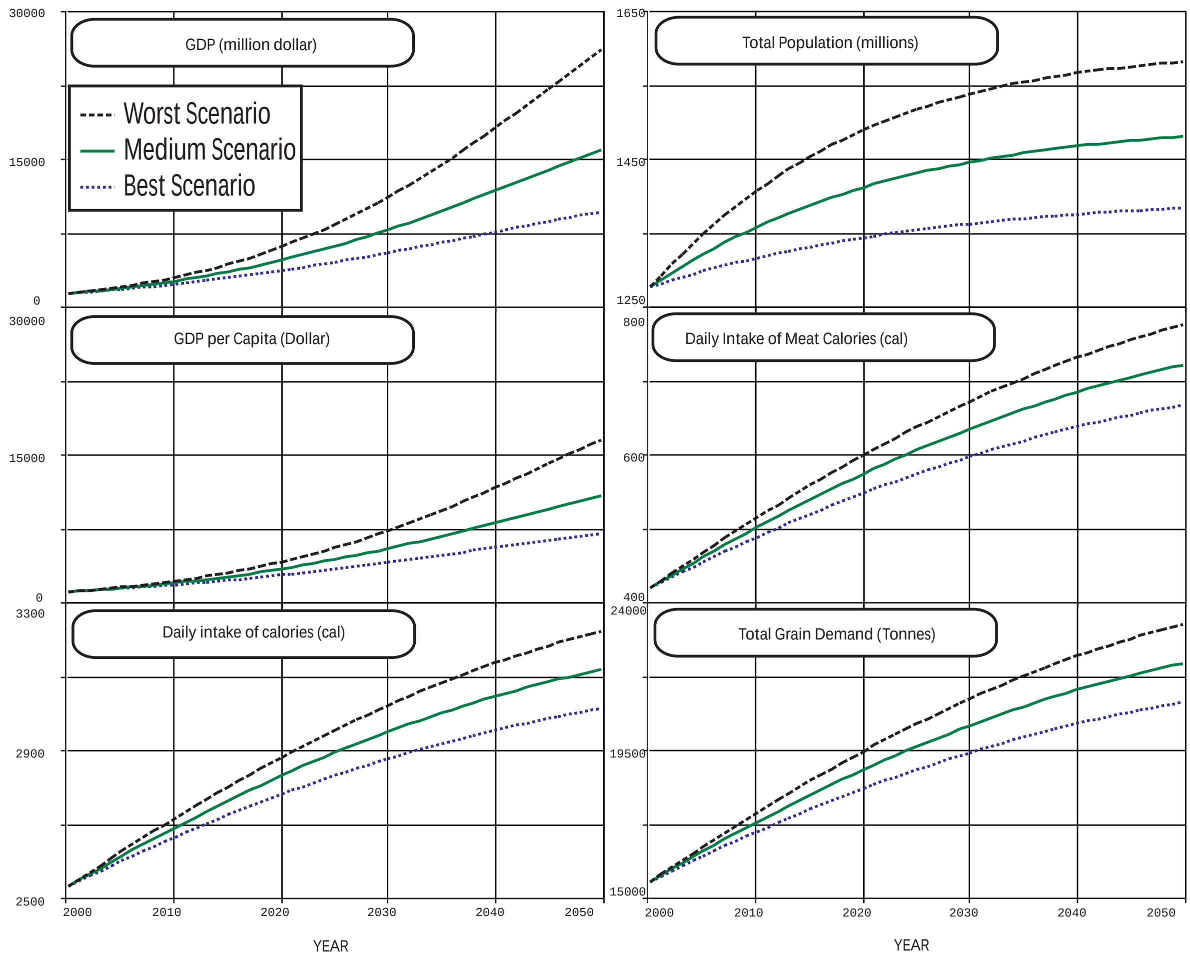

Figure 3. These charts show the result of running the model according to three scenarios.

Discussion – preliminary at this stage

The first manually tabulated results of the (first) National Agricultural Census show that 561 million people are economically active in rural areas and that of these, 424 million are involved in agriculture. (Adhikari 1999) These numbers differ from former statistics, which spoke of 453 million people working in the rural sector.

Another key revelation from the census is that China's cropland area is greater that expected, despite the continuing loss of arable land to industrial development and the building of infrastructure, roads, airports and housing across the nation. (Adhikari 1999) This means that yield increases will be possible because yield statistics have been overestimated due to the underreporting of land, by 30 - 40% (Barney et al, 1999).

Comparing world production available at the world grain market with China's import needs we came to the conclusion that there will be a deficiency around the year 2015. Running the scenario of a zero increase in global productivity, due to the degradation of cropland, the global grain market deficiency will happen in 2010.

Before this happens it is likely that there will be chaos on the global grain market.

By reducing per capita grain consumption to a maximum of about 400 kg/year there will be no deficiency. This is a rather optimistic scenario since it shows that there is a possibility of managing this "doom-day scenario" by having a sustainable consumption pattern. Biswas (1994) estimate that global food production is adequate to feed 7 billion people a vegetarian diet, with ideal distribution and no grain fed to livestock.

Limitations with the model

The assumption of the economic growth is very difficult to estimate. There is no link between economic growth and grain scarcity. It is most likely that the economic growth will suffer from grain deficiency. The economic growth is assumed to follow the same pattern as the western world with increased industrialisation, urbanisation and consumption. When changing the correlation between income and grain demand (figure 7) there was a significant change in the rate of grain demand.

We have not included water scarcity. It is most likely that water deficiency will be a limiting factor to increased grain production. As China develops, it is also likely that the domestic and industrial demand will increase which will divert water from agriculture.

We assume that the grain yield will not increase significantly (from 4.5 to 6.0 tonnes per hectare). This can be a rather pessimistic assumption since history proves that there has been dramatic increase in productivity since the "green revolution".

There are several other limitations with the model such as world production, grain area loss, etc. However, the driving forces are quite realistic and further improvements can greatly enhance the model.

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