Can We Feed the Animals?
Origins and Implications of Rising Meat Demand

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Abstract: *The paper argues that current long-term projections of global meat and feed demand may underestimate future consumption patterns for mainly two reasons. First, they do not explicitly consider increased demand for protein foods of animal origin with rising incomes in some developing contries, and second they do not allow for changes in livestock technology, in particular feed demand. We then project the impact of both mechanisms to show the empirical relevance of our comments and suggest ready-to-use tools to consider them within standard projection models.*

Keywords: Agricultural outlook, income growth, piecewise linear regression, meat and feed demand

1. Introduction

World wide income growth causes meat demand to rise. Whereas in the recent past the Green Revolution made it possible to satisfy the rising human demand for cereals, the challenge for world markets in the three decades to come is to supply sufficient animal products, in particular meat, and hence for feed grains and concentrates (IFPRI, 1999). Various authoritative studies expect meat consumption and demand for animal feed to keep on growing at rates similar to those during the past decades of strong productivity growth (FAO, 2000; OECD, 2001; USDA, 2001; and FAPRI, 2001). These studies conclude that it is technically feasible to meet the challenge if adequate efforts are made, and that this will not cause world prices to rise significantly (IFPRI, 1999; 2001).

Over the past decades, commodity projections for agricultural markets have systematically tended to overestimate future demand and to underestimate the scope for productivity increases. Consequently, the factual evidence of persistently falling real prices for food time and again refuted their recurrent prediction of rising world prices (Deaton and Miller, 1995). Developed countries currently see agricultural surpluses rather than shortfalls as their major problem, and the reference to Malthusian scenarios has lost credibility in view of the impressive successes achieved in feeding the world population, especially in East Asia. It seems that the agencies dealing with the issue have by now learned from experience and no longer predict shortfalls. However, this might obscure important issues such as the effect of high growth rates in per-capita income in recent years, in particular in some Asian economies, that have already caused significant shifts in demand towards food of animal origin (IFPRI, 2001; Mitchell et al., 1997). Thus, with per-capita income continuing to grow, a pressure on the demand side builds up that requires vast increases in the availability of animal feed. Hence, even though feeding the poor obviously remains the fundamental issue, on world food markets the relevant question has become whether we can feed the animals, rather than the people.

The studies mentioned base their projections on income extrapolation with an assumed demand elasticity, and on expert judgement. From this, feed demand is derived under fixed or slowly falling requirements per unit of meat. These projections are summarized in Table 5 below. The motivation for this paper is to show that under the assumed growth in per-capita income, this can lead to a significant underestimation of future demand for meat and cereal feeds. We argue that this is due to two mechanisms. First, per-capita demand for meat depends primarily on per-capita income. Hence, the differences in per-capita incomes must be accounted for. Furthermore, the relationship is nonlinear as the poor segments of the population tend to abstain from meat consumption until their income reaches some lower threshold,

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while rich consumers become satiated beyond an upper threshold. Regarding feed requirements, we distinguish between a traditional feeding technology based on household residuals, harvest by-products and rangeland, and an intensive livestock technology whose efficiency improves only gradually.

With IFPRI (2001) and FAO (2000) as reference, and disregarding price adjustments, we present alternative projections that include these two mechanisms. We find it important to consider both mechanisms for the following reasons. In countries with a relatively high average demand for meat a large fraction of the population may just have started consuming meat. In mid-income regions with favorable growth perspectives as in East Asia this will lead to a fast increase in demand. But even in regions such as South Asia with moderate growth perspectives the large number of people that hardly consumed meat before will also cause the growth rate of meat demand to be rising. Regarding feed requirements, the fast increase in the demand for meat will together with the tendency for urbanization make it more difficult to expand the traditional animal husbandry, with livestock roaming around the homestead.

As in FAO (2000) we do not present a full model with endogenous price and supply adjustment. Instead we merely evaluate demand for given developments in income and population, as our aim is to highlight the pressures emanating from the two mechanisms rather than to project future trends. We compare these results with the quantitative effects of other factors commonly deemed as key drivers for the future world food situation over the period under consideration. This lead us to conclude that the effect on world markets of income-growth induced increases in demand is substantially larger than, for example, those of advances in biotechnology or climate change.

The paper is organized as follows. Section 2 derives an Engel curve for per-capita meat consumption, with minimum consumption and satiation levels, that is calibrated on the basis of both cross-country and time series data for meat consumption and income. We use this curve together with information on income distribution for all major countries to project meat demand under assumed rates of income and population growth. Section 3 projects the corresponding feed demand, where a shift from traditional to modern feed technology will occur and further expand demand for feed. Section 4 concludes.

2. Meat Demand

We postulate a stylized, piecewise linear relation between per-capita meat consumption and disposable income — the Engel curve — with three different regimes. For per-capita income below some lower threshold ($\underline{y}$), meat demand is low and hardly increasing, whereas it rises steeply at higher levels of per-capita income (between $\underline{y}$ and a second threshold, $\bar{y}$ with $\bar{y} > \underline{y}$). Finally, when income exceeds $\bar{y}$, the slope of the Engel curve becomes low again, as satiation sets in. Obviously, such a relation implies that the Engel curve is convex increasing between the first and the second regime, and concave thereafter. In this section, we show that such a relation passes significance tests. Furthermore, we describe the implications of this S-shaped form in relation to income distribution and growth for the rise in aggregate meat demand worldwide.

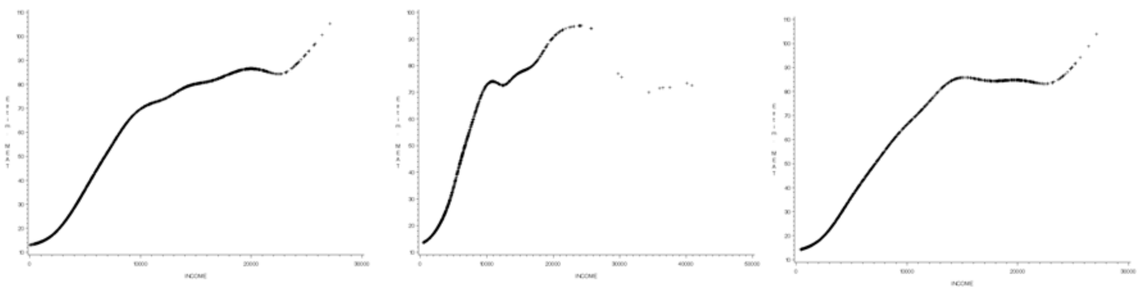
Yet we want to present the empirical evidence before postulating any functional form or thresholds. For this we use a non-parametric, kernel density regression (see e.g. Bierens, 1987). Figure 1 shows the results of such an estimation, based on the Mollifier program (Keyzer and Sonneveld, 2001) and cross-country data for 125 countries between 1975 and 1997.[1] To identify possible differences over time we also compare the results for the entire sample period (Figure 1a) with those for two sub-periods, from 1975 to 1987 and from 1985 to 1997 (Figure 1b and 1c). The curves confirm that the shape is relatively

[1] Income is given in per-capita GDP in Purchasing Power Parity (PPP)-Dollar, deflated by the consumption price index in the USA in 1992 (source: The World Bank Indicators 2000). We further reconstructed data for split and merged countries, and omitted countries for which income or meat data was missing. Meat data is taken from FAOSTAT.

stable over time, and that the slope is indeed convex increasing at low levels of per-capita income, while exhibiting a tendency towards satiation at higher income levels. We note, however, that this is a cross-country relation that neglects the distribution effects within countries that are particularly important in view of the changes in slope. However, by considering a large number of countries at different stages of development, and without weighting for population size, we hope to detect sufficient variation for our estimations, as no data are available on the within-country distribution of consumption.

a) 1975-1997 b) 1975-1987 c) 1985-1997

Per-capita consumption (in kg/year)



Per-capita income (in US-$)

Figure 1 *Non-parametric estimation of meat demand and per-capita income*

Next, we turn to a parametric estimation of the relationship between per-capita meat consumption and income. We specify per-capita consumption of meat in country i (c_i) as a piecewise linear demand function in terms of per-capita income (y_i):

$$c_i(y_i) = \begin{cases} a_1 + b_1 y_i, \ if \quad y_i \le \underline{y}, \\ a_2 + b_2 y_i, \ if \quad \underline{y} \le y_i \le \bar{y}, \\ a_3 + b_3 y_i, \ if \quad y \ge \bar{y}, \end{cases} \tag{1}$$

where $\underline{y}$ and $\bar{y}_i$ are exogenous. Furthermore, coefficients satisfy

$$a_1 + b_1 \underline{y} = a_2 + b_2 \underline{y} \qquad \text{hence, } a_1 = a_2 + (b_2 - b_1)\underline{y}$$

and (2)

$$a_3 + b_3 \bar{y} = a_2 + b_2 \bar{y} \qquad \text{hence, } a_3 = a_2 + (b_2 - b_3)\bar{y}$$

After estimating the coefficients of such a demand function, we want to test the hypothesis that the slope b_2 of the mid-consumption regime is significantly different from b_1 and b_3. For this, we express b_1 and b_3 in terms of b_2 and two new coefficients, γ_1 and γ_3:

$$b_1 = b_2 + \gamma_1$$
$$b_3 = b_2 + \gamma_3 \tag{3}$$

Substituting (2) and (3) into (1) we obtain the following system of linear equations:

$$c_i(y_i) = \begin{cases} a_2 + b_2 y_i + \gamma_1 (y_i - \underline{y}), & if \quad y_i \le \underline{y}, \\ a_2 + b_2 y_i, & if \quad \underline{y} \le y_i \le \bar{y}, \\ a_2 + b_2 y_i + \gamma_3 (y_i - \bar{y}), & if \quad y_i \ge \bar{y}, \end{cases} \tag{4}$$

Next, we extend system (4) by four country-specific dummy variables for China, India, the USA and Japan and estimate the coefficients for different levels of income thresholds ($\underline{y}$ and $\bar{y}$). Table 1 shows the results of a maximum likelihood estimation implemented as a weighted least squares (WLS) estimation of system (4), with a regime specific heteroskedasticity correction and iteration over $\underline{y}$ and $\bar{y}$ combinations until the best fit is found. We find all coefficients to be highly significant and to produce a sufficient fit of our estimation. In particular, we can not reject the hypothesis that the slope of the mid-regime is significantly different from that in the first and third regime, since γ-coefficients come out highly significant. Moreover, their negative sign confirms that the slope of the medium interval is steepest. Thus, as in the non-parametric regression, the parametric estimation supports the hypothesis that the Engel curve is convex increasing for low-income levels and becomes satiated thereafter. Furthermore, to test for changes in preferences, we include dummy variables for sub-periods to allow for shifts in coefficients, but none of these shift coefficients proved significant. If any, there appears to be a very modest and insignificant upward trend in the propensity to consume meat and definitely none towards a more vegetarian lifestyle.

To derive the implications for aggregate meat demand when individual per-capita incomes of the population are growing, we present a formal condition under which the S-shape of the individual demand curve translates into an S-shaped aggregate demand curve. We are specifically interested in charting out the time period in the future during which the aggregate demand will rise faster than income, i.e. have an elasticity larger than unity, because of the convexity. By contrast projections by FAO (2000) and IFPRI (2001) rely on elasticities of less than unity.

Table 1 *Parameters of the Engel Curve (WLS Regression at optimal thresholds)*

Parameter	Estimate	Approx. Standard Error	t-ratio
a_2	-1.182*	0.60665	-1.95
b_2	8.07**	0.12878	62.64
γ_1	-4.82**	0.44422	-10.85
γ_2	-7.09**	0.23864	-29.70
Dummy ‘China’	7.32**	1.37780	5.31
Dummy ‘India’	-9.56**	1.30257	-7.34
Dummy ‘USA’	23.81**	3.93967	6.04
Dummy ‘Japan’	-50.37**	3.79094	-13.29
Income thresholds:	$\underline{y}$ = 2200 US-$; $\bar{y}$ = 9700 US-$		
Consumption thresholds	c_1=16.6kg/year; c_2=77.1kg/year		
Number of observations	2875		
R-squared	0.6161		
Adjusted R-squared	0.6152		
* significance at the 10% level, ** significance at the 1% level.			

While we have access to income distribution data for a reference year,[2] information on the distribution of consumption is lacking and so is data on the change of income distribution over time. Hence, we need to make an assumption on the relationship between individual and average per-capita income. We initially assume, as in FAO (2000), that both are equal, i.e. that all individual incomes grow at the same rate, regardless of their initial level. This amounts to keeping the income distribution constant relative to the mean per-capita income. Then, individual income can be expressed as $y = \mu\varepsilon,$ where μ denotes mean and the (continuous) distribution of income relative to the mean has density $f(\varepsilon)$ with unit mean. Thus, aggregate demand is given by:

$$C(\mu) = \int c(\varepsilon\mu)\, f(\varepsilon) d\varepsilon\,, \tag{5}$$

[2] Deininger and Squire (1996) provide a database on income distribution for major countries.

with $c(\cdot)$ as defined in (1). We also define the cumulative deviation, or fraction of total income accruing to individuals with a ratio to mean income of η or less: $\Phi(\eta) = \int_0^\eta \varepsilon f(\varepsilon) d\varepsilon$, with $\phi(\varepsilon)$ as the associated density. We study the effect of a shift in mean income μ on the aggregate demand function (5) and formulate the following proposition:

Proposition: *Suppose that income growth is positive and identical for all individuals in a group. Then, the slope of the aggregate meat-demand curve (5) is rising (falling) with mean per-capita income if and only if there is more (less) total income spent on meat at $\underline{y}$ than at $\bar{y}$, i.e. if and only if $(b_2 - b_1)\phi(\underline{y}/\mu)\underline{y} - (b_2 - b_3)\phi(\bar{y}/\mu)\bar{y}$ is positive (negative).*

Proof. $\dfrac{\partial C}{\partial \mu} = \int \dfrac{\partial c(\varepsilon\mu)}{\partial y} \varepsilon f(\varepsilon)\, d\varepsilon = b_1 \int_0^{\underline{\varepsilon}} \varepsilon f(\varepsilon)\, d\varepsilon + b_2 \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} \varepsilon f(\varepsilon)\, d\varepsilon + b_3 \int_{\bar{\varepsilon}}^{\infty} \varepsilon f(\varepsilon)\, d\varepsilon$

$$= b_1 \Phi(\underline{y}/\mu) + b_2\left(\Phi(\bar{y}/\mu) - \Phi(\underline{y}/\mu)\right) + b_3\left(1 - \Phi(\bar{y}/\mu)\right)$$

hence, since $\dfrac{\partial \Phi(y/\mu)}{\partial \mu} = \dfrac{d\Phi(\varepsilon)}{d\varepsilon}\dfrac{\varepsilon}{\mu} = -\phi(\varepsilon)\dfrac{y}{\mu^2}$, it follows that

$$\frac{\partial^2 C}{\partial \mu^2} = \frac{b_1}{\mu^2}\left(-\phi(\underline{y}/\mu)\underline{y}\right) + \frac{b_2}{\mu^2}\left(\phi(\underline{y}/\mu)\underline{y} - \phi(\bar{y}/\mu)\bar{y}\right) + \frac{b_3}{\mu^2}\left(\phi(\bar{y}/\mu)\bar{y}\right)$$

$$= \frac{1}{\mu^2}\left((b_2 - b_1)\phi(\underline{y}/\mu)\underline{y} - (b_2 - b_3)\phi(\bar{y}/\mu)\bar{y}\right). \square$$

Regarding the interpretation of this form, since $y = \mu\varepsilon,$ it follows that $y\phi(y/\mu)$ is the total income corresponding to per-capita income *y*. Multiplication by $(b_2 - b_1)$ and $(b_2 - b_3)$ leads to the total additional expenditure on meat by the individuals crossing the regime boundaries. In other words, the slope increases as long as the difference between the weighted fraction of income spent at $\underline{y}$ and $\bar{y}$ is positive and thus, an increasing fraction of the income is spent on lifestyle 2. Hence the convexity depends on the shift in expenditure distribution, which is due to both population and income growth.

To demonstrate the empirical relevance of this proposition, Figure 2 shows the impact of future income growth on the distribution of per-capita income in two regions, South- and East Asia. The two upper diagrams of Figure 2 correspond to GDP growth rates as used for instance in FAO (2000, p. 25). In the light of the current economic slowdown, these rates seem fairly high. For example, for the period 1997-2015 they imply annual growth in per-capita income of 4.1% in India, 6.7% in China or 5.2% in East Asia. Therefore, we also include two more diagrams that refer to a second scenario where per-capita growth is reduced by one-third (low growth rates). It appears that for both scenarios, mean income will shift from the lower income threshold (vertical line on the left) towards the upper threshold. For East Asia it even crosses by 2030. Based on these shifting income densities, we compute the (weighted) fraction of income spent at each level of per-capita income (Figure A-1 in the appendix). This provides a graphical illustration of the principle set out in Proposition 1. As the weighted income fraction spent at the two thresholds $\underline{y}$ and $\bar{y}$ is indicated with vertical lines, we can simply read off from the diagram whether the corresponding difference is positive in terms of the Proposition, and thus, whether the aggregate meat demand curve is convex increasing for a particular year.

It appears that for 1997, this is indeed the case for both regions. In later years a difference emerges. Whereas for East Asia the curve already becomes concave increasing in 2000, for South Asia this only happens by 2020. IFPRI (2001) and FAO (2000) find lower growth rates, due to anticipated satiation effects but these projections disregard the lower threshold and hence the takeoff of consumption as well as the fact that large segments of the population have not yet reached satiation. These are the two aspects incorporated in our calculations.

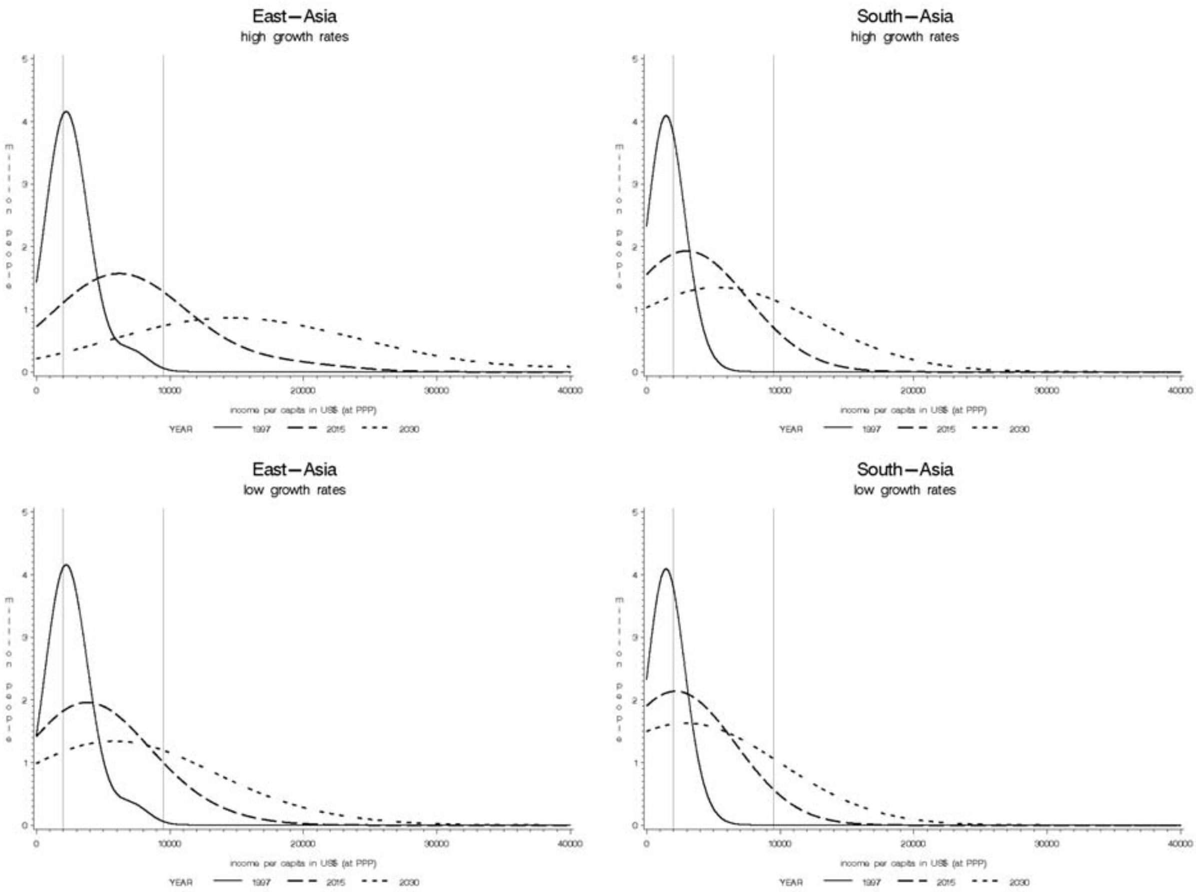


Figure 2 *Economic growth and income distribution*

Since China plays a key role in these calculations, let us elaborate on the reliability of our assumptions for this country. Several studies report substantial discrepancies between domestic consumption levels as implied by official Chinese statistics on livestock and meat output, and those reported by household surveys suggests, and come to the conclusion that official data on per-capita meat consumption are biased (Colby et al., 1998; Lu, 1998; Fuller et al., 2000) with underreporting in the early 1980s, because the statistics failed to capture the spectacular growth in production, while, in the 1990s the officials had an incentive to overstate production levels. Furthermore, consumption levels were increasingly obtained from household surveys that tend to neglect food consumed outside the home as well as consumption of migrant workers in urban areas, both of which have gained in importance during the 1990s. Nonetheless, in their overall conclusion, the three studies mentioned claim that nowadays official statistics tend to overstate consumption whereas they understated it in the early 1980s. Interestingly, our calculations based on cross country estimates confirms this: FAOSTAT data fall below our estimates in the early 1980s and increasingly exceed them after 1985 (Figure 3). Furthermore, we find our estimates for per-capita consumption of total meat in 1998 (29kg/year) to be fairly close to the adjusted estimates such as for instance given by Fuller et al. (2000) of 28kg/year. We consider this an important support for the validity of our approach.

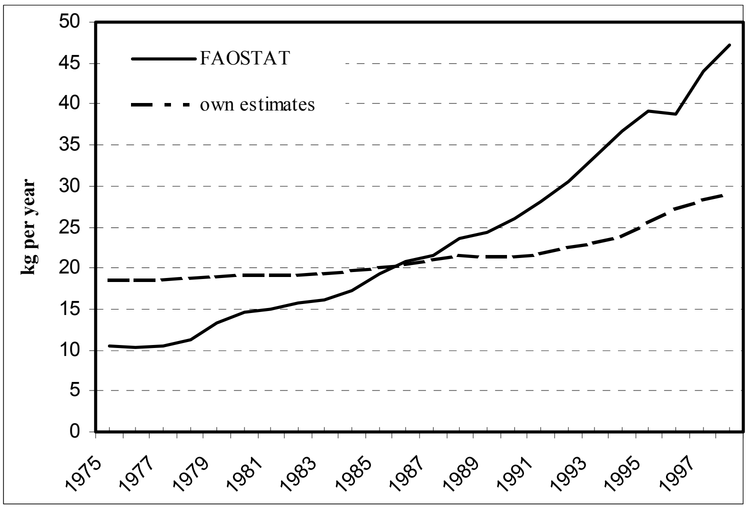


Figure 3 *Per-capita Meat Consumption in China: Official Data vs. Estimates*

Demand projections

Next, we use the estimated Engel curve to project meat demand based on per-capita income and to calculate from there the annual growth of aggregate meat demand and per-capita consumption of meat by region. To allow for country specific effects in addition to the four dummies that are already included in the estimation, we scale projected levels of per-capita consumption for each country[3] and year by a constant factor such that the projected value for 1997 coincides with the value given in the data. We compare our findings with the projections of FAO (2000).[4] As shown in Table 2, we find that only for Sub-Saharan Africa, the region with the lowest anticipated income growth but the highest population growth, FAO (2000) projects higher annual growth rates than our projections based on the same rates of growth in per-capita income (*High Growth).* In all other regions our calculations project higher increases of aggregate demand, and the difference is especially pronounced for the two Asian regions where projected growth is highest. Even if we reduce initial growth rates by one-third (*Low Growth*) we find that our estimations still tend to exceed the FAO projections for most regions such that even under lower levels of per-capita growth in income, global demand for meat still increases by higher rates.

Table 2 *Annual Growth Rates of Aggregate Meat Consumption (in %)*

	High Growth Rates		Low Growth Rates		FAO (2000)	
	1997-2015	2015-2030	1997-2015	2015-2030	95/97-2015	2030
Sub-Saharan Africa	3.0	2.9	2.8	2.5	3.4	3.1
Near East/North Africa	4.1	3.2	3.4	2.8	3.4	2.6
Latin America and Caribbean	2.6	1.8	2.3	1.6	2.3	1.8
South Asia	5.8	3.9	4.4	3.7	3.6	3.5
East Asia	4.9	2.6	3.7	2.6	2.8	1.5
Industrial Countries	1.3	1.2	1.0	0.9	0.7	0.4
Transition Countries	1.4	1.2	0.9	0.8	1.1	0.7
World	3.0	2.2	2.3	1.9	1.9	1.4

Source: FAO (2000) and own projections.

[3] Except China, for the reason mentioned earlier.

[4] In the projections, dummy variables for India only apply for regimes one and two. Satiation starts at 34kg per capita per year with USD 5000.

Differences are similar when we compare per-capita meat demands (Table 3). Again we find that our estimates exceed those of the FAO for most years under both scenarios, especially for the Asian regions, the Near East and North Africa. For the *High Growth* scenario, we find world-level differences in annual per-capita demand of 4.9kg in 2015 and 10.6kg in 2030. This corresponds to additional consumption of about 34.7 million tons in 2015 and 85.8 million tons in 2030.[5] Moreover, although global per-capita demand under *Low Growth* rates is similar to the FAO estimate for 2015, it exceeds it by 2.5kg in 2030, which amounts to a difference of 20.6 million tons.

Table 3 *Per-capita Consumption of Meat (in kg/year)*

	Base Year	High Growth Rates		Low Growth Rates		FAO (2000)		
	1997	2015	2030	2015	2030	1995-97	2015	2030
Sub-Saharan Africa	11.5	12.5	14.3	12.0	12.9	9.7	11.6	13.6
Near-East/North-Africa	22.9	32.9	43.3	29.0	35.8	20.0	26.6	32.0
Latin America and Caribbean	50.9	62.8	70.9	59.3	65.7	48.5	57.8	66.0
South-Asia	5.8	12.2	18.7	9.7	14.5	5.5	8.2	11.8
East-Asia	27.2	54.7	74.7	44.6	60.5	33.3	47.2	55.0
Industrial Countries	82.3	98.3	115.1	93.0	103.8	86.5	93.0	97.0
Transition Countries	46.1	58.6	71.0	54.2	62.3	49.4	61.0	69.0
World	32.6	44.9	54.6	39.7	46.5	34.7	40.0	44.0

Source: FAO (2000) and own projections.

Our projected per-capita demand for India of 11.8kg per year (8.9kg) in 2015 and 17.9kg (13.8kg) in 2030 for the *High Growth* (*Low Growth*) scenario differs substantially from what is implied for India by FAO (2000) or explicitly projected by IFPRI (2001) in their baseline scenario (7.4kg). This needs further comment since results for the entire South-Asian region are largely driven by projections for India that accounts for more than 70% of the total population. Traditionally meat consumption in India has been low even in relation to per-capita income, for well known religious and cultural reasons. Starting from such a low level and using income elasticities similar or even below those of other Asian countries, these studies do not find a substantial increase of per-capita demand. Evidence for such low elasticities can for example be found in Mohanty et al. (1998) who estimate Engel curves for food demand based on official consumer-expenditure data. However, these data ignore out-of-home consumption of meat, a phenomenon of increasing importance, especially in urban areas. Furthermore, there is evidence that Indian consumers tend to drift away from vegetarianism towards protein from animal origin as they become richer. Bhalla et al. (1999) for instance find that income elasticities for meat and egg in rural areas have been increasing since the early 1970s, and that an increasing share of households in both, rural and urban areas reports to eat meat.[6] Abdulai et al. (1999, p.324) find that increasing urbanization is likely to raise the consumption of this commodity group. Based on this evidence, IFPRI (2001) has considered an alternative scenario with significantly higher income elasticities. Under this scenario, the projected level of per-capita demand for meat in 2020 (18kg per capita) even exceeds our estimate for that year (13.5kg).[7] Nonetheless, it must be acknowledged that, particularly because of the religious aspects, these changes in demand patterns remain highly uncertain in India.

To indicate more sharply that the rise in demand is due to per-capita income rather than to population growth, we run an alternative scenario with zero per-capita growth. Table 4 compares the

[5] World population is assumed to total 7.1 billion in 2015 and 8.1 billion in 2030.

[6] Following Bhalla et al. (1999, p. 4), while only 43.7% and 31.5% of urban and rural households reported to consume meat in 1987/88, both shares increased to more than 50% in 1993-94.

[7] The difference is partly due to a higher rate of income growth (5.5% in IFPRI (2001) versus 4.1% in our study).

outcome with *High Growth*. It appears that for Asia, growth in per-capita income accounts for 70% (South Asia) and 80% (East Asia), respectively, of total increases in aggregate meat demand, while for Sub-Saharan Africa between 1997 and 2015, only about 20% of the growth in aggregate meat demand is attributable to income growth and 30% in the period 2015-2030.

Table 4 also reports on another variant that accounts for changes in income distribution within countries. For this we use the relation estimated by Dollar and Kraay (2000), according to which the growth rate of the poorest 20% of the population is about 17% higher than among the remainder of the population. Applying this relationship, more people enter the mid-interval with a high marginal propensity to consume, and this raises the slope of the aggregate Engel curve even further. Yet, since the average growth rate per country is kept unchanged, this is largely compensated by a drop in the growth rate of the four upper quintiles below the given average. Overall, Table 4 suggests that both effects tend to cancel out.

Table 4 *Annual Growth Rates of Aggregate Meat Consumption for Alternative Scenarios (in %)*

	High Growth Rates		Zero Growth		Dollar/Kraay	
	1997-2015	2015-2030	1997-2015	2015-2030	1997-2015	2015-2030
Sub-Saharan Africa	3.0	2.9	2.5	1.9	3.0	2.9
Near East/North Africa	4.1	3.2	1.8	1.2	4.1	3.2
South Asia	5.8	3.9	1.8	1.1	5.8	3.9
East Asia	4.9	2.6	0.9	0.5	4.9	2.7

Source: FAO (2000) and own projections.

To sum up, if we apply a kinked demand curve for meat in conjunction with information on the income distribution within countries, and assume that all individual incomes and population level grow at a common rate in every country, or differ in accordance with the Dollar-Kraay relationship, we find an acceleration of the growth in meat demand during the period 2000-2030, particularly in the first half. We conclude that current international projections might significantly underestimate world meat demand in the coming fifteen years.

3. Implications for feed demand

In this section, we study the impact of the surge in meat consumption on the demand of animal feed. For world food markets at large this is the key issue, since in the end it is the feasibility of supplying livestock with feed, and to a lesser extent of absorbing its manure, that will determine whether the growth in livestock production can be realized and how much pressure this will exercise on food markets.

As cereal grains constitute the major feed intake, we focus on the consequences for the cereal market, as is also the practice in FAO (2000) and IFPRI (1999; 2001). We also follow these studies in assuming that developing countries will have to produce domestically most of the meat they consume and determine on the basis of projected meat demand the resulting need for, possibly imported, cereal feed. We depart from both studies in that we do treat the cereal-meat ratios as dependent on meat demand. Moreover, rather than keeping these ratios fixed at levels that are much higher for developed than for developing countries, we will argue that developing countries will — just like developed countries — have to invoke more feed intensive technologies as meat demand outpaces the supply of crop residuals with continuing urbanization.

Specifically, Table 5 indicates that, according to the two studies mentioned, the feed ratios in industrial countries reflect declining improvements in feeding efficiency, e.g. due to better management, better genetic breeding material and better feeding practices. Indeed, intensive livestock production in Western Europe has realized this kind of improvement consistently over the past. Yet, the ratios stay much higher than in the rest of the world. In contrast, feeding systems in the developing countries rely to a large extent on crop residues and household waste, with some supplementary feeding from cereals and cereal substitutes. This is reflected in the lower average feed requirements, which hardly shift over time. This constancy is the outcome of two developments that appear to cancel out: improvements in feed conversion (requiring less cereals) and more intensive feeding practices, that relies more on concentrate feeds. However, as we will argue below, assuming that developing countries will be able to let their meat production grow with lower ratios than the industrial countries, amounts to confusing average and marginal input requirements. Instead, to satisfy the rapidly expanding demand for meat developing countries will need a relatively intensive livestock industry, albeit not as intensive as the technologies currently prevailing in some developed countries. This means that in the medium term their feed ratios will tend to rise rather than fall, and that the fall can only be realized in the longer term.

Table 5 *Feed Intensity as Cereal-Meat Ratio [kg/kg]*

FAO AT2015/30				
Year	84/'86	95/'97	2015	2030
Developing countries	2.38	2.26	2.34	2.35
Industrial countries	4.66	3.91	3.86	3.85
IFPRI IMPACT model				
Year	1993	1997	2020	
Developing countries	2.20	2.12	2.03	
Developed countries	4.42	4.35	4.31	

Source: adapted from FAO (2000) and IFPRI (1999; 2001)

Cereal feed requirements of developing countries

To substantiate this assertion, we will compute the cereal feed requirements in 2015 and 2030, using a feed technology representation that distinguishes cereals (as a fixed share of concentrates) and residual feeds. We specify this relation as:

$$(1+\sigma)C = aM - R \quad (6)$$

where C is cereal feed (net of other concentrates), σ measures intake of other concentrates (e.g. manioc, oilcakes, etc.), M is meat demand, R denotes residual feeds comprising other feeds such as hey, roughage, grass, household residuals and other waste (in cereal equivalents), and a the feed conversion ratio in (total) feed per unit of meat. For $R>0$, marginal feed requirement a is higher than the cereal-meat ratio:

$$C/M = (a-R/M)/(1+\sigma) \quad (7)$$

In the longer term technical progress and learning experience may allow for a reduction in a, but in the medium term, the cereal-meat ratio will rise with demand for meat (M). To keep the focus on the main issue, we abstract from technical progress (thus, we assume a to be constant).

In contrast, Table 5 shows that in both FAO (2000) and IFPRI (2001) cereal-meat ratios are essentially kept constant.[8] This amounts to assuming that the residual feed intakes R can adjust with changing meat demand so as to keep the ratio R/M in (7) unchanged. In other words, residual feed intakes would have to grow at the same rate as aggregate meat demand (see Table 2), for example at between 3% and 4% for some regions in Asia and Africa. However, pressure on availability of residual feeds is already high in those regions. In particular for Asia, the ongoing urbanization leaves little scope for expanding the supply of feeds from household wastes. Furthermore, the growth in these sources of feed is typically independent from the growth of meat demand and instead, driven by expansion of the area with pastures and traditional varieties, since high yielding varieties produce less crop residuals. Against this background, it is most unlikely that residual feed intake could increase that much in Asia and Africa. Therefore, cereal-meat ratios will have to rise there, as the feeding technology gradually shifts to modern feeding practices, which incorporate more cereals and other concentrates.

[8] Yet, in the IFPRI study a sensitivity scenario is run with gradually lower feed efficiencies. It shows that cereal use increases substantially and makes substitution to other feed intakes cost-effective (IFPRI, 1999, pp. 29-30).

Three variants that calculate the consequences for cereal feed intake may illustrate this effect further. The first variant assumes that intakes of residual feed grow at a rate that keeps cereal-meat ratios constant, which implies that residual feeds must grow at about 3% per year, world-wide. The second variant halves this growth rate but only for four regions: Sub-Saharan Africa, South and East Asia, Northern Africa and Middle East. The third variant keeps intakes of residual feed constant. While the first and third variant are clearly the extremes, the second variant tries to cover the middle ground. The results are summarized in Table 7.[9]

In the first variant global cereal feed demand rises slowly up to 1300 million tons in 2030, slightly above the prediction of about 1100 million tons in FAO (2000). The second variant shows an additional cereal feed demand of some 700 million tons in 2030 (333 million tons in 2015), i.e. 50% higher. In the zero growth variant, where other feeds do not grow at all, cereal feed has to double. These results clearly illustrate that assumptions on feed technology really matter, and that some regions will face unprecedented growth rates in cereal feeding (Table 7b).

Table 7 *Cereal Demand under Various Growth Paths for Residual Feeds*

(a. in million tons)

	Base year level	High growth of Other feed: Constant CM-ratio		Midrange growth of Other feed in four regions		Zero growth of Other feed in all regions	
Year	1995/'97	2015	2030	2015	2030	2015	2030
Sub-Saharan Africa	10	22	32	95	177	146	260
Near East/North Africa	37	95	146	130	217	153	254
Latin America, Caribbean	49	79	104	79	104	284	462
South Asia	16	42	64	65	113	79	135
East Asia	121	238	352	440	784	585	1036
Industrial Countries	317	355	421	355	421	369	480
Transition Countries	117	153	181	153	181	189	241
World	667	985	1300	1318	1997	1805	2868

(b. in annual growth rates)

	High growth of Other feed: Constant CM-ratio		Midrange growth of Other feed in four regions		Zero growth of Other feed in all regions	
year	2015	2030	2015	2030	2015	2030
Sub-Saharan Africa	4.2	3.4	12.5	8.8	15.0	10.0
Near East/North Africa	5.1	4.2	6.9	5.4	7.8	5.9
Latin America and Caribbean	2.6	2.2	2.6	2.2	9.7	6.8
South Asia	5.1	4.1	7.5	5.9	8.6	6.4
East Asia	3.6	3.2	7.0	5.7	8.6	6.5
Industrial Countries	0.6	0.8	0.6	0.8	0.8	1.2
Transition Countries	1.4	1.3	1.4	1.3	2.6	2.1
World	2.1	2.0	3.7	3.3	5.4	4.4

Source: own computations

In sum, our scenario calculations suggest that expected increases in meat demand will put considerable pressure on the cereal and concentrates markets, as livestock feeding practices have to shift to regimes with higher cereal feed intensity, due to the limited growth potential of the residual feed intakes.[10] In comparison with other factors that are generally expected to affect the future world food situation, such as Genetically Modified Organisms (GMOs) and climate change, the quantitative importance of the meat issue is impressive. Regarding GMOs controversy persists (Conko and Smith,

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[9] Calculations are based on a calibration exercise for equation (6) using information and data from Folmer et al. (1995), CAST (1999) and FAOSTAT.

[10] Of course, direct import of meat by developing countries could be an option but this would not relieve the pressure on cereal markets, as industrial countries also rely strongly on cereals as feed. This would also deprive farmers in developing countries of an attractive source of revenue from meat production.

1999; Altieri and Rosset, 1999; McGloughlin 1999), and only few studies point towards potential yield improvements (e.g. Klotz-Ingram et al., 1999). The major anticipated effects are to save on chemical inputs (Falck-Zepeda et al., 2000) and better nutritional quality of GMO-food (McGloughlin, 1999; Goto et al., 1999) but worldwide the effect on supply volumes appears to be limited (Ruttan, 1999). The effects of climate change on agricultural markets stretch out over longer period and very different across regions. Following Fischer et al. (2001), potential cereal production in 2080 will decrease by 160 million tons in some developed countries (e.g. the Netherlands and the UK) and increase by 145 million tons in others (mainly Russia and Canada). For the developing world, some countries such as Brazil or India will face total losses of about 280 million tons, while others, e.g. Kenya, South Africa and China, will have total increases of 190 million tons. Overall, the authors calculate total losses of potential cereal production in 2080 of 105 million tons. Even if this change was realized in 2030 already, it would still be modest compared to the world figures in Table 7a, that show increases in the range from 600 to 2200 million tons.

4. Conclusion

We find that per-capita meat demand will rise faster than would be predicted on the basis of fixed income elasticities, because in most developing countries the poorer half of the population has just entered or still is to access the income bracket where a significant fraction of income growth is spent on meat. We also claim that the associated demand for cereal feeds will rise faster than is suggested by past trends because incremental meat production cannot be realized on the basis of household waste and crop residuals. It appears that this conclusion holds almost irrespectively of the future degree of modernization in the livestock sector of developing countries, because a more modern mode of production can use feed grains more effectively but at the same time it relies less on crop residuals. We conclude that current predictions significantly tend to underestimate future demand.

This claim is corroborated further if we take two other trends into consideration. First, it appears from FAO's Food Balance Sheets (FAOSTAT, 2001) that the percentage of industrial and household waste exhibits a pronounced increase as the economy shifts towards more intensive food-processing technologies. For example, consumers in the economies of Western Europe appear to have a food availability in the range of 3600-3700 kcal per capita per day. This lies far above actual per-capita food intake, and this situation will remain basically unaltered even when some of the slack in the world food system is eliminated (Smil, 2000). When developing countries also experience this transition, the pressure on primary production will intensify. Second, the rise in meat demand is only one element of this process. In parallel with meat, the demand for fish will rise and in many countries consumers prefer fish to meat. Rather than easing the pressure on feed demand this will only exacerbate it. In general, the same mechanism is at work here, with a shift from marine fisheries (that requires no feed) to aquaculture that requires feeding. The feeding technology is of two kinds: a primitive aquaculture in ponds, that utilizes as feed all kind of waste, crop residues and manure, and modern aquaculture that increasingly requires advanced high-protein inputs to avoid diseases and to substitute for the animal proteins required by many fish varieties. It is generally recognized that open access fishery will not be able to sustain increased demand (SOFIA 1998 and 2000, Rana 1999, Brown et al. 2001) and that aquaculture will become a more important source of animal protein in the human diet. Using data from FAOSTAT and SOFIA (1998), Brown et al. (2001) for instance calculate annual growth rates for Aquaculture of 11.4% between 1990 and 2000, more than four times as high as growth rates for other important animal-protein sources such as pork (2.5%), beef (0.5%) or oceanic fish catch (0.1%). Here again the strong demand for fish will increasingly shift resources to modern aquaculture and thus add to the pressure on feed markets.

Finally, we emphasize that the present calculations only serve as initial explorations. Within the framework presented, more data could be accommodated to improve the estimation and calibration procedures for meat-demand and feed-requirement functions, respectively. In particular a breakdown of feeding technologies by agro-climatic conditions and type of livestock, for example ruminants and other livestock, would strengthen our empirical projections. Furthermore, feed utilization could be improved in order to distinguish between household waste, crop residues, grains and other concentrates, so that various types of feed requirement (energy, protein, roughage) match availability. We note in this context that these computations do not intend to substitute for projections by more elaborate models with endogenous prices. However, these models can only reflect the available knowledge with respect to supply and demand and in our view filling the information gaps is the first priority. This is a demanding task that calls for an important concerted effort. But the issue deserves it.

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Figure A-1 *Effect of economic growth on expenditure on meat in East- and South-Asia.*