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Economic development and food production–consumption balance: A growing global challenge ☆

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ABSTRACT

Rising affluence in major developing countries (principally China and India) and increasing diversion of agricultural resources for energy production (USA and Brazil) sharply increase agricultural resource demand. Food consumption and production changes during development are analyzed using resource-based cereal-equivalent measures. Diet upgrades to livestock products require fivefold increases in per capita food resource use, reflecting a consistent pattern which is only marginally affected by land base. Food consumption increases exceed production during early development, leading to imports. Consumption eventually stabilizes at high incomes, but production falls short in land-scarce countries. Pork and poultry consumption increase the most; less efficient beef and dairy production command a majority of agricultural resources.

Introduction

Increases in per capita food demand in developing economies follow a dynamic growth path that places increasingly strong pressure on food production resources. The claims on these production resources, however, are not evenly divided. To date, only the 15% of the world's population located in high income countries has reached food consumption stability. Yet in reaching this stability, their high income diets, focused on animal products, command 30% of the world's food production resources. In contrast, low-income countries with 15% of the world's population need only 8% of the world's production resources to satisfy their crop-based diets.[1] In the past, technological change against a fairly stable land base has allowed growth in food production to keep pace with rising demand from this limited number of high income diets. Now, given current development and demographic conditions as well as critical environmental considerations, the challenges facing our global food production systems are growing exponentially.

Two large countries, China and India, comprising some 40% of the world's population, are experiencing rapid per capita income growth. With China approaching the mid-point in the diet change process and India in the early stages, the nascent and expected future pressure on food production resources from diet change in these large population countries is becoming increasingly evident. Further exacerbating the strain on the resource base is the diversion of some food production resources to energy production as fuel prices rise. Note that soon 30% of US corn supply will be used for ethanol production (USDA, 2007), while Brazil is supplying 40% of its energy needs from combustible renewables, principally ethanol from sugar cane (World Bank, 2007).

To better understand the dynamic food changes associated with economic development and prepare for the needed changes in type and quantity of agricultural output, this study documents and provides estimates of the dimensions of individual country and aggregate world food needs caused by both population increases and diet upgrades. Further, the demonstrated ability of countries to meet these dynamic needs throughout the development process is addressed. Within this context emerges the challenge to managers of agricultural resources to provide the needed food production increases against a relatively stable but declining per capita productive land base. While population growth generates higher demand for food overall, diet upgrades place even greater strains on agricultural production, relative to direct grain consumption, in addition to requiring larger quantities of energy and contributing much more significantly to global warming. Combining population pressures, the inevitable diet upgrades, and environmental concerns underscores the magnitude of the challenges ahead.

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[1] See Fig. 2, below.

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Development-induced changes in food consumption and production

Per capita food needs and a country's production capability to meet these needs differ significantly across stages of economic development, measured here by per capita income.[2] Poor countries typically commit a considerable percentage of income as well as a major share of the active work force to the procurement of food. In the early stages of economic development, limited production technology and supporting infrastructure lead to low levels of agricultural productivity, while low income levels also constrain the ability to import food. Hence, most poor countries are of necessity relatively self-sufficient in the production of food.

Despite the large share of income and effort devoted to food, the low levels of per capita food consumption lead to the likelihood that any early growth in income will also be spent largely on food, creating a sizeable impact on food consumption at early stages of development (Rask, 1991; Kydd et al., 1997). Growth in demand for food is therefore generated not only by growing populations, but also by rising income, and in particular, as we argue, by diet changes associated with rising income. The relative importance of population growth and income growth in determining future world food needs is still open to question. However, per capita income growth in developing countries is increasingly seen as a major factor driving world food demand.

Dyson (1999) favors population growth as the major contributing factor. In discussing world food needs in the coming decades, he concludes that among others (poverty, arable land, and food prices), "population growth will be the most important factor influencing the global increase in food production and forcing the world farmers to produce more food in the coming years" (page 3). A recent Chatham House study (Evans, 2009) expands the scope of analysis by highlighting both population growth (projecting a global population of 9.2 billion within 40 years) and rising affluence as sources of increased food demand, while climate change, water shortages and competing land uses serve to hamper supply. Evans concludes that increasing food supply alone would be an insufficient response to these challenges. A true solution requires the development of a more resilient, sustainable and equitable production and distribution system (page 2 of "Executive Summary and Recommendations"). In this study, we concentrate on elucidating the nature of the diet change component within this broader context.

Our study documents the historical importance of population growth on world food needs over the 1961–2002 period (population growth was responsible for two-thirds and per capita income growth for one-third of the increase in world food needs), and thus concurs that population has historically been the principal factor driving world food demand. However, the dynamics of economic development and in particular the current position of major countries (China and India) in that development process point to per capita income growth as a potentially more important and perhaps dominant factor affecting world food needs in the immediate future.

The current and future importance of income growth in world food demand is reinforced by recent Food and Agricultural Organization (FAO of the United Nations) and International Food Policy Research Institute (IFPRI) publications. Von Braun (2007) in a report from IFPRI describes a "world food situation currently being rapidly redefined by new driving forces . . .income growth, climate change, high energy prices, globalization, and urbanization" (page 1). In describing the food demand aspects of income growth he states that "many parts of the developing world have experienced high income growth in recent years. . .especially China and India. . ..This growth is a central force in the demand side of the world food equation. High income growth in low-income countries readily translates into increased consumption of food.. . .The composition of food budgets is shifting from consumption of grains and other staple crops to vegetables, fruits, meat, dairy, and fish. . ..Today's shifting patterns of consumption are expected to be reinforced in the future" (page 2). Pingali (2006) also analyzes the shift in Asian diets, noting their convergence with western consumption choices as globalization progresses. Clearly, combining growth in income and population with such international influences on diet preferences is already having a significant impact on food demand.

A similar scenario is projected in the FAO report (2008), including the possibility of a structural change in agricultural commodity markets, comprising in part a prolonged shift to higher commodity prices. Commenting on the changing structure of world food demand they state, "It is widely accepted that economic development and income growth in important emerging countries have been gradually changing the structure of demand for food commodities (especially in China and India). Diversifying diets are moving away from starchy foods toward more meat and dairy products which is intensifying demand for feed grains" (page 5), since multiple units of grain are necessary to produce single units of livestock products. USDA analyses of trends in food consumption likewise conclude that higher incomes cause major shifts in diets as well as rising demand for quality, both of which impact consumption choices and therefore trade flows (USDA, 2001). These diet shifts also contribute to increased energy use and global warming potential (Williams et al., 2006), creating further strains on the environment and raising serious questions about sustainability of agricultural production.

This income growth – food consumption relationship is not linear, but rather demonstrates a dynamic pattern throughout the development process, including a changing relationship between domestic food production and consumption. As economic development proceeds (incomes grow), the patterns of food consumption and related production resources as noted above change dramatically. The major change is a diet shift from consumption of crop based products to livestock based products, which require considerably greater production resources and generate greater environmental externalities. In fact, we estimate that a stable per capita diet at the highest income levels requires 5–7 times more agricultural resources to produce than does a predominantly crop based diet at the lowest income levels. Thus, as continued population growth is combined with rapid diet change, many countries in the middle income levels of development are no longer able to maintain food self-sufficiency from domestic agriculture and must import a growing portion of their food needs.

At higher levels of development, the diet shift to livestock products is largely complete. The increasing per capita expenditures on food at this point reflect a demand for non-agricultural resources such as processing, packaging and away-from-home eating (Rask, 1991). At this level of development, per capita food resource requirements stabilize and agricultural productivity growth needs only to match population growth to supply a country's growing food needs. At the same time, slower growth in population at these higher levels of income reduces the population-based food demand growth (Perkins et al., 2001, pp. 253–255). With continued growth in productivity, some countries at this level of development are able to close the production–consumption gap, and a few countries with substantial agricultural resources become major food exporters.

This general development pattern has been shown to apply to a wide range of developing economies (Rask and Rask, 2004). Within these broad generalizations, however, individual countries follow

[2] The analysis in this and the following paragraph draws on Rask and Rask (2004).

divergent routes along the development path. Time frames can be dramatically different as some economies grow rapidly, others stagnate or even retreat, and populations continue to increase. Further complications arise from the non-market incentives promulgated by countries setting food self-sufficiency as a policy objective (Rask and Rask, 2006).

Clearly, food production levels vary greatly across countries due to differences in the quantity and quality of productive resources, levels of technology employed, population numbers, and agricultural policies. However, on the demand side, the food *consumption* response to economic growth, while dynamic in nature, is remarkably consistent across countries when measured in terms of resource requirements, regardless of the underlying production resource base. This consistent pattern allows us to define a common consumption path that rises during development and stabilizes at higher incomes.

Our purpose in this study is threefold: to specify the overall food demand changes associated with economic development, to identify the changing role of individual major agricultural commodities, and to measure the production response relative to the changing food demands throughout the development process.

Data

Our agricultural, food, and population data are from the FAOSTAT-Agriculture database and include most countries of the world over the 1961–2002 period of data availability. Detailed consumption, domestic supply, and production data are transformed into per capita cereal equivalent (CE) factor values to more adequately reflect the resource requirements of specific diet levels and to give a consistent single valuation for comparing varying diets. The derivation of the CE value is detailed in Rask and Rask (2004) and summarized below. The land resource is measured at two levels, hectares of arable land per capita and a computed value, hectares of land equivalent per capita, which includes a summation of arable land, land in permanent crops, and one-third of land in permanent pasture (permanent pasture is estimated to be one-third as productive as arable land).

Levels of economic development are defined by per capita gross domestic product adjusted for purchasing power parity in constant 2002 US dollars for the 1975–2002 period as determined by the World Bank. Income data are not available for all countries and all years. Complete or partial time period data exist for 159 countries yielding a total of 3788 data points for estimating food consumption and production changes during the development process. For 1975, the data set includes countries representing 75% of the world's population. This rises to 97% for the year 2002.

Cereal equivalent (CE) factor values[3]

Having identified the importance of diet changes across countries and levels of development, food consumption and production should be measured in a way that captures the changing resource requirements on which these diet changes rely. Attempts to standardize consumption level measurement using wheat, grain, or cereal equivalent factors have evolved over the years, using a series of alternative measures including weight, calorie content, cost, and the resource based measure used in this study. Weight or calorie measures provide a consistent way to aggregate food consumption but do not account for the additional resources expended in producing meat compared to producing the same quantity of cereals. Expenditures on food (studied, for example, by Clark (1963), Szulc (2001), Hossain and Ferdaus (2000), Balcombe et al. (1999), Moon et al. (2000), and USDA (2001)) likewise cannot accurately capture the agricultural resources commanded, as increasing expenditures at high income levels largely reflect "convenience and quality factors" such as packaging and food service rather than increased absolute food consumption (Rask, 1991).

Early work by Clark (1963) using a price-determined "economic wheat equivalent" measure, for example, found food consumption values similar to those of this study for very poor countries with diets high in cereal consumption, but also recognized the limitations of a price-determined measure at high income levels: "the whole method, of course, becomes progressively more inaccurate as we ascend the international income scale to communities where grain for human consumption forms only a small fraction of the whole value of agricultural production" (page 59). Clark, using the economic wheat equivalent measure, found a per capita consumption increase of tenfold between poor and rich countries as compared to the 5–7-fold increase determined here with our resource based CE measure.

Clark's concerns are justified, as we find that while expenditures on food continue to rise, the claims on food production resources actually stabilize at high levels of income. In order to depict the total impact of income changes on consumption and production of basic food resources, we use the cereal-equivalent measure described below, which accounts for both quantity and quality diet adjustments but excludes convenience and other factors inherent in price related measures.

Yotopoulos (1985) pioneered our current use of the CE measure as he identified an income-food consumption relationship that accounts for consumption of cereals in two distinct areas: direct consumption of cereals, which rises slowly with income at low income levels, before decreasing at higher incomes; and indirect demand for cereals eaten as animal protein, which is very elastic to income changes. The conversion of cereals (feed) into animal protein is extremely inefficient, creating enormous demands on total resources as global incomes rise. This model of direct and indirect cereal consumption has been expanded by others, including Gilland (1979), Sanderson and Mehra (1988), Rask (1991), and Rask and Rask (2004).

We use tons of cereal equivalents (CEs) per capita per year to measure diets consistently across countries and throughout development stages since cereals are an important food item both directly and indirectly (as animal feed). The caloric content of crop products relative to the caloric content of an equal weight of cereals generates the CE values for crop products consumed in vegetable form such as cereals, root crops, fruits and vegetables. CE values for animal products consist of indirect grain consumption, or the CEs of feeds consumed by livestock in production of consumable livestock products. We assign the CE factor value of 1 to grains and cereals. Each type of livestock is then converted to its CE factor value based on the quantity of feed CEs embedded in its production in order to arrive at a live weight measure. This measure accounts for all forms of feed, including grains, protein supplements, forages such as pasture and other feeds, and also incorporates consumption needs of breeding herds. Finally, this live weight CE figure is adjusted for dressing weight percentage, yielding a CE value for consumable livestock product.

Establishing average global parameters for feed conversion rates for various forms of livestock is a more difficult task. Clearly, the level of technology (efficiency) in feed conversion varies between producing units within a country, across countries, and through time. Fortunately, a unique USDA (1975) study for the US agricultural sector overcomes some of these hurdles and is therefore used to develop the CE livestock coefficients for this study. The USDA study estimates annual allocation of total available feed supplies to each livestock enterprise, including breeding

[3] This section draws heavily on the development of the CE measure described in Rask and Rask (2004).

herds as well as producing units, over a ten year period (1964–1973). When combined with annual country level production for each livestock enterprise, it provides a reasonable estimate of feed resource requirements for livestock products for the US during this time period. By encompassing all forms of feed across the spectrum from intensive grain-based feed to extensive grazing for all stages of livestock production for a ten year period at the country level, differences among individual producing units and between years are averaged. Further, losses that occur under normal farm level production and marketing conditions are included in the USDA estimates. In contrast, feed conversion efficiencies derived from structured feeding trials cannot account for these types of losses. This unique, inclusive data set converts all feeds to corn equivalents, allocating type and quantity of feed to each form of livestock. The large climate diversity encompassed by the US ensures that the study represents a composite of climatic conditions, ranging from humid to arid and from tropical to cool temperate, with the accompanying diversity of production technologies. When combined with annual livestock product off-take and associated dressing weight percentages, this analysis provides an accurate measure of feed utilization input for each livestock consumption product based on actual farm level conditions, raised to the national level.

The level of feed conversion efficiency for the US at this time (1964–1973) was above average for the world. Thus, for consumption data in the early years of the FAO data set, estimated resource requirements for some countries will be somewhat understated, while the opposite will be true for later years and for projections of future resource needs. There also may be some differences in the degree of change in feed conversion efficiency through time by specific livestock enterprises, but we expect that global averages are not very far removed from the data estimates obtained from this comprehensive USDA study, an expectation supported by independent work on environmental impact data (see below). Moreover, the magnitude of increases in resource needs that accompany a diet change to livestock product consumption, and the magnitude of differences in feed conversion rates among livestock enterprises ameliorate somewhat the country and time variation in these rates. We are unaware of a more recent comparable data set.

Thus, using the USDA (1975) data we are able to calculate livestock product CE coefficients for each form of livestock based on US feed consumption, feed conversion ratios, livestock production, and dressing yields. We express all feed data in terms of corn equivalents, noting that the caloric content for cereals exactly equals that for corn on a per unit weight basis, according to 1999 FAO data for the US. This correspondence makes the use of feed corn equivalents in determining CE coefficients for livestock products fully appropriate, although we note that in terms of the world average, corn has a slightly lower caloric content than cereals in general. A sample of estimated CE coefficients is shown in Table 1.

Table 1
Sample cereal equivalent (CE) coefficients[a] for crop and livestock products.

Crop products[b]		Livestock products[c]	
Cereals	1.00	Beef	19.8
Fruits	0.15	Pork	8.5
Pulses	1.08	Chicken	4.7
Starchy roots	0.26	Milk[d]	1.2
Sugar, sweeteners	1.10		
Treenuts	0.83		
Vegetable oils	2.76		
Vegetables	0.07		

[a] *Cereal equivalent coefficient* refers to number of tons of cereals that is equivalent to one ton of crop or livestock product. See text for further explanation.

[b] Calculations based on world averages from 1999–2002 FAO food balance sheet data. Coefficient values for individual countries will vary slightly.

[c] Developed from Rask (1991). The livestock CE coefficients were developed from USDA data on US feed consumption, feed conversion ratios, and livestock production and dressing yields for all forms of livestock for the ten year period 1964–1973 (USDA).

[d] The feed input to the dairy enterprise is divided and allocated proportionately to both beef output (slaughter calves, cull cows and bulls) and milk production.

Our faith in the accuracy of the conversion factors is further reenforced by the striking similarity to estimates of relative environmental impacts attained by Williams et al. (2006) and Glendining et al. (2009). In particular, our cereal equivalent coefficient for beef (equivalent to roughly 20 units of corn) conforms quite well to the environmental impact ratios calculated in the Glendining study, which finds that total environmental costs for wheat production range from about £ 25–£ 50 (depending on intensity of production), while those for beef range from about £ 600 – £ 950 per tonne, or roughly a ratio of 20 to 1 (page 123). Similarly, Williams et al. (2006) finds global warming potential (GWP) to be 19.7 times as high for beef production as for wheat production (pages 66, 72). Williams reports GWP numbers for pig meat and for poultry as being 7.9 and 5.7 times as high as those for wheat.

Global and regional food consumption changes 1961–2002

As noted, food consumption increases derive from both population growth and diet upgrades. The impact of diet change on food requirements can thus be treated as a residual after the population effect has been deducted. Over the 42 year period 1961–2002, world food consumption measured in CEs increased 154% (Table 2). Population doubled over this time period, accounting for about two-thirds of the increase in food consumption, with the remainder due to diet change.

There are, however, significant differences among country groups both in the level of increase in food consumption and in the relative contribution of population growth and diet change to this increase. For example, food consumption in developing countries as a group has increased more than 300%, more than one-half of which results from diet change. On the other hand, developed countries have more stable diets, with population being the major contributor to their (smaller) consumption growth, as predicted.

Asia (dominated by China) leads in food consumption increases, up 363%, principally from diet change. The major diet changes are reflected in increases in consumption of livestock products, up over sixfold in Asia, with the principal increases from pork and poultry exceeding 17- and 16-fold increases respectively. At the other extreme, low levels of food consumption in Africa have barely kept pace with population growth. While both pork and poultry consumption levels have significantly increased in Africa (albeit from a low initial base), beef consumption has not kept pace with population growth. Within the developed countries of Western Europe and North America, marginal increases in consumption of beef and pork, along with significant increases in poultry consumption, have been recorded over this time period. Some of the increase in poultry consumption in developed countries results from lower relative prices due to improved efficiency in poultry production, as well as from perceived health benefits attendant to moving away from red meats. These factors may explain some of the tapering of the cereal equivalent consumption function at high income levels.

The land base supporting these increases in food consumption has remained relatively constant with both arable land and land equivalent measures increasing marginally on an absolute basis but falling significantly on a per capita basis. The land constraint in Asia is particularly acute with hectares of arable land per capita in 2002 (0.14) significantly less than the world average (0.23). For this reason, increases in food production, both from population growth and from diet changes, are likely to involve increasingly intensive production techniques (as opposed to extensive). For a

Table 2
Percent change in food C consumed by world region and food commodity (1961–2002). *Source*: FAO

Region →	World	Developing countries	Developed countries	Africa	Asia	South America	Western Europe	North America, developed
(% change from 1961 to 2002)								
Total food*	154	311	56	205	363	195	52	70
Crops*	146	201	51	242	189	176	36	127
Livestock*	152	404	55	172	638	198	54	61
Beef	111	242	50	137	469	169	22	60
Dairy	93	290	37	222	336	204	41	37
Pork	287	1201	88	318	1766	250	130	68
Poultry meat	715	1768	410	891	1601	2778	354	365
Eggs	277	951	60	412	948	301	36	27
Fish	262	526	86	318	410	266	81	155
Population	102	133	35	193	122	134	20	55

* Measured in cereal equivalents.

thorough discussion of the environmental impacts of both the production adjustments (reflecting the greater externalities generated by livestock) and those associated with intensive agriculture, see Williams (2006).

Consumption dynamics of diet upgrades in the economic development process

The income-food consumption relationship expressed in CE: the model

The fact that food expenditures rise at a decreasing rate as income rises is well documented and can be expressed in this way[4]:

$$Cce = f(GDP_{PC}), \quad f' > 0, \quad f'' < 0$$

The usual format, in which changes in consumption expenditures are related to changes in disposable income, is altered here by expressing consumption in terms of cereal equivalents per capita for the reasons discussed above, most importantly because expenditures do not capture the food resource requirements commanded by various diet choices. The food consumption – income relationship will level off earlier when measured in this way, since at high incomes the increases in "food" expenditures are largely due to non-food factors. The use of real GDP (PPP) per capita as the independent variable is dictated by data availability.

The regression uses the following functional form:

$$y = A_1 - A_2 e - kx$$

which yields the observed rise in CE consumption for early stages of development, tapering off at higher income levels.[5] Regression results are shown in Table 3, and the graph of this curve for world data appears in Fig. 1.

The development-induced changes in food demand discussed above are evident in the CE-based income-food consumption relationship described by Fig. 1. In particular, consumption initially rises rapidly with income, eventually stabilizing at an income level of about $25,000 GDP (PPP) per capita. Annual consumption per capita measured in CEs increases about fivefold over this range, from less than 0.4 to about 2.0 tons. The change in diet to include more livestock products (and therefore greater indirect consumption of grains) accounts for most of the increase in cereal equivalent consumption.

The average level of food consumption for the world was 0.95 tons of CEs per capita per year in 2002, which corresponds to an income level of about $5000 GDP (PPP) per capita, according to our

Table 3
Regression results, (159 Countries) 1975–2002.

	Estimate	Asymptotic standard error
A_1	2.1153	.0265
A_2	1.7821	3.8×10^{-6}
k	9.2×10^{-5}	.0308
$R^2 = .71$, $n = 3788$		

regression results. Average consumption is therefore currently significantly less than that of a country midway along the path of economic development and therefore midway through the process of diet upgrade (Fig. 2). Seventy percent of the world's population resides in countries with average income levels under $5000. Fifteen percent are in the $5000 to $15,000 income range, and only 15% of the world's population (with incomes of $15,000 and above) reside in countries that have or are approaching diet upgrade stability. Thus, the potential increase in food needs from diet upgrade remain substantial and are characterized by a different mix of food items which involves a restructuring of the production resources to meet this new and increasing demand.

There are several mitigating factors which would affect this progression along the curve for individual countries and for countries generally, including rising food prices and cultural and traditional norms. The broadly higher food prices caused by rising global demand would tend to lower real incomes, especially in poorer countries, but this impact is captured in part by the purchasing power parity adjustment to income levels. In terms of the second factor, clearly, each individual country will follow its own specific consumption path as it develops, dictated in part by tradition and culture. Despite these differences, however, the overall trends remain remarkably robust. For example, while total food consumption in Israel in 2002 was slightly lower than the world average at the same per capita income level of $19,000 (Fig. 2), the distribution among sub-categories of livestock products such as beef, dairy, and eggs was identical to the world averages. The only observed differences lie in the sub-categories of pork and poultry, which indicate a cultural preference to avoid pork, compensated by an increased consumption of poultry: the consumption of pork was in fact negligible, while consumption of poultry was more than triple the world average. We now examine the specific food commodity changes associated with this development.

Consumption changes for specific food commodities associated with economic development

Economic development alters both crop and livestock consumption items. The per capita quantity of crop consumption remains relatively constant across all income levels, with changes primarily

[4] This model was originally developed in Rask and Rask (2004).
[5] For more discussion of the use of this form in this context, see Rask and Rask (2004).

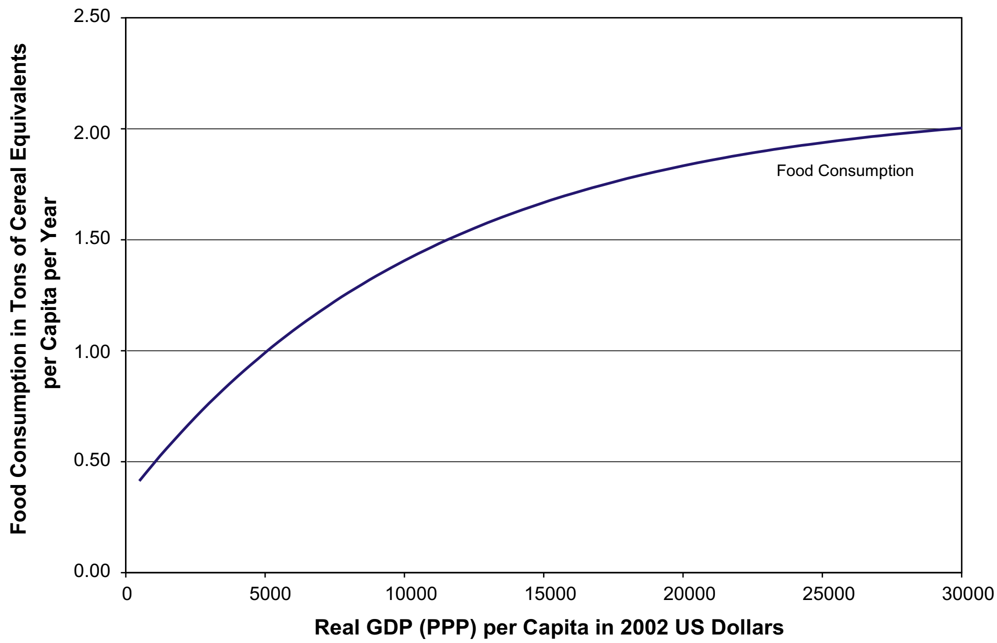

Fig. 1. Total per capita food consumption as a function of per capita income: world group 1975–2002.

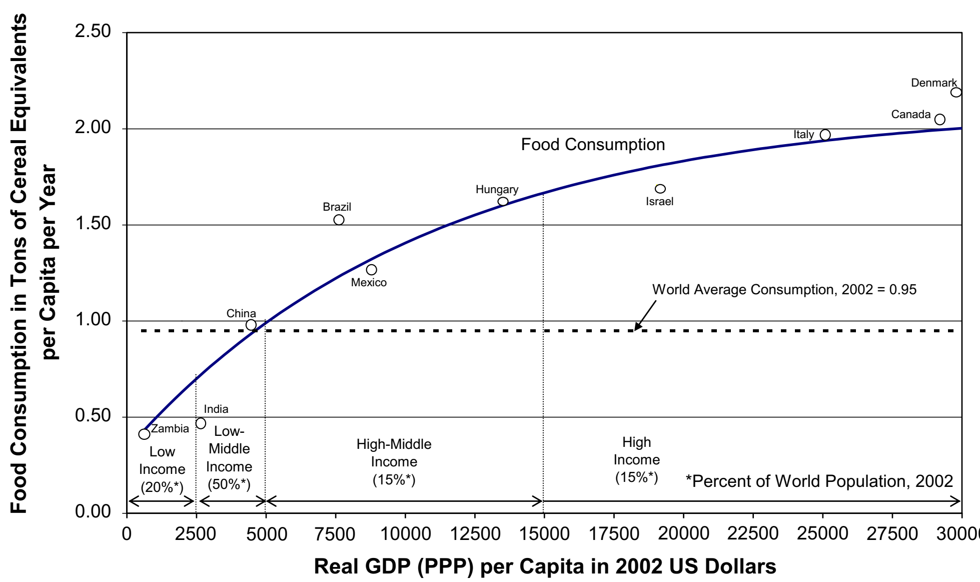

Fig. 2. Total per capita food consumption as a function of per capita income, 1975–2002: distribution of world population by income groups 2002, and income-consumption pairs for selected countries.

involving substitutions among commodities, while substantial increases in per capita consumption of livestock products occur (Table 4). For low-income countries, crop based foods account for about 40% of the diet and livestock products about 55%, when measured in cereal equivalents. At high income levels total per capita food consumption measured in CEs increases fivefold. With only a modest absolute increase, the crop component declines to 13% and livestock products increase to 82%. Fish consumption increases with income but remains at about 5% of the total at each income level.

Per capita consumption of cereals, the principal crop food item, declines marginally at higher income levels. The main substitution within cereals is from rice to wheat. Consumption of sweeteners and vegetable oils more than doubles from low to high income levels.

Note that, since our measure of food consumption reflects consumption of *food resources*, it will differ in some cases from those of others which generally reflect calories or expenditures. In addition, our forecasts look ahead to a new steady-state, a circumstance in which all countries reach the plateau we have identified for resource-based food consumption. Other forecasts consider specific timeframes or specific income growth. For example, Evans (2009, page 2 of Executive Summary and Recommendations) reports that the World Bank expects food demand to increase by 50% by 2030 and meat demand to increase by 85%. These estimates are based on specific assumptions regarding population and income growth over the next two decades and do not reflect resource use.

The food changes (diet upgrades) during economic development which are critical for resource use issues are the significant increases in per capita livestock product consumption. The least

Table 4
Estimated per capita food consumption by food item and per capita income level, in tons of cereal equivalents per capita per year. *Source*: Based on regression results, FAO and World Bank data from 159 countries (1975–2002).

Real income*	$1500	$5000	$15,000	$25,000
(tons of cereal equivalents per capita/year)				
All food	0.56	0.99	1.67	1.94
Crops	0.23	0.25	0.25	0.25
Cereals	0.13	0.13	0.11	0.09
Rice	*0.04*	*0.03*	*0.02*	*0.01*
Wheat	*0.04*	*0.07*	*0.07*	*0.07*
Others	*0.05*	*0.03*	*0.02*	*0.01*
Root crops	0.03	0.02	0.01	0.01
Vegetable oils	0.02	0.03	0.04	0.04
Sweeteners	0.02	0.04	0.05	0.05
Other	0.03	0.03	0.04	0.06
Livestock	0.30	0.69	1.32	1.59
Beef	0.12	0.25	0.43	0.48
Dairy	0.05	0.14	0.31	0.41
Pork	0.02	0.08	0.20	0.26
Poultry Meat	0.01	0.06	0.10	0.10
Eggs	0.01	0.02	0.04	0.05
Other	0.09	0.14	0.24	0.29
Fish	0.03	0.05	0.08	0.10

* Per capita real GDP (PPP) in 2002 US dollars.

efficient converters of feeds to consumable food products (and hence the most resource demanding) are ruminants, predominantly beef and dairy cattle (Table 1). Further, feed requirements for ruminants include a large percentage of forages, which are substantially available only in those countries in which the land and climate resources are uniquely and in some cases *only* suited to forage production. Other countries with very limited land resources find it difficult to dedicate a scarce resource to forage production.

Table 5
Estimated livestock product consumption in tons of cereal equivalents per capita under varying per capita land resource availability and income level[a]. Source: Based on regression results, FAO and World Bank Data from 159 countries (1975–2002).

Income	Per capita land equivalent levels[b]				
	Hectares	Less than 0.15	Between 0.15–0.5	Between 0.5–1.0	1.0 or greater
$1500 GDP (PPP) per capita (*low income*)	Livestock[c]	0.17	0.22	0.30	0.48
	Beef	0.03	0.09	0.13	0.19
	Dairy	0.05	0.04	0.05	0.07
	Pork	0.01	0.01	0.01	0.02
	Poultry	0.01	0.02	0.01	0.01
	Eggs	0.01	0.01	0.01	0.01
$5000 GDP (PPP) per capita (*middle income*)	Livestock[c]	0.57	0.61	0.70	0.92
	Beef	0.18	0.19	0.23	0.44
	Dairy	0.11	0.14	0.16	0.14
	Pork	0.07	0.09	0.10	0.04
	Poultry	0.10	0.07	0.04	0.03
	Eggs	0.02	0.02	0.03	0.02
$15,000 GDP (PPP) per capita (*upper middle income*)	Livestock[c]	1.17	1.28	1.36	1.61
	Beef	0.37	0.36	0.38	0.68
	Dairy	0.25	0.35	0.35	0.30
	Pork	0.16	0.24	0.27	0.11
	Poultry	0.12	0.09	0.09	0.08
	Eggs	0.04	0.04	0.05	0.03
$25,000 GDP (PPP) per capita (*high income*)	Livestock[c]	1.38	1.58	1.65	1.88
	Beef	0.42	0.42	0.44	0.71
	Dairy	0.34	0.48	0.42	0.42
	Pork	0.20	0.34	0.36	0.17
	Poultry	0.12	0.09	0.12	0.11
	Eggs	0.05	0.05	0.05	0.04

[a] Real GDP (PPP) per capita in 2002 US dollars.
[b] "Land equivalents" is a summation of hectares of arable land, land in permanent crops, and one-third of land in permanent pasture.
[c] Columns do not sum to bold main categories due to omitted sub-categories such as sheep, goats, horses, and rabbits.

Do these land and climate supply limitations materially affect livestock product food consumption behavior? If so, beef and dairy products would be favored in land rich countries and poultry and pork in land poor countries. Otherwise, consumption might be relatively independent of the underlying production resource conditions. To answer this question, we have divided the sample observations into four categories based on hectares of land equivalents per capita (recall that "land equivalents" is a summation of arable land, land in permanent crops, and one-third of land in permanent pasture): less than .15, .15 to .49, .50 to .99, and 1.0 and greater (Table 5). In 2002, the category of less than .15 land equivalents per capita included 22 countries comprising 10% of the world's population. The .15 to .49 category included 73 countries and 67% of the world's population, including in particular four of the most populous countries: China, India, Indonesia, and Pakistan. The latter three at .17, .17, and .16 land equivalents per capita respectively are set to move into the lower category in several years as population increases against a relatively fixed land base. The .5 to .99 category includes 33 countries and 16% of world population, and the final category holds 24 countries and 7% of world population. Based on these categories, the independence of food consumption behavior compared to productive resource availability depends on the specific food type, as detailed below.

Beef

Measured in CEs, beef is the most important contributor to livestock product consumption at all income levels. (Recall that CEs measure the resource input to consumption items, not the direct quantity of food consumed). At low incomes it accounts for 40% of livestock food consumption. Per capita beef consumption increases fourfold from low to high income, but as a percentage of total livestock products declines gradually to 30% at high income levels (Table 4). Beef consumption for land poor countries (Table 5) is somewhat depressed (less than 20% of livestock products) at low income levels, but is relatively consistent with countries possessing considerably more per capita land resources at middle and upper income levels, an indication that as development proceeds into the middle income ranges, incomes are sufficient to support significant imports of beef products or related feed inputs. In absolute terms, beef consumption continues to increase well into the high income range (Fig. 3). As expected, the few land rich countries consume a larger amount of beef both absolutely and as a percentage of livestock products.

Dairy products

Dairy product consumption is very consistent across land endowments at all levels of income and therefore relatively independent of resource availability. It is the second most important livestock product in terms of CE consumption, starting at 20% of livestock product consumption at low income levels and rising to 25% at high income levels. Per capita consumption continues to increase well into the high income levels, approaching that of beef at the very high income levels. Over the income ranges reported in Table 4, per capita dairy product consumption increases eightfold. The combination of beef and dairy products together accounts for a consistent 56% of livestock product consumption at all income levels.

Pork

Pork consumption changes across income levels are the most dramatic, rising 13-fold from low to high income, increasing strongly at all income levels. However, since swine are more than

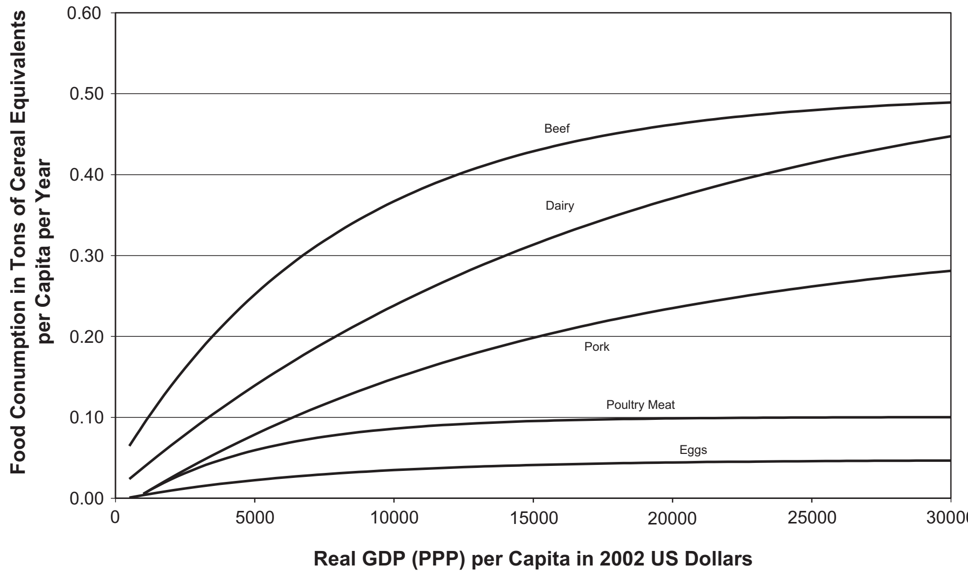

Fig. 3. Per capita consumption of livestock products as functions of per capita income: world group 1975–2002.

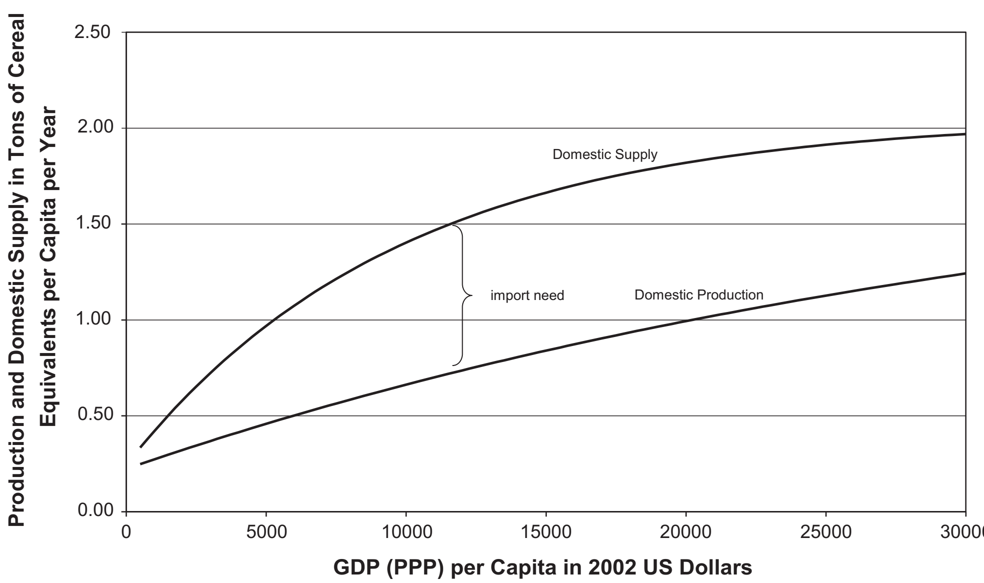

Fig. 4a. Per capita agricultural production and domestic supply as functions of per capita income: low per capita hectares of land equivalents (<0.15).

twice as efficient as beef in feed conversion, pork production commands only 16% of productive resource use at high income levels as compared to 25% for dairy products and 30% for beef. Recall that the environmental impact of pork production is also much less than that of beef. As with beef, land poor countries consume slightly less pork than do those with moderate land endowments. Countries with large per capita land endowments consume pork at considerably lower levels, but as noted above are major consumers of beef.

Poultry

Poultry products, both meat and eggs, are the most efficient in terms of resource use (Table 1). Consumption levels are quite consistent across land endowments but show a reversal for land poor countries: whereas consumption of other livestock products is lower in these countries, poultry consumption levels are marginally higher. While the per capita consumption of eggs continues to increase into high income levels, consumption of poultry meat rises rapidly at initial stages of development but peaks early at about $15,000 GDP (PPP) per capita and continues at this rate through middle and high income levels. The cause for this early stabilization in poultry meat consumption as contrasted with other livestock products is not immediately clear and should be the focus of additional study.

Meeting food needs during economic development: the food self-sufficiency dilemma

To measure food self-sufficiency throughout the development process we maintain the four-part country-level land endowment divisions and introduce two additional variables, both expressed in CEs: agricultural production and domestic supply. Domestic supply equals production adjusted for imports, exports and changes in stock. Domestic supply is slightly greater than but closely related to food consumption. In addition to product used directly for food it includes seeds and waste. The ratio of production to domestic supply is an indicator of overall agricultural self-sufficiency or in graphic terms, when the production curve exceeds the domestic supply curve (see Fig. 4), a country is self-sufficient. Where production falls short of supply, in contrast, a country must import a portion of its food needs. These are aggregate measures and do not preclude the import or export of specific commodities as countries respond to comparative advantage in particular commodities (Fig. 4a–d).

Several generalizations are apparent in the relationship between production and domestic supply over stages of development (income growth). First, at initial stages of development (low per capita income), per capita production and supply are of necessity in relative balance. Secondly, as development proceeds, domestic supply responds to rapid diet upgrades, growing more rapidly than domestic production and following a curvilinear path until stabilizing at high income levels. In contrast, production growth is slower and more linear than supply growth but continues well after supply has become stable. This differential growth pattern reflects the need at early stages of development to turn to imports to satisfy the demand for diet upgrade (livestock products). This supply-

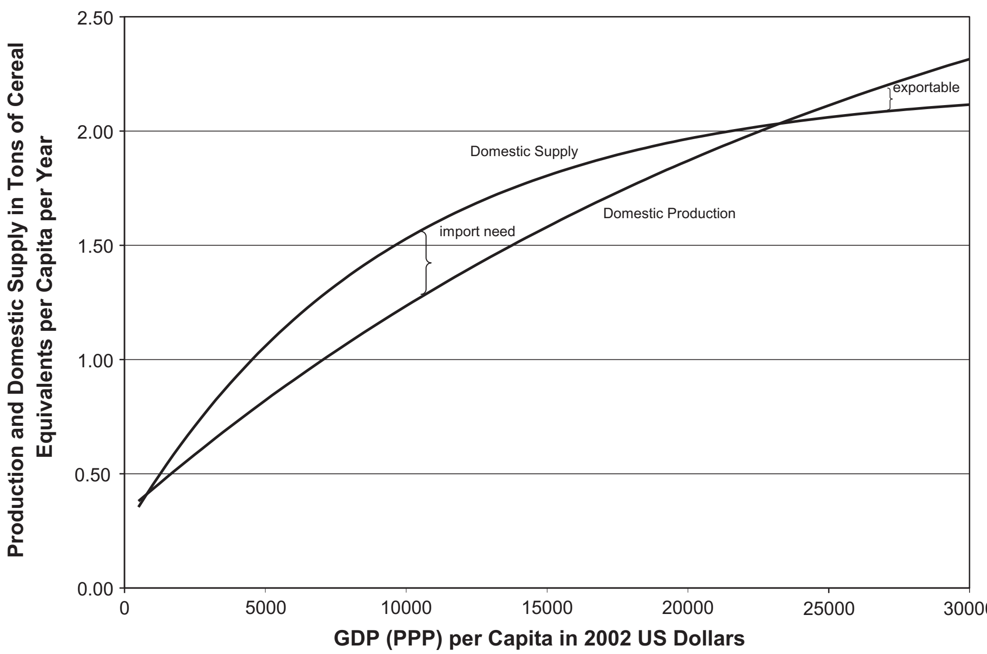

Fig. 4b. Per capita agricultural production and domestic supply as functions of per capita income: moderate per capita hectares of land equivalents (0.15–0.50).

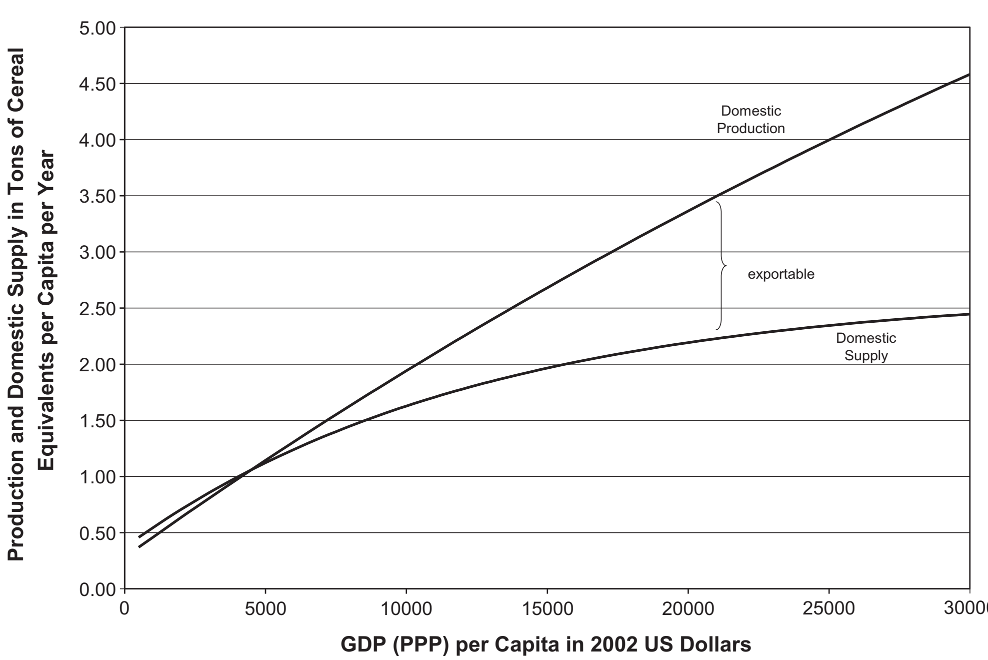

Fig. 4c. Per capita agricultural production and domestic supply as functions of per capita income: countries with high per capita land equivalents (0.50–1.0).

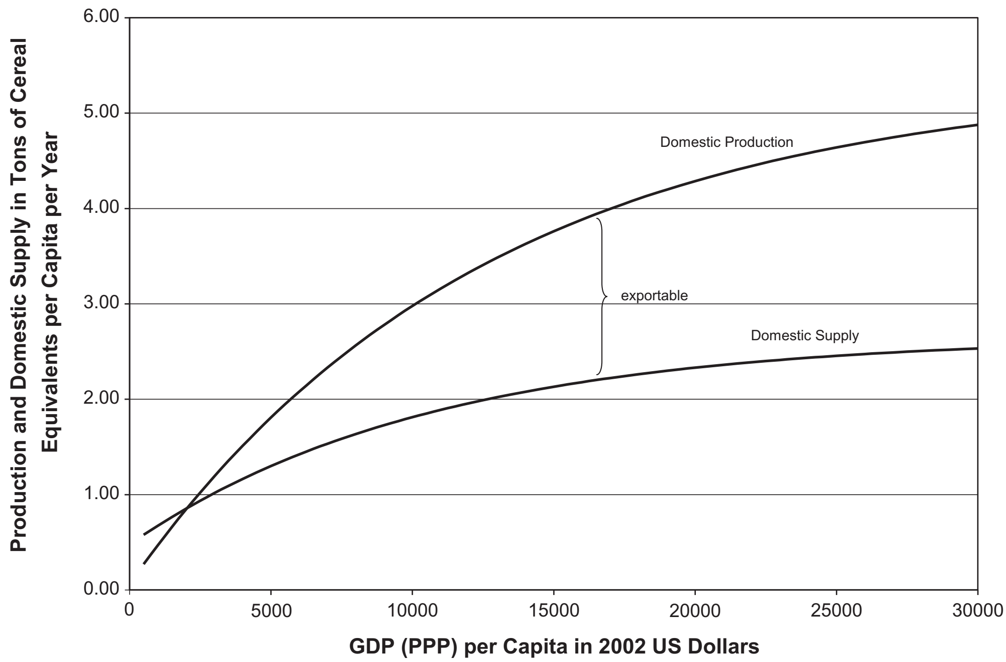

Fig. 4d. Per capita agricultural production and domestic supply as functions of per capita income: countries with very high per capita land equivalents (>1.0).

production gap closes quite early for countries with large per capita land endowments. However, for land poor countries it never closes completely, and for most countries production and supply balance only at mature levels of development. Further, these results are from a given point in time, and many countries with limited land supply and growing populations will be moving into lower per capita land equivalent categories over time, exacerbating the need for food imports. Finally, as noted earlier, over one-half of the world's population is consuming at levels consistent with average incomes below $5,000 (GDP (PPP)), an early point in the production-supply gap. Given these trading trends and the estimates of environmental impact as measured by global warming potential (GWP) (Williams et al., 2006), we would expect that as incomes rise, the environmental impact of increased demand for livestock products will fall disproportionately on the land-rich exporting countries.

Summary and conclusions

Food needs during economic development (income growth) are driven by two forces, population growth and diet upgrade, principally to livestock products. Diets rich in livestock products require considerably more agricultural resources to produce than do diets composed primarily of crop products. Using cereal equivalents to measure food consumption in a way that reflects resource use, we estimate that development-induced diet change alone will increase *per capita* food resource use by a factor of five as incomes move from low to high. Pork and to a lesser extent poultry products demonstrate the largest percentage gains among livestock products. Beef and dairy products show a lower percentage gain, but because they are less efficient in the use of agricultural resources, they combine to account for over one-half of our cereal-equivalent measure (resource use) at all levels of development. Countries with limited land resources demonstrate only moderate reductions in consumption growth of livestock products during development, continuing to consume significant levels of resource inefficient products such as beef and dairy through food or feed imports. The shift in production to supply the growing demand for livestock products from both population pressures and diet change generates increasing environmental externalities, including global warming potential.

Consumption growth outstrips the production response at early and middle levels of development. Diet upgrade appears to be complete at about $25,000 GDP (PPP) per capita and continued agricultural productivity allows some countries with sufficient land resources to close the production–consumption gap at that point and become relatively self-sufficient in the production of food. Land poor countries, while experiencing some closure, are unable to reach food self-sufficiency at any income level.

The average world diet, measured in tons of cereal equivalents per capita (0.95), has grown less than one-third of the way from low to high income (0.56–1.94), indicating that significant further diet upgrade will put continued pressure on world land resources as countries continue to develop. In fact, the changes in diet from an income level of $5000 per capita to the largely stabilized diet of the $25,000 income level require an increase of about 100% in CE food consumption *per capita*. With seventy percent of the world's population currently living in countries with income levels *below* that $5000 point, and often with declining per capita arable land available for food production, critical food supply issues emerge, even before considering population growth. Optimum agricultural resource and technology use as well as increased trade and attention to environmental impacts will be necessary to meet this growing food demand challenge.

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