6

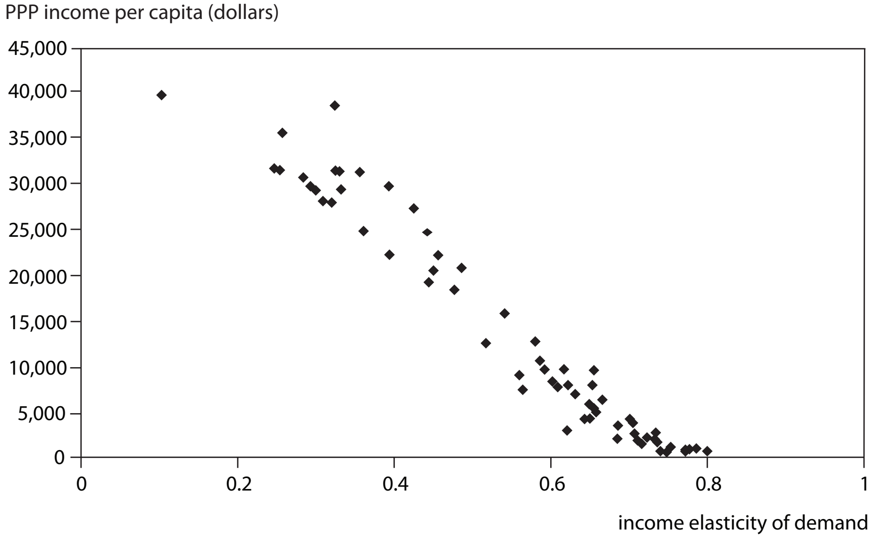
Dynamic Considerations

The analysis in this study uses current production (or population) for country weights in obtaining global estimates for the impact of climate change on agriculture. This approach tends to understate the future losses, because it is likely that by late in this century the business as usual baseline for agricultural output would have shown a much larger share for developing and low latitude countries than is the case at present. So from this standpoint the losses may be understated.

In contrast, it might be argued that dynamic considerations will typically shrink the relative importance of losses from climate change, because technological change can be expected to raise yields by far more than global warming reduces them. Comfort from the prospect of rising yields from technological change may nonetheless fail to take into account the fact that rising demand for agricultural products may run a close race with technological change, so that yield losses to climate change could still do damage that more than exceeds any excess supply trends in the baseline. Moreover, an important additional factor must be incorporated into the dynamic analysis: the likely diversion of agricultural land to production of biomass for ethanol.

This chapter seeks to arrive at some ballpark estimates of the net effect of these divergent influences. Define the ratio of demand or supply in 2085 to the level in 2005 as λ for each of several dimensions. Consider first population. The United Nations (2006) projects population in 2050 at 9.08 billion in its medium case, compared with 6.46 billion in 2004. Population grows at a pace of 0.42 percent per year in the decade 2040–2050 in this case. In its high case, the United Nations projects world population in 2050 at 10.65 billion, with annual growth at 0.93 percent in the decade 2040–2050. If these two respective levels and rates are used for projection to 2085, the resulting global population in 2085 is 10.52 billion in the

Figure 6.1 Income elasticity of demand for food, tobacco, and beverages and purchasing power parity (PPP) income per capita



medium case and 14.72 billion in the high case. The expansion factor from current levels to 2085 for population is thus $\lambda_N = 1.63$ in the medium case and 2.28 in the high case. In broad terms, global agricultural output will need to double, approximately, to keep up with population growth over this period.

Also, demand will increase from rising per capita incomes. Figure 6.1 shows the relationship of the income elasticity of demand for food, beverages, and tobacco (as calculated by ERS 2006b) to purchasing power parity (PPP) GDP per capita (World Bank 2006) for 64 countries. There is a clear inverse relationship between per capita income and income elasticity of food, which amounts to a strong form of Engel's law (which states that food expenditure rises less than proportionately with rising income).[1] If the regression equation relating the two is applied to global average PPP GDP per capita for 2004 ($6,329), the resulting global income elasticity for food at present is 0.655.[2] Even if per capita income grew at 1 percent per year through 2045 (the midpoint of the period considered), the global income elasticity would still be relatively high at 0.612.

Assuming that per capita income grows at 1 percent annually over the next 80 years, and that the average income elasticity is 0.612, then rising

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[1] A weak form would be any income elasticity less than unity.

[2] A simple regression yields the following results: $\theta = 0.744\ (100.1) - 1.4 \times 10^{-5}\ (-34.7)\ y^*$, adjusted $R^2 = 0.95$ (*t*-statistics in parentheses), where θ is income elasticity of food demand and y^* is PPP per capita GDP in dollars.

income per capita should boost demand for food by a factor of $\lambda_y = 1.63$, coincidentally the same as the medium population expansion factor.[3]

Total demand for food at unchanged real prices would thus rise by a factor that is the multiple of the expansion factor for population and the expansion factor for per capita income, or $\lambda^D = \lambda_N \lambda_y = 1.63 \times 1.63 = 2.66$ for the medium population growth case and $2.28 \times 1.63 = 3.72$ for the high population growth case.

On the supply side, one positive influence and two negative influences can be identified. The positive influence is secular rise in yield from technological change. The negative influences are diversion of agricultural land from food production to the production of energy crops and (certainly by 2085) the impact of global warming.

For land diversion to biomass, a recent study of future energy technologies by the International Energy Agency states the following (IEA 2006, 289):

> Conventional biofuel production requires about 1% of all arable land and yields about 1% of global transportation fuels. If 100% of the fuel requirements for world transport were derived from conventional biofuels, the land requirement would reach 1.4 gigahectares, an amount equivalent to all of the world's arable land. For this reason, even if large existing portions of pasture land could be converted to cropland, competition among conventional biofuel production and food production appears to be inevitable.

The study also notes that sugarcane ethanol is already (more than) competitive with oil at \$60 per barrel, that grain ethanol (e.g., from maize) would be competitive in relatively large volumes by 2030, and that lignocelluloic ethanol from such crops as switch grass would be competitive in large volumes by 2050. On this basis, it seems reasonable to expect that about one-third or more of agricultural land would be devoted to ethanol by the middle of this century. This means that from the standpoint of diversion of land to biomass for energy, the agricultural supply expansion factor for other crops from the present to the 2080s would be less than unity, at perhaps $\lambda_B = 0.7$.

To examine the prospects for rising agricultural yields from technological change, it is useful to review the record of the past few decades for the major crops and the major producers. Table 6.1 first presents estimates of production of the four most important grains, for the 21 largest-producing countries. The data are annual averages for 2001–04.

By identifying the principal world producers of each major crop, table 6.1 provides a basis for focusing the analysis of trends in agricultural yields on the most important producing countries for each product in

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[3] That is, demand for food per capita would rise at the rate of income growth per capita multiplied by the income elasticity of demand for food, or $1\% \times 0.612$. The expansion factor is thus $\lambda_y = 1.00612^{80} = 1.629$.

Table 6.1 Production of four major crops, by major producers and world, 2001–04 annual average (million metric tons)

Country	Rice	Wheat	Maize	Soybeans	Four crops, wheat-equivalent	Rank
United States	9.7	55.0	256.8	76.4	335.1	1
China	174.6	90.7	120.5	16.2	331.1	2
India	128.7	69.9	13.1	6.5	182.8	3
Brazil	11.1	4.6	41.9	45.9	89.2	4
Argentina	0.8	14.2	15.1	30.8	55.9	5
Indonesia	52.0	0.0	10.3	0.7	47.7	6
France	0.1	35.2	15.3	0.2	47.4	7
Russia	0.5	44.3	2.0	0.4	46.6	8
Canada	0.0	21.6	9.0	2.3	30.7	9
Bangladesh	37.6	1.5	0.1	0.0	29.8	10
Vietnam	34.3	0.0	2.8	0.2	28.1	11
Pakistan	6.8	19.0	2.0	0.0	25.7	12
Germany	0.0	22.1	3.7	0.0	25.0	13
Thailand	25.9	0.0	4.3	0.3	23.0	14
Turkey	0.4	19.6	2.5	0.1	22.0	15
Australia	1.0	20.7	0.4	0.1	21.7	16
Mexico	0.2	0.0	20.2	0.1	18.9	17
Myanmar	22.6	0.1	0.7	0.1	17.7	18
Philippines	13.7	0.0	4.7	0.0	13.9	19
South Africa	0.0	2.0	9.4	0.2	9.6	20
Japan	10.8	0.8	0.0	0.2	9.1	21
Subtotal	530.9	421.2	534.7	180.8	1,411.0	
Top 5	427.2	295.0	454.7	175.8	994.0	
World	589.4	589.5	647.6	188.8	1,716.1	
Shares (percent):						
21 countries	90.1	71.4	82.6	95.8	82.2	
Top 5	72.5	50.0	70.2	93.1	57.9	

Note: Weights: wheat = 1.0, rice = 0.75, maize = 0.78, and soybeans = 0.95.

Source: United Nations FAOSTAT database.

question. The table also shows several important patterns itself, however. First, it reveals substantial concentration in production. The top five producing countries account for about 70 percent of world output of both rice and maize and a surprisingly high 93 percent of world production of soybeans. Wheat production is somewhat less concentrated, but even for this product the top five producers account for half of world output.

Second, the United States and China are approximately tied for first place in agricultural production. This calculation is based on a consolidated wheat-equivalent total of output for the four crops, weighting by average world prices in 2002–05.[4]

Third, again using the consolidated wheat-equivalent, world output is approximately 1.7 billion metric tons for the four major grains, or about 264 kg per person annually (723 grams per day).[5]

Fourth, dietary differences are evident in the table, with heavy reliance on rice in Asia and much greater reliance on wheat and maize in the Western Hemisphere and Europe.

With this rough summary of global agricultural production in hand, relative country weights in production of key commodities can be applied to country-specific estimates of the pace of technological change to arrive at broad aggregates for technological change in global agriculture. Table 6.2 reports average annual yield increases for these crops in each of their major producing countries for 1961–83 and 1984–2005. These rates are estimated using statistical regressions of the logarithm of yield per hectare on time and thus avoid distortion by choice of endpoints.[6]

For each crop, the weighted average pace of increasing yield is obtained by weighting the production shares of the respective countries in the set of major producers examined. The countries are selected for each crop based on the top producing countries shown in table 6.1.

In order to obtain an overall rate of yield increase for the four crops, the weighted averages for each commodity are in turn weighted by the share of the product in global wheat-equivalent production as indicated in table 6.1. The result is a central estimate that these agricultural yields rose at an annual rate of 2.81 percent in 1961–83 and decelerated to an annual increase of 1.57 percent during 1984–2005. This trend is consistent with the stylized fact that globally the green revolution has slowed down somewhat since its heyday in the 1960s.

The final element is now in place for comparing the expansion of agricultural demand through late in the 21st century against the corresponding prospective expansion in supply. Assuming that the pace of increasing yields continues at its rate of the past two decades, or 1.57 percent,

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[4] Average prices in this period, per metric ton, were $132.5 for wheat, $98.8 for rice, $103.7 for maize, and $125.9 for soybeans (IMF 2006).

[5] Note that the corresponding "food quantity" estimates in the Food and Agriculture Organization (FAO) data are substantially smaller. For the United States, for example, the FAO estimate under this concept is a total of 692 grams per person per day for four grains (rice, wheat, maize, and soybeans) and three meat types (bovine, chicken, and pig). For India, the corresponding total is only 472 grams (UN FAOSTAT database). The difference from the higher cereal production total reflects primarily the high ratio of grains to meat production for feedgrains, as discussed later.

[6] All of the estimates are statistically significant at the 95 percent level or above except for wheat in Australia in both periods.

Table 6.2 Average annual increase in yields per hectare (percent)

Crop/country	1961–83	1984–2005
Wheat		
Argentina	1.19	1.56
Australia	0.21	1.02
Canada	2.09	1.53
China	5.88	1.82
France	3.10	0.98
India	3.70	1.94
United States	1.73	0.83
Weighted average	3.46	1.49
Rice		
Bangladesh	1.10	2.71
China	2.96	0.95
India	1.59	1.50
Indonesia	3.76	0.61
United States	0.87	1.13
Vietnam	0.86	2.95
Weighted average	2.28	1.38
Maize		
Argentina	3.12	3.72
Brazil	1.43	3.47
China	4.63	1.47
Mexico	2.60	2.33
United States	2.12	1.58
Weighted average	2.77	1.83
Soybeans		
Argentina	3.68	1.16
Brazil	2.64	2.45
India	3.46	1.27
United States	0.98	1.34
Weighted average	2.08	1.62
Four crops, wheat-equivalent weights:		
Major producers	2.81	1.57

Source: Calculated from United Nations FAOSTAT database.

then the supply expansion factor from rising yields from 2005 to 2085 amounts to $\lambda_q = (1.0157)^{80} = 3.48$.

In the absence of any influence of global warming, the prospective late-century demand expansion factors would thus be $\lambda^D = 1.63 \times 1.63 = 2.66$ from population (medium case) and rising per capita income, respectively; or $\lambda^D = 2.28 \times 1.63 = 3.72$, for the high population case. In com-

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Table 6.3 Meat consumption per capita (kilograms per person per year)

	Beef	Pork	Poultry	Mutton	Total
Industrial countries	21	25	24	2	72
Developing countries	5	11	7	1	24
Memorandum:					
Feed/meat ratio	7	4	2	4	4.1

Source: WorldWatch Institute (1998).

parison, the supply expansion factor would be $\lambda^S = 0.7 \times 3.48 = 2.44$, taking account of the diversion of land area to energy crops (the first factor) and expected increase in yields (the second).

As it turns out, in the central case there is a moderately unfavorable balance between expansion of potential demand (by a factor of 2.66) and expansion of potential supply (2.44), a divergence of almost 10 percent. So even on relatively optimistic grounds, it would be a mistake to be complacent about a sizable loss in future global yields from global warming from levels they would otherwise reach, on grounds that technological change will flood the market with agricultural goods in any event.

There are significant grounds, moreover, for a less optimistic projection. The first reason is that population growth at the high variant would set the ex ante expansion factor at considerably higher for demand (3.72) than for supply (2.44). The second reason is that just as yield increases have slowed down in the past 20 years, they might be expected to slow further in the next eight decades, mainly because the high rates of increase in the developing countries would tend to ease toward rates in the United States, Canada, and other industrial countries as best practices are adopted. If average annual yield increases eased to 1 percent, the yield expansion factor by 2085 would be only 2.22 instead of 3.48, placing the supply expansion factor at only 1.55 after taking account of diversion of land to biomass for energy. In this case, potential demand expansion at unchanged real prices would be almost twice as great as supply expansion at constant prices, even with no loss from global warming.

A third reason why the central calculations may be too optimistic is that they do not explicitly allow for a dietary shift toward meat. Table 6.3 reports estimates of average consumption of meat per capita in industrial and developing countries, along with the feed/meat ratio indicating the number of kilograms of grains required to produce one kilogram of the meat in question. Overall, on average industrial-country consumers eat three times as much meat per capita as developing-country consumers, and it requires four kilograms of grains to produce one kilogram of meat.

In 2004, average PPP income per capita stood at $31,009 for high-income countries and $4,726 for developing (low- and middle-income) countries (World Bank 2006). As a first approximation, then, approximately a sevenfold rise in real per capita income (\$31,009 / \$4,726 = 6.56) might be expected to generate a threefold rise in per capita consumption of meat (72/24, from table 6.3), with some attendant reduction in direct consumption of grains (likely especially rice). Correspondingly, if on average developing countries' real per capita incomes were to rise at 1 percent annually over the next eight decades, for an increase by a factor of 2.22, their meat consumption per capita could be expected to rise by a factor of approximately 1.6.[7]

These specific calculations somewhat surprisingly give almost an identical increase in demand for meat in developing countries as that obtained for all food applying the estimated income elasticity of 0.612, which in turn would have the implausible implication that rising income would not shift the composition of demand toward meat. So the main calculations of this chapter may not be seriously biased from this standpoint, but if there is a bias, it still seems likely that it is toward an understatement of the rise in demand for crop production because of a failure to take special account of shifting demand toward grain-intensive meat.

In short, the principal uncertainties in the estimates of expansion factors above are all on the side of downside risk to the late-century balance between potential agricultural demand and supply. These considerations reinforce the main conclusion that future technological change is no panacea for addressing concerns about the adverse impact of global warming.

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[7] With $c = y^{\gamma}$ where c is per capita meat consumption, y is real PPP income per capita, and h and d refer to high-income and developing countries, respectively, then $c_h/c_d = 3$ when $y_h/y_d = 6.56$ implies that $\gamma = 0.58$ and thus that a rise in developing-country income per capita (y_d) by a factor of 2.22 would boost per capita consumption of meat in developing countries by the factor $2.22^{0.58} = 1.59$.