Food, Agriculture,
and the Environment
Discussion Paper 28

Livestock to 2020
The Next Food Revolution

Christopher Delgado
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Claude Courbois

2020 VISION

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

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International Food Policy Research Institute
2033 K Street, N.W., Washington, D.C. 20006-1002 U.S.A.

Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla, 00100 Rome, Italy

International Livestock Research Institute
P.O. Box 30709, Nairobi, Kenya

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Contents

Tables

Illustrations

Foreword

The combined per capita consumption of meat, eggs, and milk in developing countries grew by about 50 percent from the early 1970s to the early 1990s. As incomes rise and cities swell, people in the developing world are diversifying their diets to include a variety of meats, eggs, and dairy products. This trend toward diversified eating habits is likely to continue for some time to come and it has led to considerable controversy about the risks and opportunities involved. Some observers fear that greatly increased demand for feedgrains will raise the price of cereals to the poor. Others are concerned that higher concentration of livestock production near cities adds to pollution. Still others worry about the public health effects of increased consumption of animal fats and the rapidly increasing incidence of diseases passing from animals to humans. On the other hand, many analysts point to the nutritional benefits of increased consumption of animal products for populations that are still largely deficient in intake of protein and micronutrients. Furthermore, livestock traditionally have been an important source of income for the rural poor in developing countries. Finally, increased demand for livestock products may provide an engine for sustainable intensification of smallholder food and feed production systems.

A team of researchers from the International Food Policy Research Institute (IFPRI), the Food and Agricultural Organization of the United Nations (FAO), and the International Livestock Research Institute (ILRI) collaborated to produce this comprehensive and even-handed attempt at defining the nature, extent, scope, and implications of what they term the "Livestock Revolution" in developing countries. Looking forward to 2020, they argue convincingly that the structural shifts in world agriculture being brought about by shifts in developing-country demand for foods of animal origin will continue and that increasingly global markets have the ability to supply both cereal and animal products in desired quantities without undue price rises. They emphasize, however, that policy decisions taken for the livestock sector of developing countries will determine whether the Livestock Revolution helps or harms the world's poor and malnourished. The report emphasizes the importance of continued investment in both research on and development of animal and feedgrain production and processing, and the need for policy action to help small, poor livestock producers become better integrated with commercial livestock marketing and processing. It details a host of requirements in the area of technology development for production and processing of livestock products, potential benefits from new technologies, and critical policy issues for environmental conservation and protection of public health.

Per Pinstrup-Andersen, Director General
International Food Policy Research Institute

Abdoulaye Sawadogo, Assistant Director-General, Agriculture Department
Food and Agricultural Organization of the United Nations

Hank Fitzhugh, Director General
International Livestock Research Institute

Acknowledgments

The ambitious and multidisciplinary topic of this paper hints at the extent to which the authors had to rely on help from colleagues with a wide variety of disciplinary and geographic expertise. They are too numerous to mention individually, but several colleagues stand out because of the degree of their support for this collaborative project and the depth of their insights on previous drafts. Per Pinstrup-Andersen and Rajul Pandya-Lorch, director general and head of the 2020 Vision initiative, respectively, of the International Food Policy Research Institute (IFPRI), provided an institutional framework for the project, constant encouragement, and detailed and insightful comments throughout the process. Abdoulaye Sawadogo, assistant director-general of the Food and Agriculture Organization of the United Nations (FAO), quickly recognized the value of this collaboration, discussed issues with the team, and facilitated the conditions for effective FAO participation. Hank Fitzhugh, director general of the International Livestock Research Institute (ILRI), consistently sought to integrate ILRI's broad strengths with respect to livestock issues in developing countries with our activities and facilitated ILRI's effective participation.

A number of formal and informal external reviewers of earlier drafts of the report greatly improved the final product. Particular mention should be made of the very detailed and helpful comments of Cees de Haan of the World Bank and Maggie Gill of Natural Resources International (U.K.) in this regard. While the technical livestock production aspects of this report, authored as it is by economists, probably still falls short of their high standards, there is no doubt that they substantially improved it over what it would have been otherwise. Catherine Geissler of King's College, London, helped improve the nutritional insights of the report; the remaining deficiencies are entirely the responsibility of the authors. The latter would also like to express their thanks for very helpful written comments to Mercy Agcaoili-Sombilla of the International Rice Research Institute (IRRI), Jan Slingenbergh of FAO, Steve Staal of ILRI, Claudia Ringler of IFPRI, Bob Havener of the World Food Prize Office, and Tjaart Schillhorn Van Veen of the World Bank. Finally, they would like to commend Uday Mohan, an IFPRI editor, on his cheerful and successful struggle under time pressure to turn our collectively authored, carefully hedged prose into a readable final report.

1. The Livestock Revolution

A revolution is taking place in global agriculture that has profound implications for our health, livelihoods, and environment. Population growth, urbanization, and income growth in developing countries are fueling a massive global increase in demand for food of animal origin. The resulting demand comes from changes in the diets of billions of people and could provide income growth opportunities for many rural poor. It is not inappropriate to use the term "Livestock Revolution" to describe the course of these events in world agriculture over the next 20 years. Like the well-known Green Revolution, the label is a simple and convenient expression that summarizes a complex series of interrelated processes and outcomes in production, consumption, and economic growth. As in the case of cereals, the stakes for the poor in developing countries are enormous. And not unlike the Green Revolution, the "revolutionary" aspect comes from the participation of developing countries on a large scale in transformations that had previously occurred mostly in the temperate zones of developed countries. But the two revolutions differ in one fundamental respect: the Green Revolution was supply-driven, whereas the Livestock Revolution is driven by demand.

The Livestock Revolution will stretch the capacity of existing production and distribution systems and exacerbate environmental and public health problems. Governments and industry must prepare for this continuing transformation with long-run policies and investments that will satisfy consumer demand, improve nutrition, direct income growth opportunities to those who need them most, and alleviate environmental and public health stress.

The 23 percent of the world's population living in developed countries presently consume three to four times the meat and fish and five to six times the milk per capita as those in developing countries[1] (Delgado, Courbois, and Rosegrant 1998). But massive annual increases in the aggregate consumption of animal products are occurring in developing countries. From the early 1970s to the mid 1990s, consumption of meat in developing countries grew by 70 million metric tons, whereas consumption in developed countries grew by only 26 million metric tons (Table 1).[2] In value and caloric terms, meat consumption in developing countries increased by more than three times the increases in developed countries. Milk consumption in the developing world increased by more than twice as much as milk consumption in the developed world in terms of quantity, money value, and calories.

Even more revealing is the comparison between developing-country increases in meat, milk, and fish consumption during the 1971–95 period with the increase in cereal consumption (Table 1). The period spans the well known Green Revolution, when seed-fertilizer innovations in cereal production dramatically increased wheat, rice, and maize output in developing countries, making more food available and increasing farm incomes. But during the same period there was also a dramatic, if often overlooked, rise in consumption of animal-origin food products in developing countries. On a quantity basis, the additional meat, milk, and fish consumed between 1971 and 1995 in developing countries was two-thirds as important as the increase in wheat, rice, and maize consumed (Table 1). The Green Revolution provided many more calories

[1] Fish consumption and production are also undergoing revolutionary changes, but this is outside the scope of the current paper. Interested readers are referred to Williams (1996) and Westlund (1995).

[2] All tons are metric tons in this report.

Table 1—Increase in food consumption of meat, milk, fish, and major cereals, 1971–95

Commodity	Consumption increase		Value of consumption increase[a]		Caloric value of consumption increase	
	Developed	Developing	Developed	Developing	Developed	Developing
	(million metric tons)		(billion 1990 US$)		(trillion kilocalories)	
Meat[b]	26	70	37	124	38	172
Milk	50	105	14	29	22	64
Fish[c]	5	34	27	68	4	20
Major cereals[d]	25	335	3	65	82	1,064

Sources: The changes in quantities and in calories are from FAO 1998. Money values are computed for the disaggregated commodities (shown in the notes below) using the 1990–92 average price. The commodity prices used for beef, sheep and goat meat, pork, poultry, wheat, rice, and maize are detailed in Table 28. Disaggregated fish prices are 1990–92 average import unit values calculated from FAO (1998) import data. Developed-country import unit values are used for developed-country consumption and developing-country import unit values are used for developing-country consumption.

Notes: Calculations represent aggregate changes between three-year averages centered on 1971 and 1995.

[a]Calculated using 1990 world prices expressed in constant, average 1990–92 US$.

[b]Beef, sheep and goat meat, pork, and poultry.

[c]Marine and freshwater finfish, cephalopods, crustaceans, molluscs, and other marine fish.

[d]Wheat, rice, and maize used directly as human food.

than the coinciding increase in meat consumption, but the additional meat consumed was worth almost three times the increase in cereal consumption at constant world prices.

Furthermore, if the consumption patterns in developed countries are an indication of where developing countries are going, future growth in cereal consumption as food is likely to be much smaller than that in meat. During 1971–95 additional consumption of meat, milk, and fish in the developed countries was much larger than that of cereal in terms of weight and value. In developing countries many people will soon be reaching satiation in their consumption of cereals, while meat and milk consumption is likely to continue to grow even more robustly into the next century.

Not surprisingly, major transformations of the magnitude of the Livestock Revolution are not without problems. Although domesticated animals have been a source of human food, clothing, tools, transportation, and farm power since prehistoric times, the current rapid changes in demand for animal foods in developing countries are putting unprecedented stress on the resources used in livestock production. The combination of higher demand, more people, and less space is rapidly leading to a global transformation of the livestock sector, from one that mobilizes surplus and waste resources (backyard slops, remote pastures, and grasses indigestible by humans) to one that actively seeks new resources for the production of animal food products (Steinfeld, de Haan, and Blackburn 1997).

The recent rapid expansion of livestock food production in developing countries resulted primarily from increased numbers of animals rather than higher carcass weight per animal. In developing countries this has contributed to large concentrations of animals in urban environments where the regulatory framework governing livestock production is weak (for example, Addis Ababa, Beijing, Lima, and Mumbai). Larger concentrations of animals have also led to degradation of rural grazing areas and the clearing of forest. Growing concentrations of animals and people in the major cities of developing countries also lead to rapid increases in the incidence of zoonotic diseases, such as salmonella, *E-coli*, and avian flu, which can only be dealt with through enforcement of zoning and health regulations.

Other public health issues raised by the Livestock Revolution are also of major importance. The intensification of livestock production is leading in many parts of the world to a build-up of pesticides and antibiotics in the food chain. Furthermore, as the scale of output increases, especially in the tropics, food safety risks from microbial contamination are becoming more prevalent.

Overconsumption of animal food products raises another concern. A growing consciousness of the dangers of large amounts of saturated animal fats in diets exists in most developed countries. Some experts have concluded that policies should prevent a similar over-consumption in developing countries by discouraging public investment in livestock production (Brown and Kane 1994; Geissler forthcoming; Goodland 1997; Pimentel 1997).

Increasing livestock consumption may also affect cereal prices. Because ruminant livestock such as cattle, sheep, and goats consume grain, and monogastric livestock such as pigs and poultry depend on grain in the industrial production systems of developed countries, some analysts argue that the high demand for livestock products in developed countries and rapidly increasing demand and production in developing countries deplete the grain available for direct consumption by people.

Livestock production and consumption have proponents as well. Livestock production is an especially important source of income for the rural poor in developing countries. It enables poor and landless farmers to earn income using public, common-property resources such as open rangeland. Livestock consume many crop by-products that would otherwise become waste, they often can be raised on land that has no other sustainable agricultural use, and they can employ labor during periods of slack in other agricultural activities. Poor women in particular often rely on the cash income from a dairy cow or a few chickens kept in the household. As livestock consumption increases there is considerable interest in how the poor can retain their market share of livestock production.

Livestock products are an appealing and convenient nutrient source. Protein and micronutrient deficiencies remain widespread in developing countries because people subsist on diets that are almost entirely made up of starchy staples. The addition of milk and meat provides protein, calcium, vitamins, and other nutrients that go lacking in diets that are exclusively made up of staples such as cereals.

Besides providing food, the driving force behind increased livestock production, livestock have other valuable uses. Livestock remain the most important if not the sole form of nonhuman power available to poor farmers in much of the developing world. The poor, in particular, use fertilizer from livestock operations, especially when rising petroleum prices make chemical fertilizers unaffordable. Livestock also store value and provide insurance for people who have no other financial markets available to them. Skins, wool, oil, and other resources are used as inputs in other industries.

This report will examine in detail the interrelationships over time between supply and demand for livestock and feedgrain, using IFPRI's IMPACT model.[3] It will investigate the plausibility of the projected demand increases for livestock products and the implications of these increases for world markets in feed, milk, and meat. The paper will argue that world grain markets currently have sufficient capacity to handle the additional demand for feed coming from increasing livestock production, even under a variety of different scenarios for technological development and global economic performance.

The paper will argue further that the structural shift in developing-country diets toward animal proteins is a given that must be dealt with. It will review the evidence on the impact of livestock products on nutrition in developing countries and on the food demand and income growth of the poor. The industrialization of livestock production in developing countries can harm the welfare of the poor if other policies artificially reduce the cost of indus-

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[3] The model was developed by Rosegrant and colleagues (Rosegrant, Agcaoili-Sombilla, and Perez 1995; Rosegrant et al. 1997; Rosegrant, Leach, and Gerpacio 1998; and Rosegrant and Ringler 1998). It is global in nature and balances supply and demand within agriculture with market-clearing prices for major agricultural commodities, including livestock products and feed. Starting with exogenously specified trends in national incomes for 37 country groups, the model traces food demand, feed demand, and supply levels for 18 commodities, iterating to market-clearing prices for major commodities annually through 2020. The results are based on a large number of parameter assumptions taken from the literature, including assumptions about the openness to trade.

The model is useful for illustrating how demand-led shocks in Asia, for example, work themselves out in markets around the world. It also illustrates that in systems of interlinked global markets for livestock products and feed, the net effect of price-mediated policy interventions can be quite different from what was envisaged.

trial turn-key operations and otherwise frustrate the participation of small farmers. The paper will suggest that understanding the opportunities and dangers of the Livestock Revolution is critical to designing policies that promote the incorporation of the rural poor into economically and environmentally sustainable growth patterns.

The rapid increase in demand for livestock products in developing countries presents crucially important policy dilemmas that must be resolved for the well-being of both rural and urban people in developing countries. These dilemmas involve complex environmental and public health issues in the context of weak regulatory environments. Taken together, the many opportunities and dangers of the Livestock Revolution suggest that it would be foolish for developing countries to adopt a *laissez faire* policy for livestock development. Many specific recommendations for concrete action are given in chapters ahead. The overall focus of the paper, however, is on the four broad pillars on which to base a desirable livestock development strategy for developing countries. These are (1) removing policy distortions that artificially magnify economies of scale in livestock production; (2) building participatory institutions of collective action for small-scale farmers that allow them to be vertically integrated with livestock processors and input suppliers; (3) creating the environment in which farmers will increase investment in ways to improve productivity in the livestock sector; and (4) promoting effective regulatory institutions to deal with the threat of environmental and health crises stemming from livestock.

Technological progress in the production, processing, and distribution of livestock products will be central to the positive outcome of the Livestock Revolution. Rapid advances in feed improvement and genetic and reproductive technologies offer scope for overcoming many of the technical problems posed by increased livestock production. Institutional and regulatory development will also be critical to securing desirable environmental and public health outcomes. In sum, the demand-driven Livestock Revolution is one of the largest structural shifts to ever affect food markets in developing countries and how it is handled is crucial for future growth prospects in developing country agriculture, for food security and the livelihoods of the rural poor, and for environmental sustainability.

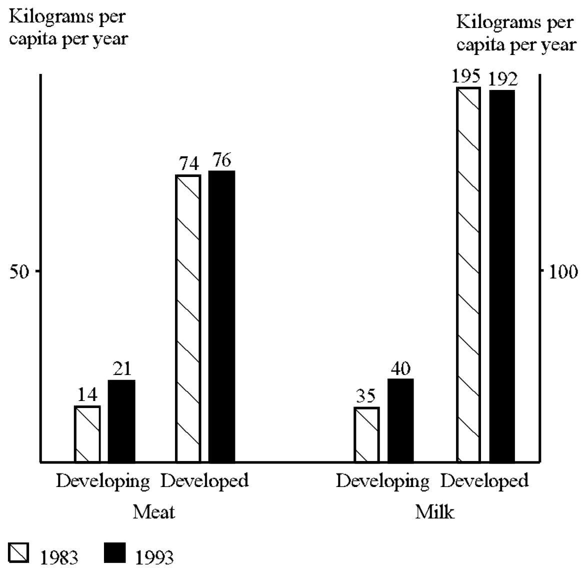
2. *Recent Transformation of Livestock Food Demand*

Per Capita Consumption

Progressive economic differentiation between countries over the last few centuries, has led to a situation where people in developed countries typically consume three to four times the meat and five to six times the milk as do those in developing countries (Figure 1). But this pattern is changing. People in developing countries have increased their consumption of animal food products over the past 20 years, and the factors driving those increases are robust and unlikely to subside in the near future.[4] Between 1983 (average of 1982–84) and 1993 (average of 1992–94) per capita annual meat consumption rose from 14 to 21 kilograms and milk consumption grew from 35 to 40 kilograms. During the same period per capita consumption of meat in developed countries rose only 2 kilograms and per capita milk consumption fell.

At the regional level, Asia witnessed the most dramatic increases in per capita consumption of animal food products. In China per capita consumption of meat and milk doubled between 1983 and 1993 (Table 2). Per capita meat consumption also increased in Other East Asia, Southeast Asia, and Latin America. Per capita milk consumption increased in India, Other South Asia, and Latin America. In Sub-Saharan Africa and West Asia and North Africa (WANA) per capita consumption of meat and milk stagnated or declined (see the Appendix for the regional classification of countries used in this paper).

Figure 1—Per capita consumption of meat and milk, developing and developed countries, 1983 and 1993



Source: FAO 1998.
Note: Meat includes beef, pork, mutton, goat, and poultry. Milk is milk and milk products in liquid milk equivalents. Values are three-year moving averages centered on the two years shown.

The relative importance of animal food products in the diets of people in developing countries rose as well. Consumers obtained a greater share of calories and protein from animal food products in 1993 than in 1983 (Table 3). Throughout Asia the share of calories and protein coming from animal food products increased, almost doubling in China, indicating that many consumers are increasing con-

[4] Throughout this paper, "food" is used to distinguish direct food consumption by humans from uses of animal products as feed, fuel, cosmetics, or coverings. Statistical data in this paper are taken from the FAO Statistical Database (FAO 1997, 1998), unless otherwise identified, and the world is classified into nine countries or country aggregates, with details given in the Appendix. The years 1983 and 1993 in all tables and figures refer to three-year moving averages centered on the years shown.

Table 2—Per capita meat and milk consumption by region, 1983 and 1993

Region	Meat 1983	Meat 1993	Milk 1983	Milk 1993
	(kilograms)			
China	16	33	3	7
Other East Asia	22	44	15	16
India	4	4	46	58
Other South Asia	6	7	47	58
Southeast Asia	11	15	10	11
Latin America	40	46	93	100
WANA	20	20	86	62
Sub-Saharan Africa	10	9	32	23
Developing world	14	21	35	40
Developed world	74	76	195	192
United States	107	118	237	253
World	30	34	76	75

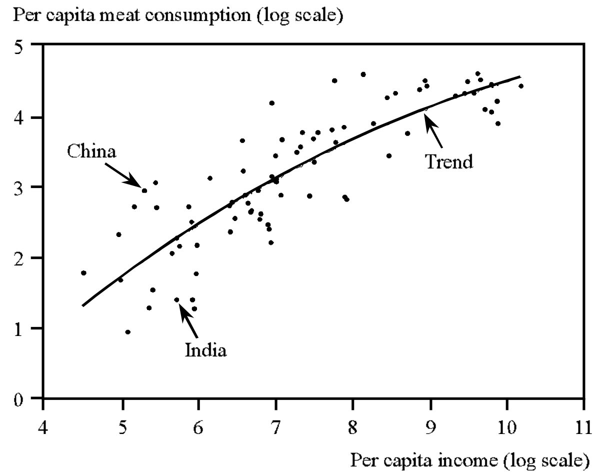
Source: FAO 1997.

Notes: Consumption refers to direct use as food, measured as uncooked weight, bone in. Meat includes beef, pork, mutton, goat, and poultry. Each number is a three-year moving average centered on the two years listed. Milk is cow and buffalo milk and milk products in liquid milk equivalents.WANA is West Asia and North Africa.

sumption of animal food products more rapidly than they are of other foods such as cereals.

But there remains a great disparity between the per capita animal food consumed in developed and developing countries. National income is a critical determinant of this disparity. Figure 2 displays the positive, curved relationship between national per

Figure 2—The relationship between meat consumption and income



Note: Each dot is an observation for 1 of 78 developing and developed countries examined. The solid line is a statistically significant trend.

capita income and per capita meat consumption. Within this trend certain countries differentiate themselves for cultural or other reasons. China, for example, lies above the trend, reflecting the importance of pork in Chinese diets, and India lies below the trend because of religious preferences against meat. At higher incomes, per capita consumption of meat levels off because people reach saturation. This explains why developed countries have had much smaller increases in per capita meat and milk consumption over the past 20 years compared to developing countries.

Countries at lower income levels are far from reaching the meat consumption satiation point despite recent increases. In the first half of the 1990s, people in developed countries consumed 76 kilograms of meat per capita per year as food, with higher amounts in the United States and lower amounts in some of the European countries (Table 2). Milk consumption in developed countries was 192 kilograms per capita. People in developing countries consumed on average 21 kilograms of meat and 40 kilograms of milk.

In Latin America, people consume 46 kilograms of meat and 100 kilograms of milk per capita, levels that are much higher than elsewhere in the developing world, though still about half the developed-country average. Per capita meat consumption in Other East Asia (44 kilograms per cap-

Table 3—Percent of calories and protein from animal products, 1983 and 1993

Region	Calories from animal products 1983	Calories from animal products 1993	Protein from animal products 1983	Protein from animal products 1993
	(percent)			
China	8	15	14	28
Other East Asia	11	15	29	38
India	6	7	14	15
Other South Asia	7	9	19	22
Southeast Asia	6	8	23	25
Latin America	17	18	42	46
WANA	11	9	25	22
Sub-Saharan Africa	7	7	23	20
Developing world	9	11	21	26
Developed world	28	27	57	56
World	15	16	34	36

Source: FAO 1997.

Notes: Each number is a three-year moving average centered on the two years listed. Animal products, using the FAO definition, include meat, dairy, egg, and freshwater and marine animal products. WANA is West Asia and North Africa.

ita) does come close to the Latin American average and exceeds the Chinese average. Sub-Saharan Africa has some of the lowest per capita consumption levels: 9 kilograms of meat and 23 kilograms of milk per capita per year.

The share of calories and protein coming from meat is also much lower in developing countries than in developed ones (Table 3). In developed countries people obtain an average of 27 percent of their calories and 56 percent of their protein from animal food products. The averages for developing countries are 11 percent and 26 percent, respectively. People in Sub-Saharan Africa, WANA, Southeast Asia, Other South Asia, and India get a third or less than a third as many calories and half as much protein from animal products as people in developed countries.

These low consumption levels give an indication of how far animal food product consumption in developing countries could grow. The Livestock Revolution of the past 20 years will begin to look modest in comparison to the one to come if the factors that promote meat and milk consumption exert their full influence.

Determinants of Changes in Per Capita Consumption

The growth rate of per capita consumption of animal food products is determined by economic factors such as incomes and prices and lifestyle changes that cause people's dietary patterns to evolve in qualitative ways. Per capita consumption increased in the regions where incomes grew rapidly during the 1980–95 period. For developing countries as a whole, GNP per capita grew at 2.1 percent per year (Table 4). In China, which had the most dramatic increases in per capita meat and milk consumption, GNP per capita grew at the extraordinary rate of 8.6 percent per year. India and Southeast Asia also had high income growth rates, fueling increases in per capita animal food product consumption. Latin American income growth was about zero (– 0.4 percent), but the region still managed a slight increase in per capita meat and milk consumption. Sub-Saharan Africa's per capita GNP fell significantly, explaining the region's drop in per capita consumption of meat and milk during the period.

Table 4—Past population, urban population, and GNP per capita growth rates

Region	Population 1970–95	Urban population 1970–95	GNP per capita 1980–95
	(percent change per year)		
China	1.6	3.8	8.6
India	2.1	3.3	3.2
Other East Asia	1.6	3.0	n.a.
Southeast Asia	2.1	4.0	4.3
Latin America	2.1	3.0	–0.4
Sub-Saharan Africa	2.9	5.0	–1.3
Developing world	2.1	3.8	2.1
Developed world	0.7	1.1	1.7
World	1.7	2.6	0.9

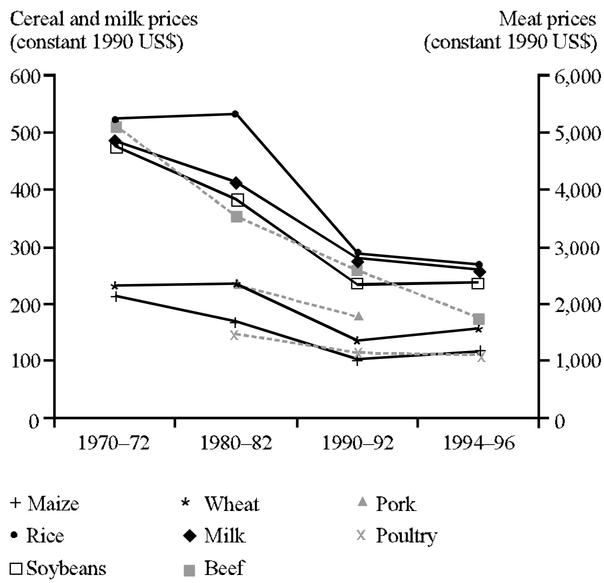
Source: UNDP 1998.
Note: n.a. indicates not available. Developed world is the UNDP industrial countries. Data for WANA were unavailable.

Prices of major meat and cereal food commodities have trended downward over the past 20 years, making food more affordable to consumers of all incomes (Figure 3). Real cereal prices fell 38–46 percent (depending on the grain in question) between the early 1980s and early 1990s, while deflated liquid milk prices fell 37 percent and real meat prices fell 23–35 percent. Although cereal prices fell faster than meat and milk prices, many consumers have begun to diversify their diets into meat and milk because they are nearly satiated with cereals. Some have even reduced their consumption of cereals.

The most important lifestyle change occurring in recent years is urbanization. Consumers in urban areas are more likely to diversify their diets into meat and milk (Huang and Bouis 1996; Anderson et al. 1997). Urban consumers have greater food choices and more diverse dietary and cultural influences than those typically found in rural areas. Urban consumers also often prefer foods that offer variety and convenience rather than maximum caloric content.

Urban population growth has been substantial throughout the developing world in recent years (Table 4). Between 1970 and 1995 cities in Asia grew 3 percent per year and higher. The highest rate of urban growth, 5 percent, occurred in Africa. The average for all developing countries was 3.8 percent, more than three times the developed-country rate.

Figure 3—Trends in the prices of major cereal and meat commodities, 1970–72 to 1994–96



Sources: Past data are from ERS 1997, IMF 1997, USDA 1997, and World Bank 1993. World Bank projections and the Manufacturing Unit Value index used for expressing values in constant 1990 US dollars are from World Bank 1997.

Notes: Wheat is U.S. no. 1, hard red winter, ordinary protein, export price delivered at Gulf ports for shipment within 30 days. Rice is Thai 5 percent broken, WR, milled indicative survey price, government standard, f.o.b. Bangkok. Maize is U.S. no. 2, yellow, f.o.b. U.S. Gulf ports. Soybeans are U.S. c.i.f. Rotterdam. Soymeal is any origin, Argentina 45–46 percent extraction, c.i.f. Rotterdam, prior to 1990, U.S. 44 percent. Fishmeal is any origin, 64–65 percent, c.i.f. Hamburg, n.f.s. Beef is Australian/New Zealand, cow forequarters, frozen boneless, 85 percent chemical lean, c.i.f. U.S. port (East Coast), exdock. Pork is European Comunity pork, slaughter wholesale price. Poultry is broilers, twelve-city composite wholesale price, read to cook, delivered. Lamb is New Zealand, frozen whole carcasses, wholesale price, Smithfield market, London. Milk is U.S. whole milk sold to plants and dealers, U.S. Department of Agriculture.

In addition to income growth, price changes, and urbanization, cultural differences have played an important role in consumption patterns. Poultry meat and eggs are the most acceptable livestock commodities throughout the world. Lactose-intolerance, found particularly in East Asia, has limited milk consumption. Pork, while particularly valued by East Asians and people of European descent, is excluded from the diet of a large share of the world's population, especially Moslems in the Near East, Asia, and Sub-Saharan Africa. South Asia has lower levels of meat consumption than low income alone would suggest because of cultural and religious reasons. Growing health consciousness in developed countries has increased consumption of lean meats such as poultry and limited growth in the of consumption of red meat. These preferences are reflected in the aggregate changes in per capita consumption between 1973 and 1993 (Table 5).

Total Consumption

The importance of even small increases in per capita consumption is compounded by rapidly increasing populations in many developing regions. On average, population in developing countries grew by 2.1 percent per year between 1970 and 1995 (Table 4). The population in Sub-Saharan Africa grew the most—almost 3 percent per year during the period. Rapid population growth coupled with increased per capita consumption resulted in dramatic increases in the total consumption of animal food products throughout the developing world (Table 6). For developing countries as a whole, total meat consumption grew 5.4 percent per year and total milk consumption grew 3.1 percent. The comparable figures for developed countries were 1.0 percent for meat and 0.5 percent for milk. China experienced an extremely high meat consumption growth rate of 8.6 percent, a value that is disputed. China's role as the fastest growing market for livestock products in the world is not in dispute, but its growth rate may not have been so far ahead of the next fastest growing region, Other East Asia. The issue is controversial because China constitutes a large component of world demand.

The food consumption figures used in this report are from the FAO statistical database (FAO 1997, 1998). For China, as for most countries, the numbers are taken from food balance sheets prepared from national sources and are based primarily on estimates of production and net trade to derive estimates of consumption. Recently, the use of this methodology for estimating livestock production figures in China in the 1990s—but not in the 1980s—has been challenged (Ke 1997).

Although there is some uncertainty here, independent estimates of consumption based on household surveys and feed use suggest that meat con-

Table 5—Annual per capita consumption of selected livestock food products and percent of total calories consumed from each product, 1973 and 1993

Commodity	Developed countries				Developing countries			
	1973		1993		1973		1993	
	(kilograms)	(percent)	(kilograms)	(percent)	(kilograms)	(percent)	(kilograms)	(percent)
Beef	26	3	25	3	4	1	5	1
Mutton and goat	3	1	3	1	1	0	1	0
Pork	26	4	29	5	4	2	9	3
Poultry	11	1	20	2	2	0	5	1
Eggs	13	2	13	2	2	0	5	1
Milk and products excluding butter	188	9	195	9	29	2	40	3
Four meats	67	10	78	11	11	3	21	6
Four meats, eggs, and milk	268	20	285	21	42	6	65	9

Source: FAO 1997.

Notes: Four meats includes beef, pork, mutton and goat, and poultry. Values are three-year moving averages centered on the two years shown; percentages are calculated from three-year moving averages. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Food is used to distinguish direct food consumption by humans from uses of animal products as feed, fuel, cosmetics, or coverings.

sumption in the early 1990s in China probably ran closer to 30 million metric tons (25 kilograms per capita) than the 38 million metric tons (33 kilograms per capita) given in the tables in this report (Ke 1997). If the lower figure is correct, the actual growth rate of meat consumption in China from the early 1980s to the early 1990s would be 6.3 percent, closer to the 5.4 percent per year observed in the rest of Asia.

Whether the true growth rate of meat consumption in China was exceedingly high (6.3 percent per year) or astronomically high (8.3 percent per year),

Table 6—Consumption of meat and milk by region, 1982–94

Region	Annual growth rate of total meat consumption 1982–94	Total meat consumption		Total milk consumption	
		1983	1993	1983	1993
	(percent)	(million metric tons)		(million metric tons)	
China[a]	8.6	16	38	3	7
Other East Asia	5.8	1	3	1	2
India	3.6	3	4	34	52
Other South Asia	4.8	1	2	11	17
Southeast Asia	5.6	4	7	4	5
Latin America	3.3	15	21	35	46
WANA	2.4	5	6	21	23
Sub-Saharan Africa	2.2	4	5	12	14
Developing world	5.4	50	88	122	168
Developed world	1.0	88	97	233	245
World	2.9	139	184	355	412

Sources: Annual growth rate of total meat consumption for 1982–94 is the growth rate from regressions fitted to FAO annual data (FAO 1998). Total milk and meat consumption for 1983 and 1993 are three-year moving averages calculated from FAO 1998.

Notes: Consumption refers to direct use as food, measured as uncooked weight, bone in. Meat includes beef, pork, mutton, goat, and poultry. Milk is milk and milk products in liquid milk equivalents. Metric tons are three-year moving averages centered on the two years shown. Milk is cow and buffalo milk and milk products in liquid milk equivalents. WANA is Western Asia and North Africa.

[a]See text for qualification on China. A lower estimate of 6.3 percent per year growth, closer to the 5.4 percent observed in the rest of Asia, may be more accurate. This would mean a 1993 total meat consumption of 30 million metric tons.

the total amount in contention is less than 5 percent of estimated annual world meat consumption in the early 1990s. It should also be noted that the controversy does not include the distribution of consumption among meats in China, nor does it involve international trade in meat, because the downward revision in the production figures is matched by a corresponding downward revision in the consumption numbers.

According to FAO, the total quantity of meat consumed worldwide rose by 45 million metric tons between 1983 and 1993 (Table 6). Total milk consumption rose by 57 million metric tons in liquid milk equivalents. In 1983 developing countries consumed 36 percent of all meat and 34 percent of all milk consumed worldwide. By 1993 those percentages had risen to 48 percent and 41 percent, respectively.

The breakdown of the growth rates of consumption of particular commodities (Table 7) shows that in developed countries total consumption grew slowly for all commodities except poultry. In the developing countries poultry led the field as well with 7.6 percent growth in consumption per year. Beef and milk grew at about 3 percent, and pork consumption grew at 6.2 percent.

Quantifying the Effects of Growth Factors

Quantifying the effects of individual forces that are driving real consumption requires a modeling approach to statistical estimation that is capable of sorting out the simultaneous influences of a host of determinants in order to isolate the contribution of each element. Researchers typically use a multiple-regression econometric approach, although the degree of complexity in their models varies greatly. The end objective is the estimation of robust elasticities that measure the effect on consumption of a 1 percent increase in the determinant in question. These estimates often are obtained from a cross-section of households in a particular region at a particular time, yielding elasticities that are usually quite satisfactory for the time period and region concerned, but which are too specific to use across countries or over long time periods.

Elasticities from national data over long time periods are rarely estimated because of the difficulty in gathering data sets that satisfy the economic and econometric assumptions of the underlying demand model. Such estimation can, however, provide a better forecast of the evolution of national

Table 7—Trends in the food consumption of various livestock products, 1982–94

Region/product	Annual growth rate of total consumption 1982–94	Total consumption 1983	Total consumption 1993	Per capita consumption 1983	Per capita consumption 1993
	(percent)	(million metric tons)		(kilograms)	
Developed world					
Beef	–0.0*	32	32	27	25
Pork	0.6	34	36	29	28
Poultry	3.1	19	26	16	20
Meat	1.0	88	97	74	76
Milk	0.5	233	245	195	192
Developing world					
Beef	3.2	16	22	5	5
Pork	6.2	20	38	6	9
Poultry	7.6	10	21	3	5
Meat	5.4	50	88	14	21
Milk	3.1	122	168	35	40

Sources: Annual growth rate of total consumption 1982–94 is the growth rate from regressions fitted to FAO annual data (FAO 1998). Total and per capita consumption for 1983 and 1993 are calculated from FAO 1998.

Notes: Consumption refers to direct use as food, measured as uncooked weight, bone in. Meat includes beef, pork, mutton, goat, and poultry. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Metric tons and kilograms are three-year moving averages centered on the two years shown. WANA is Western Asia and North Africa.

*Not significantly different from zero at the 10 percent level.

consumption patterns over time. Despite the difficulties, Schroeder, Barkley, and Schroeder (1995) estimated the effects of national per capita income growth on national per capita consumption, using annual data from 32 countries for 1975–90. The authors found that the largest effect of a US$1 increase in income on meat consumption occurred in countries with the lowest levels of national income and meat consumption. As countries got richer the impact of an increase in income on meat consumption got weaker.

Schroeder, Barkley, and Schroeder (1995) found that for countries with annual per capita incomes in the neighborhood of US$1,000 (at 1985 prices), each 1 percent increase in per capita income would increase consumption of pork by 1 percent, poultry by nearly 2 percent, beef by more than 2 percent, and lamb by more than 3 percent. At per capita income levels above US$10,000, a 1 percent increase in income would increase per capita consumption of any of the commodities by approximately 1 percent or less. These results indicate first, that an increase in income in a richer country will have a substantially smaller impact on meat consumption than the same increase will have in poorer countries. Second, the results indicate that in countries with low but rising per capita incomes, per capita consumption of most meat commodities is likely to grow faster than growth of per capita income.

Schroeder, Barkley, and Schroeder did not report price elasticities or the effects of other structural changes on per capita consumption. Delgado and Courbois (1998) estimated expenditure, price, and urbanization elasticities based on data from 64 developing countries for 1970–95. They used a system of equations that sorted out relative price effects among animal products and that controlled for many cultural, geographic, physical, and economic differences between countries.

The resulting expenditure elasticities (Table 8) estimate the percentage increase in the weight of beef, pork and mutton, poultry, or milk consumed due to a 1 percent increase in total expenditure on all animal food products in the developing countries in the sample. Thus the whole-sample expenditure elasticity of 1.36 for milk suggests that the relative share of milk in total animal product consumption increases as real expenditure on animal food products increases across countries and over time, once the effects of relative prices, urbanization, and other factors are taken into account. The 0.27 coefficient for poultry suggests that its share decreases with a 1 percent increase in total expenditure on all animal food products,

A comparison of the poorest third of countries to the richest third at subsample means suggests that the preference for additional milk and beef decreases marginally when moving from poorer to richer developing countries. Preference for poultry

Table 8—Demand elasticities for major food products of animal origin from a cross-country, systems estimation, 1970–95, developing regions

	Expenditure elasticity[a]				
Commodity	Poorest[b] third of countries	Whole sample	Richest[b] third of countries	Own price elasticity	Urban population share elasticity
Beef	0.72	0.65	0.57	–0.14	–0.20
Pork and mutton	0.96	1.10	1.30	–0.39	0.46
Poultry	0.28	0.27	0.26	–0.17	0.38
Milk	1.43	1.36	1.26	–0.86	–0.17

Source: Delgado and Courbois 1998.

Notes: These parameters were estimated as a system (with other explanatory variables and exclusions not shown) for 64 countries using annual data. N=1,143 and McElroy's multiequation R^2 (Judge et al. 1985, 477) was 0.86. All coefficients were statistically significant at a 10 percent level or better.

[a]Expenditure is the total expenditure on animal food products included in the study. Expenditure elasticities are calculated at the subsample mean, to proxy for income elasticities for specific subgroups.

[b]Mean per capita gross domestic product during the 1970–95 period was used to classify all countries into one of three groups: poorest (<$800), middle ($800–$3,000), and richest (>$3,000). The sample was divided into thirds, with each third having the same number of countries.

is remarkably stable across wealth groups of countries. Preference for pork and mutton rises with increasing income.[5] The last result may hide changes in the quality of meat products consumed when moving to richer countries, especially given the large variation in quality in pork/mutton meats. Furthermore, while these elasticities are useful for indicating the relative responsiveness of consumption of different products to income, demand for individual products in individual countries may be more or less responsive than these multicountry estimates indicate. Demand would depend in large part on whether the country in question exhibited more or less income-responsiveness for animal products as a group.

The own-price elasticities in Table 8 measure the change in consumption of various animal products in response to relative price changes within the group of animal products. As expected, price rises for a given commodity are associated with decreased consumption of that commodity, other things being equal. The estimated price responsiveness for both beef and poultry is rather modest. The price responsiveness of pork and mutton is higher, but still inelastic. Only milk among the major livestock food items is somewhat price responsive in the cross-country regressions.

It would be an error, however, to infer that there is little scope for price policies to slow down the growth in demand for meat. Delgado and Courbois (1998) briefly surveyed elasticities from several rigorous econometric demand analyses that included disaggregated animal product demand using multiyear samples and national level data for individual countries. They found a consumption response to own prices for meats of – 0.5 to –1.0, suggesting that price responsiveness within countries is much higher than across countries.

The cross-country regression system reported in Table 8 involved dozens of variables to control for the many differences across time and countries that affect consumption of animal food products. Most important among these was the measure of urbanization. The urbanization elasticities suggest that as the percentage of the population living in cities increased, so did the importance of pork, mutton, and poultry in animal food product consumption, while the importance of beef and milk decreased.

The two key messages of the data and analysis summarized in this chapter are that animal food product demand has increased dramatically in the past and that it is very likely to increase in the future. The same factors that drove the enormous increases in total meat consumption are expected to exert their influence into the next century. Population is projected to grow more modestly but still at an average of 1.5 percent per year in developing countries (UNDP 1998).

With that rate of population growth, even without a change in per capita consumption, demand for animal foods will grow enormously. But per capita consumption is also expected to increase. In the next 15 years, urban populations are expected to grow 2.9 percent per year on average for all developing countries (UNDP 1998). Per capita income will also grow. Provided the poor benefit from these trends, they will significantly increase their demand for animal food products with that new income. Other factors may further boost demand. Greater trade and communications, for example, will expose people even in remote areas to other cultures and foods.

Whether the world has the capacity to meet this surging new demand with increased animal food production will be a major question for the rest of this report. The next chapter will look at the evolution of supply systems over the past two decades leading up to the Livestock Revolution. Subsequent chapters will examine whether future demand trends coincide with future resource availability and at what cost. Finally, the paper will address similar questions more qualitatively and look at environmental, health, nutritional, food security, and technological issues.

[5] Pork and mutton are combined since most countries consume a large amount of one or the other, but not both. Depending on the country, either pork or mutton is the main substitute for beef.

3. *Accompanying Transformation of Livestock Supply*

Production of animal food products grew most rapidly in the same regions where consumption did. Total meat production in developing countries grew at 5.4 percent per year between 1982 and 1994, almost five times the developed-country rate (Table 9). The highest production growth rates for meat occurred in Asia, especially in China where total meat production increased by at least 6.3 percent and possibly as much as 8.4 percent annually (Table 10).[6]

Per capita meat and milk production rose between 1983 and 1993 in all regions except Sub-Saharan Africa and WANA (where milk production fell marginally), indicating that domestic supply kept up with population growth in most areas (Table 10). In 1993 both Other East Asia and WANA had substantial discrepancies between per capita meat consumption and production, indicating that those regions imported large amounts of meat to keep up with growing demand (Tables 2 and 10). Southeast Asia and Sub-Saharan Africa had substantially higher per capita milk consumption than production in 1993.

Poultry had the fastest total production growth rate in both developing and developed countries

Table 9—Production trends of various livestock products, 1982–94

Region/product	Annual growth of total production 1982–94	Total production		Per capita production	
		1983	1993	1983	1993
	(percent)	(million metric tons)		(kilograms)	
Developed world					
Beef	0.1*	36	35	27	26
Pork	0.7*	35	37	29	29
Poultry	3.2	19	27	16	21
Meat	1.1	90	100	76	78
Milk	–0.4*	365	348	305	272
Developing world					
Beef	3.1	16	22	5	5
Pork	6.1	21	39	6	9
Poultry	7.8	9	21	3	5
Meat	5.4	51	88	15	21
Milk	3.7	113	164	32	39

Sources: Annual growth of total production 1982–94 is the growth rate from regressions fitted to FAO annual data (FAO 1998). Total and per capita production 1983 and 1993 are calculated from FAO 1998.

Notes: Beef includes meat from cattle and buffalo. Poultry includes all fowl listed in FAO 1998. Meat includes beef, pork, mutton, goat, and poultry carcass weights. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Metric tons and kilograms are three-year moving averages centered on the two years shown.

*Not significantly different from zero at the 10 percent level.

[6] See discussion of China data in Chapter 2. The more likely figure of 6.3 percent per year is still the highest in the world. Meat production grew at a modest 2.9 percent in Latin America and just 2.1 percent in Sub-Saharan Africa. In China, Other East Asia, Latin America, and Sub-Saharan Africa total meat production grew less than total meat consumption, though for developing countries as a whole production grew at the same rate as consumption.

Table 10—Trends in the production of meat and milk, by region, 1982–94

Region	Annual growth of total meat production 1982–94	Per capita meat production 1983	Per capita meat production 1993	Per capita milk production 1983	Per capita milk production 1993
	(percent)	(kilograms)		(kilograms)	
China	8.4	16	33	3	6
Other East Asia	5.0	16	24	15	30
India	3.7	4	5	51	66
Other South Asia	4.8	6	8	50	62
Southeast Asia	5.7	11	16	2	3
Latin America	2.9	43	48	94	101
WANA	3.9	14	16	58	57
Sub-Saharan Africa	2.1	10	9	19	19
Developing world	5.4	15	21	32	39
Developed world	1.1	76	78	305	272
World	2.9	30	34	102	93

Sources: Annual growth of total meat production 1982–94 is the growth rate from regressions fitted to FAO annual data (FAO 1998). Per capita meat and milk production for 1983 and 1993 are calculated from FAO 1998.

Notes: Meat includes beef, pork, mutton, goat, and poultry carcass weights. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Kilograms are three-year moving averages centered on the two years shown. WANA is West Asia and North Africa.

between 1982 and 1994 (Table 9). Production grew slowly in developed countries for all other livestock products, with total and per capita output of beef and milk falling. In developing countries total meat and milk production grew rapidly, especially pork and poultry. Even the growth of beef production, which was near zero in developed countries, amounted to a robust 3.1 percent per year in developing countries. Per capita production of pork, poultry, and milk increased for developing countries as a group.

The large discrepancies between developing- and developed-country total production growth rates are shifting world animal production, with all its benefits and costs, from developed to developing countries (Table 11). In one decade the developing-country share of world meat and milk production rose from 36 to 47 percent and from 24 to 32 percent,

Table 11—Shares of total world production of meat and milk, by region, 1983 and 1993

Region	Beef 1983	Beef 1993	Pork 1983	Pork 1993	Poultry 1983	Poultry 1993	Meat 1983	Meat 1993	Milk 1983	Milk 1993
					(percent)					
China	1	4	25	38	5	12	12	20	1	1
Other East Asia	0	1	1	1	1	1	1	1	0	0
India	4	5	1	1	0	1	2	2	8	12
Other South Asia	2	2	0	0	1	1	1	1	2	4
Southeast Asia	2	2	3	4	5	6	3	4	0	0
Latin America	19	20	6	4	13	15	12	12	8	9
WANA	2	2	0	0	5	5	3	3	3	4
Sub-Saharan Africa	5	4	0	1	2	2	3	3	2	2
Developing world	34	41	37	51	32	44	36	47	24	32
Developed world	66	59	63	49	68	56	64	53	76	68
					(million metric tons)					
World	48.8	55.0	55.7	75.5	28.8	47.3	141.4	188.0	477.4	511.8

Source: FAO 1998.

Notes: Meat includes beef, pork, mutton, goat, and poultry carcass weights. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Values are calculated from three-year moving averages centered on the two years shown. WANA is West Asia and North Africa.

respectively. China's share of global meat supply rose from 12 to 20 percent. Milk production is mainly concentrated in the developed world, but India increased its share of world production from 8 to 12 percent during the period. At the rate that production has been shifting to developing countries, it is likely that more than 50 percent of the world's meat is now produced in the developing world and that the same will be true for milk by 2020.

Sources of Growth in the Output of Livestock Food Products

The geographic distribution of the world's livestock animals reflects different consumption preferences and trends (Table 12). Cattle and buffalo are found where beef and milk are consumed in large amounts, primarily the developed world and Latin America, which are high beef-consuming regions, and South Asia, which is a high milk-consuming region. Growth in numbers of cattle and buffalo occurred throughout the developing world, with most developing regions increasing their share.

Pigs are concentrated in the key pork-consuming countries of East and Southeast Asia. China's share of the world's pigs rose from 38 to 44 percent between 1983 and 1993, and the majority of the world's pigs reside now in Asia. Numbers of chicken and other fowl grew rapidly between 1983 and 1993, especially in Asia where 40 percent of all chickens and other fowl were located in 1993. China had the largest increase in numbers of chicken and other fowl as well. Sheep and goats were most highly represented in WANA and Sub-Saharan Africa. The regional distribution of sheep and goat numbers shifted little from 1983 to 1993.

In developing countries rapidly increasing meat and milk production coincided with rapidly increasing numbers of animals. The developing-country share of the world's stock of animals rose to two-thirds of all pigs, fowl, sheep, and goats, and three-quarters of all cattle and buffalo in 1993. By contrast, numbers of cattle and pigs fell between 1983 and 1993 in the developed countries, despite increased beef and pork output. In developed countries growth in numbers of animals was important only for poultry output. Increased output in developed countries was made possible primarily by increased productivity per animal, defined as greater amounts of meat or milk output per animal and per unit of inputs.

Comparing the location of the world's livestock in Table 12 to output shares in Table 11 provides an indication of the relative productivity levels of the regions. Although three-quarters of the world's cattle and two-thirds of the world's pigs, poultry, sheep, and goats lived in developing countries in 1993, those countries produced less than half of the world's meat and a third of the world's milk.

Table 12—Distribution of the world's livestock animals, 1983 and 1993

Region	Cattle and buffalo		Pigs		Chickens/fowl		Sheep and goats	
	1983	1993	1983	1993	1983	1993	1983	1993
	(percent)							
China	5	7	38	44	15	24	11	12
Other East Asia	0	0	1	1	1	1	1	1
India	19	20	1	2	3	2	9	10
Other South Asia	5	5	0	0	2	2	6	7
Southeast Asia	3	4	5	5	7	11	1	2
Latin America	22	23	10	9	12	12	9	8
WANA	3	2	0	0	6	7	14	13
Sub-Saharan Africa	11	12	1	2	5	5	15	16
Developing world	69	74	57	64	52	65	65	69
Developed world	31	26	43	36	48	35	35	31
	(million head)							
World	1,378	1,457	776	878	8,680	12,936	1,607	1,722

Source: FAO 1998.
Note: WANA is West Asia and North Africa.

Table 13 compares growth rates of animals slaughtered or milked with growth rates in meat and milk output, giving an indication of the extent to which productivity and increased numbers of animals contributed to output growth. Countries in the relatively land-abundant Latin America and Sub-Saharan Africa relied mostly on growth in numbers of animals for their increased livestock production. In Latin America and Sub-Saharan Africa, the number of cattle that were slaughtered or milked grew at rates nearly equal to, or above, the growth rate of beef and milk output, indicating that number of animals was more important than productivity in providing the additional meat. Pig numbers grew at about the same rate as pork output in both regions, indicating little productivity growth. The number of chickens grew at about the same rate as poultry output in Africa. In Latin America the number of chickens grew more slowly than poultry output, suggesting the existence of productivity growth in poultry output.

In Asia, where land is scarce, growth in numbers of animals made up a smaller proportion of output growth for beef and pork. Productivity growth was relatively more important. Not including China, where reported productivity growth was even greater, cattle numbers grew less than 2 percent per year between 1982 and 1994, while both milk and beef output grew by more than 3 percent. Also in Asia without China, pig numbers grew at about four-fifths the rate of pork output, indicating a small amount of productivity growth. Less productivity growth occurred in poultry production, as chicken numbers grew at approximately the same rate as output.

Productivity is much higher in developed countries than that typically found in developing countries. Table 14 presents the number of kilograms of meat or milk produced per animal. Productivity by this yardstick was clearly higher in developed countries, especially for beef and milk. Pork and poultry productivity levels showed greater similarity across regions.

Certain developing regions appear to be catching up with developed-country rates for per animal productivity. Productivity growth rates in some developing countries exceed those in developed countries for some commodities (Table 14). Beef productivity throughout Asia has been growing at rates higher than the 0.9 percent growth rate in the developed world. Milk productivity growth rates in Asia, with the exception of China, also exceeded those in developed countries. Beef and milk productivity in Latin America and Sub-Saharan Africa fell increas-

Table 13—Growth rates of livestock output and number of animals slaughtered or milked, 1982–94

	Cattle		Milk		Pigs		Chickens	
Region	**Output**	**Slaughtered**	**Output**	**Milked**	**Output**	**Slaughtered**	**Output**	**Slaughtered**
	(percent growth per year)							
China	20.0	15.5	10.0	11.6	7.2	5.8	13.1	10.3
Other East Asia	3.3	2.0*	8.1	3.0	5.6	3.5	8.9	8.4
India	3.6	2.2	6.4	1.6	2.8	2.8	11.9	11.9
Other South Asia	2.4	0.7	2.9	1.7	4.9	3.8	8.2	6.3
Southeast Asia	4.2	3.4	4.4	2.1	5.7	4.8	7.1	7.5
Asia, excluding China	3.4	1.8	4.2	1.8	5.7	4.6	7.5	7.4
Latin America	2.1	1.8	2.5	1.8	0.1*	–0.4*	6.6	5.5
WANA	3.0	0.3*	2.7	1.2	5.9	5.8	5.9	5.6
Sub-Saharan Africa	0.3	0.8	2.9	2.3	7.8	7.7	4.0	4.1
Developing world	3.0	2.5	3.8	2.0	6.1	4.8	7.7	6.9
Developing world, excluding China	2.1	1.6	3.6	1.8	3.3	2.9	6.6	6.2
Developed world	0.1	–0.8	–0.4	–1.7	0.7	0.3	2.7	1.9
World	1.1	0.6	0.5	0.3	3.1	2.5	4.7	4.0

Source: Estimated from FAO 1998 data.

Notes: As discussed later in the report, the official China production figures for the mid-1990s are currently under revision and may be reduced. China has been excluded from the Asia figures to avoid any bias this may introduce.

*Not significantly different from zero at the 10 percent level.

Table 14—Productivity by region and animal type, 1992–94, and productivity growth rate, 1982–94

Region	Beef from cattle		Milk		Pork		Poultry	
	Productivity	Growth rate	Productivity	Growth rate	Productivity	Growth rate	Productivity	Growth rate
	(kilograms/ head)	(percent/ year)	(kilograms/ head)	(percent/ year)	(kilograms/ head)	(percent/ year)	(kilograms/ head)	(percent/ year)
China	149	4.5	1,530	–1.6	76	1.4	1.3	2.8
Other East Asia	207	1.3†	1,983	5.1	72	2.1	1.1	0.5*†
India	103	1.4	973	4.8	35	. . .	0.9	0.0
Other South Asia	111	1.7	538	1.2†	37	1.1	1.0	1.9
Southeast Asia	170	0.9†	628	2.4	58	0.8	1.1	–0.3
Asia, developing countries, excluding China	147	1.5	672	2.3	61	1.1	1.1	0.0*
Latin America	194	0.2	1,137	0.7	71	0.5†	1.4	1.1†
WANA	135	2.7	1,236	1.5†	69	0.1*†	1.1	0.2
Sub-Saharan Africa	132	–0.5	340	0.6	45	0.1	0.9	–0.1*
Developing world	162	0.5	896	1.9	72	1.2	1.2	0.8†
Developing world, excluding China	164	0.5	879	1.8	63	0.5†	1.2	0.5
Developed world	242	0.9	3,739	1.3	82	0.4	1.4	0.8
World	204	0.5	2,073	0.2	76	0.6	1.3	0.7

Source: FAO (1998) figures on total food commodity production per region and item are divided by the corresponding number of animals slaughtered (or milked) from FAO 1998. Growth rates of productivity are from regressions fitted to annual estimates of productivity obtained through this means. WANA is West Asia and North Africa.

*Not significantly different from zero at the 10 percent level.

†Not significantly different from developed world at the 10 percent level.

ingly behind the developed countries. Pork productivity growth rates exceeded developed-country levels in Asia. Poultry productivity growth was on average more rapid in developed countries than in developing countries excluding China.

Sources of Productivity Growth

Productivity growth in developed regions mainly occurs through further technological progress. Farmers can raise many more animals per unit of land by using capital-intensive mechanization that reduces labor requirements, by increasing per animal feed use and feed quality, and by investing in improved animal genetics and health. Nearly 37 percent of the world's meat supply comes from industrialized livestock production (FAO 1995b). In recent years, industrial livestock production grew globally at twice the rate (4.3 percent) of more traditional, mixed-farming systems (2.2 percent), and more than six times the rate of grazing system (0.7 percent) (Sere and Steinfeld 1996).

Industrial livestock production is knowledge- and management-intensive, especially when delivering products for an increasingly quality-conscious urban population. Industrial livestock production maximizes the use of scarce resources, notably land, labor, and feed, and it involves the development of genotypes, application of biotechnology, general improvement in animal husbandry and veterinary care, and advances in the backward and forward linkages of livestock output (such as meat marketing systems, feed mills). Production costs of monogastrics, such as pigs and poultry, tend to fall faster than those for ruminants in land-scarce situations because monogastrics require less space and are more efficient at converting feed concentrates to meat.

Livestock production in developing countries relies much more on traditional operations. A quarter of the world's land is used for grazing, which sustains about 10 percent of world meat production (FAO 1995b). Grazing systems typically increase production by increasing the number of heads and the land area used. As land becomes scarce, grazing systems lead to either land degradation and economic decline or mixed or industrial livestock production systems.

Mixed livestock and crop production is the most common form of livestock operation in developing countries, providing more than 50 percent of the meat produced in the world (FAO 1995b). The crop component of the farm provides residues for roughage, while the livestock component provides animal traction, fertilizer, animal fibers, a form of savings or collateral, and a role in social functions. Livestock kept in mixed systems are primarily large and small ruminants because they are efficient at converting pastures, crop residues, and other roughages into meat. Such fibrous materials and grasses have little or no alternative use. Large ruminants can also provide farm power.

Currently an estimated 250 million working animals provide draft power for mixed farms that cover about 28 percent of the world's arable land. Approximately 52 percent of available cropland in developing countries is farmed using animal draft power. The use of animal draft power increased in the 1970s and 1980s in those parts of West Africa where the technology was relatively new, disease was being controlled, and introduction of new crops such as cotton and maize required added farm power (Pingali, Bigot, and Binswanger 1987). Eastern and Southern Africa and South Asia in particular have longer traditions in the use of draft animals and are likely to continue to use them for some time to come.

Mechanization is rapidly occurring in other areas, such as East and Southeast Asia (Steinfeld 1998). In these areas mixed farming is evolving as the food value of animals increases and the value of their other uses declines. The diffusion of machinery, fertilizer, synthetic fibers, and financial services reduces the value of livestock's other roles. Mechanization improves the productivity of animal food production because animals no longer need to be kept into adulthood for draft power, enabling more rapid slaughter rates. Mechanization also makes possible a shift from large and small ruminants to animals such as pigs and chickens that require less time and space for production.

In past decades livestock development in Asia suffered from an extreme shortage of land and quality feed but enjoyed a relative abundance of labor and water. Capital, first in short supply, became less of a limiting factor as rapid industrial development took place and incomes increased. Progress in development led to the adoption of a number of technologies that dealt first with land scarcity and then replaced labor with capital.

The first set of innovations introduced into Asian mixed-farming systems included basic animal health care, such as control of infectious diseases and parasites. Next came the provision of additional feed, first from crop byproducts, but then increasingly from cereals and other concentrates. In Indonesia and elsewhere, cut and carry systems, essentially a combination of forage cultivation and stall feeding, developed for milk production. Breeding continued to be based on local selection for preferred traits; crossbreeding was practiced to some extent.

As demand for livestock foods expanded rapidly, mixed-farming systems could not keep up. Feed requirements could no longer be met from domestic supplies of cereals and other concentrates. Asia began to import large amounts of feedgrains, mainly from the developed countries. At this point the industrial production of pork, poultry, and eggs that emerged was more efficient at using imported feeds. Industrial systems make use of imported livestock genetic material and sophisticated feeding practices, such as phased feeding, the use of feed additives, and, at an even more advanced stage, synthetic amino-acids. As of this writing, in early 1999, these systems appear to have been disproportionately disadvantaged by the Asian economic crisis, which raised the cost of imported feeds and depressed urban demand.

WANA exhibits different trends. Land is not a limiting factor per se but agricultural potential is, given the scarcity of water. Traditional pastoralism and, to a limited extent, mixed farming continue to exist, but oil revenues and the resulting economic expansion since 1973 have introduced imported industrial production units, for poultry and dairy in particular. These units have state-of the-art technology but require many imported inputs and the domestic production of others (for example, forage production for dairy cows). For the most part they cannot compete with world markets but are maintained through protection as a matter of political choice.

Because of the emergence of these subsidized industrial production systems, as well as other major distortions in the food market, little technological change has occurred in the grazing and small mixed-farming sectors in WANA. Feed lots for small ruminants have developed to some extent, mainly in response to the market requirements of the region. These requirements include the seasonal demand for whole animals during religious holidays. In more ecologically favorable environments, notably the Nile valley in Egypt, competitive dairy systems have emerged that use a mixture of domestic and imported feed resources and intermediate labor-intensive technology.

The relative abundance of land and extreme scarcity of capital resulted in little productivity increase per animal in Sub-Saharan Africa over the past two decades. Without significant per capita income growth the region lacked the stimuli and the means for adopting meat production technology outside the poultry sector in large coastal markets. Dumping of livestock products from developed countries during the late 1970s and throughout the 1980s also discouraged production innovation, as did overvalued exchange rates that favored imports.

Sub-Saharan Africa's livestock sector continues to be largely made up of ruminants located in tsetse-free areas and fed locally available feed. By and large health care is rudimentary and only simple feed supplements, such as minerals, are provided. Close to urban centers, and where agro-ecological conditions permit, semi-intensive and intensive dairying has developed using cultivated fodder and agro-industrial by-products. Poultry production has begun to industrialize. Apart from low income and a shortage of quality feed, livestock production technology in Africa continues to be severely constrained by disease, especially trypanosomiasis, which is spread by the tsetse fly (Alexandratos 1995). Cattle production is difficult in areas infested with the tsetse fly. Other diseases must be controlled as well before widespread intensification of pork and poultry production can occur.

Latin America is characterized by an abundance of land. The region experienced considerable livestock development prior to the 1960s. Urbanization had already advanced by that point, unlike in the rest of the developing world. Income stagnation in the 1970s and early 1980s and low world market prices for meat slowed productivity growth and technology adoption. It was generally cheaper to expand livestock production into new areas than invest in new technology. Pastures continue to be unimproved, except for areas close to consumer centers, and the technology used in extensive ranching only involves such basic measures as fencing, disease prevention and treatment, and some genetic development.

Recently, intensive poultry production and, to some extent, dairying have developed in Latin America. These livestock systems took advantage of the traditionally high urbanization rate and a resurgence of economic growth in the 1990s. Intensive in nature, these systems use many of the same basic technologies found in developed countries but use them at lower levels of intensification.

Feed Use

Recent rapid increases in meat production caused global use of cereal as feed to rise at 0.7 percent annually between 1982 and 1994. This growth rate reflects negligible growth in use of cereal as feed in the developed countries and a more than 4 percent per year growth rate in the developing countries (Table 15). Despite the higher growth rate, developing countries still use less than half as much cereal for feed as do developed countries. In 1990–92 concentrated cereal feed provided between 59 and 80 percent of the nutrition provided to animals in the developed world. By contrast, cereals accounted for only 45 percent of total concentrate feed in Southeast Asia, the developing region with the most intensive use of feedgrains.

As output of livestock products grows in developing regions, animal production methods and feeding patterns are shifting rapidly. Grazing systems are rapidly diminishing in importance throughout the world. Land available for grazing is caught in a squeeze. Urbanization and crop production are encroaching on traditional grazing areas. Preservation efforts are limiting expansion of grazing operations into virgin areas.

Mixed-farming systems also face limits. Innovations in crop production have reduced crop residues and nongrain biomass available for feeding. Crop research has largely ignored the feed value of crop residues. Unimproved varieties in low external input systems typically produce three to four times as much nongrain biomass as grain, whereas modern hybrids often produce an equal share or less nongrain biomass as grain.

Table 15—Trends in the use of cereal as feed, 1982–94

Region	Annual growth rates: Total cereal production, 1982–94	Annual growth rates: Total cereal use as feed, 1982–94	Total cereal use as feed: 1983	Total cereal use as feed: 1993
	(percent)		(million metric tons)	
China	2.1	5.8	40[a]	84
Other East Asia	–2.3	6.8	3	7
India	3.0	3.5	2	3
Other South Asia	2.0	0.9	1	1
Southeast Asia	2.4	7.2	6	12
Latin America	0.9	2.6	40	55
WANA	3.7	1.9	24	29
Sub-Saharan Africa	4.0	5.2	2	3
Developing world	2.3	4.2	128	194
Developed world	0.2*	–0.5*	465	442
World	1.2	0.7	592	636

Sources: Production and use growth rates for 1982–94 are from regressions fitted to FAO annual data (FAO 1998). Total use for 1983 and 1993 is calculated from FAO 1998.

Notes: Cereals include wheat, maize, rice, barley, sorghum, millet, rye, and oats. Metric tons are three-year moving averages centered on the two years shown. WANA is West Asia and North Africa.

[a]Simpson, Cheng, and Miyazaki (1994) report 40 million metric tons from U.S. Department of Agriculture data. That figure is used here because it is more consistent with the feed quantities and feed/meat conversion ratios in Rosegrant et al. 1997. FAO (1998) reports 49 million metric tons.

*Not significantly different from zero at the 10 percent level.

Household food waste, such as tuber skins, stems, and leaf tops, has traditionally been another important feed resource, for backyard monogastric production in particular. But small-scale backyard operations are disappearing because of low returns to labor and increased competition from large-scale producers. Although each backyard operation is small, at the aggregate level such systems act as major transformers of waste into meat and milk. Because large operations are unlikely to find it cost-effective to collect small amounts of waste from many households, this source of animal feed may be underused in industrial systems.

The use of cereals as feed has been fastest in Asia, where output growth has risen the most and land is scarce (Table 15). In Other East Asia, Southeast Asia, and Sub-Saharan Africa, cereal use as feed grew faster than meat production, indicating that those regions are intensifying their use of feed per unit of meat output (Tables 10 and 15).

Most of Asia, WANA, and Sub-Saharan Africa lack the capacity to produce substantial amounts of feedgrain at competitive prices. The growing amounts of feedgrains imported into these regions attest to this deficiency. Given that many developing countries cannot expand crop area, two possibilities remain: intensification of existing land resources and importation of feed. Because much of the gain from intensification will probably go toward meeting the increasing demand for food crops, substantially more feedgrains will have to be imported by developing countries in the future. Will feedgrain availability, the infrastructure for moving large amounts of grain, and other access-related factors keep up with projected surges in demand?

4. *Projections of Future Demand and Supply to 2020*

Trends during the past 15 years suggest that the developing countries are in the midst of a demand-driven Livestock Revolution that already has increased the shares of world livestock products consumed in those countries by a substantial margin. Even more important effects are expected in the foreseeable future. These future changes are of such magnitude that they cannot occur in a vacuum. They will affect the global economy and in turn be affected by it.

This chapter and the next will examine the likely magnitude of the changes, the feasibility of the changes given the world's capacity to produce livestock and feed, the likelihood of the required production increases occurring in developing or developed countries, and the implications for world prices of meat, milk, and cereals. This chapter presents both an approach to addressing these questions and some answers in the form of baseline results from a global economic model. It also looks at what some plausible changes in future scenarios might entail for world milk and meat. Chapter 5 examines the projected impact of the Livestock Revolution on world trade in meat and milk and world food prices under different scenarios.

Global economic models are subject to many uncertainties and are typically specified at such a high level of product aggregation (meat and milk are usually lumped in with "food"), that they are not very useful for the purpose at hand. Fortunately, the authors have at their disposal a model developed at IFPRI (Rosegrant, Agcaoili-Sombilla, and Perez 1995; Rosegrant et al. 1997; Rosegrant, Leach, and Gerpacio 1998; and Rosegrant and Ringler 1998) that is particularly appropriate for looking at these issues and assessing the sensitivity of results to different assumptions. The tool in question is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), June 1998 version.[7] (For further information on the model, see the box.)

Projected Consumption Trends to 2020 in the Baseline Scenario

The baseline scenario represents the most realistic set of assumptions governing international and national economies. With the sole exceptions of beef in the developed countries and milk in the developing countries, consumption of food products of animal origin is projected to grow at a substantially lower annual rate over the 1993–2020 period than it did in the 1982–94 period (Tables 16 and 7). The projected rates of growth to 2020 are expected to be about half those observed in the last 15 years in most cases. Three factors produce these lower growth rates to 2020. First, recent rapid growth in consumption means that the base for projecting growth beyond 1993 is larger than that in 1983. Thus a given absolute annual incre-

[7] The June 1998 version of IMPACT incorporates parameters and assumptions that reflect lower expected overall economic growth in Asia relative to the assumptions in prior versions, in addition to updated parameter estimates for Africa (Rosegrant and Ringler 1998). Demand and supply parameters for milk have also been extensively reviewed and revised in this version; milk was included previously, but not reported on separately. Readers interested in the structure of model equations, which have not changed, are referred to the appendix of Rosegrant, Agcaoili-Sombilla, and Perez (1995), published in the same series as the present paper.

The Baseline IMPACT Model

IMPACT is a global food model that divides the world into 37 countries or country groups. Its baseline version represents the most realistic set of assumptions according to the model team. The countries and groups can be conveniently aggregated into regions that are compatible with FAO definitions (see the Appendix). Fan and Agcaoili-Sombilla (1998) compared the results of early versions of the model and other international models for cereal production and consumption in China in 2010 and 2020. They found that the projections from the IMPACT model are middle of the road in outlook and neither pessimistic nor bullish with respect to the issues raised at the beginning of this chapter.

The IMPACT model covers 18 commodities, including beef, pork, poultry, sheep meat, goat meat, bovine milk, and eggs. The base data used in the current version are averages of the 1992–94 annual data from the FAO Statistical Database (the same source used for the tables in previous chapters, with 1993 data exactly equivalent to the IMPACT base year). Since each of the 37 country groups produces and/or consumes at least some of each commodity, literally thousands of supply and demand parameters had to be specified (income, price, and cross-price elasticities of demand; production parameters including crop area, yield growth trends, and herd size and productivity; price response parameters; initial levels and trends in feed conversion; trade distortion parameters; and so on). Parameter estimates were drawn from econometric analysis, assessment of past and changing trends, expert judgement, and synthesis of the existing literature. The myriad assumptions are too detailed to report here, but attention is given to those parameters that matter the most, such as the detailed structural parameters of shifting meat demand in China, taken from Huang and Bouis (1996).

National income, population, and urban growth rates are also assumed for each country group, along with anticipated changes in these rates over time. The model uses the revised United Nations medium-variant projections for 1996 for demographic assumptions. National income projections are estimated based on a review of projections drawn from sources such as the World Bank. The model is solved on an annual basis by linking each country model to the rest of the world through commodity trade. The market-clearing condition solves for the set of world prices that clears international commodity markets, so that the total imports of each commodity equals total exports. World prices of commodities thus act as the equilibrating mechanism and maintain the model in equilibrium. When an exogenous shock is introduced in the model, such as an increase in crop yields from higher investment in crop research, the world price will adjust and each adjustment is passed back to the effective producer and consumer prices. Changes in domestic prices subsequently affect the supply and demand of the commodities, necessitating their iterative readjustments until world supply and demand are in balance and world net trade again equals zero.

The outcome of this annualized iterative process is an estimated annual series of projected market-clearing prices, consumption levels by commodity and country

ment accounts for an increasingly smaller percentage increment. Second, slowdowns in the rate of overall income and urbanization growth will occur for the same reason. Third, consumers begin to get satiated as the importance of meat in their diets increases.

Even by 2020, per capita consumption of milk products in developing countries is expected to be on average only one-third that of developed countries (up from less than one-fifth in the early 1990s). Per capita consumption of meat in developing countries is projected to be 36 percent of that in developed countries in 2020, up from 28 percent in the early 1990s. Yet in aggregate terms 62 percent of the world's meat and 60 percent of milk consumption will take place in the developing countries in 2020. This is a major change from the early 1990s, when 52 percent of the world's meat and 59 percent of the world's milk were consumed by the developed world.

The consumption trends by region and the annual growth rates to 2020 are given in Table 17. The projected consumption growth rates for China of 3 percent for meat and 2.8 percent for group, feed-use levels, production area, yield and production levels by commodity and region, and net trade across country groups by commodity. The analysis extends to the year 2020. The increasing globalization of agricultural markets is represented in the model by its set of endogenous world prices estimated through annual iterative solutions. Events affecting net exports from one country group will affect prices in others, in turn changing supply, demand, and net trade, eventually converging to a solution.

An important advantage of a modeling approach such as IMPACT is that it can be used to investigate the feasibility of production increases simultaneously with the determination of production costs and output prices. Actual production of commodities in the model requires the use of sufficient quantities of all needed inputs in the country and year concerned. Particular attention is devoted to cereal-based feeds. Cereal feed demand in IMPACT is driven by livestock production, cereal feed ratios, own- and cross-price relationships among feed crops, and an exogenously specified "efficiency parameter" that can be used to model exogenous technical progress or other secular changes affecting feed demand.

The mix of feeds used for a specific livestock product starts from actual averages in the 1992–94 base period. For each livestock product, the feeding ratio for each main feed commodity in the model—maize, other coarse grains, wheat, oilcakes, cassava, sweet potatoes, and potatoes—is specified for the base period. What happens to the amount of each commodity fed after the base period is modified by the relative price movements of feeds, which change in the model depending on both human and animal demand and by the specified rates of change in feeding efficiency due to technical progress. Browse, backyard slops, and other noncereal, nonoilcake feeds are implicitly costed as free, and are thus not explicitly modeled. Reporting focuses on cereals used as feed, since this is the aspect of feed use that is controversial and it is also in all likelihood the binding constraint in producing adequate mixed feed rations.

The approach has the drawback that where production systems are shifting from low cereal use systems (as in backyard poultry or range-fed ruminants) to industrial feedlots, current ratios of cereal feed to specific meat products may underestimate future ratios. The exogenous feed ratio efficiency parameter in the feed demand equation is specified to compensate for this in some countries. It also allows further sensitivity testing in this area.

The ratio of total cereal feed use to total meat production (with feed use for milk and eggs netted out) in the early 1990s was 1.40 to 1.00 in China and 3.64 to 1.00 in the United States. Between 1983 and 1993, feed conversion efficiency in the United States increased by about 15 percent across all meats, with the increases for poultry outstripping those for beef (CAST forthcoming). The proportionately greater use of natural pastures, household wastes, roots, tubers, and byproducts for feeding in developing countries explains why their cereal feed ratios are lower than those in developed countries.

milk are on the low side of the literature (Ke 1997).[8] They are fully comparable to those projected for other parts of Asia, but are significantly above the 0.6 and 0.2 percent averages projected for developed countries as a whole. Per capita meat consumption in 2020 is projected to remain

[8] As noted in Chapter 2, the FAO consumption and production figures for meat in China in the early 1990s, used here for the 1992–94 base, may overstate actual consumption and production by up to 30 percent (Ke 1997). Ke studied the discrepancy between food-balance-sheet and survey estimations of meat consumption in China in detail. He concludes that actual total demand for meat is only likely to grow at 3 to 5 percent per year in China in the foreseeable future, a lower rate than that predicted by "some" (unspecified) persons. While the IMPACT-estimated level of meat demand in China in 2020 might be seen as somewhat high because of a base period estimate of meat consumption that is "too high," the IMPACT estimation is also the result of projected annual growth over 27 years that is "low" because of the conservative assumptions built into the model. There is also little concern about the effect of an overestimate of Chinese livestock production in the base period (1992–94) on imports in IMPACT because the overestimate of production, if there is one, is balanced by an overestimate of consumption. There does not appear to be a compelling reason to revise the estimates for China given here.

Table 16—Projected trends in the food consumption of various livestock products, 1993–2020

Region/Product	Projected annual growth of total consumption, 1993–2020	Total consumption 1993	Total consumption 2020	Annual per capita consumption 1993	Annual per capita consumption 2020
	(percent)	(million metric tons)		(kilograms)	
Developed world					
Beef	0.4	32	36	25	26
Pork	0.3	36	41	28	29
Poultry	1.0	26	34	20	25
Meat	0.6	97	115	76	83
Milk	0.2	245	263	192	189
Developing world					
Beef	2.8	22	47	5	7
Pork	2.8	38	81	9	13
Poultry	3.1	21	49	5	8
Meat	2.8	88	188	21	30
Milk	3.3	168	391	40	62

Sources: Total and per capita consumption for 1993 are calculated from FAO 1998. Projections are updated figures following the same format as that reported in Rosegrant et al. 1997.

Notes: Consumption refers to direct use as food, measured as uncooked weight, bone in. Meat includes beef, pork, mutton, goat, and poultry. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Metric tons and kilograms are three-year moving averages centered on the two years shown.

low in Sub-Saharan Africa, partially vegetarian India, and other countries in South Asia. The assumptions concerning tastes for meat in India will be tested below as part of the sensitivity analysis, as will assumptions about productivity growth and the severity of the Asian financial crisis.

Projected Production Trends to 2020

Projected production trends for meat to 2020 closely follow those projected for consumption, with the exception of WANA (Tables 17 and 18). Generally IMPACT projects that in 2020 deficit

Table 17—Projected trends in meat and milk consumption, 1993–2020

Region	Projected annual growth of total consumption, 1993–2020: Meat	Milk	Total consumption in 2020: Meat	Milk	Per capita consumption in 2020: Meat	Milk
	(percent)		(million metric tons)		(kilograms)	
China	3.0	2.8	85	17	60	12
Other East Asia	2.4	1.7	8	2	67	20
India	2.9	4.3	8	160	6	125
Other South Asia	3.2	3.4	5	41	10	82
Southeast Asia	3.0	2.7	16	11	24	16
Latin America	2.3	1.9	39	77	59	117
WANA	2.8	3.0	15	51	24	80
Sub-Saharan Africa	3.5	3.8	12	31	11	30
Developing world	2.8	3.3	188	391	30	62
Developed world	0.6	0.2	115	263	83	189
World	1.8	1.7	303	654	39	85

Sources: Projections are updated figures following the same format as that reported in Rosegrant et al. 1997.

Notes: Consumption refers to direct use as food, measured as uncooked weight, bone in. Meat includes beef, pork, mutton, goat, and poultry. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Metric tons and kilograms are three-year moving averages centered on the two years shown. WANA is West Asia and North Africa.

Table 18—Projected trends in meat and milk production, 1993–2020

Region	Projected annual growth of total production, 1993–2020		Total production in 2020		Per capita production in 2020	
	Meat	Milk	Meat	Milk	Meat	Milk
	(percent per year)		(million metric tons)		(kilograms)	
China	2.9	3.2	86	19	60	13
Other East Asia	2.4	3.9	7	3	55	29
India	2.8	1.6	8	172	6	135
Other South Asia	2.6	3.1	4	46	9	92
Southeast Asia	3.1	2.9	16	3	25	5
Latin America	2.2	2.0	39	80	59	121
WANA	2.5	2.6	11	46	18	72
Sub-Saharan Africa	3.4	4.0	11	31	10	30
Developing world	2.7	3.2	183	401	29	63
Developed world	0.7	0.4	121	371	87	267
World	1.8	1.6	303	772	39	100

Sources: Projections are updated figures following the same format as that reported in Rosegrant et al. 1997.

Notes: Meat includes beef, pork, mutton, goat, and poultry. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Metric tons and kilograms are three-year moving averages centered on the two years shown. WANA is West Asia and North Africa.

countries will import feed rather than meat. This contradicts the conventional wisdom that it is cheaper to trade the commodity with the higher value-added (meat as opposed to bulk cereals). But it is consistent with current trade patterns and with the experience of rapidly developing countries such as Taiwan. These livestock trade patterns may reflect the realities of relative overall costs and benefits of producing and trading strategies better than a simple comparison of value to bulk.

Comparison of projected milk production and consumption in 2020 shows a somewhat different story. Unlike meat, milk is itself a major input into domestic livestock production. The consumption figures in Table 17 include only what is consumed by humans, but milk production figures include milk used as feed. Milk production in 2020 in the developed countries is projected to exceed milk consumption by 108 million metric tons (or 29 percent of projected production). Seventy-seven million metric tons of milk will be used as feed and the remaining surplus will be exported to developing countries. Only 41 million metric tons (10 percent of projected production) are likely to be used as feed in developing countries, despite a herd size larger than that in the developed countries.

In developed countries the annual growth rate of production through 2020 is projected to be 0.7 percent or less for each of the major livestock food commodities other than poultry (Table 19). In the developing countries the projected annual rates of growth are 2.7 percent for meat and 3.2 percent for milk. The majority share of livestock production will take place in developing countries, even though per capita production levels will be much higher in the developed countries.

Projected Cereal Feed Use to 2020

The trends in cereal feed use since the early 1980s (Table 15) highlighted the fact that the growth rates of cereal feed use exceeded cereal production growth rates in all regions of the world except WANA. Comparison of projected and historical growth rates of cereal feed use shows a slowdown through 2020 in China, Other East Asia, Southeast Asia, and Sub-Saharan Africa (Tables 15 and 20). But feed use accelerates in India, Other South Asia, and WANA, largely due to fast-growing milk production.

Per capita cereal use as feed increases by only 8.1 percent in aggregate from the early 1990s to 2020 in developed countries, but rises by 44 percent in developing countries. Given this stagnation in

Table 19—Projected trends in production of various livestock products, 1993–2020

Region/product	Projected annual growth of total production, 1993–2020	Total production 1993	Total production 2020	Per capita production 1993	Per capita production 2020
	(percent)	(million metric tons)		(kilograms)	
Developed world					
Beef	0.6	35	38	26	28
Pork	0.4	37	41	29	29
Poultry	1.2	27	36	21	26
Meat	0.7	100	121	78	87
Milk	0.4	348	371	272	267
Developing world					
Beef	2.6	22	44	5	7
Pork	2.7	39	81	9	13
Poultry	3.0	21	47	5	7
Meat	2.7	88	183	21	29
Milk	3.2	164	401	39	63

Sources: Total and per capita production for 1993 are calculated from FAO 1998. Projections are updated figures, following the same format as that reported in Rosegrant et al. 1997.

Notes: Meat includes beef, pork, mutton, goat, and poultry. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Metric tons and kilograms are three-year moving averages centered on the two years shown. WANA is West Asia and North Africa.

developed countries, which presently have high cereal feed use, global cereal feed use is projected to increase by only 46 percent by 2020. This translates to a 1.4 percent compounded annual rate of growth, noticeably higher than the 0.7 percent annual growth rate observed from the early 1980s to the early 1990s. Cereal production is projected to grow by 1.3 percent per year through 2020.

An additional 292 million metric tons of cereals will be used as feed in 2020 compared to the early 1990s. For further comparison, a normal U.S. maize crop in the early 1990s totaled around 200 million metric tons of grain. The increase in grain use as feed will be met primarily through expansion of yields in the traditional exporting countries and expansion of cultivated area in South and East Asia.

Table 20—Projected trends in use of cereals as feed, 1993–2020

Region	Projected annual growth rate of total cereal use as feed 1993–2020	Total cereal use as feed 1993	Total cereal use as feed 2020	Per capita cereal use as feed 1993	Per capita cereal use as feed 2020
	(percent)	(million metric tons)		(kilograms)	
China	3.4	84	178	62	125
Other East Asia	2.2	7	20	116	167
India	5.0	3	14	4	11
Other South Asia	2.9	1	4	6	7
Southeast Asia	2.7	12	30	32	45
Latin America	2.0	55	92	116	140
WANA	2.5	29	66	93	104
Sub-Saharan Africa	3.5	3	5	4	5
Developing world	2.8	194	409	45	65
Developed world	0.6	442	519	346	374
World	1.4	636	928	115	120

Sources: Total and per capita use for 1993 is calculated from FAO 1998. Projections are updated figures following the same format as that in Rosegrant et al. 1997.

Notes: Cereals includes wheat, maize, rice, barley, sorghum, millet, rye, and oats. Metric tons and kilograms are three-year moving averages centered on the two years shown. WANA is West Asia and North Africa.

Table 21—Changes in IMPACT's baseline assumptions: A severe Asian crisis and high Indian meat consumption

Scenario	Phenomenon being modeled	Mechanism	Nature, magnitude, and duration of changed parameters
Severe Asian crisis	Enduring depreciation of Asian exchange rates	Insertion of additional wedge between domestic and world commodity prices for Asian countries	Lasting one-shot increase in wedge of 5 to 13 percent of world prices depending on country
	Lower nonagricultural income growth in Asia	Decrease in exogenously specified growth rates of GDP for Asia	Lasting decrease of 30 to 45 percent in GDP growth rates, depending on country
High Indian meat consumption	Shift of Indian tastes toward animal foods including beef	Income elasticity for animal foods raised for India	Lasting rise in elasticity to 1.5 to 2.0, depending on the commodity
	Production response of Indian herds	Permanent increase in the trend of Indian herd growth rates	Fixed intercepts shift upward by 0.3 to 0.7 percent by commodity
	Increase in cereal feed use in India	Progressive upward shift in feed conversion ratios (kilogram of cereal/kilogram of animal food)	By 2020, India has ratios higher than most other developing countries, but lower than developed countries

Source: The scenario for a severe Asian crisis is described in Rosegrant and Ringler 1998.

Feedgrain cultivation has been of relatively minor importance in South and East Asia compared to foodgrain cultivation, but maize production is increasing rapidly while rice production is slowing.

Sensitivity of Projections to Changes in Assumptions

Four experiments that test some of the assumptions in IMPACT and take into account some major changes that might occur in the world are discussed here: (1) a prolonged decline in economic growth in Asia; (2) a structural change in tastes in India toward increased consumption of milk and meat; (3) a broad, secular increase over time in feed conversion efficiency (due to technological progress, perhaps); and (4) a broad secular decrease in cereal feed conversion efficiency over time (due perhaps to increasing use of cereal feeds as livestock production intensifies).

What Happens in the Event of a Long-Run Economic Crisis in Asia?

Because demand from developing countries, primarily in East Asia, drives the Livestock Revolution, a prolonged Asian economic crisis could have a major effect on livestock trends through 2020.[9] The scenario for a more severe outcome in Asia is laid out in Table 21. The scenario includes an enduring depreciation of Asian exchange rates and a lasting decrease in income growth rates. Depending on the country, price wedges between domestic and world prices are increased by 5 to 13 percent. Annual GDP growth rates are cut by 30 to 45 percent.

[9] The June 1998 baseline used here already incorporates less optimistic assumptions about Asian growth than previous versions of IMPACT. See Rosegrant and Ringler (1998) for a detailed discussion. The current baseline assumes that long-term nonagricultural GDP will grow at 5.5 percent per year in China, 4.5 percent in Indonesia, 5 percent in Malaysia, 3.5 percent in Korea, 5 percent in India, and 5 percent in Thailand.

This scenario, presented in detail in Rosegrant and Ringler (1998), is a “worst-case” pessimistic scenario, especially because the effects are assumed to last until 2020. The results are presented here to illustrate the robustness of the Livestock Revolution, even in the face of a lasting slowdown in Asia.

A comparison of the results of the severe Asian scenario to those of the baseline model are given in Table 22. A severe Asian crisis would cause meat, milk, and feed consumption to fall, most notably in China and India. But even where consumption declines by 20 percent relative to the baseline, the baseline projections of 200–300 percent growth for meat and milk in India and China by 2020 mean that consumption will grow 160–240 percent in those countries, still a large increase.

Even with a severe Asian crisis, the prospects for long-term livestock expansion in Asia and the world are quite robust. In Latin America and Sub-Saharan Africa the severe Asian scenario increases meat and milk consumption slightly because of price effects (cheaper world prices for meat and feed). For the world as a whole, consumption of livestock commodities declines by 8 percent or less relative to the baseline, a negligible change considering it is spread over 27 years.

What Happens if People in India Dramatically Increase Their Meat Consumption?

Another major structural change that could affect the global livestock economy is a shift in Indian tastes that accelerates meat consumption (Bhalla, Hazell, and Kerr 1998). Urbanization, income growth, and secularization could cause people in India to increase their meat consumption at a rate similar to high milk consumption growth rates. Total milk consumption in India grew by 53 percent between the early 1980s and 1990s (Table 6).

This scenario assumes that Indian income elasticities increase to between 1.5 and 2.0, depending on the product (Table 21). It also assumes that Indian production systems change in tandem, with permanent increases of 0.3–0.7 percent in the trend of Indian herd-size growth rates. Finally, the scenario assumes that livestock production in land-scarce India increases primarily through intensifi-

Table 22—Difference between baseline projections and projections of aggregate consumption in 2020 due to changes in assumptions about the Asian crisis and Indian consumption

	Severe Asian crisis				High Indian meat consumption			
Region	Beef and mutton	Pork and poultry	Milk	Cereal used as feed	Beef and mutton	Pork and poultry	Milk	Cereal used as feed
	(percent difference between new scenario and baseline)							
China	–20	–19	–18	–13	–3	–2	–7	4
India	–14	–17	–27	–16	343	505	154	250
Other Asia (including WANA)	–8	–13	–5	–1	–4	–3	–9	7
Latin America	1	4	2	–5	–3	–4	–4	8
Sub-Saharan Africa	2	4	4	–4	–4	–2	–8	5
Developing world	–6	–13	–13	–8	33	6	59	14
Developed world	–2	2	0	–2	0	0	–2	3
World	–4	–8	–8	–5	19	4	34	8

Notes: The severe Asian crisis incorporates lower projected income growth and depreciation in exchange rates for countries in Asia. Depending on the country, income growth projections are 30–45 percent lower than in the baseline scenario, and exchange rate depreciation results in 5–13 percent higher domestic prices.

The high Indian meat consumption scenario incorporates a shift in tastes toward consumption of animal foods and increases in production and feed use ratios by Indian livestock producers. Income elasticities for animal products rise to between 1.5 and 2.0, depending on the commodity. The trend growth rate of Indian herd size rises by 0.3–0.7 percent (depending on the commodity), and feed conversion ratios rise above those typical in developing countries.

Mutton includes sheep and goat meat. Milk includes all dairy products in liquid milk equivalents.

The large percentage changes for meat and feed in India reflect a low initial base. Projected beef consumption in 2020, for example, is still only 31 kilograms per capita under the high meat scenario, less than in China today. WANA is West Asia and North Africa.

cation and that the amount of cereal feed required per kilogram of meat rises as a consequence.

The high Indian meat consumption scenario pulls in the opposite direction from the severe Asian crisis scenario. The effect on the growth of Indian consumption is huge in both absolute and percentage terms, but still relatively modest in per capita terms (Table 22). Milk consumption and cereal feed use rise the most in absolute terms. For the world as a whole, milk consumption in 2020 would exceed the baseline by 34 percent and feed use by 8 percent.

Scenarios with Different Rates of Feed Conversion Efficiency

Feed can make up to three-quarters of the variable cost of livestock production in intensive systems (Sere and Steinfeld 1996). Changes in the feed requirements of meat and milk production play an important role in determining the final cost of livestock production. Technological innovations that increase the amount of meat obtained per unit of high energy feed and intensification of production (substitution of cereals for browse or slops) both can change the amount of cereal used per unit of meat and milk produced. Two opposite scenarios are presented: an increase in the rate that feed use efficiency improves and a decrease in that rate. These are both modeled in somewhat extreme form to test the sensitivity of results to changes in the assumed conversion ratios in either direction. The baseline scenario basically assumes that these two effects cancel each other out.

In the first, "optimistic" scenario, feed conversion ratios improve progressively. About 1 percent more meat per year is produced per kilogram of feed in developing countries, with a compounded effect over time. This mirrors the rapid technological progress observed in the developed countries from the early 1980s to the early 1990s. Under the optimistic scenario, feed conversion efficiency in developed countries improves by only 0.5 percent per year. This lower rate reflects less scope for adopting technology from other regions. The result is that in 2020 developing countries produce approximately 60 percent more meat per kilogram of feed than they do in the baseline projections. The effect is half as large in developed countries.

In the second, "pessimistic" scenario, feed conversion ratios worsen progressively. About 1 percent less meat per year is produced per kilogram of feed in developing countries, with the effect compounding over time. This scenario reflects increasing shifts from backyard production to more intensive feeding in lots. Because intensified feeding practices have already taken hold in developed countries for the most part, the worsening conversion ratio for developed countries is assumed to be only 0.5 percent per year. The result is that in 2020

Table 23—Difference between baseline projections and projections of aggregate consumption in 2020 due to changes in assumptions about feed conversion

	Increasing feed conversion efficiency				Decreasing feed conversion efficiency			
Region	Beef and mutton	Pork and poultry	Milk	Cereal used as feed	Beef and mutton	Pork and poultry	Milk	Cereal used as feed
	(percent difference between new scenario and baseline)							
China	0	0	0	–15	0	0	0	17
India	0	1	0	–9	0	0	–1	11
Other Asia (including WANA)	0	1	1	–10	–1	0	–1	12
Latin America	1	1	0	–15	0	–1	–1	19
Sub-Saharan Africa	0	0	0	–12	0	0	0	14
Developing world	0	1	0	–13	0	0	–1	16
Developed world	0	0	0	–2	0	0	0	2
World	0	0	0	–7	0	0	0	8

Notes: The increasing feed conversion efficiency scenario assumes an increase in the efficiency of converting maize to meat. This results in a decreased rate of increase for conversion ratios in regions where they are increasing, and an increased rate of decrease for conversion ratios in regions where they are decreasing.

The decreasing feed conversion efficiency scenario assumes a decrease in the efficiency of converting maize to meat. This results in an increased rate of increase for conversion ratios in regions where they are increasing, and a decreased rate of decrease for conversion ratios in regions where they are decreasing.

Mutton includes sheep and goat meat. Milk includes all dairy products in liquid milk equivalents. WANA is West Asia and North Africa.

developing countries produce approximately 60 percent less meat per kilogram of feed than they do in the baseline projections. The effect is half as large in developed countries.

Table 23 shows the effects of the optimistic and pessimistic feed conversion scenarios on consumption in 2020. The most striking result is that large changes in either direction have virtually no impact on livestock product consumption. Large changes, however, are associated with differences in the amount of cereal used to produce livestock products. Although not shown, changes in feed conversion ratios also cause changes in the location of livestock production in a competitive market system. A crucial point to note in Table 23 is that the amount of cereal used for feed in 2020 changes by only 2 percent in developed countries and 13 to 16 percent in developing countries, relative to the baseline. The change is small because increased feed efficiency leads to falling cereal feed prices, which encourages substitution back into cereal feeds among all producers, lessening the overall effect of changes in efficiency.

Progressively lower feed efficiency raises the world price of cereal feed to the point where substitutes become cost-effective. Production shifts from regions and commodities that cannot undertake these substitutions at low enough cost to those that can. Countries such as Argentina, with large production capacity on ranges, are favored in the "pessimistic" scenario because they can compete more easily, with more expensive lot-fed beef, for example. The reverse is true under the "optimistic" scenario. Higher feed efficiency (lower conversion ratios) tends to encourage increased use of cereals as feed and favor those countries where cereal supply is relatively cheap and cereal feeding practices are well-established.

A striking result is that as long as cereals are available worldwide in relatively elastic supply, feed conversion does not play a critical element in determining human consumption of livestock products, although it does affect the competitiveness of individual producers of livestock product. Feed efficiency and relative cereal prices, therefore, are likely to be quite important in determining the geographic direction of trade.

5. Implications of the Livestock Revolution for World Trade and Food Prices

An emerging, central feature of world markets for meat, milk, and feed is that they are increasingly interlinked. IMPACT implicitly takes this interlinkage into account with its annual market-clearing feature, which allows prices to move until supply and demand are in balance. Domestic markets are cleared in the model through backward and forward iterations between sets of domestic and world prices. World prices differ from domestic ones by means of fixed price wedges specified for each country group that catch the effect of protectionist policies or major transport costs to remote markets.

Domestic prices in equilibrium may always be above or below world prices for meat and feed, depending on the country group in question, but they are always affected in the model by movements in world prices. This interlinked movement of prices is a better approximation of reality than delinked markets. In IMPACT, changes in demand for livestock products in Asia, for example, affect livestock and cereal feed prices everywhere. No part of the world will be unaffected by the events in Asia or India or changes in feed use efficiency.

Trade flows are modeled in IMPACT as the net annual residual between production and consumption at world market-clearing prices for each country group and commodity, leading to either net exports or net imports (negative net exports) for that commodity and country group in the year in question. The model does not determine trading partners, but the worldwide sum of net exports for a given commodity is zero for each year in equilibrium.

Projected Trade in Livestock Food Products and Feed to 2020

Net exports of specific commodities by region are given in Table 24, for 1993 and 2020. World beef trade was minimal in the early 1990s. Roughly 0.4 million metric tons flowed on a net basis from the developed to the developing world. WANA imported the most, while Latin America accounted for 18 percent of net world exports of beef. Developed countries imported a net total of 0.7 million metric tons of pork from developing countries in the early 1990s, much of it from China. Developed countries had net exports of 0.5 million metric tons of poultry, almost 19 million metric tons of milk, and a little more than 93 million metric tons of cereals.

Beef is projected to become the most significant meat import of developing countries in 2020, at 2.7 million metric tons net. Pork will remain a net export of developing countries, though only marginally. Poultry imports will rise to 1.8 million metric tons. Milk will almost double in size as a net export of the developed world. Cereals will continue to be the most significant net agricultural export from the developed to the developing world. Compared to 1993, net exports from developed to developing countries are projected to rise by 133 million metric tons, an amount equivalent to approximately 60 percent of the entire U.S. average corn crop in the early 1990s (FAO 1998).

Changes in Net Exports under Changed Asian Assumptions

The livestock and feed trade picture in 2020 changes significantly under the severe Asian crisis and high Indian meat consumption scenarios (Table 25). The extreme assumptions in the Asian crisis scenario do not change aggregate livestock consumption by much. However, they do promote large changes in projected world cereal feed flows. The changes in feed flows are in fact the most sig-

Table 24—Net exports of various livestock products in 1993 and 2020, baseline scenario

Region	Beef		Pork		Poultry		Milk		Cereals	
	1993	2020	1993	2020	1993	2020	1993	2020	1993	2020
	(million metric tons)									
China	0.1	0.1	0.7	0.3	0.1	0.3	−0.9	0.5	–0.9	–46.2
Other East Asia	−0.4	−0.6	0.0	−0.1	−0.3	−0.6	−0.5	−0.4	–20.0	–31.9
India	0.1	0.1	0.0	−0.1	0.0	0.0	0.0	0.1	1.3	–7.1
Other South Asia	0.0	−0.3	0.0	0.0	0.0	−0.3	−0.6	−2.8	–4.5	–21.9
Southeast Asia	−0.2	−0.6	0.2	0.6	0.1	0.5	−4.0	−7.8	–3.2	–5.4
Latin America	0.7	0.6	−0.2	−0.2	0.1	−0.1	−5.7	−5.6	–16.0	–13.0
WANA	−0.7	−1.7	0.0	0.0	−0.4	−1.3	−5.0	−12.2	–37.7	–74.6
Sub-Saharan Africa	0.0	−0.2	0.0	−0.1	−0.1	−0.2	−1.5	−1.8	–11.6	–24.9
Developing world	−0.4	−2.7	0.7	0.2	−0.5	−1.8	−18.7	−30.9	–93.3	–226.1
Developed world	0.4	2.7	−0.7	−0.2	0.5	1.8	18.7	30.9	93.3	226.1

Source: Projections are from IMPACT.

Notes: Net trade in 2020 is projected production minus consumption for the commodity and region shown. Metric tons are three-year moving averages centered on the two years shown and, for meat, refer to carcass weight. Milk is cow and buffalo milk and milk products in liquid milk equivalents. Cereals include wheat, maize, rice, barley, sorghum, millet, rye, and oats. Net export figures may not sum to zero overall because of rounding. WANA is West Asia and North Africa. Minus signs indicate imports.

Table 25—Difference between baseline projections of net exports in 2020 and projections with changes in assumptions about the Asian crisis and Indian consumption

Region	Severe Asian crisis				High Indian meat consumption			
	Beef and mutton	Pork and poultry	Milk	Cereals	Beef and mutton	Pork and poultry	Milk	Cereals
	(percent difference between new scenario and baseline)							
China	211	556	62	27	169	612	321	−2
India	86	53	18,857	19	−4,038	−2,719	−55,464	−480
Other Asia (including WANA)	21	293	13	–1	28	66	30	4
Latin America	–172	–527	–55	4	168	176	95	–2
Sub-Saharan Africa	–112	–119	–90	–15	141	24	157	33
Developing world	2.9	261	43	4	–47	4	–83	–10
Developed world	–2.9	−261	−43	−4	47	−4	83	10

Notes: The severe Asian crisis incorporates lower projected income growth and depreciation in exchange rates for countries in Asia. Depending on the country, income growth projections are 30 – 45 percent lower than in the baseline scenario, and exchange rate depreciation results in 5 –13 percent higher domestic prices.

The high Indian meat consumption scenario incorporates a shift in tastes toward consumption of animal foods and increases in production and feed use ratios by Indian livestock producers. Income elasticities for animal products rise to between 1.5 and 2.0, depending on the commodity. The trend growth rate of Indian herd size rises by 0.3 – 0.7 percent (depending on the commodity), and feed conversion ratios rise above those typical in developing countries.

Mutton includes sheep and goat meat and edible products. Milk includes all dairy products in liquid milk equivalents.

The large percentage changes for meat and feed in India reflect a low initial base. WANA is West Asia and North Africa.

nificant result of the severe Asian crisis assumptions, especially because the absolute amounts of feed traded in the baseline scenario are already large. Baseline livestock trade is relatively modest, which should be borne in mind when interpreting the large percentage changes shown for livestock items in most cases.

Geographically the severe Asian crisis scenario sharply decreases projected net imports of livestock foods and decreases projected net exports from Latin America and Sub-Saharan Africa.[10] Projections of net imports of feedgrains by Asia also decline appreciably, by as much as 27 percent in China. Net cereal feed imports by developing countries decline by 4 percent. Net Chinese meat exports rise by 3.4 million metric tons and milk exports rise by 0.3 million metric tons.

For Asia other than China and India, the severe Asian crisis scenario changes the region from a net meat importer in 2020 to a net exporter of 3.2 million metric tons. The region's net milk imports decrease by 5.3 million metric tons. The effects of the Asian crisis decrease domestic demand and increase competitiveness in world markets. India remains a minor participant in world trade of livestock products in 2020 under the baseline and Asian crisis scenarios. Countries outside Asia tend to increase their imports of livestock products under severe Asian crisis assumptions because of lower world prices.

The high Indian meat (and milk) consumption scenario turns India into a major world importer of meat, milk, and cereal feed in 2020, a substantial shift from its minor trading role in the baseline projections (Table 25). Other regions of the world increase their net exports of meat and milk, although China and Latin America actually marginally increase their imports of cereal feed in response to the expanded meat and milk export opportunities. The very large percentage changes for India are caused by the very low projected trade levels in the baseline projection. Baseline net exports of 77,000 metric tons of liquid milk equivalents in 2020 turns into 42.6 million metric tons of net imports in the high Indian meat consumption scenario. Even in the face of the unrealistic assumptions of the high Indian scenario, the world system is flexible enough to adjust without major dislocations in consumption.

Changes in Net Exports under Changed Assumptions about Feed Efficiency

The previous chapter assessed the sensitivity of baseline results to assumptions about feed conversion ratios and found that consumption patterns of livestock products did not change much, but cereal use as feed rose or fell depending on whether efficiency decreased or increased. The results are different for trade, as shown by the wide geographic variation in trade projections relative to the baseline (Table 26).

An equal percentage increase in feed conversion efficiency applied to all developing countries leads to differing results in different countries, including a 25 percent increase in net exports of beef from India and a 9 percent decline in net beef exports from China. The price changes that result from decreasing feed conversion efficiency work to increase net exports of cereal feed from the developed countries, India, and Sub-Saharan Africa, and increase net imports of cereal feed by China and Latin America. The small percentage of trade in total baseline production and consumption causes the large percentage trade responses seen in some cases.

Past Trends in Real World Prices for Crop and Livestock Products and Projections to 2020 under Different Scenarios

Debates over the use of cereals as feed need to be cast in the context of steadily lower returns to feeding cattle for meat production over the past 25 years. Real world agricultural prices have slipped steadily relative to manufactured goods prices since the early 1970s (Table 27). Clearly, livestock

[10] The concept of "net exports" could equally well be expressed in this case as increasing net exports from Asia or decreasing net imports by Latin America and Sub-Saharan Africa.

Table 26—Difference between baseline projections of net exports in 2020 and projections with changes in assumptions about feed conversion efficiency

Region	Increasing feed conversion efficiency				Decreasing feed conversion efficiency			
	Beef and mutton[c]	Pork and poultry	Milk	Cereals	Beef and mutton	Pork and poultry	Milk	Cereals
	(percent difference between new scenario and baseline)							
China	–9	16	–6	46	7	–21	5	–53
India	25	2	–1,075	–32	–26	–2	1,075	36
Other Asia (including WANA)	–1	–3	8	5	1	3	–9	–6
Latin America	–5	–14	1	26	6	14	–1	–40
Sub-Saharan Africa	–3	8	46	–31	1	–11	–50	34
Developing world	–2	2	6	9	2	–3	–7	–12
Developed world	2	–2	–6	–9	–2	3	7	12

Notes: The increasing feed conversion efficiency scenario assumes an increase in the efficiency of converting maize to meat. This results in a decreased rate of increase for conversion ratios in regions where they are increasing, and an increased rate of decrease for conversion ratios in regions where they are decreasing.

The decreasing feed conversion efficiency scenario assumes a decrease in the efficiency of converting maize to meat. This results in an increased rate of increase for conversion ratios in regions where they are increasing, and a decreased rate of decrease for conversion ratios in regions where they are decreasing.

Mutton includes sheep and goat meat and edible products. Milk includes all dairy products in liquid milk equivalents. WANA is West Asia and North Africa.

Table 27—Past trends in real prices of selected crop, feed, and livestock products

Year	Wheat	Rice	Maize	Soybeans	Soymeal	Fishmeal	Beef	Pork	Poultry	Lamb	Milk
	(constant 1990 US$/metric ton)										
1970–72	232	524	215	476	415	750	5,144	n.a.	n.a.	3,248	485
1980–82	236	534	169	384	338	615	3,536	2,344	1,474	3,730	413
1990–92	135	288	104	234	195	444	2,585	1,781	1,139	2,440	280
1994–96	156	270	116	238	192	424	1,761	n.a.	1,113	2,474	261
World Bank projections											
2000	135	279	102	230	189	n.a.	1,773	n.a.	n.a.	n.a.	n.a.
2010	118	262	92	236	196	n.a.	1,629	n.a.	n.a.	n.a.	n.a.

Sources: Past data are from USDA 1997a and b, IMF 1997, and World Bank 1993. World Bank projections and the Manufacturing Unit Value index used for expressing values in constant 1990 U.S. dollars are from World Bank 1997.

Notes: Wheat is U.S. no. 1, hard red winter, ordinary protein, export price delivered at Gulf ports for shipment within 30 days. Rice is Thai 5 percent broken, WR, milled, indicative survey price, government standard, f.o.b. Bangkok. Maize is U.S. no. 2, yellow, f.o.b. U.S. Gulf ports. Soybeans are U.S. c.i.f. Rotterdam. Soymeal is any origin, Argentine 45–46 percent extraction, c.i.f. Rotterdam, prior to 1990, U.S. 44 percent. Fishmeal is any origin, 64–65 percent, c.i.f. Hamburg, n.f.s. Beef is Australian/New Zealand, cow forequarters, frozen boneless, 85 percent chemical lean, c.i.f. U.S. port (East Coast), ex-dock. Pork is European Community pork, slaughter wholesale price. Poultry is broilers, twelve-city composite wholesale price, ready-to-cook, delivered. Lamb is New Zealand, frozen whole carcasses, wholesale price, Smithfield market, London. Milk is U.S. whole milk sold to plants and dealers, U.S. Department of Agriculture. n.a. indicates that comparable prices for those years are not available.

producers have felt the pain in recent years. Beef in 1994–96 was priced at only 34 percent of its inflation-adjusted level in 1970–72, while maize was 54 percent of its inflation-adjusted price in the same period.

Furthermore, the 10 percent global expansion of cereal feed use by weight between the early 1980s and 1990s (Table 15) occurred at a time when maize and soybeans declined in price by more than one-third. This lends support to the argument that additional concentrate feeds will be supplied with little real increase in price. This argument is tested by the IMPACT model, which produces a series of market-clearing world prices in equilibrium

(Table 28). For comparison, single-equation price projections to 2010 by the World Bank are reported at the bottom of Table 27.

Compared to the World Bank projections to 2010, the IMPACT baseline projections show 38 percent higher maize prices and 3.5 percent higher beef prices. The global food supply and demand approach of IMPACT captures the effect of the Livestock Revolution on cereals prices, whereas single-equation methodology does not. Even so, IMPACT projects that real world maize prices in 2010 will be only about 10 percent above actual 1994–96 prices, which were historically low. Thus, the Livestock Revolution prevents cereal prices in the baseline projections from falling further from their currently low levels, and perhaps even increases them slightly, but nowhere near their level in the early 1980s.

The severe Asian crisis assumptions decrease real world prices in 2020 by 7 percent for maize and 5 percent for beef. These are significant effects, but the assumptions for this scenario are extreme because they posit that the crisis lasts though 2020. The high Indian meat scenario increases world maize prices by 13 percent and world beef prices by 9 percent. Changing tastes in India have even greater effects on world livestock markets than does a severe economic crisis in Asia, but in the opposite direction.

Increasing feed conversion efficiency lowers real world maize prices by 17 percent relative to baseline projections for 2020. Decreasing feed conversion efficiency increases maize prices by 21 percent. Livestock prices, on the other hand, are hardly affected. Cereal producers and consumers clearly have a lot at stake in feed conversion efficiency. Livestock producers in individual countries have a lot at stake as well, even if technology is shared by all producers, because increasing feed efficiency favors some producers while decreased feed efficiency favors others. Livestock consumers have surprisingly little at stake, at least as far as the cost of livestock food products is concerned.

Why Is the Livestock Revolution Not Likely to Raise World Cereal Prices Significantly?

Comparison of the IMPACT price projections under various scenarios with the historical rate of decrease of real food prices in the last quarter century suggests that the rate of decline of food prices

Table 28—Real prices of selected crop and livestock products as projected by the IMPACT model

Year	Wheat	Rice	Maize	Soybeans	Beef	Pork	Poultry	Lamb	Milk
				(constant 1990 US$/metric ton)					
Baseline prices									
1992–94	148	275	126	263	2,023	1,366	1,300	2,032	234
Baseline projections									
2010	146	293	127	244	1,835	1,260	1,175	1,915	217
2020	133	252	123	234	1,768	1,209	1,157	1,842	199
Severe Asian crisis scenario projections									
2020	124	248	114	221	1,676	1,104	1,074	1,807	187
High Indian meat consumption scenario projections									
2020	148	268	139	267	1,927	1,287	1,259	2,203	219
Increasing feed conversion efficiency scenario projections									
2020	126	243	102	228	1,738	1,188	1,134	1,817	196
Decreasing feed conversion efficiency scenario projections									
2020	141	262	149	242	1,802	1,233	1,183	1,870	202

Sources: The updated IMPACT baseline projections and the severe Asian crisis scenario are from Rosegrant et al. 1997 and Rosegrant and Ringler 1998.
Notes: The scenarios are independent of each other. The IMPACT baseline prices in 1992–94 are fully comparable to the actual series given in Table 27.

during the next quarter century is likely to be much weaker than in the past. This is undoubtedly a result of the Livestock Revolution. Real cereal prices, however, are not likely to rise very much by 2020, contrary to the fears of some reported in Chapter 1.

The primary explanation for IMPACT's projection that cereal prices will continue to be low even as demand for both food and feed increases is that the world is thought to have considerable reserve capacity for additional cereal production. This assumption not only fits the evidence of the past 25 years, during which world production output changed in response to price, but also accords with the dozens of price response parameters for cereals (for 37 countries and regions times a half dozen crops) built into the model and mostly taken from independent sources (Rosegrant, Agcaoili-Sombilla, and Perez 1995; Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997).

The traditional explanation for the high supply responsiveness of cereals found in the empirical literature is that the large grain-exporting countries, such as Australia, Canada, and the United States, have the ability to bring large amounts of land typically not sown to grain into cereal production as prices rise. Furthermore, cereal cultivation by the large grain exporters usually is less input-intensive than in many importing countries. Average wheat yields in Britain, for example, are much higher than in the United States. This leaves considerable scope for exporting countries to increase production through higher fertilizer use, which becomes profitable when cereal prices are high. The tremendous productivity increases in cereals in recent years also attest to the spur of prices. These increases have come about to a large extent in response to the higher cereal prices that made investing in production innovations economic (Hayami and Ruttan 1985).

Another explanation of the high supply responsiveness of cereals is that in a system of global markets, where actors all over the world respond to changing price incentives, individual shocks are smoothed out over time through myriad adjustments throughout the system. In other words, world supply will be more price-responsive than individual country supply, a phenomenon well-captured in IMPACT.

A final phenomenon of direct relevance to cereal supply is that in areas containing a significant share of the world's poor, the rise in the consumption of calories from animal products is matched by a decrease in calories from starchy staples. People in China's rural areas, for example, consumed nearly 200 kilograms per capita of grain directly as food in 1991, while people in the richer urban areas consumed an average of 130 kilograms per capita, a figure much closer to average consumption levels elsewhere in the developing world (Huang and Bouis 1996). Rice and wheat are the grains typically consumed in China. These grains have significantly lower average yields per hectare than maize, a feedgrain increasingly cultivated by Chinese farmers. Thus, substitution of meat and milk for grain in the diet liberates some grain from direct consumption as food, and the consequent increase in aggregate grain supply is amplified by the relatively higher yields of feedgrains per hectare. All of this suggests that the Livestock Revolution is intimately wrapped up with nutritional and food security, the subject of the next chapter.

6. Nutrition, Food Security, and Poverty Alleviation

The trends noted in the previous chapters strongly suggest that livestock consumption patterns in developing countries are rapidly converging with those in developed countries, putting severe pressure on production systems in developing countries to do the same. The considerable controversy in both the popular and scientific literature about the desirability of livestock consumption and production patterns in the richer countries raises concerns about what the Livestock Revolution portends for human welfare in the poorer countries. It seems probable, for example, that massively larger amounts of cereals will be used as feed to produce items consumed primarily by better-off urban people in countries where outright lack of food is still common (Brown and Kane 1994; Goodland 1997; Pimentel 1997).

These concerns raise complex nutritional, food security, and poverty alleviation issues. Nutritional issues in this context include the effect of consumption of specific animal food products on health and well-being in specific situations. Food security issues encompass the ability of people to secure enough food on a regular basis for healthy and productive lives. Poverty alleviation issues include the extent to which the production and sale of animal products might lead to widespread net improvement in the livelihood of the rural poor.

The IMPACT projections shed light on likely trends in cereal and animal product prices under different scenarios for the Livestock Revolution. The impact of livestock on the purchasing power of the poor, the other side of the cereal affordability issue, must be assessed with highly disaggregated data. As will be seen below, evidence from household studies around the developing world suggests that in many cases the rural poor, especially women, get a larger share of their income from livestock sources than do the relatively wealthy. These findings raise questions about the morality of blanket "anti-livestock" positions in policymaking. But whether the traditional livestock enterprises of the rural poor can coexist with increased industrialization of livestock production is an open question. Finally, increasing intensification of production raises other ethical issues, including concerns about animal welfare and the unpleasantness suffered by those who live downwind from major industrial hog farms.

As with other structural changes in the food sector that are important to human welfare, such as the Green Revolution in cereals, popular discussion of the effect of the Livestock Revolution on developing countries is occasionally highly emotional and often imperfectly grounded in facts. The objective of this chapter is to show how the research presented in the rest of this paper relates to the discussion of welfare issues.

The Livestock Revolution and Nutrition in Developing Countries

The discussion of nutritional issues in this section does not address the health effects of consuming contaminated food products. Those effects are discussed in Chapter 8. Even if contamination can be dealt with, is increased consumption of meat and milk a good thing? Concerns about medical problems clearly associated with very high meat and milk consumption in societies such as the United States must be taken seriously (Barnard, Nicholson, and Howard 1995). But sometimes these concerns are extrapolated directly to developing countries in fairly blanket fashion (Goodland 1997; Pimentel 1997) and sometimes selectively, as in the case of China's cities (Geissler forthcoming).

Scientific conclusions about the effects animal products can have on nutrition in developing countries not only depend on the demographics and income levels of target groups and the commodities under study (CAST 1997a), but they vary also because of the methodologies employed (Hu and Willett 1998). And randomized clinical endpoint trials or other forms of investigation designed to control for spurious correlations when comparing long-term "before" and "after" conditions may be difficult to conduct.

One often-cited approach to studying the link between meat consumption and health relies on correlations between disease rates and patterns of livestock product consumption across locations. A prominent example is a study that looks at such correlations across 65 counties of rural China (Chen et al. 1990). Yet while this approach raises issues quickly and exploits large amounts of data, its reliability is open to question as Chen et al. (1990) themselves point out. The China study could not fully control for other variables that might also explain the results (Hu and Willett 1998).

Hu and Willet recently (1998) conducted a thorough review of the relationship between consumption of animal products and the risk of chronic disease for the World Bank. The goal was to sort through conflicting evidence in order to provide guidance to the World Bank's investment policies in developing countries. They drew in evidence from all over the world, assuming that while diets and nutritional needs change across environments and work regimes, human biology probably does not.

Hu and Willett found that red meat (beef, pork, lamb) consumption beyond a low threshold level probably increases the risks of coronary heart disease (CHD); dairy products may also do so but to a lesser extent; eggs are probably unrelated to CHD up to one egg a day; and poultry and fish probably decrease CHD. Moderate red meat intake, however, may reduce the risk of hemorrhagic stroke in cases where initial intake levels are very low. High levels of red meat intake may increase the risk of various forms of cancer, but substitution of poultry and fish for red meat probably reduces the risk. Dairy products may be a risk factor in prostate cancer. Hu and Willett conclude that health policy in developing countries should distinguish poultry and fish from beef and pork because the former probably provide greater nutritional benefit than the latter. Hu and Willett also see benefits from expansion of egg and dairy consumption where consumption levels are as low as they are in developing countries.

Authoritative literature on human nutrition in the developing world stresses the widespread prevalence of mild to moderate protein-energy malnutrition affecting up to one-third of all children and perhaps a higher share of pregnant or lactating women. The literature emphasizes the critical role adequate balance and adequate levels of bioavailable protein, calories, and key micronutrients (such as vitamin A, iodine, and iron) play in mental and physical development (Calloway 1995; Sharma et al. 1996; Latham 1997; Neumann and Harris 1999; Geissler forthcoming). Research also shows that adequate, balanced nutrition helps prevent morbidity. Animal products are portrayed in this literature as excellent sources of absorbable forms of iron, zinc, vitamin B_{12}, and retinol. Certain meats and milk products are cited as variously being good sources of thiamin, calcium, vitamin B_6, riboflavin, vitamin A, and other minerals required in higher amounts during growth periods (Calloway 1995; Latham 1997; Neumann and Harris 1999).

Although a large combination of crop-based nutrients could also provide the necessary amino acids and trace nutrients to meet nutritional needs, securing such a balance throughout the year with vegetable matter alone is not easy for the rural poor in developing countries. On the other hand, increased consumption of even a relatively small additional amount of meat and milk would supply the necessary protein and micronutrients and a fair share of needed additional calories, especially to children, and would do so with a much less varied vegetable-matter diet than using crops alone (Latham 1997; Hu and Willet 1998; Geissler forthcoming; Neumann and Harris 1999).

For all these reasons the Livestock Revolution appears to have many potential benefits for nutrition in developing countries. At present these potential benefits probably outweigh the potential nutritional costs. Whether nutrient balance is secured through a wide variety of crops or a smaller variety of crop and animal products, good nutrition clearly requires the overall intake of an adequate amount of food. The primary nutritional issue for most poor people in most developing countries probably remains securing both an adequate amount of food and a balanced diet.

Once a person regularly consumes excess food calories, the sorts of health problems associated with excess consumption of cholesterol and saturated fatty acids in the developed countries will probably become more prevalent in developing countries, especially among the relatively wealthy in urban areas. However, average per capita consumption of meat and milk in developing countries in 2020 are projected to be less than half the present developed-country average (see Table 16). At levels that low in 2020, the majority of people on the planet are unlikely to face the problem of excess meat and milk consumption for quite some time.

The possibility that the people who could most benefit from increased meat consumption may not share in the Livestock Revolution should be a greater concern than overconsumption. Whether they do benefit will depend principally on the evolution of food prices and the incomes of the needy, topics discussed in the following section.

The Livestock Revolution and Food Security of the Poor

Both ecologists and animal scientists, unlike economists, tend to view the effect of increased animal production on food supplies in developing countries as a trade-off between using cereals (and the land and water used to produce them) as food or feed. Calculations are then presented to argue whether extra production of animal products adds or subtracts from a hypothetical calorie balance available for humans (CAST 1994; Pimentel et al. 1997; Goodland 1997; Brown and Kane 1997).

Pro-livestock authors tend to stress that ruminant animals in developing countries mostly use natural grasses and other feed with little use as food. They also stress the important nonfood uses of livestock (Fitzhugh 1998; CAST forthcoming). “Anti-livestock” authors emphasize that monogastric livestock account for much of the growth of production under the Livestock Revolution, that these animals require high energy feed such as cereals, and that they do not fully replace the cereal calories used to produce them. These authors also argue that because livestock food product consumption increases rapidly with income, the rich probably will bid away the foodstuffs of the poor in the marketplace (Pimentel 1997; Brown and Kane 1997).

Economists tend to reduce the issue to whether increased animal production increases or decreases cereal and meat and milk prices relative to the incomes of poor people, other things being equal. This approach has the merit of defining food security in terms of the ability people have to purchase food staples. But it does not address fully whether all members of the household have physical access to food at average world prices or whether people who are sick can usefully absorb that food at all times. Assessing the impact of increased livestock production on household incomes and food prices is an improvement over nonentitlement approaches and about the best that can be done here.

The previous chapter showed that the simple inference that increased livestock consumption will significantly raise cereal prices by 2020 does not mesh with the rather different and complex picture drawn by the IMPACT projections. Recall that baseline, inflation-adjusted rice and wheat prices in 2020 are projected to be 8 to 10 percent below levels in the first half of the 1990s. Maize prices are projected to decline by only 2 percent. Furthermore, average world cereal prices in the mid-1990s were only about two-thirds (maize) to half (rice) their average inflation-adjusted prices in the early 1980s (Table 27).

In the “worst-case” scenario investigated by IMPACT, rice and wheat prices exceed their inflation-adjusted levels in 1992–94 by only 8–11 percent (Table 28). The price of maize goes up 21 percent. IMPACT also projects modest long-term declining price trends for various meats and milk. The consumption patterns of the rich may prevent livestock products from becoming even more affordable to the poor, but they do not appear to be likely to raise the price of livestock products much above their current levels.

In sum, food prices have been decreasing over the long term, despite rapid increases in the use of cereal feeds. The Livestock Revolution is likely to slow this decreasing trend somewhat by 2020. But the trend reverses only under extreme conditions, and even if it does, the price increases are expected to be small relative to the real price declines seen since the early 1980s. The Livestock Revolution’s effect on the food security of poor people, through cereal prices, is likely to be far less important than its effect on the income of the poor.

The Livestock Revolution and Incomes of the Poor

Livestock are central to the livelihood of the rural poor in developing countries in at least six ways (Livestock in Development 1998). First, they are an important source of cash income. Second, they are one of the few assets available to the poor, especially poor women. Third, livestock manure and draft power are vital to the preservation of soil fertility and the sustainable intensification of farming systems in many developing areas facing increasing population density. Fourth, livestock allow the poor to exploit common property resources, such as open grazing areas, in order to earn income. Fifth, livestock products enable farmers to diversify incomes, helping to reduce income variability, especially in semiarid systems characterized by one cropping season per year. Sixth, livestock provide a vital and often the only source of income for the poorest and most marginal of the rural poor, such as pastoralists, sharecroppers, and widows.

A broad variety of anecdotal evidence from case studies in Africa, Asia, and parts of Latin America shows that the poor and landless derive a higher share of their household income from livestock sources than do the relatively better-off in the same rural communities. Estimates of the share of household income coming from livestock for households with different income levels, farm sizes, and dietary adequacy from all over the world are presented in Table 29. In Pakistan in the late 1980s, for example, Adams and He (1995) found that about 25 percent of the income of the poorest 20 percent of rural households in their sample came from livestock. The richest 20 percent received only 9 percent of their income from livestock. In Egypt in the mid-1970s, Fitch and Soliman (1983) found that an average of 63 percent of the income of landless or near landless households came from livestock. Only 14 percent of the income of large landowners came from livestock. Von Braun and Pandya-Lorch (1991) identify four countries where the malnourished get more of their incomes from livestock than those who are not malnourished. Vosti, Witcover, and Carpentier (1998) show an exception to this trend in their study of Brazil. In parts of Latin America, such as the Amazon and Argentine Pampas, successful animal grazing requires control of large amounts of land.

Poor people have few opportunities to increase their incomes because of limited access to land and capital. Small-scale and backyard livestock production enables the poor to earn income from animals grazed on common property pastures or fed household waste. Livestock production offers one of the few rapidly growing markets that poor, rural people can join even if they lack substantial amounts of land, training, and capital.

The importance of livestock for women's incomes in developing countries has been widely em-

Table 29—The place of livestock in the income of the rich and poor

Country	Wealth/poverty indicator	Stratum	Percent of household income from livestock	Period/size of sample	Source
Brazil (Western Amazon)	Household income stratum	Lowest 1/5 Highest 1/5	37[a] 64[a]	1994, 154 rural households	Vosti, Witcover, and Carpentier 1998
Ethiopia	Household income stratum	Very poor Poor	6 24	1988–89, 550 rural households	Webb and von Braun 1994
Kenya	Household income stratum	Lowest 1/5 Highest 1/5	61[b] 38[b]	1998, 310 dairy farmers	Staal and Baltenweck 1998
Pakistan	Household income stratum	Lowest 1/5 Highest 1/5	25 9	1986–89, 727 rural households	Adams and He 1995
Philippines	Household income stratum	Lowest 1/5 Highest 1/5	23[c] 10[c]	1984–85, 500 rural households	Bouis 1991

(continued)

Table 29—Continued

Country	Wealth/poverty indicator	Stratum	Percent of household income from livestock	Period/size of sample	Source
Senegal					Kelly et al. 1993
Sahelian (driest) zone	Household income stratum	Lowest 1/3	24	1988–90, 29 rural households	
		Highest 1/3	14		
Sudanian (transition) zone	Household income stratum	Lowest 1/3	10	1988–90, 58–67 rural households	
		Highest 1/3	8		
Guinean (forested) zone	Household income stratum	Lowest 1/3	6	1988–90, 92–102 rural households	
		Highest 1/3	6		
Sudan	Household income stratum	Lowest 1/5	14	1989, 240 rural households	Teklu, von Braun, and Zaki 1991
		Highest 1/5	13		
Egypt	Landholdings	Landless or near landless	63	1976–77, 165 households	Fitch and Soliman 1983
		Largest landholders	14		
India (Andhra Pradesh and Maharashtra)	Landholdings	Lowest 1/5 of land distribution	5	1997, 699 households	Kerr 1998
		Highest 1/5 of land distribution	6		
India (Andhra Pradesh and Maharashtra)	Landholdings	Landless	7	1975–78, 240 households	Singh, Asokan, and Walker 1982
		Largest landholders	15		
Mozambique					Mozambique MOA/MSU/UA Research Team 1992
Monapo	Landholdings	Lowest 1/4 of land distribution	2	1991, 343 smallholder households	
		Highest 1/4 of land distribution	5		
Ribaue	Landholdings	Lowest 1/4 of land distribution	6		
		Highest 1/4 of land distribution	5		
Angoche	Landholdings	Lowest 1/4 of land distribution	3		
		Highest 1/4 of land distribution	2		
Pakistan	Landholdings	Landless	14	1986–89, 727 households	Adams and He 1995
		Largest landholders	11		
Brazil	Dietary adequacy	Malnourished	32	1984, 384 rural households	von Braun and Pandya-Lorch 1991
		Not malnourished	27		
Pakistan	Dietary adequacy	Malnourished	16	1986–87, 1,082 rural households	von Braun and Pandya-Lorch 1991
		Not malnourished	14		
Philippines	Dietary adequacy	Malnourished	10	1983–84, 792 rural households	von Braun and Pandya-Lorch 1991
		Not malnourished	9		
Sri Lanka	Dietary adequacy	Malnourished	4	1984, 480 rural households	von Braun and Pandya-Lorch 1991
		Not malnourished	1		

[a]Percent of income from cattle.
[b]Percent of income from dairying.
[c]Percent of income from livestock, fruit, and vegetables.

phasized (Quisumbing et al. 1995; Valdivia, Dunn, and Sherbourne 1995). Dairy cooperatives have in fact been a major means of bringing women in poor areas successfully into the cash economy in East Africa (Brokken and Seyoum 1992), India (Schneider 1995), and Bolivia (Valdivia, Dunn, and Sherbourne 1995).

A pattern that shows that the poor earn a higher share of their income from livestock than do the wealthy raises the possibility that the Livestock Revolution will be good for the poor. The revolution offers two main reasons for optimism. First, the poor can more easily improve their incomes when they have a major stake in a sector that is growing. Second, the current rapid intensification of animal production comes at a time when the rural poor desperately need higher returns to their shrinking land than field crops alone can offer.

The main reason for concern is that increased intensification might make small operators uncompetitive compared to large producers. But true economies of scale in livestock production may not be great once explicit and implicit government subsidies to larger producers are taken into account. Large producers in many areas enjoy capital subsidies, tax holidays, free government services, exoneration from certain pollution and health requirements, and subsidies on public grazing land rented in large units. Elimination of subsidies or their redirection toward small-scale producers could shift the market in favor of the poor.

A less tractable problem is that large producers often find it easier to contract or vertically integrate with processors than do small producers in developing countries, and there are major economies of scale in the processing of perishable products. Trade in perishables benefits greatly from processing arrangements that standardize quality and make the quantity supplied plentiful and reliable. Large producers also benefit greatly from marketing infrastructure that alleviates the need to sell perishables the same day to the end user, as is traditionally the case in the developing tropics.

Small operators can overcome these barriers by joining institutions of collective action, such as outgrower schemes or participatory producer cooperatives (Staal, Delgado, and Nicholson 1997; Delgado 1998). But the establishment of such institutions requires organization and investment that does not currently exist in most developing countries.

Opportunities for rapid growth are rare in poor rural areas. Livestock production may provide one such opportunity. The poor around the world have shown their ability to produce livestock, and the future for the sector as a whole looks good. However, policymakers and researchers urgently need to find the best market-oriented means for ensuring that small operators benefit from growth in the livestock sector. To accomplish this, policies will have to focus on rural organization. Livestock production may provide one of the major operational themes in effective rural poverty alleviation during the next 20 years, but things could also go the other way. Failure to address how policies have tended to skew livestock development in favor of overly large production units, and failure to promote the vertical coordination of small operators with processors, will lead to a major missed opportunity. Worse, those who need the activity most could be driven out of livestock production.

Other Ethical Issues Raised by Trends in Livestock Production

Some nonfood ethical issues associated with the Livestock Revolution cannot be neglected. To date these issues have manifested themselves primarily in developed countries, where intensification has proceeded the most. But there is no reason to think that these concerns will not show up elsewhere soon.

Animal welfare is a growing ethical concern in the era of massive hog factories and industrial chicken houses (CAST 1997b). As production intensifies in developing countries, concerns over animal welfare will surely surface. Evidence for this is suggested by cultural attitudes toward cows in India, by the strong religious views on ritual slaughter held in many parts of the world, and by the esteem that traditional stockraisers everywhere hold for their cattle.

The air and water pollution that intensive animal industries occasionally create for their neighbors, especially in periurban areas with little participatory government, is also likely to bring increased conflict. Pure market forces in the absence of effective political backlash could create hog lagoons alongside residential neighborhoods. Advance planning and appropriate regulation by accountable government authorities can help overcome the fact that markets do not always reflect the full costs borne by all parties, including neighbors.

Finally, genetic engineering could push the limits of ethical debates in the next 20 years (see Chapter 9 for a discussion of the technology). Cloning of animals raises understandable concerns about possible abuses, particularly given the temptation to work next on humans. Yet the insertion of human genes into transgenic livestock in order to mass produce human proteins in animal milk may be essential for lowering the production costs of numerous pharmaceuticals that remain out of reach for all but the relatively rich. Such experiments may also lead to the development of new drugs, for example for the treatment of cystic fibrosis (Gillis 1999). Regardless of the viewpoint adopted, few people anywhere who are aware of the issues will remain morally indifferent.

7. Environmental Sustainability

Rapidly increasing livestock production can cause serious damage to the environment, but it can also be harmonious with or even beneficial to the environment when appropriate types and levels of production are in place.[11] Technological progress can further reduce damaging effects while increasing output. This chapter will identify the environmental problems that are now or likely to become the most severe and the policies that exacerbate these problems. It will also identify technologies and policies that can enhance the environmental sustainability of livestock production as the Livestock Revolution unfolds.

Livestock-Environment Compatibility

Historically, livestock have played a critical role in the process of agricultural intensification. Livestock recycle nutrients on the farm, produce valuable output from land that is not suitable for sustained crop production, and provide energy and capital for successful farm operations. The integration of livestock and crop operations is still the main avenue for sustainable intensification of agriculture in many regions of the developing world. This is especially true in semiarid and subhumid savanna areas receiving 600 to 1,200 millimeters of annual rainfall. Much of the interior of West, East, and Southern Africa, northeast Brazil, and much of South Asia belong to this agroclimatic category.

Livestock can help maintain soil fertility in soils lacking adequate organic content or nutrients (Ehui et al. 1998). Adding manure to the soil increases the nutrient retention capacity (or cation-exchange capacity), improves the soil's physical condition by increasing its water-holding capacity, and improves soil structure. Animal manure also helps maintain or create a better climate for micro flora and fauna in soils. Grazing animals improve soil cover by dispersing seeds, controlling shrub growth, breaking up soil crusts, and removing biomass that otherwise might be fuel for brush fires. These activities stimulate grass tillering and improve seed germination, and thus improve land quality and vegetation growth.

Livestock enable farmers in the resource-poor areas of developing countries to allocate plant nutrients across time and space. Land that cannot sustain crop production can be used for grazing to produce manure that can make other land more productive. Grazing livestock can accelerate transformation of nutrients in crop byproducts to fertilizer, speeding the process of land recovery between crops.

Large parts of the developing world, especially in subhumid Africa, are only now beginning to gain the benefits of farming that mixes crops and livestock. As disease constraints are removed, large livestock animals can be integrated into crop operations, providing farm power and manure. In other parts of the world, such as Asia, high cropping and land-use intensities have been sustained over centuries by integrating crop and livestock activities. Livestock continue to be kept for manure and power in these areas, but food production is becoming more prominent with increasing commercialization.

Mixed livestock and crop farming takes on a different form in the more intensified production systems in both developed and developing countries. Crop and livestock operations are integrated into a local system where waste from each operation is processed and transported to become a cheap

[11] This chapter draws on Steinfeld, de Haan, and Blackburn (1997) and de Haan, Steinfeld, and Blackburn (1997).

input for the other. Regionwide integration of livestock and crop operations emerges fairly soon in mixed farming. Small-scale rural infrastructure, such as feeder roads and light motorized or animal transport, facilitate this integration. In more intensive industrial farming systems, the potential for overloading fields with nutrients from farm manure becomes a problem.

Environmental Problems in the Low-Intensity Livestock Systems of Developing Countries

Traditional, low-intensity livestock production methods remain in many regions of the world. Production levels in these systems are determined by locally available resources. Increased demand pressure can push these systems to produce beyond their capacity. This can bring them into conflict with the environment, necessitating changes in traditional practices to reduce damage.

Livestock graze on about 26 percent of the world's land area. Grazing systems in developing regions mainly rely on native grassland and are only partially mixed with crops. These systems usually do not involve inputs from outside the system. Overgrazing can cause soil compaction and erosion, and can decrease soil fertility, organic matter content, and water infiltration and storage. Overgrazing in hilly environments can accelerate erosion.

The United Nations Environment Programme (UNEP) estimates that since 1945 about 680 million hectares, or 20 percent of the world's grazing lands, have been significantly degraded (Oldeman, Hakkeling, and Sombroek 1991). Recent evidence suggests, however, that grazing systems are more resilient than once thought, even in the worst cases, where drought has extended desert margins. Satellite imagery shows recent vegetation growing in the West African Sahel at the same northern limits where it once grew before the big droughts of the 1970s and 1980s (Tucker, Dregne, and Newcomb 1991).

Arid grazing systems have extremely limited potential for increasing productivity and great potential for suffering lasting damage. Production in these areas has adapted continuously to highly variable rainfall and feed availability (Behnke, Scoones, and Kerven 1993). Where irrigation or crop production have interfered with livestock resources and movement patterns, ecologically sound systems often have been disrupted. Populations have become sedentary around water points in many cases. The resulting overgrazing and land degradation have threatened the livelihood of pastoral communities.

Flexibility and mobility are essential for achieving sustainable rangeland use in arid areas. Unfortunately, both were seriously impaired in the past by policies that settled pastoralists and attempted to regulate stocking rates from above rather than in consultation with stock raisers. Well-intentioned changes often disrupt traditional systems and sometimes make them unsustainable. For example, new water points induce settlement of large animal and human populations in dry areas. They also make possible year-round grazing instead of allowing stocking levels to fluctuate so that they are low during the dry season. The resulting overload of animals on the range severely degrades grazing resources around the new source of water.

Semiarid zones can sustain more intensive agriculture than arid zones, making possible greater human and livestock populations. Crop encroachment on pastures, deforestation through fuelwood collection, and overgrazing of remaining pastures can then ensue. Crop encroachment on marginal land not only exposes the soil directly to the erosive effects of winds and heavy rains, but it hampers the flexibility of animal movement by obliterating passages between wet- and dry-season grazing areas. Drought emergency programs that hand out subsidized concentrate feed further contribute to range degradation by enabling too many animals to be maintained on the range and preventing natural regeneration of the range vegetation after drought. These feed subsidies increasingly have become an entitlement for pastoralists, especially in North Africa and the Middle East.

Human population pressure is a key contributor to environmental degradation in many areas where livestock are kept. When institutional failure allows people to extract private goods (livestock production) from public goods (common rangeland) without limit, the degradation is even greater. The situation is aggravated further when stock numbers can be kept high at all times because of water development and local cropping in previously pastoral areas. These well-intentioned but ecologically harmful policies often explain why degradation tends to be more severe in semiarid zones than in arid rangelands.

Tropical rainforests cover about 720 million hectares and contain approximately 50 percent of the world's biodiversity. More than 200 million hectares of tropical rainforest have been lost since 1950. Contributing factors include ranching, crop cultivation, and forest exploitation. Ranching-associated deforestation has been linked to the loss of some unique plant and animal species in South and Central America, the world's richest source of biodiversity. In Central America the area under pasture has increased from 3.5 million to 9.5 million hectares since 1950, and cattle populations have more than doubled from 4.2 million to 9.6 million head (Kaimonitz 1995).

Clearing forest and savanna to establish pastures in humid areas causes soil nutrients to leach out rapidly under high rainfall and high temperatures. Weeds soon displace grasses and artificial pastures can only be sustained for a period of up to 10 years. More than 50 percent of the pasture areas in the Amazon are now ungrazed fallow, with a significant portion being abandoned because of degradation. Natural regeneration of forests is difficult, especially when the cleared areas are large.

Policies that make titling of land easy and provide financial incentives for large ranches have been the main reasons for ranch-induced deforestation (Kaimonitz 1995). In the late 1960s and 1970s, Brazil subsidized agricultural loans and beef exports, playing an important role in ranch expansion. These policies have now been phased out and investment in large ranches by absentee owners has declined, and so has the rate of deforestation. In Central America in the 1980s rainforests disappeared at an annual rate of 430,000 hectares per year. In 1990–94 that rate was 320,000 hectares annually. The lesson of the 1960s and 1970s is that subsidizing horizontal expansion of livestock production can cause great environmental damage and create disincentives for intensification.

Increasingly evident in the Amazon today are small crop farmers who switch their cleared-forest fields over to livestock grazing only after the soil nutrients necessary to raise crops have been expended (Faminow and Vosti 1998). How these farmers will survive on land that is increasingly degraded is uncertain. No clear alternatives exist.

In many regions farm sizes may shrink because of population pressure, urban encroachment, and subdivision among heirs. Expanding farm operations into communal or new land under these conditions often leads to deforestation or overgrazing. As communal grazing and new land become increasingly scarce, whole farming systems may lose their livestock component. First to go are large stock such as cattle, jeopardizing the nutrient balance in farms along with farmers' livelihoods. Reported nutrient deficits range from about 15 kilograms of nitrogen per hectare per year in Mali, to more than 100 kilograms of nitrogen per hectare per year in the highlands of Ethiopia (de Wit, Westra, and Nell 1996).

In virtually all tropical highland areas (for example, the Himalayan hills, African highlands, Andean countries, and Java) relatively high human population densities are traditionally sustained by complex mixed farming systems. Further population growth in many of these regions has made it impossible for the traditional mixed systems to survive. Modified mixed smallholder farming is possible when market development permits investment in intensive technologies and inputs.

Environmental Problems of High-Intensity Industrial Livestock Production

As livestock production intensifies, producers adopt technologies that minimize overt direct costs associated with land and labor and take maximum advantage of free access to environmental public goods and capital subsidies. These highly intensive industrial production methods are the rule in developed countries and growing rapidly in importance in the developing world.

Escalating demand for animal products leads to animal concentrations that are out of balance with the waste absorption and feed supply capacity of available land. High concentrations of animals close to human agglomerations often cause enormous pollution problems. Large areas of Western Europe (Netherlands, northwestern Germany, Brittany [France], the Italian Po valley), the northeastern United States, and, increasingly, coastal Southeast Asia and large plain areas in China now show enormous nutrient surpluses that range from 200 to more than 1,000 kilograms of nitrogen per hectare per year (Steinfeld, de Haan, and Blackburn 1997).

Globally pig and poultry industries produce 6.9 million tons of nitrogen per year, equivalent to 7 percent of total inorganic nitrogen fertilizer produced in the world. Excess nitrogen and phosphorus leach or run off the land, affecting groundwater quality and damaging aquatic and wetland ecosystems. Tests in Pennsylvania have shown that about 40 percent of the soil samples from mixed dairy and crop farms exhibited excessive phosphorus and potassium levels. Surplus nutrients from saturated soils leach into surface water and pollute the environment (Narrod, Reynnells, and Wells 1994). A similar scenario is unfolding in Brittany, where one in eight districts had soils with nitrate levels of more than 40 milligrams per liter in the 1980s. Now all eight districts report such nitrate levels, which can cause extensive damage to the region's aquatic systems (Brandjes et al. 1995).

Excess concentrations of livestock and livestock waste also produce gases. Some, such as ammonia, remain local. Others, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) affect the world's atmosphere by trapping the sun's energy and contributing to global warming.

There are three main sources of livestock-related carbon dioxide emissions. First, domesticated animals emit carbon dioxide as part of basic metabolic functioning or respiration, at an estimated level of 2.8 billion metric tons annually. Second, carbon dioxide emissions result from biomass burning, part of which can be attributed to land clearing and bush fires on pasture used to enhance pasture growth. Third, carbon dioxide is released when fossil fuels are consumed for livestock-related manufacturing and transportation.

Livestock and manure management contribute about 16 percent of the global annual production of 550 million tons of methane. Ruminants mainly produce the methane as a by-product of digesting large amounts of grasses and other fibrous feeds. Pigs and poultry emit relatively low amounts of methane because they cannot digest these fibrous feeds. Methane emissions per unit of product are highest when feed quality is low, which is common, especially in the lowland tropics and subtropics of developing countries.

Twenty percent of methane emanating from animal production comes from manure stored under anaerobic conditions, such as in holding ponds (USEPA 1995). The high levels of methane emanating from anaerobic conditions are usually associated with high levels of productivity and intensity and large production units.

Animal manure also produces nitrous oxide, the most damaging greenhouse gas (320 times more so than carbon dioxide). Animal waste contributes about 0.4 million tons of nitrogen per year, or 7 percent of the total global emissions (Bouwman, Batjes, and Bridges 1992).

The feed requirements of expanding meat and milk production exceed what can be sustained by traditional feed resources such as grazing land and crop by-products. Increasingly the world livestock sector resorts to external inputs, notably high-energy feed such as cereals and oilcakes. Roughage is decreasing in importance as feed and being replaced by cereal and agro-industrial by-products. A corresponding shift toward producing monogastric animals, mainly poultry and pigs, is taking place. While ruminant meat accounted for 54 percent of total meat production in the developing countries in 1970 (FAO 1995a), it accounted for 35 percent in the early 1990s. This species shift is driven in part by the better conversion rates for concentrate feeds offered by monogastric animals.

Feedcrops differ in their pesticide needs and propensity to deplete soil moisture, water, and nutrients. In general, cereal crops (maize in particular) have the potential to cause greater environmental damage than other crops. Cereals require heavy fertilizer and pesticide use and a great deal of water and offer poor ground cover in the early stages of plant development. Legumes, such as soybeans and pulses, generally have the least potential for damage. Maize and wheat deplete nitrates and phosphates the most, while cassava and sweet potatoes deplete the most soil nutrients.

The Environmental Challenge

Industrial livestock production is rapidly springing up close to urban centers in developing countries, because of weak infrastructure, high transport costs, and weak regulation. Like many cities in East and Southern Africa, Dar-es-Salaam, the capital of Tanzania, now has 20,000 dairy cows kept within the city limits. Urban piggeries are increasingly common in Asia, especially coastal China. Large-scale poultry operations are found in periurban areas throughout the developing world.

Industrial and intensive mixed farming systems present the most severe environmental challenge in the livestock sector. These systems have often benefited from policy distortions and the absence of regulations or their lack of enforcement. The regulatory vacuum has often given this type of production a competitive edge over land-based systems. Furthermore, some policies have misdirected resource use and encouraged the development of technologies that are inefficient outside the distorted context. Many developing countries not only provide direct subsidies for feed but also for energy and capital, which constitute some of the major direct costs of industrial production. Economywide policies that offer subsidies for energy and credit often end up favoring industrial production over less-intensive mixed farming and grazing.

Technology can offer solutions to many environmental problems, especially under industrial conditions. But most policy frameworks enable the cheap supply of animal products at the expense of the environment. Self-sufficiency in animal products and continuous supply of high-value food commodities to urban populations are often the overriding policy objectives, particularly in developing countries.

In the developed world the pollution of land, water, and air has raised acute awareness of the environmental problems associated with industrial livestock production. In many cases this has triggered the establishment of policies and regulatory measures that address these problems. Developing countries, on the other hand, typically exhibit an absence of appropriate and enforceable regulations, together with a surge in demand and a lack of effective political expression of concern about growing environmental and health hazards.

Concerns about the long-term productivity of natural resources, including land, water, air, and biodiversity, will not be reflected in market prices unless governments and international organizations define and establish mechanisms to reflect the present and future value of natural resources. Institutions that provide regulatory frameworks need to be developed, local groups need to be empowered, and a legal authority that implements environmental policies needs to be established or reinforced. Prices should be adjusted through taxation to correct for uncharged environmental costs and encourage efficient resource use. Appropriate technological change, the key to solving environmental problems, must be facilitated by government support.

8. Public Health

Livestock production is a source of risk to human health in both low- and high- intensity production systems. Risks exist not only from the uncontrolled endemic diseases found in developing regions, but also from those that appear in highly developed production systems when animal concentrations are high, feeds contain contaminants, or meat and milk are improperly handled. Humans are exposed to these risks through several pathways. Zoonotic diseases, those shared by humans and animals, can mutate and spread in animal hosts before passing to humans. Animal wastes can carry disease or chemical toxins into the environment. And milk and meat can expose humans to disease and toxins contained in the animals or produced by improper handling and processing.

Although great progress has been made in controlling endemic diseases of animals, intensification of both traditional and modern livestock production systems has brought about new risks. High concentrations of animals, often moving between locations for different stages of production, can become breeding grounds for disease. Proximity of these facilities to high human populations can magnify the potential damage of an outbreak.

Livestock pose a particular risk in developing regions, where animal concentrations are often located near and around cities because of limited transportation facilities and infrastructure. The risks are compounded by inadequate or nonexistent health infrastructure, regulations, monitoring, or enforcement. Zoonotic diseases such as tuberculosis and brucellosis, which are nearly or entirely controlled in developed regions, continue to pose major problems in these regions.

Health risks in developing countries are still often monitored only at the household level. As livestock production levels rise, the ability of people to gauge the quality of the animal food products they purchase in market places becomes increasingly difficult. The classic worry in developing countries is the microbial contamination of food. Bacilli or bacteria such as *Salmonella*, *Escherichia coli*, *Clostridium botulinum,* and *Staphylococcus* are the most frequently observed causes of food-borne diseases. They are usually related to improper food preparation or inadequate refrigeration.

The World Health Organization (WHO) reports that hundreds of millions of people worldwide suffer from diseases caused by contaminated food and that products of animal origin rank at the top of the list of causes (WHO 1997). More than 3 million children under five years of age die each year because of diarrhea. Contaminated water and food-borne pathogens cause much of this diarrhea. Salmonella infections are also on the rise and threaten to become major public health concerns, especially in big Asian cities where large bird flocks are kept for food and fecal contamination is hard to control.

Risks from the intense industrialization of livestock production are also appearing in developed countries. Movements of animals for birthing, weaning, and fattening have aggravated health risks because animals from different locations are exposed to each other and to humans. Risks of transmission are further increased by greater international trade of livestock and livestock products.

Intensive livestock production units can also breed new and more virulent strains of zoonotic diseases. Antibiotics used in intensive animal production of poultry have led to the emergence of *Salmonella*, *Listeria*, and *E. coli* resistant to antibiotics. There is increasing concern about new strains of influenza developing in pigs and chickens that could be transmitted to humans, such as the avian flu strain that forced eradication of chickens in Hong Kong in 1997. Some researchers go so far as to say that the next lethal flu pandemic might emerge from Europe’s crowded pig barns (MacKenzie 1998).

Despite long-established food quality assurance systems in developed countries, new food contamination risks have emerged. According to WHO, seven food-borne pathogens *(Campylobacter jejuni*, *Clostridium perfringens*, *E. coli* O157:H7, *Listeria monocytogenes*, *Salmonella*, *Staphylococcus aureus*, and *Toxoplasma gondii*) are responsible for an estimated 3.3 to 12.3 million infections and 3,900 deaths annually in the United States (WHO 1997). Furthermore, global surveys by WHO indicate that food-borne diseases may occur 300-350 times more frequently than reported.

Salmonellae are blamed for more than 50,000 cases of bacterial food poisoning in the United States every year (WHO 1997). Transmission of this microbe usually occurs through insufficiently cooked meats and eggs. Chickens are a major reservoir of salmonella. Ingesting foods contaminated with significant amounts of salmonella can cause intestinal infection.

The increased size of production units and frequency of contact between animals greatly increases the overall impact of outbreaks of illness. Six million pigs were destroyed in Holland to eradicate classical swine fever in 1997. As this report was being written, Malaysians were in the process of destroying a million pigs in their largest pork producing region to stem an outbreak of a new form of viral encephalitis that has killed more than 100 people in six months (*Washington Post* 1999; ProMed 1999).

Use of new feed resources has also brought new risks. Insufficient temperatures used in rendering animal tissue into feed has been clearly linked to the appearance of BSE (bovine spongiforme encephalopathy), or mad-cow disease, in cattle. The infectious prions involved are similar to those that cause CJD (Creutzfeldt-Jakob disease). More than 20 human victims in the United Kingdom are thought to have contracted the disease through ingestion of animal nerve tissue.

Infection with *Escherichia coli* O157:H7 (*E. coli*) was first described in 1982. *E. coli* has emerged rapidly as a major cause of diarrhea and acute renal failure. The infection is sometimes fatal, particularly in children. Outbreaks, generally associated with beef, have been reported in Australia, Canada, Japan, the United States, various European countries, and southern Africa (WHO 1997).

Beef that was contaminated in the slaughterhouse is the principal cause of *E. coli* infection in humans. Bacteria are transmitted when infected meat is consumed raw or undercooked. Ground meats, such as hamburgers, are particularly associated with infections because the infected material is mixed throughout the product during the grinding process.

Hygienic slaughtering practices will reduce contamination of carcasses but will not guarantee the absence of microbial contamination from products. Similarly, the contamination of raw milk on the farm cannot be completely prevented. The only effective method of eliminating dangerous microbes is to heat (thoroughly cook or pasteurize) or irradiate food.

Listeria monocytogenes (*Lm*) has been recognized as a risk only recently. It infects cheese and meat that has been refrigerated for a long time. *Listeria monocytogenes* infections can cause miscarriage in women and septicemia (blood poisoning) and meningitis in infants and persons with weakened immune systems.

Nonmicrobial contamination of food also poses a risk. Food-borne chemical toxins increasingly prevalent in rapidly developing countries include pesticide residues (often containing mercury or arsenic), metals (zinc, cadmium, and copper), and heavy metals (especially mercury from pigs eating fungicide-treated corn).

Livestock feeding is partly to blame as well for the accumulation of toxic levels of heavy metals in the environment. Trace elements are often added to animal feeds to supply micronutrients and enhance feed conversion efficiency. Copper and zinc are deliberately added to a variety of animal feed concentrates, while heavy metals like cadmium are introduced involuntarily via feed phosphates. During digestion the elements are concentrated, resulting in manure and slurries that can contain high levels of the toxic elements. Soils on which pig and poultry manure are regularly applied at high rates can accumulate large amounts of heavy metals, which can in turn contaminate crops and pose a health risk to humans. High concentrations of toxic elements can also accumulate in the meat of animals fed feeds with trace metals.

Residues of growth hormones, antibiotics, and insecticides are increasingly found in the tissues of animals raised in industrial production systems. The presence of antibiotics in animal food products can cause allergies. Overdoses of antibiotics are often used illegally in feed to promote growth where enforcement systems are weak. Considerable debate (and trade dispute) also exists about the safety of growth hormones such as BST (bovine somatotropin). The illegal use and misuse of growth promoters such as DES (diethyl-stilbetrol) and clenbuterol can also create problems.

Traditionally the health risks from livestock and livestock products have been borne by consumers and farmers. With intensification has come recognition that many risks cannot be controlled at the household and farm levels alone. Consumers cannot adequately judge the safety of food that was produced and processed far from the household. Farmers acting individually cannot fully protect their animals from diseases that spread from farm to farm. In many cases institutions are required to develop, monitor, and enforce quality standards across the marketing chain. Unfortunately, government services are being curtailed in this area in many poor countries as the size of the overall public sector is being reduced.

9. Technology Needs and Prospects

Increases in the productivity of animal food production come from the development and transfer of animal production technologies, particularly for animal health; improved feed and feed use; genetic enhancement; and better postharvest handling. Livestock technology policy faces two challenges in its efforts to raise productivity. First, appropriate existing and new technologies and production systems have to be adapted and disseminated to the developing world to eliminate low productivity. Second, the limits of livestock production technology and systems have to be extended to increase efficiency further and the environmental and public health problems that have appeared in high-intensity livestock production have to be solved. This chapter surveys the technologies and policies available or in development to meet these challenges.

Addressing Animal Health Constraints

Infectious and parasitic diseases affecting livestock remain important constraints to profitable livestock operations in many developing regions. Diseases reduce incomes directly by causing considerable livestock losses and indirectly by necessitating health restrictions on exports. In some areas (including the former socialist countries) the problem is worsening because of weak veterinary and administrative services, the absence of accountable local government, and civil strife.

Infectious diseases such as rinderpest, foot and mouth disease (FMD), contagious bovine pleuropneumonia (CBPP), and *peste des petits ruminants* (PPR) still pose major threats to livestock production in developing countries. These epizootic diseases, so-called because they often manifest themselves as epidemics affecting large numbers of animals of the same species in a given area, are most prevalent in production systems in which animals move uncontrolled and unmonitored over large distances. Vaccination and surveillance programs are needed to keep these diseases in check. The global eradication of rinderpest by 2010, for example, remains an achievable and important goal for developing countries.

Livestock disease control has undergone a paradigm shift in recent years. More flexible control strategies that focus on regions of highest returns within a country are replacing countrywide eradication programs. Risk analysis and animal health economics help determine where disease control investment will have its greatest benefit. The acceptance of disease-free or low-risk status for regions (rather than for entire countries) in international agreements such as the sanitary and phytosanitary (SPS) agreement of the World Trade Organization (WTO) illustrates this trend. The treaty makes possible export of meat and other livestock products from a country where a disease such as FMD exists, as long as the disease is either not present in the region where the meat is produced or the risk of transmission through multiple controls is extremely low.

Biotechnology offers promise for the improved diagnosis and treatment of animal disease. Even as the incidence of zoonotic diseases rises because of increased concentrations of animals near people, livestock health research benefits from the greater resources available to human health research (Fitzhugh 1998). For example, genomics is a new science applicable to humans and livestock that permits sequencing and mapping of the genome (a genetic map of a living organism). Genomics takes advantage of the work on the genomes of disease organisms and permits the development of new generations of vaccines, including those that use recombinant antigens to pathological agents. Livestock disease organisms can also provide useful models for studying human health (Ole Moi-Yoi 1995).

African swine fever is a major constraint to expanding pork production in Africa. In a series of recent outbreaks, pig numbers have been reduced by between 30 and 70 percent in a wide range of coastal African countries. Movement and sanitary control can limit future outbreaks but require more effective veterinary institutions.

Farmers in developing regions typically lack low-cost, easy-to-use diagnostics, vaccines, and control strategies for disease organisms and vectors. Among the parasitic diseases, trypanosomiasis (sleeping sickness) transmitted by tsetse flies, poses an enormous constraint to cattle production in most of the humid and subhumid zones of Africa.

Combinations of aerial insecticide sprays, adhesive pyretheroid insecticides, impregnated screens and traps, sterile insect mating, and trypanocide drugs hold the promise of gradually recovering infested areas for mixed farming and increased livestock output. These strategies also are likely to improve crop output.

Other important parasitic disease groups include helminthiasis and tick-borne diseases. Helminths are rarely fatal, but they limit productivity in many production systems. They become a limiting factor in the intensification stage but can be controlled. Ticks have the capacity to transmit diseases, notably east coast fever in Eastern and Southern African countries. An effective vaccine for this disease may soon be available, with a potentially large impact on ruminant productivity in these countries (ILRI 1998).

Improving Feed Quantity and Quality

A large number of the world's livestock, particularly ruminants in pastoral and low-input mixed-farming systems, suffer either permanent or seasonal nutritional stress. In many regions these pressures have been alleviated through better storage of locally available resources. Storage and conservation of forage, use of high-protein leguminous fodders and fodder trees in rations, treatment of crop residues, and addition of mineral nutrients to feed all offer ways to improve forage in some areas.

The potential to generate locally available fodder and cereal feed resources is great. But governments may need to create the scientific and transportation infrastructure necessary to reap the benefits of world feed resources and new feed technologies as they become available. The projections in Chapter 4 indicate that the necessary supplies of feed concentrates will be available on world markets without undue price rises. These projections depend on maintaining trends in technological progress that raise yields of major feedgrains such as maize.

But even if aggregate quantities are available, ensuring that hundreds of millions of small producers have access to feed markets under developing-country conditions will be no small challenge. China's port and grain-importation infrastructure indicates the kinds of problems requiring remedy. In 1995 China imported an additional 15 million metric tons of grain, putting considerable stress on handling and distribution facilities (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1997). Significant bottlenecks occurred. Yet the baseline projection for 2020 indicates that China will import 45 million metric tons more cereals than in 1993 (Table 24).

Both developed and developing regions must continue to use rations more efficiently. The requirements and the quality and quantity of feed resources used for rations differ across species, breeds, systems, and regions. Research to reduce costs and improve efficiency will have to be highly targeted, but even so it will have spillover effects. Research that defines chemical composition and digestibility characteristics will contribute to crop-breeding strategies, particularly the need to change the phytochemistry of primary crop products and residues fed to livestock (Fitzhugh 1998).

New technologies that enhance the quantity and quality of available tropical feed resources are being assessed through nutrition research. The identification of suitable traits and their molecular markers help improve the quality of tropical feeds derived from foodcrops. Breeders use the markers to develop dual-purpose crops with improved grain yields and protein content for humans and nonruminants and higher-quality crop residues for ruminants.

Plant genomics and phytochemistry will tackle antinutritional factors (ANFs) in plants. Some of these ANFs can be poisonous to ruminants. Microbiological techniques will help enrich ruminant ecosystems with microbes that can better detoxify ANFs. Maize with reduced phytic acid content has recently been reported to improve feed conversion for chicks by up to 11 percent (CAST forthcoming).

The ability to increase starch content in feedgrains already evident in the developed world may become more attractive to developing countries by 2020. But these technologies for maize and sorghum are unlikely to extend feeding value per unit by more than 15 percent, even in developed countries. Pulverizing grain with steam before feeding probably will offer a more feasible and economical means for improving conversion efficiency (CAST forthcoming).

In developed countries, and increasingly also in intensive production systems in developing countries, a wide range of probiotic and antibiotic feed additives are part of the ration fed to livestock. Microbial action can help break down otherwise hard-to-digest roughage so that nutrients are better absorbed.

Finding better ways to use the vast abundance of fibrous biomass available in the world offers a particularly exciting area of research. Rumen microbiology research focuses on the isolation of fiber-degrading enzymes. Better use of fibrous feed materials will increase the availability of feed resources inedible to humans. Changing the capacity of the rumen to digest high-fiber fodders would dramatically improve the prospects of ruminant production in the subhumid savannas of Africa and Latin America, where extremely large quantities of biomass of low feed quality are produced. Inserting enhanced cellulase-producing capacity into rumen bacteria should be possible in the not too distant future (de Haan, Steinfeld, and Blackburn 1997; Cunningham 1997). Microbial genomics will increase the pace of progress in this area of research (Wallace and Lahlou-Kasi 1995; Odenyo, Osuji, and Negassa 1999).

With the great advances taking place in genetics, more progress should also be made in the feed conversion of monogastrics. During the past decade feed conversion rates for pigs and poultry have improved by 30-50 percent, in part through breeding and in part through addition of enzymes to feeds. Still, monogastrics capture only 25 to 35 percent of the nutrients in their feed. Genetic improvement and better balancing of feed will enable this trend to continue. Precision in animal feeding is foreseeable in developed countries. Nutrients excreted by animals will be greatly reduced, so that nutrients needed and supplied will be fairly equal (CAST forthcoming).

Finally, using growth hormones, such as bovine somatotropin (BST), with high-energy feeds has the potential to increase milk yields. But the technology is likely to benefit farms in developed countries more than those in developing countries. Estimated yield responses for BST vary widely, favoring farms with feeds, breeds, and management practices that are already extremely productive (Jarvis 1996).The harsh conditions in developing countries are unlikely to provide the environment necessary for large-scale benefits from BST. This will change in the long run, however, once livestock productivity in developing regions has benefited from other, less sophisticated technologies (Jarvis 1996).

Improved Reproductive and Genetic Technologies

Artificial insemination has been used for more than 50 years in developed countries, primarily on commercial dairy herds. An established technology, its further spread is likely to occur primarily through market processes. In the early 1990s, no more than 17 percent of the 50 million first inseminations given annually took place in developing countries. But usage is advancing rapidly in Asia, especially India, where growing milk demand has made it economical (Chupin and Thibier 1995; Chupin and Schuh 1993). Artificial insemination has considerably spurred genetic upgrading as large-scale testing of the progeny of bulls and the subsequent use of valuable breeders has become possible. Widespread adoption of artificial insemination is likely to occur in the more favored production environments of developing countries, such as temperate highlands and peri-urban commercial production areas. The demand for milk will provide returns for its introduction and the necessary technology and infrastructure are becoming available.

The use of embryo transfer, allowing cows of high genetic potential to produce a much larger number of calves than with normal reproduction, is currently limited to only a small part of the commercial herds in some developed countries. This form of reproduction probably will not become widespread in the developing countries within the next 20 years (Cunningham 1997).

Crossing of local breeds in developing countries with highly productive varieties from the developed countries has become commonplace for dairy cattle in the tropics. Considerable gains in productivity per animal (25 percent) have been obtained. Those gains can be maintained with judicious interbreeding or rotational breeding. However, the gains are typically lost in subsequent generations (Cunningham 1997). Other authors report gains of up to 50 percent, but stress the one-shot nature of the transfer and the restricted number of breeds that can be drawn upon (CAST forthcoming). Selection from local breeds, especially for mutton and goat meat, may hold considerably more promise.

The characterization, conservation, and use of tropical animal breeds are vital to the ability to respond to inevitably changing production environments. Adapted livestock are more resistant to disease and environmental challenges. They can maintain productivity without the need for high-value inputs, increase farm income, and contribute to poverty alleviation (Rege 1997; Hammond and Leitch 1995).

Advances in genetics also offer new means to improve livestock. Marker-assisted selection and detection of quantitative trait loci, for example, combine results from molecular and quantitative genetic research. Interactions between genetic traits and the environment need to be addressed in order to employ adaptation traits, such as genetic resistance to parasites, as production traits. As with disease resistance, insights from human genetics research can be brought to bear on the genetic improvement of livestock (Fitzhugh 1998).

It became possible during the past decade to produce maps of genetic linkages in order to identify the gene locations of economically important traits (disease resistance, performance). This technology, which is being developed for a large range of traits by a number of research institutes worldwide, carries the promise of a shortcut to genetic improvement in developing countries. Livestock can be bred for specific productive traits and the ability to adapt to harsh climates and resist diseases.

Genetic research in developed regions focuses less on producing the hearty animals that are necessary in stressful developing-country environments and more on making animals that produce higher quality products at minimum cost. Understanding the genetic make-up of animals has allowed particular product traits, such as low cholesterol levels or the ability to produce high concentrations of a pharmaceutical, to be added to animals. Recent advances in cloning of embryos could potentially have a large impact on livestock production, particularly of dairy cattle in developed countries. But this is still an area where a number of complex ethical and scientific issues have yet to be resolved (Cunningham 1997).

Postharvest Technology: Protecting Public Health and Increasing the Value of Livestock Output

In the next 20 years the transfer of meat and milk processing technology to developing countries by the private sector under public regulation is likely to be especially important for food production. Growth rates for the output of processed products will probably be even higher than the growth rates for meat and milk production in developing countries. An increasing share of total food production is expected to pass through marketing and processing channels.

The establishment of dairy plants and slaughterhouses in producing areas, together with market development, will play an important role in stimulating market-oriented production. The increasing importance of trading meat and milk over long distances in tropical climates will also encourage technology development and transfer for food commodities such as ultra-pasteurized dairy products and vacuum-packed meat. Food safety is likely to provide the major impetus for technology development over time. Food safety concerns will occasionally conflict with the objective of small operators to remain competitive. Current debates over milk pasteurization in East Africa bear witness to this conflict. East African consumers usually boil unpasteurized fresh milk collected earlier in the day because pasteurization makes products much more expensive (Staal, Delgado, and Nicholson 1997).

In the developed countries risk analysis is typically used to help evaluate existing programs for food safety. The trend toward globalization of trade makes this kind of analysis increasingly important. Risk analysis will have to be widely introduced in developing countries over the next two decades. It involves an iterative process with three sets of elements. First is risk assessment, estimating the probability and potential severity of damage resulting from food hazards. Second is risk management, the development of policy for food safety and food safety programs. Third is risk communication, productive interactions between policymakers and stakeholders.

Hazard Analysis Critical Control Points (HACCP) analysis is presently the tool of choice for handling the risks noted above. It identifies critical areas in the food chain that must be monitored to ensure food safety. Four steps are involved: assessment of risks in the food chain, determination of the critical control points and critical limits for ensuring food safety, development of monitoring systems, and implementation of procedures for verification. Postharvest methods that a short time ago seemed feasible only in the context of developed-country industrial processing are now becoming commonplace in the shrimp and high-value fisheries export sector of developing countries. Similar procedures for high-value meat and milk products should follow suit in the next two decades.

Technology to Improve the Environmental Effects of Livestock Production

Livestock are often cited as the source of environmental woes (Chapter 7). Not all of this negative publicity is merited, especially under developing-country conditions. Where the problem does exist, it is often a matter of fundamental economic structures and institutions that must be addressed through policy change rather than technology per se. Environmental degradation from deforestation and overstocking on the commons are cases in point. Yet technological development can offer some hope in developed countries, and will be increasingly useful in this regard in developing countries.

Livestock are cited as culprits in global climate change because they emit greenhouse gases. In developed countries livestock methane emissions can be reduced through the use of treated feeds and a ration closer to nutritional requirements. While emissions will continue to grow in absolute terms in developing countries, intensification of production will enhance the digestibility of feed, reducing emissions per unit of output.

Livestock also affect the environment by compacting the soil structure, which results in accelerated run-off and soil erosion. High stocking rates and uncontrolled grazing create this problem, especially in the hilly areas of developing countries. In order to manage the biomass needs of animals at varying grazing intensities and maintain a critical vegetative cover to minimize soil erosion, grazing options and pasture species have to be defined (Mwendera and Mohamed Saleem 1997; Mwendera, Mohamed Saleem, and Woldu 1997). Grazing systems will remain an important source of animal products for the foreseeable future. To some extent these systems can sustainably intensify production with stronger institutions, local empowerment, and regulation of access to resources.

Mixed farming systems around the world will continue to intensify and grow in size. Grazing systems may evolve into mixed farming systems where there is potential for mixed farming, as there is in the semiarid and subhumid tropics. Important productivity gains can be achieved in mixed farming by further enhancing nutrient and energy flows between crops and livestock. In mixed systems livestock substitute for natural and purchased inputs, in addition to producing meat and milk. The environmental and economic stability of mixed systems make this form of farming in developing countries a prime candidate for technology transfer and development.

Novel concepts are being developed to integrate crop and livestock production in a farming area rather than on individual farms. Areawide crop-livestock integration allows individual, specialized enterprises to operate separately but energy for farming and flows of organic and mineral matter to be linked by markets and regulations. This produces the highest efficiencies at the enterprise level while maximizing social benefits. A form of areawide mixed farming is already fairly common in developing countries, where manure is bartered for feed.

Industrial systems usually have a competitive edge over land-based systems. But in areas with high animal densities, industrial systems will have to absorb increased production costs as a result of more stringent regulations and pollution levies. In some cases, this will remove the competitive edge of industrial production.

Technology will play an important role in the processing of animal wastes into useful products. Such technologies, for the production of dry-pellet fertilizer from chicken waste, for example, are becoming fairly common in developed countries (CAST 1996). The economics of waste disposal in crowded developing countries are likely to evolve in this direction as well, though probably not in the next 15 years.

Likely Pathways for the Transfer of Livestock Technology to Developing Countries

A number of important technological developments are taking shape, particularly in genetics and reproduction, feeding, and animal health. By 2020 these developments probably will be widely in use. Demand-driven production systems in developing countries will likely adopt these technologies fairly rapidly. Most of these systems will be in East Asia, periurban India, and Latin America outside the Andean areas. Where demand is growing less quickly—most of South Asia, Sub-Saharan Africa, and the Andean countries—technology uptake will be slower and important pockets of technological stagnation will remain. Public-sector research and extension for livestock will have a high payoff in the fast-growing areas if they complement private-sector activity and facilitate access to small farmers. In the slow-growing areas public-sector research and extension will provide the main technological vehicle for addressing these issues.

In demand-driven settings, adoption usually occurs through market forces, as long as input prices reflect the relative scarcity of inputs and create the appropriate incentives. In particular, technologies for increased production of pork and poultry will be largely transferable.

Issues relating to livestock and the environment cannot be solved with technical innovations alone. A comprehensive policy framework is needed to facilitate the adoption of effective technologies. Technology remains the key component because future development, including that of the livestock sector, will depend upon land- and water-saving technology to substitute for use of natural resources. This trend toward knowledge-intensive systems can be widely observed. Smart technologies, supported by astute policies, can help to meet future demand while maintaining the integrity of the natural resource base. Better information on which to base decisionmaking is, therefore, urgently required.

New forms of commercial and specialized production that are based upon the resource endowments of a region and that maintain nutrient balances will have to be established. Intensive systems need to be integrated into a wider framework for land use in order to blend resource-saving technologies with the absorptive capacities of the surrounding land. This is particularly necessary for pig and poultry production. New organizational arrangements will have to be found to allow specialized units to capitalize on economies of scale. The future is likely to bring a transformation of family-based mixed farms into specialized and commercial enterprises in rural areas.

Policies will need to promote areawide integration (as opposed to individual farm integration). This kind of production organization is a long-term objective of environmentally sustainable agriculture in high-potential zones. In the developed world, excessive animal concentration is being controlled through quantitative limits on animal numbers and relocation of animal production to areas of lower density. Regulations for industrial production systems in urban and periurban environments need to enforce virtually zero greenhouse gas emissions and restrictive licensing.

To maintain the nutrient balance in nutrient-deficit mixed farming and to enhance crop-livestock integration in developing countries, policies need to provide incentives and services for technology uptake. To reduce nutrient surplus in mixed farming systems, regulations to control animal densities and waste discharge and incentives for waste reduction are required. Often this implies that subsidies on concentrate feed and inputs used in the production of feed need to be removed.

To address environmental degradation in the grazing areas of developing countries, policies need to facilitate local empowerment and create property-rights instruments, while allowing for the flexibility of movement of pastoralists. Land-tenure arrangements can also help limit the expansion of ranching into the rainforest frontier in Latin America. Lack of market access also degrades the land and needs to be addressed. Other incentives may help to reduce grazing pressure in the semiarid zones, for example, the introduction of full cost recovery for water and animal health services. Grazing fees would provide incentives. Similarly, taxation for pasture and cropland in rainforest areas can discourage forest conversion. This needs to be accompanied by regulations protecting the most valuable areas in terms of the environment or biodiversity.

Finally, as policymakers and development partners become increasingly aware of the key poverty alleviation role of livestock in developing countries, agencies charged with facilitating increased livestock productivity are likely to put poverty alleviation concerns higher on their agenda. This in turn is likely to bind technology development more tightly with cooperatives and other small-producer institutions that help small operators overcome the transaction costs of entry into a major commercial activity.

10. Taking Stock and Moving Forward

Truly it is not inappropriate to use the term "Livestock Revolution" to describe events in world agriculture in the next 20 years. Like the well-known Green Revolution, the label is a simple and convenient expression that summarizes a complex series of interrelated processes and outcomes. As in the case of cereals, the stakes for the poor in developing countries are enormous. Not unlike the Green Revolution, the "revolutionary" aspect comes from the participation of developing countries on a large scale in transformations that had previously occurred mostly in the temperate zones of developed countries. And like the gradually but steadily rising cereal yields in the 1970s and 1980s that typified the Green Revolution, the Livestock Revolution started off gradually and increased its rate of growth. But the similarities end there.

The Green Revolution for cereals was a supply-side phenomenon; it rested on fundamental technological change and the adaptation and extension of seed-fertilizer innovations in developing countries. The Livestock Revolution is demand-driven. With notable exceptions for milk and poultry in the developed countries, where technological progress arguably preceded and precipitated changes in demand through lower prices, the supply side of the Livestock Revolution until now has mostly responded—often under distorted incentives—to rapid increases in demand.

This paper shows that the Revolution has seven specific characteristics, each of which offers both dangers and positive opportunities for human welfare and environmental sustainability. The seven are: (1) rapid worldwide increases in consumption and production of livestock products; (2) a major increase in the share of developing countries in total livestock production and consumption; (3) ongoing change in the status of livestock production from a multipurpose activity with mostly nontradable output to food and feed production in the context of globally integrated markets; (4) increased substitution of meat and milk for grain in the human diet; (5) rapid rise in the use of cereal-based feeds; (6) greater stress put on grazing resources along with more land-intensive production closer to cities; and (7) the emergence of rapid technological change in livestock production and processing in industrial systems.

The dangers and opportunities raised by each of the seven characteristics of the Livestock Revolution will be examined in turn. Then four major pillars on which to base forward-looking policymaking for the livestock sectors of developing countries will be suggested. Many of the specific actions are discussed in more detail in the conclusions to Chapters 6 through 9 of the report.

Characteristics of the Livestock Revolution

Rapid Increases in Demand That Affect Production Patterns and Trade

Rapid demand growth in developing countries propels the global Livestock Revolution. Expanding demand is the result of a combination of high real income growth, swelling populations, rapid urbanization, and the ongoing diversification of developing-country diets away from very high levels of starchy staples. Milk consumption has grown more than 3 percent per year in developing countries since the early 1980s and is projected to grow even faster through 2020. Meat consumption has been growing about 5 percent per year and is expected to grow 2.8 percent per year through 2020.

These developing-country growth rates can be compared to the slow forecast for consumption growth in the developed world: 0.7 percent per year for meat and 0.4 percent per year for milk through 2020. This low growth in developed countries is largely explained by slow population growth, slowing urbanization, satiation of diets, and growing health concerns about high intakes of cholesterol and saturated fatty acids from some animal products.

The rapid growth in consumption of food from animals has not been and is not likely to be evenly distributed across regions or even within countries. Since the early 1980s, most growth in consumption of meat and milk has occurred in the rapidly developing countries of East and Southeast Asia and to a lesser extent in Latin America. Africa has lagged behind, as has India in the case of red meat, although India has recently witnessed rapid growth in milk and poultry consumption.

Production trends in the developing countries are following consumption trends. By 2020 the developing countries are expected to produce 95 million metric tons more meat per year and the developed countries 20 million metric tons more compared to production levels observed in the early 1990s. This production level equals an additional 15 kilograms per capita of meat in the developing world, given expected population in 2020. The value of the annual increase in animal food production in developing countries currently far exceeds that of the growth in production of all the major cereals combined. The caloric value of animal livestock food product increases will exceed the caloric value of cereals some time in the next 10 years. The developed countries are also expected to add an additional 15 kilograms per capita of annual meat production by 2020, much of which will be sold to the developing countries.

Such rapid change is creating new opportunities for livestock producers in developing countries, where some of the world's poorest people live. The increase in livestock food products also holds promise for relieving widespread micronutrient and protein malnutrition, while making positive contributions to the sustainable intensification of smallholder agriculture. Yet, significant new dangers are also arising. Some forms of livestock production encouraged by policy distortions are leading to serious environmental and health risks. Furthermore, increasingly global livestock and feed markets are sharing economic pains faster and more directly, even as they share economic prosperity. Understanding the stakes involved helps motivate those who seek to meet the emerging challenges.

World Market Share Steadily Shifts to Developing Countries

A steady increase is under way in the share of developing countries in the world's production of meat and milk. Shares for the latter commodities amounted to only 31 and 25 percent, respectively, in the early 1980s. The baseline projections estimate that developing-country shares in 2020 will be 60 percent and 52 percent. Clearly the brunt of the benefits and costs expected from the Livestock Revolution will accrue to the developing countries.

Sensitivity analysis suggests that these projected trends are robust. Even under the assumption of prolonged economic crisis in Asia, the growth of aggregate consumption of livestock products remains strong in developing countries. Furthermore, if tastes in India shift toward increased red meat consumption, as they already appear to have done for chicken, the negative effects of a severe Asian economic crisis on world livestock markets are wiped out.

Change in Status from a Local Multipurpose Activity to a Global Food Activity

Traditionally, livestock in both the developed and developing countries were kept on-farm for a variety of purposes, including food, savings, animal draft power, fiber, hides, and so forth. In developed countries the use of livestock has become specialized. The same trend is being observed in developing countries because the opportunity for selling meat and milk has increased and the share in production of specialized food animals, such as pigs and poultry, has risen in response to food demand.

Livestock food sectors—traditionally a major forum for nontariff barriers—are now undergoing rapid changes in national policies, including trade liberalization; investment in trade infrastructure (roads, ports, refrigeration facilities); privatization of production and marketing; deregulation of internal markets; and reduced government spending on research, extension, and inspection. These changes have spurred consumption of livestock products and increased trade.

The expansion and globalization of world markets for feed and livestock products increases the extent to which demand and supply shocks, and the overall effects of economic boom or bust, are spread to feed and meat prices throughout the world. Major exporting countries such as Argentina, Australia, and United States need to pay close attention to Asia. The 50 percent fall in prices for feedgrains and meat during 1998 in the midwestern United States was largely attributable to macroeconomic events in Asia and the former Soviet Union. Even persons solely interested in the course of future livestock prices in East African countries, for example, cannot neglect events affecting livestock in Asia at the present time, although doing so would not have been so unthinkable only a short time ago.

Substitution of Meat and Milk for Grain in the Human Diet

Widespread evidence exists that as societies grow wealthier they substitute higher-priced livestock calories for lower-priced starch calories, at a decreasing rate as the substitution proceeds. In rural China, for example, where meat and milk consumption is still very low, people may well reduce their direct annual per capita consumption of cereals over the next few decades by 20 to 30 kilograms. Their cereal consumption levels will approach those in the wealthier segments of developing societies today. On the other hand, the annual per capita use of cereals as feed is projected to rise by about 60 to 70 kilograms in China by 2020. This widely reproduced trend in developing countries will be hard to stop if income and urban population growth continue.

Contrary to the situation in developed countries—especially the United States, where livestock foods are heavily consumed—even small increases in the consumption of meat and milk would be beneficial for most women and children in developing countries, at least outside the richest urban areas. Protein and micronutrient deficiencies remain widespread in developing countries, as Chapter 6 points out. Some evidence exists that increased poultry and fish consumption would be preferable to increased red meat consumption above a certain level. As income growth and urbanization proceeds, the diseases of affluence associated with excess cholesterol intake could well become more of a problem, as they already are in much of the developed world.

Rapidly Rising World Demand for Purchased Feed Concentrates

Available evidence, both from historical trends and from in-depth econometric studies, suggests that price responsiveness is considerable in world cereals production. Simulations under various scenarios indicate that the net effect of the Livestock Revolution on cereal prices in 2020 would be to prevent them from falling further from their currently low levels. Under pessimistic assumptions prices may increase by 10 to 20 percent, but nowhere near the high levels of the 1980s.

This view of cereal prices is confirmed further by events in world markets during the past 25 years. Demand increases for meat and milk have largely been met through expansion of feed production or imports at world prices that are declining in real terms. Historically, the livestock sector has helped stabilize world cereal supply. Evidence from cereal price shocks in the 1970s and 1980s suggests that reductions in cereal supply were largely absorbed by reductions in feed for livestock.

In any event, IMPACT projects that an additional 292 million metric tons of cereals will be used annually as feed by 2020, with minimal impact on cereal prices (a 2 percent increase in 2020 relative to the early 1990s in the baseline simulation). In the worst case scenario, maize prices rise 21 percent above the baseline projections for 2020.

Simulations testing the effect of changes in the efficiency of grain conversion to meat or milk show that efficiency and cost matter greatly to the relative competitiveness of individual countries. Livestock exports in countries with ample grazing resources, such as Argentina, did well when feedgrain prices were high because they use less feed to produce a unit of meat. Countries with ample feedgrain production and feed-intensive production practices, such as the United States, exported more livestock when feedgrain prices were low. Feed conversion efficiency also mattered to the composition of specific feeds used, cereal demand generally, and world trade patterns, but it barely affected the level and distribution of livestock consumption across countries. In a price-responsive global system of markets, increased feed demand will be met with increased supply, with minimal changes in the final supply of meat.

Yet the soaring feed demand projected under the Livestock Revolution also raises a major caveat. Just because world maize and other feed-grain yields expanded steadily under significant public and private investment in the past, does not guarantee that this will continue in the future, especially if productivity research stops or public policy discards the yield potential of biotechnology. IMPACT projections show that annual growth in maize yields for most countries averages just above 1 percent through 2020, a rate significantly below historical trends. If future yield growth rates fall below those baseline projections, cereal prices would be higher than predicted. Furthermore, an unforeseen meltdown in global maize production, perhaps due to diseases spread because of decreased genetic diversity in maize varieties, would increase grain and meat prices in the immediate term because of the Livestock Revolution.

Greater Stress on Extensive Resources and More Intensive Livestock Production Closer to Cities

Demand-led increases in livestock production have led to the intensification of production near major urban markets and areas with plentiful supplies of high energy feed. These increases have degraded production resources, such as pasture. To date, the highest levels of intensification have occurred primarily in the developed countries. Developed-country experiences may provide examples of pitfalls that developing countries can avoid.

The past expansion of livestock food production in developing countries has come primarily from increased herd sizes. Range degradation has been observed in extensive production areas, such as grazing land in the Sahel. In forest areas such as the Amazon, perverse incentives led to irreversible deforestation by large cattle ranches in the 1970s. As the Livestock Revolution proceeds, increments to production will have to come increasingly from higher productivity of meat and milk per unit of land to avoid further degradation of extensive resources.

Thirty-seven percent of global livestock production already occurs under industrial farming conditions. Increasing the level of industrial production in many cases is leading to difficult problems of manure disposal and nutrient overloads in adjoining soils and bodies of water. While these problems have raised concerns primarily in developed countries, they will soon become serious problems in a number of fast-growing developing countries as well.

Growing concentration of animals and people in the developing world's major cities (Addis Ababa, Beijing, Lima, and Mumbai, for example) are leading to rapid increases in food safety problems. Infections from salmonella and *E. coli*, and emerging diseases such as the avian flu observed in Asia, give much cause for concern. Pesticides and antibiotics are also building up in the food chain because of livestock production practices in the developed countries and in countries where monitoring and enforcement are lax. Furthermore, as the consumption of livestock products increases in tropical climates, especially among those populations for whom everyday use of such products is relatively new, food safety risks from microbial infection become more prevalent.

While the list of dangers above may seem uniformly negative, this is also the appropriate place to note that the prospects for sustainable intensification of smallholder agriculture under rainfed conditions would be much more difficult without a dynamic livestock sector. Families living on a hectare or two cannot survive economically with crops alone, especially in periurban areas. More intensive livestock production on these farms provides both a higher return to farmers' labor and land and a source of organic material and soil nutrients generally lacking in such systems. Women's smallholder dairy development in East Africa illustrates the promise that a new livestock activity can offer to a farming system under economic stress.

An Era of Rapid Technological Progress, Especially for Industrial Livestock

As set out in detail in Chapter 9, the last two or three decades have seen rapid technological progress in industrial livestock production, mostly in developed countries. Progress has come in the form of improved feed conversion, higher output per animal, and higher quality of final product.

In the developed countries, technological progress for both ruminants and monogastric animals involved reproductive and genetic technology, including advances in biotechnology; feed improvement through blending, processing, genetic means, and chemical treatment; use of growth hormones; and improvements in animal health maintenance. Some of these industrial technologies, especially for pigs and poultry, have been fairly easily transferred to developing countries.

The private sector has played an important and often dominant role in boosting livestock productivity and solving environmental problems in industrial systems. While livestock systems and productivity levels in some developing countries have begun to converge with those in developed countries, some whole regions, such as Sub-Saharan Africa, have fallen behind. This raises the question of how productivity increases in those areas are best developed and propagated.

Strategic Elements for Livestock Policy in Developing Countries

Taken together, the many opportunities and dangers of the Livestock Revolution discussed above suggest that it would be foolish for developing countries to adopt a *laissez faire* policy for livestock development. Many specific recommendations for concrete action are given in the individual conclusions to Chapters 6–9. The focus here, however, is on the four broad pillars on which to base a desirable livestock development strategy for developing countries. These are (1) removing policy distortions that artificially magnify economies of scale in livestock production; (2) building participatory institutions of collective action for small-scale farmers that allow them to be vertically integrated with livestock processors and input suppliers; (3) creating the environment in which farmers will increase investment in ways to improve productivity in the livestock sector; and (4) promoting effective regulatory institutions to deal with the threat of environmental and health crises stemming from livestock.

Removing Policy Distortions that Promote Artificial Economies of Scale in Livestock Production

The political economy in developing countries often favors systems that significantly benefit a few targeted individuals or institutions rather than providing small increments for large numbers of people. Inappropriate livestock development patterns, such as high-cost and highly capitalized industrial pig, milk, and poultry production in the periurban areas of developing countries, are often the result of deliberate policy choices. Artificially created economies of scale in production add to technological economies of scale that may exist for poultry and pigs (though they probably do not exist for dairy or ruminant meat). The result may be a livestock industry dominated by a few large producers, with few opportunities for poor farmers and little control of environmental or health risks.

Even in the absence of specific tax breaks or subsidies, distortions in domestic capital markets that provide cheap capital to large enterprises and limited or expensive loans to small-scale operations, favor the large over the small and the substitution of capital for labor. Policies dealing with infrastructure and access to natural resources can unintentionally benefit large-scale producers at the expense of smaller ones.

Urban piggeries and dairies that do not adequately dispose of waste materials often operate in poor regulatory environments, under distortions in the marketing chain that prevent competition from rural areas, and without legal accountability for pollution. Overgrazing often results from inadequate property rights development and enforcement mechanisms as well as politically motivated subsidies to large producers. The point is that there is a degree of choice in how governments promote livestock development, and the deck is often stacked in favor of systems that harm the environment and provide lesser benefits to large numbers of poor rural people.

Alternatives to large, industrial production systems might be developed through vertical coordination of specialized crop and livestock activities in high-potential areas. This would permit specialized enterprises to perform efficiently while maintaining the biophysical links between crops and livestock. Such contracts between specialized feed and livestock producers are more likely to emerge if vertically integrated companies in the industrial system have to bear the full costs of their use of the environment.

The main alternative to an industrial production system in many developing countries is one that uses the labor and quality-control of many small farmers in production, but also benefits from the expertise, technology and assets of large-scale companies that are under contract for input provision, processing, and distribution of output. Such arrangements in fact characterize the poultry industry in the United States and correspond to contract farming of high-value crops in many developing countries. As discussed above, many apparent economies of scale are in fact located in input supply and output processing and distribution. This suggests that institutional innovations can allow the poor to enjoy a greater share of the benefits of the Livestock Revolution.

Building Institutions for Incorporating Poor Producers into the Benefits of the Livestock Revolution

Considerable evidence from field studies around the world shows that the rural poor and landless presently earn a higher share of their income from livestock than better-off rural people. Poverty alleviation policies must find a way to help the rural poor participate in the growth made possible by the Livestock Revolution. The alternative might be that the poor are driven out by industrial livestock producers, and the one growing market they presently compete in will be closed to them.

Small producers face many hidden costs under developing-country conditions. They find it difficult to gain access to productive assets such as credit and refrigeration facilities and to information such as knowledge of microbial contamination prevention procedures. In addition, the small producer of perishables in the tropics typically is at a bargaining disadvantage with marketing agents, because the product must be moved immediately or lose its value. Contract institutions restore the balance and also benefit distributors by assuring quality and reliable supply. The probable existence of genuine economies of scale in input supply to livestock enterprises and in processing and distribution of perishable commodities generally, suggests ways should be found to integrate small producers vertically with livestock food processors who are also in a position to manage input supply. In developed countries this has been accomplished through contract farming or participatory producer cooperatives, especially in the case of milk and poultry.

Governments and development partners seeking to invest in economic capacity-building, while facilitating the participation of the poor in commercially viable activities, need to follow the Livestock Revolution closely. The stakes are high and growing, and the rapidly rising demand for output increases the probability of success. The worst thing that well-motivated agencies can do is to prevent public investments that could facilitate sustainable and market-oriented livestock production by small producers. This will not stop the Livestock Revolution, but it will help ensure that the form it takes is less favorable for poverty alleviation and sustainability.

Creating Urgently Needed Public Goods for Livestock Production Creation in Developing Countries

The benefits provided by technology development and extension in the industrial livestock sectors of developed countries largely accrue in the marketplace. The private sector, therefore, will continue to play the leading role in further livestock technology development and diffusion in developed-country industrial systems. Industrial technologies for pigs and poultry are largely transferable to developing countries, suggesting that the need for public goods provision for these items is modest. The problem is that technology development and extension are also required for cattle and other types of livestock production. The role of the public sector becomes an issue here, especially in developing countries, where large private companies rarely operate outside the industrial livestock sector.

As the stakes rise with the Livestock Revolution, policy regarding the costs of livestock production in developing countries become even more critical than before. Educational, veterinary, research, extension, and input provision are not yet fully privatized and in many cases cannot yet be privatized at prevailing stages of development. The public goods aspect of livestock development in developing countries has always existed. The difference now is that because the market is growing, creating opportunities and risks, the public goods aspect really matters, especially in disease-control for smallholder-produced animals in vertically integrated industrial systems.

Meat and milk presently contribute more than 40 percent of the value of food and agricultural production in the world, but receive a disproportionately small allocation of public investments for facilitating production. Greatly increased attention must be given to livestock productivity issues in developing countries, including postharvest processing and marketing. Policy not only needs to facilitate the shift from increasing herd size to increasing productivity, but it needs to steer this development away from overintensification and environmental degradation.

Above all, publicly funded research and extension should focus on agricultural resource management that comprehensively furthers policy goals that relate to human needs. Rather than emphasizing output maximization above all else, research and extension should find ways to use a dynamic livestock sector to improve food security and alleviate poverty and at the same time minimize adverse effects on public health and the environment. The design of public investment must therefore go beyond a strict technical orientation and consider the social, economic, and ecological dimensions of the interaction of livestock with the betterment of livelihoods.

Enhancing the design of public investment in the livestock sector of developing countries requires substantial improvements in the creation, dissemination, analysis, and use of policy-relevant information concerning livestock. Specifically, an improved inventory and monitoring system of the changes in the availability, use, and management of the agricultural resource base worldwide has to be created. Differences and overlaps between the ecological and economic efficiency of livestock production need to be defined. These steps will require the compilation and dissemination of extensive ecological and economic data pertaining to livestock production to complement the extensive technical data available.

Regulating Environmental and Public Health Concerns

In the present phase of livestock development in the more dynamic developing countries, the size, composition, and end destination of livestock production arguably have outgrown the limited institutional capacity of ministries to cope with resulting environmental and public health issues. Regulatory agencies need to function in a way that is commensurate with the kinds of problems arising. For example, meat hygiene needs to be better enforced in urban China and grazing better managed in West Africa. Generally, technologies that deal with environmental and public health dangers stemming from the Livestock Revolution will not work unless regulatory enforcement backs them up. Such institutional developments will likely occur only when the political demands for better regulation become strong. Such was the case in an earlier era in the developed countries. In developing countries, an ounce of prevention may eliminate the need for a pound of cure.

In sum, it is unwise to think that the Livestock Revolution will somehow go away in response to moral suasion by well-meaning development partners. It is a structural phenomenon that is here to stay. How bad or how good it will be for the populations of developing countries is intricately bound up with how countries choose to approach the Livestock Revolution. Policies can significantly improve poverty alleviation, environmental sustainability, and public health, but only if new actions are undertaken. Failing to act risks throwing away one of the few dynamic economic trends that can be used to improve the lives of poor rural people in developing countries.

Appendix: Regional Classification of Countries Used in this Paper

Region	**Member countries**
China	Mainland China
Other East Asia	Hong Kong, Macau, Mongolia, North Korea, and South Korea
India	India
Other South Asia	Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka
Southeast Asia	Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam
Latin America	South and Central America and Carribean
Western Asia and North Africa	Algeria, Bahrain, Cyprus, Egypt, Gaza Strip, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, Western Sahara, and Yemen
Sub-Saharan Africa	Africa south of the Sahara except for South Africa
Developed	Australia, Canada, Eastern Europe, European Union, other Western European countries, Israel, former Soviet Union, Japan, New Zealand, South Africa, United States
Developing	All other countries in FAO Statistics Database
World	All countries included in FAO Statistics Database

Sources: Regional groupings were chosen based on FAO 1998, which is consistent with classification in Rosegrant et al. 1997.
Note: Data from some small countries were not available in all series in all years. Missing values for very small countries are ignored without note.

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Christopher Delgado and Mark Rosegrant are senior research fellows and Claude Courbois is a research analyst at the International Food Policy Research Institute. Henning Steinfeld is senior officer for livestock development planning at the Food and Agriculture Organization of the United Nations. Simeon Ehui is coordinator of the Livestock Policy Analysis Project at the International Livestock Research Institute.

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