Human choice and climate change

EDITED BY
Steve Rayner & Elizabeth L. Malone

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"What have we learned?"

Human choice and climate change

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CHAPTER 2

Population and climate change

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According to one school of thought (e.g., Myers 1993), population growth in less industrialized countries is the main cause of global environmental stress; according to another (e.g., Rahman et al. 1993), the major factor is the high level of personal consumption in the North. A hybrid view (e.g., Ehrlich & Ehrlich 1990) is that, given the tremendous difference in annual per capita levels of natural resource utilization, population growth in more industrialized countries, although slow, bears as much responsibility as rapid population growth in the South. This latter view has been marginalized in the debate, although there is no reason to do so a priori; at least the accounting that backs it up is sound. Thus, the population–consumption debate has remained essentially bipolar.

The most vehement authors in the climate policy debate (e.g., Agarwal & Narain 1991) speak openly of "blame"; others use the more neutral terms "cause," "responsibility," or "share." Even thus watered down, however, the population–consumption debate is still about the equity of proposed mitigation policies in view of the skewed distribution of resources and responsibility for past accumulation of atmospheric carbon dioxide. What synthesis of the positions has occurred has consisted merely of putting all three (especially the first two) views together and calling for sacrifices—forgoing both desired consumption and fertility—all around (e.g., Harrison 1992).

The population–consumption debate came to dominate public discussions of climate change and of global environmental stress more broadly despite the existence of at least two well-developed alternative framings of the issue. Commoner (1971, 1991) continues to blame neither population nor mass consumption, but rather the promotion by entrenched interests of large-scale, centralized, energy- and capital-intensive, highly polluting industrial technologies, as well as the encouragement via advertising of consumption habits (such as the *throwaway culture*) that depend on them. Orthodox neoclassical economists, for their part, have stood aloof from the population–consumption debate, for at least three reasons. First, they trust markets can defuse and mediate pressures on the environment whatever their origins; the issue, according to this interpretation, is the removal of impediments to markets, not reducing the scale of human population or its level of consumption. (Hence, Ch. 4 distinguishes this diagnosis as a distinctive voice in climate change discourse, focused on pricing and property rights.) Second, the population–consumption debate explicitly or implicitly makes a distinction—empty from the point of view of utility theory—between luxurious or wasteful consumption and virtuous or necessary consumption (Ekins 1991, Durning 1992). This distinction is found to be insupportable (see Ch. 3). Third, participants in the debate commit the elementary mistake (from the standpoint of utility theory) of making interpersonal utility comparisons. We cannot know (rigorously) whether the couple in a more industrialized country who forgo a desired second car are giving up more or less

utility than a couple in a less industrialized country who forgo a desired birth.

In the international political arena, the population–consumption debate has become the focus of the broader debate about equity and fairness (see Ch. 4). For example, whenever Northern delegates at the UN Conference on Environment and Development (UNCED) in Rio raised the issue of rapid population growth in less industrialized countries, Southern delegates countered with the issue of overconsumption (Rowlands 1992). As a result, population issues were watered down: Principle 8 of the nonbinding Rio Declaration calls on states to reduce and eliminate unsustainable patterns of production and consumption and to promote to appropriate demographic policies, but this is purely hortatory. When delegates from less industrialized countries proposed even the modest step of monitoring consumption patterns, industrialized nations, led by the United States, not surprisingly vetoed the idea.

By focusing attention on responsibility for causing global climate change, the population–consumption debate diverts attention from the more important issue of coping with climate change. Obscured almost entirely in the debate is one of the most consistent findings to emerge from climate change research: that the populations most adversely affected will be poor, marginal populations in less industrialized countries who depend on ecologically fragile renewable natural resources. Only by focusing on means of adaptation can the needs of these seriously affected populations be addressed.

The first section of this chapter discusses the demographic situation and outlook, commenting on the decline in fertility now underway in less industrialized countries and the relative certainties: population will grow substantially beyond its current size, its distribution will continue to tilt toward less industrialized countries, and it will continue to age.

The second section assesses studies of the role of population in the global change debate and critically reviews the common model used in the population–consumption debate. This polarized debate adds little value to addressing the questions related to climate change and diverts attention from important issues of vulnerable populations and fragile ecosystems.

The third section extends the neoclassical economic model of population and the environment to incorporate poverty, insecurity, the low status of women, and the fragility of marginal environmental zones where many of the world's poor live. To use language introduced by Gunnar Myrdal in his classic An American dilemma (1944), this results in a vicious circle model in which societies find themselves captured in a high-fertility low-income trap. Because it is comprehensive and it addresses a range of concerns within a broadly orthodox neoclassical framework, this vicious circle model has become the dominant model for research on, and policy advice regarding, population–environment interactions in less industrialized countries.

The fourth and fifth sections assess the social science research related to two population-specific phenomena that might be associated with climate change, specifically climate warming: health impacts, and effects on land and water, leading to migration and conflict. Higher temperatures would lead to a direct increase in heat-related mortality, but the public health implications of this would be relatively small. Changes in climate conditions might also change the distribution of disease vectors, such as malarial mosquitoes, and alter host–parasite relationships, with implications for the distribution and severity of vector-borne diseases. Moreover, changes in the variability of weather conditions might lead to greater frequency of extreme climatic events, especially droughts and floods, and might make fragile renewable resource systems more prone to breakdown. The result might be an increase in the number of distress migrants or, as they have come to be known in the popular literature, environmental refugees. One school of thought holds that tensions over impaired natural resource systems might escalate into wars over natural resources.

The conclusion grapples with the question of why, in a world where virtuous ends outstrip scarce public means, policymakers should concern themselves with slowing population growth. The answer, often held to be so obvious in the public debate, is found in this chapter to be highly contingent on contexts and conditions, and ultimately on values. Current wisdom, embodied in the deliberations and Statement of the 1994 UN International Conference on Population and Development (ICPD), is deeply informed by vicious circle arguments. The new basis for international population policy is widening the choice set of women, children, and the poor, based on an uneasy coalition between advocates for women and the poor and the neoclassical economic orthodoxy.

A constructive criticism of the vicious circle argument shows that some themes are lacking. First, equity concerns have been framed in strictly neoclassical economic terms; this cannot help but weaken the coalition that must implement policies. Second, global ecological fragility and risk are not addressed; in short, the view that human population growth is a bad thing in and of itself, is missing. The chapter concludes with a plea that plural norms and values, which have been more or less missing or suppressed in the population debate, be recognized and allowed to form the basis of a constructive dialogue.

Population situation and outlook

This section summarizes the current demographic situation and describes the global demographic transition which is now entering its late stage. Human population growth results not from a mechanistic biological growth process but from human choices and, ultimately, human values. The key uncertainty,

in part reflecting disagreements among researchers on the nature of the underlying model, is the speed of the fertility decline now occurring in less industrialized countries.

Demographic trends and outlook: a global summary

World population at present is approximately 6 billion. In 2050, according to population projections made by researchers at the International Institute for Applied Systems Analysis (IIASA; Lutz 1996), it is extremely likely to be in the range 7.1–13.3 billion, and in 2100 3.9–22.7 billion. These high/low bands reflect only extreme sets of mortality and fertility assumptions and should not be interpreted as probabilistic confidence intervals. By applying probabilistic methods, the IIASA researchers estimate that in 2050, the 95 percent confidence interval is 8.1–12.0, billion and in 2100 it is 5.7–17.3 billion. This level of uncertainty might be considered high by traditional scientific standards, but in the area of global environmental change, the population outlook is one of the more robust factors to be considered.

Demographic takeoff and transition

The dominant feature of the global socioeconomic landscape is the demographic contrast between the well-off populations of Europe, North America and Japan and the poor populations of Asia, Africa, the Middle East and Latin America. According to UN Population Division estimates (Table 2.1), the population of the industrialized countries is small in absolute numbers (1143 million in 1990) and expanding very slowly over time (0.40 percent per year growth between 1990 and 1995). That of the less industrialized, mostly agricultural, and commodity-producing countries is large in absolute numbers (4141 million in 1990) and expanding at a rapid rate (1.88 percent per year). The total fertility rate (TFR) in more industrialized countries is estimated to be 1.70, in less industrialized countries 3.48; life expectancy at birth for both sexes combined is 74.4 in the first group of nations and 62.3 in the second.[1]

1. Unless otherwise noted, "fertility rate" refers to the total fertility rate (TFR), defined as the average number of births per woman on the assumption that she survives to the end of her reproductive years. Mathematically, this is the integral from 15 to 45 of the age-specific fertility rates (births to women aged x divided by number of women aged x) observed in a given year. Life expectancy at birth is the number of years that would be lived by a hypothetical person who was born and passed through life, subject to the age-specific mortality rates observed in a given year; mathematically, it is the integral from zero to infinity of age-specific survival rates (one minus the age-specific death rate). Both the TFR and life expectancy are synthetic indices reflecting age-specific event rates in a given year; they do not give the actual number of births per woman or average age at death in a specific cohort.

Table 2.1 Demographic trends in the world since 1950.

	Total population (millions)			Growth rate			Life expectancy (both sexes)			Total fertility rate		
	1950	1970	1990	1950–55	1970–75	1990–95	1950–55	1970–75	1990–95	1950–55	1970–75	1990–95
World	2520	3697	5285	1.78	1.96	1.57	46.4	57.9	64.4	4.97	4.88	3.10
More industrialized	809	1003	1143	1.20	0.81	0.40	66.5	71.2	74.4	2.77	2.36	1.70
Less industrialized	1711	2695	4141	2.05	2.37	1.88	40.9	54.6	62.3	6.13	5.96	3.48
Africa	224	364	633	2.23	2.56	2.81	37.8	46.0	53.0	6.64	6.67	5.80
Asia	1403	2148	3186	1.90	2.27	1.64	41.3	56.3	64.5	5.86	5.06	3.03
Europe	549	656	721	0.96	0.60	0.15	66.1	70.8	72.9	2.56	2.14	1.58
Latin America & Caribbean	165	283	440	2.68	2.44	1.84	51.4	61.1	68.5	5.87	4.98	3.09
North America	166	226	278	1.80	1.10	1.05	69.0	71.5	76.1	3.47	2.01	2.06
Oceania	13	19	26	2.21	2.09	1.54	60.8	66.6	72.8	3.84	3.21	2.51

Source: UN (1994).

The term *less industrialized country* is so often taken as almost synonymous with the word "poverty" that a qualification is in order. Poverty in less industrialized countries is a bounded phenomenon. The proportion of the population of these countries living in poverty is estimated by the World Bank to have remained at about 30 percent between 1985 and 1990, with significant declines in East and Southeast Asia being offset by increases in Latin America, the Middle East, North Africa, and sub-Saharan Africa. The greatest incidence of poverty is in sub-Saharan Africa. Images of urban slums notwithstanding, roughly 70 percent of the world's poor live in rural areas and roughly 50 percent live in environmentally fragile rural areas. However, the urban share of the impoverished population is expanding. Just as the extent of poverty is overblown in the popular imagination, symmetrically, the size of the middle class is underappreciated. The World Resources Institute (1994) estimates that the top income class in India, containing 1.5 percent of the population, is as large as the population of Belgium.

Demographic takeoff The second half of the twentieth century is a unique episode in the history of world population. Never before has the population multiplied at such a speed, and almost assuredly, in view of ecological constraints and human values, it will never do so again. Before world population took off in the eighteenth century, fluctuations in birth and death rates almost canceled each other out and on average resulted in slow population growth. It took all of human history, until 1800, for population to reach one billion (roughly equal to today's population of Europe and North America combined). It took 130 years, until 1930, to add the second billion. It took only 60 years, until 1960, to add the third billion. The fourth billion was added between 1960 and 1975 and the five billion mark was passed in 1987. At present rates of increase, the sixth billion should be added in 1997.

Simple extrapolation of the current world population growth rate gives rise to spectacular increases in human numbers: growing at the estimated global growth rate of 1.57 percent per year, compounded annually, population would more than double in 50 years, then more than double again in the next 50, reaching almost 30 billion by the year 2100. In fact, if birth and death rates remained frozen at current levels, world population could rise to the neighborhood of 700 billion by the end of the next century, because the high fertility, less industrialized countries would be accumulating a steadily growing weight.

But, to put it simply, since no one would choose to live in such a world, no one will live in it; the human population, in contrast to all other species, has the potential to control its own reproduction and is increasingly doing so. Although annual absolute increments to population continue to rise, the annual growth rate of world population has declined from its peak of 2.1 percent per year in the late 1960s and will decline further. The often-heard comment that the human population is *exploding* is in error; what is surprising is not how fast it is growing, but how decisively that growth is decelerating.

Demographic transition Writing at the end of the twenty-first century, historians will almost certainly consider the last decades of the twentieth century as those during which the world, considered as a whole, entered the terminal stages of the *demographic transition* which began in more industrialized countries the late eighteenth century and spread to less industrialized countries in the last half of the twentieth (Davis 1954, 1991, Coale 1973, Notestein 1975). The theory of the demographic transition predicts that, as living standards rise, first mortality rates decline and then, somewhat later, fertility rates decline. Perhaps we should qualify the term theory, because demographic transition theory is really just a generalization of events in what are now the more industrialized countries, where mortality rates declined comparatively gradually, beginning in the late 1700s, and then more rapidly in the late 1800s and where, after a lag of 75 to 100 years, fertility rates declined as well. We might also wish to use the plural, demographic transitions, because the long-term historical record shows that different societies experienced transition in different ways and from recent history that the various regions of the world are following distinctive paths (Tabah 1989). Nonetheless, the broad result was, and is, a gradual transition from a small, slowly growing population with high mortality and high fertility to a large, slowly growing population with low mortality and low fertility rates. During the transition itself, population growth accelerates because the decline in mortality precedes the decline in fertility.

The broad outlines of demographic transition in less industrialized countries can be seen in Table 2.1. Between 1950–55 and 1970–75, life expectancy increased from 40.9 to 54.6 years for both sexes combined, while fertility remained almost unchanged at a TFR of about 6. As a result, the population growth rate accelerated from 2.05 percent per year in the first five-year interval to 2.37 percent per year in the second. Between 1970–75 and 1990–95, however, the TFR fell by over 40 percent, to approximately 3.5. As a result, despite continued improvements in mortality conditions (life expectancy increased to 62.3), the growth rate of population in less industrialized countries declined to 1.88 percent per year. Underlying this average were, of course, very different regional patterns; for example, in Latin America the rate of population growth declined throughout the period, while in Africa it accelerated throughout the period.

Such regional differences remind us that blind extrapolation on the basis of cross-sectional data is risky. That is, it is not necessarily sage to assume that, just because the TFR is inversely correlated with level of income in cross-section, individual less industrialized countries will inevitably experience fertility

decline as their economies grow. Nonetheless, trends have overwhelmingly confirmed the relevance of demographic transition theory, formulated on the basis of historical experience in more industrialized countries, to less industrialized countries. With the exception of pockets where religious or cultural beliefs are strongly pro-natalist, fertility decline is well advanced in all regions except sub-Saharan Africa and, even in that region, early signs of fertility decline can be perceived. In Southeast Asia and many countries in Latin America, fertility rates are on a par with those in more industrialized countries only several decades ago, and in extreme cases such as Taiwan and Korea, fertility is at subreplacement levels.[2] Thus, the assertion made at the beginning of the previous paragraph: taken as a whole, more and less industrialized countries together, the world is entering the later stages of the demographic transition that began in the eighteenth century.

The greatest difference between the demographic transition processes in the more and less industrialized countries has been the speed of mortality decline. Life expectancy in Europe rose gradually from about 35 in 1800 to about 50 in 1900, 66.5 at the end of the Second World War and 74.4 in 1995. In less industrialized countries, by contrast, life expectancy shot up from 40.9 at the end of the Second World War to 62.3 in 1995; that is, the increase that took more industrialized countries about one and a half centuries to achieve came to pass in half a century. As a result of the speed of the mortality decline, populations in less industrialized countries are growing much more rapidly today than did the populations of the present more industrialized countries at the comparable stage of their own demographic transition. The effect is compounded because, whereas mortality decline in more industrialized countries was relatively uniform over the age spectrum, mortality decline in less industrialized countries was heavily concentrated in infancy and early childhood. This has a pronounced multiplier effect on population growth, as females who would have died in childhood survive to bear children of their own. An important implication of this is that population growth in less industrialized countries is not only rapid, it is *very* rapid—three times the rate of growth in the present more industrialized countries during the comparable stage of their demographic transition.

2. Replacement-level fertility is the TFR which, if maintained over the long term, would result in an equilibrium in which each generation precisely replaced itself. Because of population momentum, discussed below, an instantaneous transition to replacement-level fertility would not immediately arrest growth in a population which has been expanding. The replacement-level TFR depends on the sex ratio at birth (which varies slightly from population to population) and the toll taken by mortality between infancy and the end of the reproductive lifespan. In countries that have undergone the initial mortality decline stage of the demographic transition, the replacement-level TFR is roughly 2.1.

Age structure, momentum, and near-term projections

Trends in population growth far into the future are already, to a large extent, embedded in the current population. Population growth is characterized by a momentum that arises from the persistence of a population's age structure; thus, even if age-specific fertility rates decline rapidly, the youthful age structure of a high fertility population ensures that it will continue to grow, albeit at a diminishing rate, for many years, as progressively larger cohorts of young women enter their reproductive years. Age structure is highly persistent, in turn, because *Homo sapiens* is what ecologists call a *K-species*, as opposed to an *r-species*: its evolutionary strategy revolves around physical robustness and behavioral complexity, that is, resistance to random shocks, not speed of reproduction following a random shock (MacArthur & Wilson 1967). One of the characteristics of K-species is a relatively long periodicity of generations; in the case of human beings, 25 to 35 years.

Differences in population age structure are illustrated in Figure 2.1, which compares two extreme cases—the young, rapidly growing population of Africa and the old, practically stagnant population of western Europe. Africa has more than twice as many children under the age of 5 than adults aged 20–25, four times more than those aged 40–45, and ten times more than elderly aged 65–70. In western Europe, the pattern is completely different and does not even resemble a pyramid. Because of very low fertility in recent decades, the pyramid becomes narrower at the base.

The narrowing of population pyramids at the base (from low fertility) and fattening at the top (from the aging of baby-boom cohorts and medical advances extend longevity) describes the phenomenon of *population aging*. As anyone who has followed political discussions regarding the uncertain future of social security systems can attest, population aging is an enormously important social phenomenon. Aging will continue in more industrialized countries and has already started in less industrialized countries, reflecting declines in fertility rates since the Second World War. Just as the speed of mortality improvements accentuated the implications of demographic transition for population growth rates, the speed of fertility decline in less industrialized countries will accentuate the aging phenomenon. In other words, not only will populations age in less industrialized countries, but they will age much more rapidly than did populations in more industrialized countries.

Just as engineers can predict the path of a braking vehicle with a relatively narrow margin of error because of inertia, demographers can project population several decades into the future with a fair degree of confidence. This does not arise from any methodological sophistication or particularly impressive insight; it is mostly because of the momentum of population; that is, the fact that

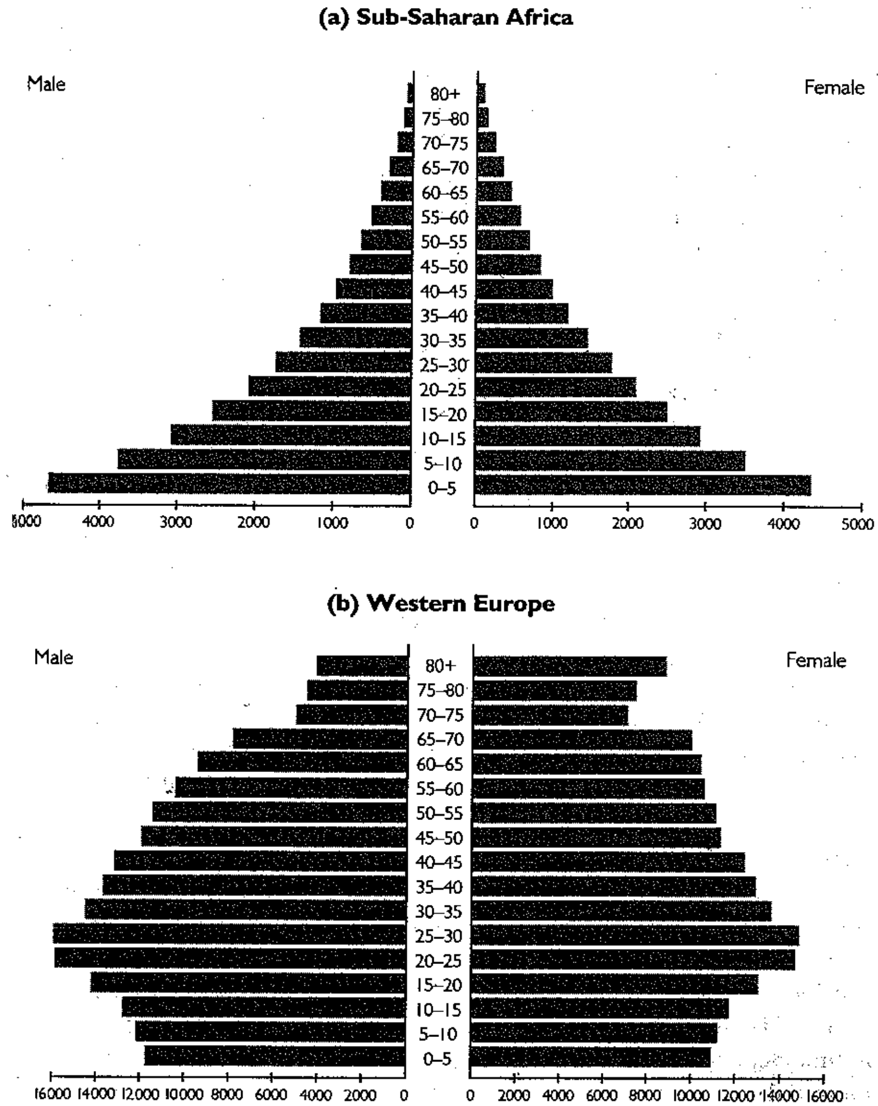

Figure 2.1 Differences in population age structure between a highly industrialized region and a less industrialized region.

a large part of the population which will be alive 25 years from now has already been born. Most, although not all, of the remainder will comprise the offspring of females who have already been born (i.e., we can estimate the number of potential mothers rather closely) and whose reproductive behavior is unlikely to differ drastically from that observed today.

Cumulated errors and long-term projections

Long-term projections, on the other hand, are another matter entirely. Because of the nature of the compounding process, small errors in the early years of a projection translate into massive inaccuracies in the outer years. Therefore, extremely long-run population forecasts are really little more than reasoned speculations. The wide high/low band and confidence interval cited above for the year 2100 arises mostly from uncertainty regarding fertility, not mortality. That the outlook is much more sensitive to variations in fertility than mortality is explained by the fact that, since high mortality in infancy and childhood has been substantially reduced in all regions and practically eliminated in some, variations in mortality rates do not make much difference in the numbers of women who survive to bear children. The striking fact is that, because of the nature of compounding, seemingly minuscule variations in the path of fertility over the next few decades will exert a disproportionate influence on the size of the population a hundred years from now.

The IIASA population projection

In this section, we take a detailed look at the assumptions and results of the population outlook whose global results were summarized above. Most citations to the research literature are suppressed because these are available in the original publication (Lutz 1996).

The cohort component method

In the cohort-component approach, an initial-year population by age and sex is *survived forward* according to assumed age-specific mortality, fertility, and migration rates. The size of the youngest age group is determined by age-specific fertility rates applied to the female population in reproductive age groups. Hence, the projected size and age structure of a population at any point in time depend exclusively on the size and age structure of the population in the initial year and on age-specific fertility, mortality and migration rates during the projection period. These four inputs—an initial year population and three sets of assumptions—are the inputs to any cohort-component population projection.

Most population projections are done by choosing assumptions which will result in a sensible range of forecasts; after the fact, the projections are labeled middle-, high- and low-growth variants. Usually the differences between baseline and alternative assumptions are fairly ad hoc. For example, until 1992, the UN Population Division's low-variant population projection assumed faster

fertility decline in less industrialized countries, but did not alter the assumed path of mortality rates. One school of thought held that faster fertility decline would be most likely to occur under conditions of accelerated development, in which case mortality would also be likely to decline more rapidly, tending to offset the deceleration of population growth arising on the fertility side. The problem is that differences of opinion regarding the causal models that underlie the components of demographic dynamics are too great to permit a systematic scenario approach. Thus, despite frequent misperceptions to the contrary, the high and low variants of most population projections cannot be interpreted as probabilistic confidence intervals; they simply represent alternative paths.

The IIASA population projection approach took the scenario approach one step further by asking an international panel of experts to make high/low variant assumptions for each of the three required sets of parameters for each of thirteen regions (see Tables 2.2 and 2.3 for mortality and fertility assumptions). The experts were instructed to construct assumptions in such a way that

Table 2.2 Alternative assumptions for life expectancy at birth in 13 world regions.

	1995	2000			2000–35			2000–85		
		L	C	H	L	C	H	L	C	H
Male										
North Africa	62.7	63.0	63.8	64.7	64.6	71.1	77.7	64.6	74.9	85.2
Sub-Saharan Afr.	50.6	49.6	51.1	52.6	43.1	54.4	65.6	43.1	58.1	73.1
China and CPA	66.4	66.9	67.2	67.4	70.2	72.0	73.9	70.2	75.8	81.4
Pacific Asia	63.1	63.1	64.1	65.1	63.1	70.6	78.1	63.1	74.4	85.6
Pacific OECD	76.1	76.6	77.1	77.6	79.9	83.6	87.4	79.9	87.4	94.9
Central Asia	65.1	65.6	66.1	66.6	68.9	72.6	76.4	68.9	76.4	83.9
Middle East	65.6	65.9	66.7	67.6	67.5	74.0	80.6	67.5	77.8	88.1
South Asia	59.7	59.7	60.5	61.2	59.7	65.3	71.0	59.7	69.1	78.5
Eastern Europe	67.3	67.8	68.3	68.8	71.1	74.8	78.6	71.1	78.6	86.1
European FSU	61.1	61.1	62.1	63.1	61.1	68.6	76.1	61.1	72.4	83.6
Western Europe	72.1	72.6	73.1	73.6	75.9	79.6	83.4	75.9	83.4	90.9
Latin America	66.3	66.8	67.3	67.8	70.1	73.8	77.6	70.1	77.6	85.1
North America	72.3	72.8	73.3	73.8	76.1	79.8	83.6	76.1	83.6	91.1
Female										
North Africa	65.3	65.6	66.4	67.3	67.2	73.7	80.3	67.2	78.7	90.3
Sub-Saharan Afr.	53.9	52.9	54.4	55.9	46.4	57.7	68.9	46.4	62.7	78.9
China and CPA	70.1	70.6	71.1	71.6	73.9	77.6	81.4	73.9	82.6	91.4
Pacific Asia	67.4	67.4	68.4	69.4	67.4	74.9	82.4	67.4	79.9	92.4
Pacific OECD	82.2	82.7	83.2	83.7	86.0	89.7	93.5	86.0	94.7	103.5
Central Asia	72.5	73.0	73.5	74.0	76.3	80.0	83.8	76.3	85.0	93.8
Middle East	68.0	68.3	69.1	70.0	69.9	76.4	83.0	69.9	81.4	93.0
South Asia	59.7	59.7	60.7	61.7	59.7	67.2	74.7	59.7	72.2	84.7
Eastern Europe	75.0	75.5	76.0	76.5	78.8	82.5	86.3	78.8	87.5	96.3
European FSU	72.8	73.3	73.8	74.3	76.6	80.3	84.1	76.6	85.3	94.1
Western Europe	78.6	79.1	79.6	80.1	82.4	86.1	89.9	82.4	91.1	99.9
Latin America	71.5	72.0	72.5	73.0	75.3	79.0	82.8	75.3	84.0	92.8
North America	79.1	79.6	80.1	80.6	82.9	86.6	90.4	82.9	91.6	100.4

Source: Lutz (1996).
L = low, C = central, H = high.

Table 2.3 Alternative assumptions for total fertility rates in 13 world regions.

	1995	2000			2000–35			2000–85		
		L	C	H	L	C	H	L	C	H
Male										
North Africa	4.35	3.92	4.13	4.35	2.00	3.00	4.00	1.54	2.04	2.54
Sub-Saharan Africa	6.18	5.56	5.87	6.18	2.00	3.00	4.00	1.44	1.94	2.44
China and CPA	2.00	1.60	2.00	2.40	1.50	2.25	3.00	1.37	1.87	2.37
Pacific Asia	2.88	2.30	2.65	3.00	1.70	2.35	3.00	1.29	1.79	2.29
Pacific OECD	1.53	1.22	1.53	1.84	1.30	1.70	2.10	1.24	1.74	2.24
Central Asia	3.35	2.68	3.34	4.00	2.00	3.00	4.00	1.45	1.95	2.45
Middle East	5.47	4.92	5.20	5.47	2.00	3.00	4.00	1.45	1.95	2.45
South Asia	3.77	3.39	3.58	3.77	1.70	2.35	3.00	1.20	1.70	2.20
Eastern Europe	1.66	1.33	1.66	2.00	1.30	1.70	2.10	1.39	1.89	2.39
European FSU	1.50	1.20	1.50	1.80	1.30	1.70	2.10	1.55	2.05	2.55
Western Europe	1.67	1.34	1.67	2.00	1.30	1.70	2.10	1.39	1.89	2.39
Latin America	3.10	2.48	2.79	3.10	1.70	2.35	3.00	1.60	2.10	2.60
North America	1.97	1.58	1.94	2.30	1.40	1.85	2.30	1.59	2.09	2.59

Source: Lutz (1996).
Notes: L = low, C = central, H = high. CPA = Centrally Planned Asia, FSU = Former Soviet Union.

their high/low variants represented a subjective 90 percent confidence interval. A ninth, central variant, set of assumptions was constructed by averaging high/low variant assumptions for mortality, fertility and migration. This implies eight alternative sets of forecast assumptions (high, low, and central) for fertility, mortality and migration. The IIASA approach, while still ad hoc, is somewhat more systematic, and it brings out explicitly the subjective probability distributions of experts in fertility, mortality and migration.

Experts' high/low assumptions were made for each five-year period out to 2030–35; these were then extrapolated to 2080–85. In the case of fertility, the endpoints chosen for 2080–85 were assumed to lie in the range 1.7–2.1, depending on the population density of the region. This procedure is ad hoc, but no more so than the common alternative, which is to assume that fertility falls (or rises, as the case may be) to replacement level and then remains fixed there. In the high mortality scenario, life expectancy was assumed to reach a maximum in 2030–35 and stay there; in the low mortality scenario, life expectancy continued to improve between 2030–35 and 2080–85. In the extremely long run, between 2080–85 and 2100, all rates are assumed to remain constant.

Tables 2.4, 2.5 and 2.6 present three sets of projection results. The scenario labeled Central (Table 2.4) combines central assumptions for fertility, mortality, and migration. The scenario labeled High (Table 2.5) combines high fertility rates with low mortality rates; migration rate assumptions are left at their central level. The scenario labeled Low (Table 2.6) combines low fertility rates with high mortality rates, again keeping migration at its central level. Thus, the two alternative scenarios give high/low growth bands. As discussed above, they have no probabilistic interpretation, but merely bound experts' assessments of

Table 2.4 Central scenario (central fertility, central mortality, central migration).

	Population by region (millions)		
	1995	2050	2100
More industrialized regions			
North America	297	406	467
Western Europe	447	469	413
Eastern Europe	122	109	77
European FSU	238	187	135
Pacific OECD	147	148	125
Total	1251	1319	1217
Less industrialized regions			
Latin America	477	906	1056
Central Asia	54	138	195
Middle East	151	517	738
North Africa	162	439	607
Sub-Saharan Africa	558	1601	1759
China and CPA	1362	1837	1796
South Asia	1240	2340	2202
Pacific Asia	447	776	783
Total	4451	8554	10353
World total	5702	9873	10228

For definition of regions, see Lutz (1996).

Table 2.5 High scenario (high fertility, high mortality, high migration).

	Population by region (millions)		
	1995	2050	2100
More industrialized regions			
North America	297	505	812
Western Europe	447	582	736
Eastern Europe	122	140	160
European FSU	238	246	289
Pacific OECD	147	181	217
Total	1251	1654	2214
Less industrialized regions			
Latin America	477	1169	2096
Central Asia	54	197	435
Middle East	151	685	1491
North Africa	162	593	1288
Sub-Saharan Africa	558	2390	4770
China and CPA	1362	2503	4055
South Asia	1240	3056	4701
Pacific Asia	447	1049	1688
Total	4451	11642	20524
World total	5702	13296	22738

Notes: CPA = Centrally Planned Asia, FSU = Former Soviet Union.
For definition of regions, see Lutz (1996).

Table 2.6 Low scenario (low fertility, low mortality, low migration).

	Population by region (millions)		
	1995	2050	2100
More industrialized regions			
North America	297	321	251
Western Europe	447	371	209
Eastern Europe	122	84	30
European FSU	238	139	51
Pacific OECD	147	118	65
Total	1251	1033	606
Less industrialized regions			
Latin America	477	687	454
Central Asia	54	92	70
Middle East	151	375	299
North Africa	162	311	227
Sub-Saharan Africa	558	1001	479
China and CPA	1362	1311	640
South Asia	1240	1743	872
Pacific Asia	447	550	289
Total	4451	6070	3331
World total	5702	7103	3937

Notes: CPA = Centrally Planned Asia, FSU = Former Soviet Union.
For definition of regions, see Lutz (1996).

possible demographic futures. Although the high and low scenarios bound probable futures, they also contain an inconsistency. If mortality is at its high assumption level, it is far more likely that fertility will also be at its high level; this scenario might be called slow demographic transition. Conversely, a rapid demographic transition scenario would combine low mortality with low fertility. These less extreme scenarios (from the standpoint of population growth) are given in Tables 2.7 and 2.8.

The rapid and slow demographic transition scenarios are more relevant for population policy than the more extreme high and low scenarios. This is because policies designed to accelerate fertility decline are also, to a large extent, policies that lead to mortality improvements. Policies to encourage population stabilization must, in this sense, cope with an internal contradiction that the faster fertility declines, the faster mortality declines as well. This also invests population policy with a more intense aging ratchet than is evident in the extreme low-growth (low fertility/high mortality) scenario. Although fertility reductions give rise to aging over the long term, reductions in mortality rates give rise to an aging effect in the immediate term as well, because older persons now alive survive longer.

Table 2.7 Slow demographic transition scenario (high fertility, high mortality, central migration).

	Population by region (millions)		
	1995	2050	2100
More industrialized regions			
North America	297	463	697
Western Europe	447	525	616
Eastern Europe	122	125	128
European FSU	238	209	217
Pacific OECD	147	164	183
Total	1251	1486	1841
Less industrialized regions			
Latin America	477	1080	1700
Central Asia	54	184	361
Middle East	151	610	1088
North Africa	162	519	912
Sub-Saharan Africa	558	1654	1827
China and CPA	1362	2321	3331
South Asia	1240	2558	2872
Pacific Asia	447	884	1136
Total	4451	9810	13227
World total	5702	11296	15068

Notes: CPA = Centrally Planned Asia, FSU = Former Soviet Union.
For definition of regions, see Lutz (1996).

Table 2.8 Rapid demographic transition scenario (low fertility, low mortality, central migration).

	Population by region (millions)		
	1995	2050	2100
More industrialized regions			
North America	297	360	318
Western Europe	447	424	278
Eastern Europe	122	97	45
European FSU	238	171	79
Pacific OECD	147	135	87
Total	1251	1187	807
Less industrialized regions			
Latin America	477	756	612
Central Asia	54	101	93
Middle East	151	426	453
North Africa	162	362	357
Sub-Saharan Africa	558	1437	1305
China and CPA	1362	1449	862
South Asia	1240	2098	1528
Pacific Asia	447	673	492
Total	4451	7302	5702
World total	5702	8489	6509

Notes: CPA = Centrally Planned Asia, FSU = Former Soviet Union.
For definition of regions, see Lutz (1996).

Forecast assumptions
Lutz (1996) contains chapters devoted to fertility, mortality and migration in less industrialized and more industrialized countries, as well as methodological chapters and special focus chapters on AIDS (discussed below and in Box 2.1) and the world food situation. In the following paragraphs, forecast assumptions are summarized in a few brief sentences.

Fertility Because the overwhelming evidence favors further fertility decline in less industrialized countries, even high fertility variants in these regions generally call for fertility to be lower than it is today. One exception is China, where the high variant assumes that the one-child policy is relaxed to allow fertility more in line with desired fertility levels. The second exception is Latin America, where there is some evidence that fertility decline in some countries has stalled at a TFR of around 3.0, and desired fertility might rise again. High-variant fertility scenarios for other regions assume that the continuing fertility transition is retarded or stalled. That this can easily happen is illustrated by the important case of India, where fertility decline was arrested in the early 1980s at a TFR of about 4.0. Low-variant assumptions imply that fertility decline in less industrialized countries, as in more industrialized countries, does not stop at a TFR of 2.1 but continues to decline, carrying countries into the range of subreplacement fertility. The central assumptions that result from averaging high and low variants are slightly above replacement-level fertility in most less industrialized regions and substantially above it in sub-Saharan Africa.

In more industrialized countries, fertility rates rose through the mid-1960s, then declined to subreplacement levels in the 1970s. Southern European countries such as Spain and Italy lagged behind northern European countries such as Germany and Sweden in experiencing fertility decline, but the decline, when it came, was steeper. Fertility has recently turned up again in northern Europe, spectacularly so in Sweden, where provision of excellent daycare and other pro-natalist policies have encouraged childbearing. On the other hand, it is not clear that high fertility will persist. Similarly, it seems unlikely that the extraordinarily depressed fertility levels that have prevailed in eastern Europe and the former Soviet Union during the crisis of economic transition represent a long-term state of affairs.

Population forecasts have traditionally assumed that low fertility, more industrialized countries approach replacement-level fertility from below, just as less industrialized countries approach it from above. On the other hand, Westoff (1996a) has pointed out that there is no empirical basis for this assumption, and some observers (e.g., Bumpass 1990) see no end in sight to individuation and the low fertility that, practically by definition, it implies. Room for further decline exists, since, even in very low fertility societies, surveys reveal

that a high proportion of pregnancies are unplanned. In view of the potential for further fertility decline, the low fertility variant assumption for the TFR was set at 1.4 in North America and 1.3 in all other more industrialized regions. The high fertility assumptions are 2.3 in North America and eastern Europe and 2.1 in western Europe and Japan and Australia.

Mortality Mortality decline in Europe, North America, and Japan came about over the course of two centuries as a result of reduced variability in the food supply, better housing, improved sanitation and, finally, medical progress. Mortality decline in less industrialized countries, by contrast, can be compared to one tremendous downward ratchet, made possible by the application of Western medical and public health technology to infectious, parasitic, and diarrheal diseases, since the Second World War. Apart from the acquired immunodeficiency syndrome (AIDS) epidemic (Box 2.1), there is every reason to expect the gap between life expectancy in more industrialized and less industrialized countries to narrow further.

The low mortality variant for Africa assumes that AIDS is brought quickly under control, in which case life expectancy is projected to increase at a rate of three years per decade. Under the most pessimistic AIDS conditions, life expectancy in Africa might fall by three years per decade. Thus, the central mortality assumption for Africa is no change in life expectancy. In South Asia and Pacific Asia, the high mortality variant assumes no increase in life expectancy because of AIDS mortality. The low mortality variant assumes that AIDS can be brought largely under control and mortality from other causes will continue to improve quickly.

Analysis of trends in age- and cause-specific mortality rates in more industrialized countries do not indicate an imminent leveling-off of improvements, so life expectancy is expected to continue rising in developed regions. Studies on occupational mortality differentials in Nordic populations, which are ethnically rather homogeneous, reveal substantial mortality differentials by socioeconomic status. This indicates that changes in lifestyle behaviors such as smoking and alcohol consumption may give rise to further reductions in mortality rates. The decline in male life expectancy, which was experienced since the 1970s by most eastern European populations and the population of the then Soviet Union, was caused in significant part by factors associated with the economic crisis and may be expected to reverse as these countries recover.

Controversy surrounds the question of whether there are biological limits to longevity and, if so, whether humans are anywhere near these limits. The traditional view sees aging as a process intrinsic to all cells of the human organism. Under this view, recent and future mortality improvements are interpreted as elimination of premature deaths and massing of mortality risk near the

Box 2.1 AIDS and Africa

Even today, it is sometimes heard that AIDS is "solving Africa's population problem." This is vicious nonsense. By subjecting members of the most economically active and productive groups to a wasting and premature death, AIDS is imposing an economic and social toll on Africa which is far in excess of any conceivable costs of rapid population growth (Ainsworth & Over 1994).

Yet, although the sheer numbers of deaths, and hence the magnitude of the AIDS epidemic on a human and social scale, is immense, the effects of AIDS on population growth rates is now known to be modest, even in Africa. Bongaarts (1996) estimates that by 2000, the AIDS death rate in sub-Saharan Africa will approximately equal the HIV seroprevalence rate (the number of cases based on diagnosis of blood sera), implying that seroprevalence will plateau. In the worst case, this results in an increase of the crude death rate by 10.7 deaths per 1000 members of the population; in the best case, 1.7 deaths per 1000 members of the population. Regarding (even modest) social response, a simulation analysis by Cuddington et al. (1994) finds that, in a typical African population, a rise in condom usage from zero to 10 percent cuts steady-state AIDS prevalence by over one-third, from 31 to 19 percent of the population.

In its 1992 round of population projections, the UN Population Division incorporated AIDS mortality into its national population projections for 15 of the most seriously affected African countries, with a combined population of 42 million in 1990. In these 15 countries, the UN estimates that AIDS mortality will reduce the average annual growth rate between 1990 and 2025 by 0.5 to 0.8 percentage points (roughly speaking, from 3 to 2 percent per year). In no case was the doubling time of a population, estimated to be on the order of 20–25 years without AIDS, found to be increased by more than two or three years by the effect of the epidemic.

How can it be that so devastating an epidemic can have only a limited effect on the population as a whole? The answer lies in the nature of AIDS mortality and the fact that the fertility rate in Africa remains very high. A woman infected with the HIV virus at 20 may not die of AIDS until 27, by which time she may have had five babies, only two or three of whom are seropositive. In other affected areas of the developing world, such as Thailand and India, much less is known about the possible effect of AIDS; however, it seems implausible that the impact on population growth would be relatively more serious than in sub-Saharan Africa, with its acutely elevated rate of seroprevalence.

biological limit of longevity. One study based on this view calculated a maximum lifespan of 115 years, with an average age at death of about 90 years. However, even this remarkable extension would imply a marked slowdown in the rate of gains in life expectancy which populations of most more industrialized countries have enjoyed in recent decades.

The alternative, and less orthodox, view, sees aging as a multidimensional process of interaction in which partial loss of one function in one organ can be compensated for by others, and only total loss of an organ system would result in death. Given improved living conditions and, possibly, direct intervention into the process of cell replication and aging, dramatically higher life expectancy could be attained. Small populations followed for short periods of time have been observed to have life expectancies well in excess of 90 years. Further

supporting evidence can be found by studying changes in very old age mortality over time. Swedish data since 1900 show that mortality rates at 85, 90, and 95 have declined at an accelerating rate.

The traditional and orthodox views of old-age mortality conveniently bracket low mortality and high mortality assumptions for more industrialized countries. The high mortality assumption is that life expectancy for both men and women increases at a rate of one year per decade—that is, at a substantially slower rate than in the past. The low mortality variant assumes that life expectancy increases at a rate of three years per decade. The central mortality assumption is thus an increase of two years per decade in life expectancy. A special set of assumptions was made for eastern Europe to reflect the broader range of uncertainty and the recent deterioration in mortality conditions. If conditions continue to be unfavorable, life expectancy is assumed to increase by only half a year per decade; on the other hand, if conditions improve and, especially, if lifestyles change for the better, it will increase by four years per decade. Under the latter set of conditions, the gap between eastern Europe and more industrialized countries, which has broadened recently, will close again.

International migration The future of international migration is particularly difficult to assess, for several reasons. First, reliable data are scarce and historical trends are very volatile. International migration tends to proceed in spurts, not as a continuous flow. Second, international migration depends closely on the prevailing economic, social, and political state of the world. Third, international migration is contingent on policy decisions in receiving regions. Low migration assumptions for all regions were set simply at zero, meaning that the number of in-migrants equals the number of out-migrants. High migration assumptions set the number of net in-migrants per year at 2 million in North America, 1 million in Europe, and 350000 in Japan, Australia and New Zealand. These migrants were distributed among sending regions using currently observed patterns of flows. In this section, only the central migration variant is discussed.

Results

If every region in the world followed the central fertility, central mortality and central migration scenarios—which are assumed to be the most likely ones as seen today—world population would increase from 5.7 billion in 1995 to 9.9 billion in 2050 and to 10.3 billion in 2100. Population would increase by another 4 billion before stabilizing around mid-century. The most extreme case of rapid population growth results from combining high fertility and low mortality assumptions in each region. In this bounding case, world population would double before mid-century and reach 22.7 billion by 2100. At the other extreme, if every region followed the path dictated by low fertility and high mortality assumptions, world population would peak before mid-century (in about 2030; this cannot be inferred from the data presented in the table) and commence a steady decline. By 2100, it would have returned to its level in the early 1970s, a little short of 4 billion.

The extremes are not only unlikely by construction (experts were asked to make bounding assumptions) but somewhat lacking in meaning. For example, if fertility remains high in less industrialized countries, it is likely to be because economic and social progress have been slow, in which case it is more likely that mortality would be high, not low. Similarly, if rapid change results in low fertility, it is more likely that mortality would be low, not high. These alternative scenarios, rather than corresponding to rapid population growth and slow population growth, as above, would correspond to something that might be called slow demographic transition and rapid demographic transition. In the first case, world population would rise to 15.1 billion in less industrialized countries by 2100; in the second case, it would rise to 8.5 billion in 2050 before declining slowly to return to approximately its current level, 6.5 billion, in 2100.

Probabilistic extension

But all of these scenarios merely represent ad hoc combinations of assumptions; they have no probabilistic interpretation. The application of probabilistic methods to population projection is not conceptually simple (Lutz et al. 1996). The confidence intervals reported above result from fitting normal probability distributions to the high, medium, and low assumptions and combining assumptions randomly in a Monte Carlo simulation. These simulations also considered the possibility that fertility and mortality trends may be correlated within regions (e.g., high fertility in sub-Saharan Africa is more likely to go hand in hand with high mortality than with low mortality) and that regional trends may be either independent of each other (e.g., fertility in sub-Saharan Africa uncorrelated with fertility in Latin America) or correlated. As reported in the first paragraph of this section, the 95 percent confidence interval in 2050 is 8.1–12.0 billion and 5.7–17.3 billion in 2100. For regional results, the reader is referred to Lutz (1996).

It is often heard that world population will double in years to come. Yet world population doubles in only about one-third of the cases examined in the Monte Carlo simulation. This is the strongest evidence to date that at least the more extreme rhetoric in the international population debate is incorrect. To repeat, what is surprising is not how rapidly the human population is growing; it is rather how decisively that growth is decelerating.

Three certainties

However, three certainties emerge from the range of scenarios and from the Monte Carlo simulation:

- World population will increase substantially from its current level. Even in the lowest growth extreme scenario, population increases by close to 2 billion before starting to decline.
- The distribution of world population will continue to shift toward less industrialized countries. Even assuming rapid fertility decline and little improvement in mortality, less industrialized countries still account for a rising share of world population.
- The world population will continue to age. In the central scenario, the share of the world population aged over 60 is expected to rise from 9.5 percent in 1995 to 19.6 percent in 2050 and 26.8 percent in 2100. But even under the high fertility / high mortality (slow demographic transition) scenario, the share of the elderly rises to 14.7 percent in 2050 and 17.8 percent in 2100.

Sensitivity

Regarding the level of world population, fertility assumptions have a far greater impact on the outlook than do mortality assumptions. Holding fertility and international migration assumptions at their central values and allowing only mortality assumptions to vary, the forecast range for 2100 is between a population of 8.1 billion in the high mortality case and 12.7 billion in the low mortality case. Holding international migration and, this time, mortality assumptions at central values and allowing only fertility to vary, the range of variation is between 5.1 billion in the low fertility scenario and 19.0 billion in the high fertility scenario.

From the standpoint of long-run population aging, fertility assumptions also have the greater impact. Under central fertility and migration assumptions, the high mortality scenario implies 24.0 percent of the population aged over 60 in the year 2100, and the low mortality scenario implies 30.8 percent. Under central mortality and migration assumptions, the high fertility scenario implies 19.9 percent over 60 and the low fertility scenario implies 37.2 percent. Somewhat contrary to population wisdom, mortality and fertility trends are more important from the standpoint of population aging than are migration assumptions. Western Europe is a good example. Holding mortality and fertility assumptions at central levels and allowing only migration assumptions to vary, the forecast range for the proportion of the population aged over 60 is only from 34.1 percent in the low migration case to 36.5 percent in the high migration case.

Fertility decline in less industrialized nations

The rapid increase in the size of world population has always attracted the most attention, although population aging is arguably as important. And it is the far-reaching consequences of current fertility decisions for future population size that underlie the urgency permeating discussions, such as those at the 1994 ICPD in Cairo, of population policy in general, and family planning policy in particular. The regional focus on less industrialized countries stems from two causes: fertility levels in more industrialized countries are already at, and in many cases below, the replacement level and are unlikely to go much lower; second, less industrialized countries account for the largest share of world population. In terms of the size of global population, the most important uncertainties relate to the future path of fertility in less industrialized countries.

The literature on fertility in less industrialized countries is so vast—citations would be superfluous, since entire journals are practically devoted to the subject—that even an adequate summary is beyond the scope of this subsection. Much of the literature revolves around empirical data made available by three major data collection and analysis projects: the European Fertility Project, the World Fertility Survey (WFS), and its successor, the Demographic and Health Surveys (DHS). The first studied the European demographic transition; the latter two concentrate on less industrialized countries. In the paragraphs that follow, we concentrate on the question of what causes fertility decline. Insights into what sorts of programs and policies will accelerate fertility decline follow fairly closely from the answer. Whether fertility decline ought to be accelerated in the first place is a much thornier question.

Proximate determinants of fertility

The idea that parents in traditional settings aim at maximum family size is uninformed. In all but a handful of observed human populations, fertility is much lower than its theoretical maximum, which is on the order of 15 births per woman. The adoption of modern methods of contraception has, in some degree, simply involved the substitution of new methods for traditional ones. In some cases, it has occurred at the same time as the erosion of practices and mores, such as late marriage, prolonged breastfeeding (which lengthens the sterile period following a birth) and periods of postpartum sexual abstinence, which formerly depressed fertility (Tabah 1989).

The proximate determinants of fertility are age at marriage, prevalence and effectiveness of contraception, prevalence of induced abortion, and duration of postpartum inability to conceive, especially because of breastfeeding (Bongaarts & Potter 1983). Fertility decline must come through changes in one or more of the four proximate determinants. In fact, the adoption of contraception has been far and away the major source of fertility decline. Adoption of contraception has, in turn, been modeled as a diffusion process consisting of stages of awareness, information, evaluation, trial, and adoption.

Coale (1973) put the conditions required for fertility decline in a nutshell: fertility must be regarded as being within the realm of conscious choice, there must be advantages to lower fertility, and the means of fertility reduction must be available. More succinctly, couples must be willing, ready, and able. We do not devote attention to the first, important as it is (van de Walle 1992), because information technology has reduced the totally fatalistic attitude toward fertility to pockets, especially in sub-Saharan Africa.

This suggests three avenues from high to low fertility (Murphy 1993):

- rising availability of family planning technology and services, including maternal and child health programs, which reduce infant mortality
- changes in socioeconomic variables, mostly neoclassical economic costs and benefits arising from variables such as child labor, female participation in the labor force, and support in old age
- attitudinal and cultural changes, such as declines in the prestige value of children and improvements in the status of women.

In the first case, advantages to having fewer children were always present, but the means of fertility control were unavailable; in the second and third cases, the means were available all along, but advantages to having fewer children emerge. In economic language, the first case corresponds to one in which demand for fertility limitation is already present and what triggers fertility decline is an increase in the supply of family planning; in the last two cases, an adequate supply of the information and technology necessary to reduce fertility exists; what triggers fertility decline is a reduction in demand for children.

The proximate cause of fertility decline is not in dispute: in the less industrialized world it has occurred as more married women have adopted contraception (Weinberger 1994). The statistical association between various indices of family planning program effort and the prevalence of contraceptive practice is unquestioned at the national level. The problem is the fundamental chicken-and-egg ambiguity over causation: does family planning through national programs lead to lower fertility via increased adoption of contraception, or do parents' declining fertility desires, translated into demand for contraception, induce the supply response of a national family planning program (Box 2.2)? The difference between the positions was well captured by the rallying cries of delegates from more—and less—industrialized countries to the 1974 Population Conference in Bucharest: "Contraception is the best contraceptive," on the one hand, and "Development is the best contraceptive," on the other. A new position that emerged forcefully at the 1994 ICPD in Cairo, might be expressed as "Security and improved status of women are the best contraceptives."

Box 2.2 Fertility decline in Bangladesh.

The debate over sources of fertility decline has concentrated on Bangladesh, where the rate of contraceptive use grew from 3 percent in 1971 to 40 percent in 1991 and the TFR fell from 7 to 5 between 1975 and 1988. Cleland et al. (1994) argue that there was no conspicuous economic development or change in the standard of living for most of Bangladesh's households. In such conditions, they suggest, the explanation for reductions lies in supply side factors, including national commitment to deliver family planning services, as well as in nonspecific socioeconomic and cultural changes which can be subsumed under *ideational change*. In rejecting explanations primarily based on economic variables, they note that reproductive behavior has changed among all major social groups.

Kabeer (1994) argues against this view, seeing in fertility decline a neoclassical response to long-term erosion of the returns to family size brought about by growing population pressure against the resource base. Although both wealthy and poor individuals reduced fertility rates, their motivations differed. In wealthier households, investments in education and the quality of children offered a more diversified pool of assets, contracts, and opportunities. For poor and landless households the initially large dependency ratio, combined with an erosion of familial ties and intergenerational obligations, provided an incentive to reduce expenditures by having fewer children. Despite high risks of mortality caused by natural catastrophes, insecurity of property rights, and the persistence of economic dependency of women on men in Bangladesh, women from the poorest households showed the greatest willingness to use contraception, often without their husbands' permission (Kabeer 1985).

In the Matlab Family Planning Health Services District of Bangladesh, contraceptive prevalence is high relative to other areas of the country despite, the fact that income, status of women, and other typical explanatory variables are no higher. Cleland (1993) and Degraaf (1991) attribute this to aggressive provision of family planning services in the district. Thomas (1993) argues that the massive provision of public health assistance amounted to a reduction in insecurity and poverty. Robinson (1986) echoes Kabeer's view above by arguing that the explanation lies in the massive long-term decline in per capita income in the district. Finally, Pritchett (1994) pointed out that the that the level of expenditure per capita on family planning in the district was so high that fertility decline was virtually unavoidable, that is, that the example cannot be generalized.

The difficulties of generalization are highlighted by persistent disagreements among researchers, even within one intensively studied country.

There has been a natural, but unfortunate, tendency to treat these positions as straw men to be knocked down. All research suggests that fertility decline is complex, regionally differentiated, and context dependent. Generalizations are risky even within regions, let alone worldwide. Every truism has at least one counterexample. For example, fertility decline has sometimes occurred in the context of vigorous national family planning programs (e.g., Thailand) but it has also occurred in countries that have almost no national family planning policy at all (e.g., Brazil). Whereas economic growth has generally been a prerequisite for fertility decline, cross-sectional plots reveal outliers such as Sri Lanka and Mauritius, where fertility levels have long been much lower than would be predicted on the basis of per capita income alone. Finally, although

fertility decline has sometimes occurred in the context of improving women's status (e.g., Kerala State in India), there are counterexamples (e.g., Indonesia) that experienced spectacular fertility decline with virtually no change in male/female inequality.

There is a clear synergism among the various factors; national family planning programs, combined with material and socioeconomic development, combined with improvements in the standard of living of the poor and empowerment of women, result in fertility decline.

The role of national family planning programs

From comparing fertility trends in broadly similar countries, such as Mexico and Colombia, and Pakistan and Bangladesh, Cleland (1996) has concluded that government attitudes toward family planning were a crucial variable. However, experience over several decades has shown that family planning programs have an impact only when desired fertility has already declined because of socioeconomic development and that they work best when integrated into other government policies in areas such as health, education and rural development (Concepcion 1996). The mere supply of contraceptive technology, backed up by government propaganda, is no guarantee of change; indeed, in Europe, marital fertility began to decline decades before modern contraceptive methods were available. Even in cases where fertility decline has occurred despite any evident change in economic variables or cultural values, scholars have argued that decline in infant mortality had triggered latent demand for lower fertility (Cleland & Wilson 1987, Cleland 1993). As a general proposition, national family planning programs are at best a necessary, but never a sufficient, condition for fertility decline. On the other hand, assuming that the socioeconomic preconditions for lower fertility are present, well-designed family planning programs can greatly enhance couples' ability to meet fertility goals and thus accelerate fertility decline.

Neoclassical economic costs and benefits

A reduction in the desired number of children can be described either in terms of shifting economic costs and benefits of fertility or evolving group norms and values; a third view stresses the barrier posed by poverty, insecurity and the low status of women in traditional patriarchal society. The economic benefits from children are of two types: old-age security and current income flows, which can arise from labor, from earnings turned over to parents, or from remittances sent by children who have left the household (Clay & Van der Haar 1993). Economic costs relate mostly to the costs of education and the opportunity costs of time expended in childbearing and childcare.

Fertility can be viewed as the outcome of a utility-maximizing decision made by parents in response to economic costs and benefits (Becker 1981, Becker & Barro 1988, Becker et al. 1991). Parents' well-being is considered to be a function of child quantity, child quality, and the level of consumption of a third, composite, good. The price of child quantity involves fixed costs, such as time expended in childbearing, and the price of child quality involves costs related to education and other investments in human capital. The availability of natural resources and environmental assets can be dealt with by adding these to the utility function, on the assumption that parents make a three-way tradeoff between number of children, material consumption, and state of the environment. Altruism can be added to the model by including well-being of the children as an additional argument in parents' utility function (Nerlove et al. 1987).

Fertility decline, according to the neoclassical model, results from a combination of increasing costs of child quantity (e.g., an increase in the formal-sector labor force participation rate of women, which raises the opportunity costs of time expended in childcare), and declining costs of child quality (e.g., increasing availability of opportunities for education). All else being equal, gains in income per capita associated with economic development would lead to increases in fertility, just as these gains lead to increases in the consumption of material goods. All else is not equal, however, as development is also accompanied by shifts in the relative prices of child quantity and quality. To these price-shifts must be added direct reductions in the economic rate of return on children as assets: modernization reduces the importance of child labor, and the opening of avenues for financial saving, and public social security schemes, reduce the value of children as pension and insurance assets. Shifts in relative prices and declines in the asset value of children combine to cause households to shift their consumption baskets away from child quantity in favor of child quality, as well as material goods.

However, empirical evidence for the neoclassical model is thin (Murphy 1992). Apart from various indices related to female education, measures of socioeconomic status as collected in survey data fail to disclose any significant associations with the number of children desired (Westoff 1996b). Multivariate cross-sectional analysis with national level data, as well as analysis of time-series data within countries, show only an ambiguous relationship between per capita income and fertility. This does not necessarily invalidate the model, because the shifts in relative prices that accompany rising per capita income are complex and hard to measure. Most evidence, however, shows that social and nonmaterial aspects of development play a larger role in fertility decline than simple increases in per capita gross domestic product (GDP).

Group norms and values

Although the neoclassical economic view is explicitly individualistic, a more sociological view encompasses group norms and values (see Box 2.3 for one model). From this perspective, high fertility in less industrialized countries can be regarded as a temporary, but stubborn, deviation from a pre-transition demographic regime in which high fertility was balanced out by high mortality (Cleland 1993). Although the biological imperative for high fertility has disappeared, the group norms and values derived from it have persisted. Worse yet, these high fertility norms have persisted while traditional practices that limited fertility have disappeared under the onslaught of modernization.

Norms and values can be purely ideational or have a strong material basis (Thomas 1993); in the latter case, they can blend with neoclassical economic

Box 2.3 Fertility and cultural values.

Simons (1986) related reproductive behavior in Europe to cultural values as measured by a questionnaire; he argues that, while economic considerations are important determinants of fertility, these are mediated and, ultimately, validated by cultural values. Simons situates countries in the quadrants formed by two axes: one runs from absolutism (absolute acceptance of norms dictated by the moral hierarchy) to relativism; the other from social collectivism (high value placed on the collective expectations of the community) to individualism. Loosely speaking, absolutism emphasizes prescribed norms, whereas relativism downplays them; individualism prizes standing out from the crowd, but collectivism prizes fitting in. Simons finds that countries with high fertility tend to combine moral absolutism and social collectivism; those with low fertility tend to combine moral relativism with social individualism.

Simons' model is essentially the same as that which emerges from cultural theory (Thompson et al. 1990), especially the closely associated grid-group typology introduced by Douglas (1978). Group refers to the individualist/collectivist dimension and grid to the personal/positional authority dimension. The combination of positional authority with collectivism establishes a *hierarchical* perspective in which persons are bound to socially imposed rules by strong group pressure, whereas the combination of personal authority with collectivism defines an *egalitarian* perspective in which individuals define their own norms but are under strong group pressure not to differentiate themselves from other group members. Individualism combined with personal authority gives rise to an *individualistic* perspective; individualism combined with positional authority defines a *fatalistic* perspective is which social norms are perceived to be absolute but their attainment is a matter of chance, not individual actions in response to group pressure. Interestingly, the gradient of high to low fertility lies not along the axis of group, as is conventionally assumed, but along the axis of grid. This suggests that fertility decline can perhaps be interpreted, not in terms of growing individualism at the expense of community identity and *belongingness*, but in terms of growing ethical relativism at the expense of moral hierarchies.

Van Asselt et al. (1995) have elaborated a comprehensive model of population policy in which views of nature, views of human nature, and attitudes toward desired number of children, contraception and abortion are classified according to the four perspectives of grid-group analysis. Global fertility outcomes, in this approach, are the aggregation of fertility outcomes in households falling into the four quadrants, each of whom set and meet fertility goals differently.

costs and benefits. Caldwell & Caldwell (1987) stressed material norms in arguing that, in traditional societies, a lifelong net flow of material resources from children to parents was maintained by rigorous adherence to the dictates of intramural and community hierarchies. Lesthaeghe (1983; see also Lesthaeghe & Meekers 1986) stresses nonmaterial norms, especially those related to individuation—the erosion of values that privilege the established order and the community over values that place the individual first. Ideational shift may be accelerated by government propaganda programs, education of girls, and so on, but the effectiveness of such programs will depend heavily on the prevailing cultural and normative context.

A vicious circle model: poverty, insecurity, and low status of women

The logic above implies that, in the normal course of events, development would give rise to changes in costs and benefits of children and to ideational evolution; these would combine to reduce demand for children. So long as adequate family planning infrastructure were available—a big "if", according to members of the international public health community—fertility decline would be more or less automatic. Why, then, does high fertility persist among many populations that appear to have access to the means of contraception? One interpretation is that high fertility is a rational response to insecurity, poverty, and the low status of women (Thomas 1993); this is the starting point for the vicious circle model, which will concern us often throughout the remainder of this chapter.

The link between women's status and fertility finds support in the fact that the strongest correlate (far stronger than income, occupation, labor force participation, and the like) of fertility has long been known to be female education (Cochrane 1979, Cleland & Wilson 1987, Cleland & Rodriguez 1988). Even when controlling for socioeconomic status, the independent effect of education tends to exceed that of any other socioeconomic factor (UN 1993). Although part of the effect of schooling is to raise age at marriage, the strongest link between female educational attainment and lower fertility is the greater likelihood that married women who were schooled as girls will use contraception. There are increasing returns (in terms of lowered fertility) as years of schooling rise, but women who have had even a few years of primary schooling are observed to be more likely to practice contraception. Education raises women's status within the household, enabling them to follow their own, usually lower, desired family size rather than that of their husbands; it also tends to shift values in favor of smaller family size by raising the probability that women will work outside the home. Parents' decisions to endow girls with even a modicum of education, as opposed to none at all, reflects a fundamental shift in the fairness with which women are treated. It sets in motion an irreversible

shift in women's perceptions, ideals, and aspirations (Cleland & Wilson 1987).

The causal nature of the links between high fertility and low status of women has been studied most intensively by Lloyd (1994) and many collaborators. In addition to diluting household resources available to all children, high fertility has three effects that fall disproportionately on girls:

- an *opportunity effect*, that is, high fertility may lead parents to deny girls access to available public resources (such as schooling)
- an *equity effect*, that is, high fertility may make more unequal the distribution of available resources among household members
- an *intergenerational effect*, that is, high fertility may impede attitudinal change.

These and similar equity problems dominated the discussions of the 1994 ICPD in Cairo. The list of rationales for intervening to accelerate fertility decline is not a long one. One such rationale is that the preferences that underlie existing fertility preferences are unjust and iniquitous. This view, couched in neoclassical language which refers to broadening the choice set of women, prevailed in Cairo.

Conclusion

This section has identified three certainties in the world population outlook: further population growth, further tilt toward less industrialized countries in the world distribution of population, and further population aging. These follow from a sophisticated probabilistic population projection exercise that embodied the sectoral expertise of an international panel of researchers. It has identified one key uncertainty: the nature, and hence the speed, of fertility decline in less industrialized countries. The most recent discussions have stressed equity aspects of fertility, arguing that high fertility is a component of a vicious circle whose other components are poverty, insecurity, and subordination of women.

Population in the global climate change debate

Much of the discussion about the link between population and global climate change has taken the form of a population–consumption debate over the contribution to greenhouse gas emissions (and global environmental stress more generally). This section reviews the population–consumption debate and concludes that it polarizes discussions while adding rather little value. The impact = population × affluence × technology (I=PAT) model, which informs and in large part drives the debate, is seriously flawed. A more hopeful trend has been the emergence of an extended version of the vicious circle model described above into global change discussions. This has the effect of focusing attention, not on responsibility for global climate change, which may be in significant degree unavoidable, but on possibilities for strengthening the response capabilities of the populations most likely to be adversely affected.

The I=PAT model and the population–consumption debate

The population–consumption debate is indissolubly linked to the I=PAT model. "So entrenched is I=PAT," wrote one feminist critic (Hynes 1993: 3), "that critics and advocates alike debate from within it; like a mental boxing ring, it locks in those who take it on."

Demographic impact identities and I=PAT

I=PAT is a multiplicative *demographic impact identity* of the sort often used to characterize the effect of population on the environment. This model was introduced by Ehrlich & Holdren (1971):

$$I(t) = P(t) \times A(t) \times T(t)$$

where

I = natural resources utilized or pollution generated (impact)
P = population
A = GDP per capita (affluence)
T = natural resources used or pollution produced per unit output (technology)
t = time.

In its original form, the equation was $I = P \times F$, where F was an unspecified function that measured per capita impact on the environment. F was conceived of as a complex function of the level of per capita consumption, the composition of the consumption basket, production technology and the level of population itself. For Ehrlich & Holdren (1971: 112), this complexity took the form of nonlinear "disproportionate" impact of population on the environment. However, in order to operationalize the concept of environmental impact per capita, they abandoned the complex and unspecified function F in favor of a simple measure of material well-being or affluence, namely, income per capita. This resulted in the now-familiar I=PAT identity.

Using prime notation to denote annual growth rates, the I=PAT identity may be expressed in the following growth-rate approximation:

$$I' = P' + A' + T'$$

This simple linear expression lends itself to decomposition exercises in which global impact is divided into portions attributable to population growth, per capita income growth, and technical change. Such simple I=PAT decompositions have played a major role in the policy debate over global warming and environmental change more generally. Among authors who have presented allocations of responsibility based on I=PAT decompositions are Harrison (1992), Holdren (1991) and Bongaarts (1992). For example, the introduction of the I=PAT identity in 1971 set off a bitter dispute, carried on in the pages of the *Bulletin of the Atomic Scientists*, between Ehrlich & Holdren, who blamed environmental deterioration on rising population, and Commoner, who blamed the introduction of more polluting technologies (see Marden & Hodgson 1975).

An I=PAT decomposition of sources of growth in world energy consumption

The following paragraphs present an example of the sort of decomposition exercise that has become prominent in climate discussions. Although energy consumption is by no means the only link between population, economic activity, and climate change, it is arguably the most important. Tables 2.9–2.11 present the results of using the I=PAT model to decompose growth in global energy demand between 1970 and 1990 into demographic and economic components and to perform some simple simulations for 1990–2030.

Table 2.9 shows basic data on population, GDP, and energy utilization. The regions used are consistent those in Table 2.1. The key dynamics of the I=PAT framework are as follows:

- Population growth is concentrated in the less industrialized countries (2.2 percent per year over the period 1970–90, as opposed to 0.7 percent per year in more industrialized countries) where per capita energy consumption is low. On the other hand, equity considerations require that economic growth be concentrated in the same region where energy consumption per unit of GDP is high.
- Energy consumption is growing more rapidly than GDP in less industrialized countries; thus, the energy:GDP ratio rose from 0.466 to 0.611 between 1970 and 1990. It is growing more slowly than GDP in more industrialized countries. This is because energy demand is elastic with respect to GDP when economies are rapidly shifting away from agriculture and toward industry, but inelastic with respect to GDP when economies are moving away from industry toward services; in addition, within some sectors, less industrialized countries are substituting energy-intensive production methods for labor-intensive ones. Thus, change in the $T(t)$ term in the I=PAT identity represents the combination of structural change in the form of changing sectoral shares in total economic activity, and technical change in the form of new production methods within sectors.

Table 2.9 Population, affluence and technology: c. 1970 and 1990.

	1970		1990
Less industrialized countries			
Population (millions)	2695		4141
Average annual change (%)		2.2	
GDP[a] per capita (1990 US$)	498		900
Average annual change (%)		3.0	
Energy consumption (mkoe[b])	625240		2277550
Average annual change (%)		6.7	
Per capita (koe[c])	232		550
Average annual change (%)		4.4	
Energy: GDP (koe/$)	0.466		0.611
Average annual change (%)		1.4	
More industrialized countries			
Population (millions)	1003		1143
Average annual change (%)		0.7	
GDP per capita (1990 US$)	10095		15000
Average annual change (%)		2.0	
Energy consumption (mkoe)	3797358		5715000
Average annual change (%)		2.1	
Per capita (koe)	3786		5000
Average annual change (%)		1.4	
Energy: GDP (koe/$)	0.375		0.333
Average annual change (%)		−0.6	

Source: Population, see Table 2.1

(a)GDP figures are based on market exchange rates (MERs) and thus exaggerate the income gap between less and more industrialized countries and, as a result, the energy-efficiency gap as well. Siddiqi (1994) discusses the possibly serious bias which may result from using MER instead of purchasing power parity (PPP) GDP estimates in energy analyses.
(b) Million kilograms of oil equivalent.
(c) Kilograms of oil equivalent.

Per capita GDP c. 1990 and growth rate of per capita GDP 1970–90 estimated by authors from United Nations Secretariat (1994).
Per capita energy consumption c. 1990 and growth rate of total energy consumption 1970–90 estimated by authors from United Nations Secretariat (1994).

Table 2.10 presents growth in energy demand in each of the two regions decomposed conventionally into growth in population, growth in income per capita, and change in the energy:GDP ratio. In both less and more industrialized countries, the growth rate of population was one-third as rapid as the growth rate of total energy consumption; following conventional logic, then, population growth accounted for one-third of the increase in energy consumption,

holding all other factors constant. Growth in income per capita combined with structural economic change and shifts in production methods—in other words, economic change, broadly considered—accounted for the remaining two-thirds. Table 2.11 applies the growth rates in Table 2.9 to initial levels, so that the contribution to the absolute increase in world energy consumption can be judged. Between 1970 and 1990, world energy consumption grew by 178497 million kilograms oil equivalent (mkoe) per year, of which 82615mkoe (46.3 percent) represented increase in less industrialized countries and 95882 (53.7 percent) represented the increase in more industrialized countries.

As a crude way of estimating sensitivities, we can calculate the effect of freezing different variables at their initial year levels. Calculations employing the data in Tables 2.10 and 2.11 indicate that, if there had been zero population growth in more industrialized countries during the period in question, all other rates of growth remaining unchanged, the level of world energy consumption in 1990 would have been 8.8 percent lower than its actual observed value. If there had been zero population growth in less industrialized countries, the reduction would have been a roughly equivalent 9.9 percent, because per capita energy consumption is lower in less industrialized countries. If the level of per capita output in more industrialized countries had remained frozen at its initial-year level, but the energy:GDP ratio had continued to decline at 0.6 percent per year, world energy consumption in 1990 would have been 23.4 percent lower than the baseline observed level. If zero economic growth in more industrialized countries also meant no technical and structural economic change in the region, the reduction would be limited to 17.4 percent.[3] We do not consider the case of zero economic growth in less industrialized countries.

Table 2.10 Sources of growth of energy consumption, c. 1970–90 (average annual change, %).

	Growth rate of energy consumption (% per year)	Attributable to growth of population	Attributable to growth of income per person	Attributable to change in technology
Less industrialized countries	6.7	2.2 (32.8%)	3.0 (44.7%)	1.5 (22.4%)
More industrialized countries	2.1	0.7 (33.3%)	2.0 (95.2%)	−0.6 (−28.6%)

Source: Calculations based on data in Table 2.9.

3. Bartiaux & van Ypersele (1993) present a similar simulation over the period 1950–90 for carbon dioxide emissions, with more pronounced results partly because of the longer time period. Freezing more industrialized countries' population at their 1950 level growth reduces 1990 emissions by 22.9 percent vis-à-vis its 1990 observed level; freezing less industrialized countries' population effects an 18.2 percent reduction; freezing the carbon dioxide emissions per capita of more industrialized countries effects a 30.5 percent reduction.

Table 2.11 Sources of growth of energy consumption, c. 1970–90 (average annual absolute change; million kg oil equivalent).

	Population	Income and change in technology	Total
Less industrialized regions	27127 (15.2%)	55488 (31.1%)	82615 (46.3%)
More industrialized regions	31961 (17.9%)	63921 (35.8%)	95882 (53.7%)
Total	59088 (33.1%)	119409 (66.9%)	178497 (100.0%)

Source: Calculations based on data in Tables 2.9and 2.10.

These back-of-the-envelope calculations give rise to two conclusions. First, if the numbers which emerge from the *I=PAT* model itself are to be believed, the population–consumption data offer few guidelines for policies to reduce emissions, at least in the near term. The assumptions made above are extreme (population momentum makes it impossible to stop demographic increase in its tracks, and the chances are remote that policymakers in more industrialized countries would choose to limit economic growth substantially, let alone renounce it altogether). Yet even under these extreme assumptions, global energy consumption would still have grown substantially over the twenty-year period.

Second, if the discussion is to be couched in terms of blame, then blame must be shared all around. Both less and more industrialized countries have experienced rapid energy consumption growth, and both population growth and economic growth combined with changes in economic structure and technology have contributed to rising energy use. Even within the simplistic *I=PAT* framework itself, there is no single "climate bomb" (Rahman et al. 1993).

Carbon dioxide emissions

The results above are for energy consumption, but some studies have looked directly at emissions of carbon dioxide. Among the various greenhouse gases, human links to carbon dioxide emissions are the most important in terms of global warming potential. While criticizing the conventional decomposition methodology employed above, MacKellar et al. (1996) assigned 41 percent of world growth in carbon-equivalent greenhouse gas emissions from industrial sources over the period 1965–90 to population growth. Working from the US Environmental Protection Agency's "No Response" scenario (Lashof & Tirpak 1990), Bongaarts (1992) assigned 50 percent of growth in global carbon dioxide emissions from fossil fuels between 1985 and 2025 to population growth. Over the entire simulation period (1985–2100), population accounted for 35 percent of growth in carbon dioxide emissions. Raskin (1995) used a modified decomposition procedure to analyze emissions of carbon dioxide only, and assigns to population growth a share of 32 percent for the period 1950–90 and 75 percent over the period 1990–2050 in the IPCC IS92a scenario.

Results vary depending on the definition of impact, on the time period being covered, and on the population scenarios employed. Some studies (e.g., Kolsrud & Torrey 1992) that have looked at mitigation strategies have found that future growth in energy consumption and carbon dioxide emissions is not very sensitive to reasonable alternative demographic assumptions. The reasons were summarized by Birdsall (1992: 13–15):

> First, differences in projections of population growth on a global scale are not that great. . . . Second, the potential for affecting future population size is greatest in those countries of the world where per capita emissions are currently lowest. . . . Third, it is likely that for given per capita income . . . a smaller population will produce somewhat higher per capita emissions, due to substitution of energy for labor.

The first point is especially important. Shares assigned in *I=PAT* decompositions implicitly compare a baseline population growth scenario with one of zero growth (as in the illustrative energy example above). The policy-relevant comparison is, rather, one of projected baseline population growth to a reasonable alternative scenario. Population momentum alone is enough to ensure that the differences between the two are modest.

But reductions in population growth are only one way of meeting targets and may not be the preferred way. This is illustrated in Table 2.12, which combines three alternative IIASA population projections with three IPCC per capita greenhouse gas emissions scenarios (from commercial energy consumption only, in carbon-equivalent terms) to arrive at total emissions levels.[4] Looking only at the year 2100, holding per capita emissions at IPCC central scenario levels and allowing only the population scenario to vary, the range of global carbon dioxide emissions projections is from 12.4 gigatonnes of carbon in the rapid demographic transition (low mortality / low fertility) case to 28.5 gigatonnes in the slow demographic transition (high fertility / high mortality) case. Now holding population at levels implied by central fertility / central mortality assumptions, and allowing only the per capita emissions scenario to vary, the projection range is from 7.1 to 34.4 gigatonnes. Clearly, future emissions are much more sensitive to a reasonable range of variation in emissions per capita associated with economic growth, structural change and technical progress than to a reasonable range of variation in fertility and mortality rates. Reducing per capita emissions

4. Since the IPCC population assumptions differ from those the IIASA projection, the levels in Table 2.4 do not correspond to IPCC *total* emissions projections. There is nothing comparable about the magnitude of the differences in assumptions in the IIASA population projections and those in the IPCC high/low emissions scenarios. The example is meant only to be illustrative.

Table 2.12 Projected GHG emissions from commercial energy (GIC).

	Low (IS92c)			Central (IS92a)			High (IS92e)		
Demographic projections	2020	2050	2100	2020	2050	2100	2020	2050	2100
Low mortality/low fertility									
More developed	4.5	3.5	1.7	5.7	5.4	4.6	6.8	7.7	7.5
Less developed	3.2	4.0	3.2	4.3	6.6	7.8	5.6	9.5	14.4
Total	7.8	7.5	4.9	10.0	12.0	12.4	12.4	17.2	21.9
Central mortality/central fertility									
More developed	4.7	3.8	2.6	5.9	6.0	6.9	7.1	8.5	11.3
Less developed	3.4	4.7	5.1	4.5	7.7	12.4	5.8	11.2	23.2
Total	8.1	8.6	7.7	10.5	13.8	19.4	12.9	19.7	34.4
High mortality/high fertility									
More developed	4.9	4.3	3.9	6.1	6.8	10.5	7.3	9.6	17.1
Less developed	3.5	5.4	7.4	4.7	8.9	18.0	6.1	12.8	33.5
Total	8.4	9.7	11.3	10.8	15.7	28.5	13.4	22.5	50.6

from central to low levels can reduce total emissions in the year 2100 by about 60 percent; slowing the rate of population growth from that of the central IIASA scenario to that implied by the rapid demographic transition scenario can reduce emissions by only 36 percent.

A critical look at I=PAT

The discussion above suggests that there is less to the population–consumption debate than meets the eye. Flawed models often give rise to such unproductive debates, and in this section we critically review the shortcomings of *I=PAT*. Some of the shortcomings we find are technical and may be amenable to solutions such as more careful specification of the model, resolution of mathematical issues, and availability of finer-grained data. Others are essentially irremediable and point the way toward a better model.

Mathematical ambiguities

Some conceptually simple but intractable mathematical problems arise in *I=PAT* decompositions. Among these are the following:

- The commonly employed growth-rate expression of the *I=PAT* identity is only a mathematical approximation, and over long periods of time (or even over relatively short periods of time if average annual rates of change are very rapid), it can give rise to misleading results. To give a single-year example, if *X* and *Y* each grow by 10 percent, then their product *XY* grows, not by 20 percent, but by 21 percent. Cumulated year after year over time-frames on the order of a century, such errors become significant.
- When a global *I=PAT* identity is expressed as the weighted average of regional *I=PAT* identities, care must be exercised in choice of weights: for example, fixed weights reflecting initial-year shares will give rise to misleading results in long-term scenarios.
- A related problem (Lutz et al. 1993) is that when the decomposition method is applied over long periods of time, and when the regions employed are characterized by different rates of population growth, the breakdown between population and economic factors at the global level (the column sums at the foot of Table 2.11) is highly sensitive to the number of regions employed. In other words, an analysis of more industrialized versus less industrialized countries would give a different result from an analysis of more industrialized countries versus low-, middle- and upper-income less industrialized countries. Bartiaux & van Ypersele (1993) pointed out that several works that are influential in the public debate, among them Ehrlich & Ehrlich (1990), UN Population Fund (1991), and Gore (1992) make similar elementary mistakes that arise from aggregating heterogeneous regions.
- Interpretation of decomposition results is difficult when terms on the right-hand side have different signs; that is, when changes in one variable are canceling out changes in another. The most common manifestation of this is when, as in the case of more industrialized countries in Table 2.10, the energy:GDP ratio is declining while the other two terms are rising. How can change in a term on the right-hand side account for a negative proportion of change in a term on the left-hand side; or account for more than 100 percent of change in a term on the left-hand side (which is possible if one of the terms on the right-hand side is negative)? The mathematics may be correct, but the meaning is ambiguous. When the terms canceling on the right-hand side are large relative to the term on the left-hand side, minor changes in rates of growth on the right-hand side can make for major changes in proportional allocations of responsibility (Box 2.4).

Box 2.4 Ambiguities arising from opposite signs

An example: in state of the world A, population grows at 1 percent per year, per capita GDP grows at 2 percent per year and the ratio of impact to GDP declines at 2 percent per year, making for a rate of growth of impact of 1 percent per year. According to conventional logic, population growth accounts for 100 percent of rising impact, economic growth for 200 percent, and changing technology for –200 percent. In state of the world B, impact per unit GDP declines by 1.5 percent per year, all else remaining equal, so that impact on the left-hand side grows at 1.5 percent per year. Population growth, again according to conventional logic, now accounts for 66.7 percent of rising impact, economic growth for 133 percent, and changing technology for –100 percent. A minor change in a variable on the left-hand side has completely changed results.

Ecological threshold and scale effects

The proportional rate of increase in environmental impacts is not of greatest concern, but their absolute magnitudes are: tonnes of carbon residing in the atmosphere, tonnes of topsoil washed away, tonnes of biomass lost through deforestation, and so on (Keyfitz 1992). By this logic, any discussion in terms of dimensionless growth rates is irrelevant. I=PAT expressions in terms of growth rates can easily be translated back into absolute magnitudes, as in Table 2.11, but this is not always done in practice. If ecological discontinuities exist, nonlinearities and threshold effects, then the log-linear I=PAT identity will underestimate scale effects.

Ecological complexity and feedbacks

The operational definition of impact as total utilization of natural resources or total emission of pollution (as opposed to Ehrlich & Holdren's original complex F) is straightforward when the natural resource is a nonrenewable one or the pollutant is one for which the environment has no assimilative capacity. However, this strategy amounts to carving up overall environmental impact, which is too complex to express in a tractable identity, into a series of linearly separable impacts: utilization of fossil fuels, utilization of copper, emissions of carbon dioxide, emissions of chlorofluorocarbons, and so on. A disadvantage of this divide-and-conquer strategy is that the effect of each individual impact on overall environmental sustainability may not be linearly separable from the effect of other impacts; that is, there may be complex interactions that make the whole greater than the sum of the parts.

Ambiguities regarding the demographic unit of account

I=PAT assumes that the individual, not the household or the community, is the relevant unit of demographic account (Box 2.5). Yet, to take energy consumption as an example, substantial economies of scale are possible at the household level.[5] Thus, all else (household income and the composition of the household consumption basket) being equal, a given percentage decline in household size

5. For references to studies in both more and less industrialized countries and a summary of findings, see MacKellar et al. (1996). To get an idea of the significance of such effects, US energy data from the end of the 1980s indicate that, not controlling for income, households consisting of two persons consume 58.1 percent more vehicle fuel and 37.6 percent more residential energy than households consisting of one person. Households consisting of three persons consume 30.4 percent more fuel and 15.1 percent more residential energy than households consisting of two persons, and economies of scale continue to grow as household size increases energy consumption. Based on a survey of studies, the authors conclude that energy consumption tied to the hearth and not the number of members of the household may account for up to 50 percent of residential energy consumption (including household transportation) in both more and less industrialized countries.

will be accompanied by a less-than-proportional decline in average household energy consumption. For a constant population, total energy consumption—average household consumption times number of households—will rise. Therefore, under conditions of declining household size, the share of environmental impact attributed to demographic factors will be higher if the demographic unit of account is the household than it will if it is the individual. Households versus individuals is not the only problem of demographic accounting; for example, calculations that take into account rapid urbanization in less industrialized countries, and differences in urban and rural energy consumption, give rise to dramatically different results than those that combine urban and rural populations (MacKellar et al. 1996).

Ambiguities regarding the economic unit of account

Fundamental accounting questions also arise about whether impacts should be considered in terms of impact per unit of GDP, gross output, domestic absorption, or some other unit. Impact per unit of GDP does not include production of intermediate goods. Impact per unit of gross output includes exported goods, the impact of whose production should reasonably be imputed to someone else's domestic absorption. Impact per unit of domestic absorption includes imports (weighted averages of impacts per unit of production in trading partners). Empirical difficulties aside, even the conceptual issues are not easily resolved.

Interrelationships between variables

The difficulties enumerated above are troublesome but are, in varying degree, amenable either to future research or to due diligence in the presentation and interpretation of results. But the greatest weakness of the I=PAT approach, which is irremediable, is its lack of social science content. Shaw (1993: 190) put it this way:

> How much attention should be devoted to apportioning blame to population versus other factors? Rigorous measurement of population impacts requires an appropriate explanatory framework, controls for variables other than population, testable hypotheses concerning population's direct and indirect effects, suitable data, a good understanding of multivariate analysis, and the inevitable round of debate over the accuracy of the findings. Some people are impatient with all this.

Thomas (1992) argues that authors who cite I=PAT results as justification for favored policy interventions (e.g., UN Population Fund 1991) seem unaware that I=PAT calculations arise from an accounting framework which is empty of causal or behavioral content.

Box 2.5 Population or households?

Between 1950 and 1990, average household size in industrialized countries underwent a decline which, in proportional terms, can fairly be termed massive, from 3.6 to 2.7. This decline was attributable more or less equally to changes in population age structure (mostly aging) and reductions in age-specific household headship rates. The latter reflect the weakening of the extended family, young persons moving away from home earlier and declining age-specific nuptiality rates, with consequent increase in mean age at marriage. In less industrialized countries, by contrast, average household size remained practically unchanged between 1950 and 1990, declining only from 5.0 to 4.8; in fact, if China is excluded from the total, average household size increased somewhat. Analysis indicates that, although age-specific household headship rates will presumably rise with modernization, changes in population age structure are likely to dominate changes in average household size. In the case of both regions, population aging will favor smaller household size. Perversely, the fertility decline that directly reduces environmental impact gives rise to smaller average household size through its effect on the age distribution, thus weakening the effect.

A study (MacKellar et al. 1995) which replicated the *I=PAT* decomposition presented in Table 2.10 in household terms (i.e., an *I=HAT* decomposition), assigned 58.3 percent of world energy demand growth in 1970–90 to demographic change, in the form of rising population combined with declining average household size, rather than 33.1 percent as in Table 2.10. Further research by the same team (MacKellar et al. 1996) found that the differences between household-based and population-based greenhouse-related emissions projections were significant. Because of population aging, with consequent decline in average household size, household-based estimates of total emissions were higher than population-based estimates. The scenarios also underscored the complications, in the form of changing age-structure of the population, which must be faced in translating different demographic scenarios into emissions estimates. Fertility decline reduces absolute population size, but the consequent rapid population aging tends to raise the number of households. For example, in the early years (until around 2020) the IIASA rapid demographic transition (low fertility/low mortality) scenario actually results in more households than the slow demographic transitions (high fertility/high mortality) scenario. Although fertility decline has no impact on the number of households for some 20 years, lower mortality at older ages results in an immediate increment to the number of households, in the form of aged persons living alone. Only in the longer term does the slower overall population growth in the rapid demographic transition scenario result in fewer households.

The lack of social science input may be expressed as a long list of ceteris paribus assumptions. Among these are the following:

- P *does not determine* P′ Population does not grow blindly as density and the resulting environmental impacts rise. Fertility, mortality and migration are all fundamentally density dependent.
- P *does not determine* A Since research has failed to uncover a strong relationship between the rate of population growth and the rate of economic growth, this may not be an unreasonable assumption in the relatively near term. Over the long term, however, this assumption denies the possibility of the learning-by-doing and increasing returns to scale which are at the very heart of modern economic growth theory.

- A *does not determine* P The relationship between fertility, mortality and per capita income is far from well understood (see above); indeed, the relationships may be so dependent on conditioning variables as to be well nigh incomprehensible. But the least likely theory is that there is no relationship at all, and it is this theory that informs *I=PAT*.
- P *does not determine* T Economic structure and technology are, in large degree, responses to population pressure. For example, rapid population growth and the ensuing elevation of the population-to-land ratio may have the effect of concentrating output into the agricultural sector (Gilland 1986). On the other hand, neoclassical substitution mechanisms of the sort that underlie the Boserup (1965, 1981) model of agricultural intensification and technical change might lead to substitution of labor for scarce natural resources.
- T *does not determine* A It seems a commonplace that the more efficiently materials can be transformed into economic product and the less noxious residuals are generated during the process, the higher will be the level of income. Indeed, the core result of the neoclassical economic growth model is that, in equilibrium, the rate of per capita economic growth will be given by the rate of technical progress, where the latter is defined as the rate of increase in economic output, the level of all inputs remaining the same.
- A *does not determine* T It has been abundantly documented that economic structure varies predictably with level of development (Chenery & Syrquin 1975, Maddison 1989, Pandit & Cassetti 1989). Partly as a result, environmental impact per unit GDP either declines monotonically with level of development or first rises, then falls, that is, follows an inverted U-shaped path (World Bank 1992). This path reflects not only changes in economic structure but also the fact that rising income stimulates demand for environmental quality. The combination of changing economic structure and rising demand for environmental quality defines an *environmental transition* (Ruttan 1971, Antle & Heidebrink 1995) in which economic growth is associated with environmental deterioration when a country is poor but environmental improvement after a critical point in national economic development has been reached (Box 2.6). Carbon dioxide is, on first consideration, an apparent exception to the environmental transition model—international cross-sectional evidence indicates that emissions per capita rise monotonically with income over the entire range. When emissions are considered per unit GDP, however, the canonical inverted U-path reasserts itself.

Box 2.6 The environmental transition and its critics.

The empirical literature on the environmental transition is growing rapidly, as is criticism of the model. The principal background paper for this aspect of the 1992 World Bank *World development report* was Shafik & Bandyopadhyay (1992), who examined access to safe water, access to sanitation, urban atmospheric concentrations of particulate matter, urban atmospheric concentrations of sulfur dioxide, municipal waste per capita and carbon dioxide emissions per capita. In international cross-section, the first two declined monotonically with level of income; the second two followed an inverted U-curve peaking at a few hundred dollars in the first case and at just over $1000 in the second case. Antle & Heidebrink (1995) found an inverted U-curve relating to deforestation, as did Panayotou (1993) and Cropper & Griffiths (1994), and availability of national parks; the peak occurred at $1200–2000. Grossman & Krueger (1995) found inverted U-curves for a wide range of water and air pollutants and estimated turning points ranging from $2700 (dissolved oxygen content of rivers; this a trough rather than a peak) to $11600 (cadmium). According to their estimation results, by the time per capita income reaches $8000, levels of virtually all pollutants fall with further economic growth. All prices are in 1985 Summers–Heston purchasing-power parity terms; for reference, GDP per capita in the early 1990s was roughly $1000 in India, $5000 in Mexico and $10000 in Spain.

Preston (1994) points out the importance of the interaction effect between per capita GDP and carbon dioxide emissions per unit GDP. He took advantage of the *I=PAT* model's log-linearity to express variance (across regions of the world) in the growth rate of carbon dioxide emissions as the sum of variances in the growth rates of GDP per capita, emissions per unit GDP and population; plus two times the sum of the pairwise covariances. He concluded, first, that variance in the rate of population growth was a negligible player (Birdsall 1992 makes the same observation); second, that even when the two covariances involving population were included in the calculation, variance in population growth rates could not be made to account for more than one-quarter of variance in emissions growth rates; and, third, the linear decomposition of variance is dominated by the huge negative covariance between the rate of per capita economic growth and the rate of growth of emissions per capita. Replication of the Preston decomposition using data at national level (MacKellar et al. 1996) has not only confirmed the basic thrust of these results, but suggests tentatively that the importance, not only of the A–T covariance, but of all pairwise interaction effects, has increased over time.

Arrow et al. (1995) have, however, expressed strong concern lest the environmental transition model be invoked as a panacea. It is relevant, they argue, only in the absence of ecological feedbacks and when local social and economic institutions can be counted on to respond to environmental damage. To some extent, Arrow et al. set up a straw man: although the policy document most heavily informed by the environmental transition model, the 1992 World Bank *World development report*, paid little effect to ecological instabilities, it in no way claimed that economic growth was a substitute for efficient and equitable institutions. Antle & Heidebrink (1995) are similarly cautious; Panayotou (1993) proposes that the environmental transition curve may shift up or down depending on the institutions in place. On the other hand, Arrow et al. evoked a strong comment from Ayres (1995) in which he expressed opposition to *any* further economic growth (including growth due to income-raising efficiency gains) which involves materials consumption or energy use.

Costs and benefits

Another aspect of the lack of social science content is that *I=PAT* contains no reference to the costs and benefits of various policies, which can be estimated only with economic prices that depend in part on values and tastes. For example, analyses based on *I=PAT* have generally found that the potential for abating emissions by policies to slow population growth in less industrialized countries is modest. Birdsall (1992), on the other hand, offers a solid rationale for such strategies despite the small magnitude of direct effects: the cost of fertility reduction attained by means of providing family planning services and female education is extraordinarily low. When this is taken into account, population policies in the less industrialized world compare favorably, in terms of the benefit–cost ratio, with carbon taxation policies. Wexler (1996) has estimated, on the basis of standard economic models of climate change (such as Nordhaus's DICE), large external economies to averting births, in which case Birdsall's logic would be further strengthened. We wrote above that, within the *I=PAT* framework, possibilities for mitigation of climate change appear modest, but when weighted by costs and benefits, the numbers may tell a very different tale. This failure to take account of human preferences places the *I=PAT* model in the same league with another framework which has often been invoked in the global environmental change debate—human carrying capacity of the Earth (Box 2.7).

The neoclassical economic tradeoff between utility from childbearing, from the consumption of goods, and from environmental quality, is absent from the *I=PAT* framework. Much argument based on the *I=PAT* model and virtually the entire population–consumption debate are based on the convenient assumption that people would really be happier if they either consumed less (mainly in more industrialized countries) or had fewer babies (especially in the case of less industrialized countries). One or both of these propositions may be true; a priori we do not know (see Ch. 4).

Conclusion

In this section we have analyzed a central tool used in the population–consumption debate, the *I=PAT* framework. This tool is not only weakened by conceptual and methodological problems, but it is flawed by its failure to take the social science perspective into account. A broader and more flexible view of population and the environment is necessary to avoid policy mistakes whose costs are potentially large. Although *I=PAT* and the population–consumption debate remind us that environmental impact arises from more than one factor, they do not provide a sound basis for policy discussions, let alone decisions.

Box 2.7 Human carrying capacity

Like the *I=PAT* model, the concept of the human carrying capacity of the planet has played a large role in climate change discourse. The carrying capacity of an ecosystem is the largest population that can be supported without reducing the supportive capacity of the ecosystem, that is, supported in perpetuity. Carrying capacity is one of the simplest and most important models in ecology and the model has been extensively applied to laboratory and field populations.

Estimating the human carrying capacity of the Earth under various assumptions about natural resource consumption and efficiency in production is a perennial activity. Cohen (1995) has published an encyclopedic review of estimates made since the seventeenth century. With a few exceptions, these cluster in the range of 4 to 16 billion—by coincidence (but no more), a range very close to the range of population projections discussed earlier. Yet social scientists, especially but not only economists, have taken little interest in applying the carrying capacity concept to human beings. Hardin (1991) observes that the US National Research Council (US NRC 1986) report on population and development contains no reference to carrying capacity. This, he complains, is like an accounting textbook leaving out assets and liabilities. However, neoclassical economists are far from alone in criticizing the relevance of carrying capacity. Keyfitz (1990: 21) refers to it as "congenial to natural scientists and an irritation to social scientists." One obvious reason is that culture, institutions, accumulation and so on allow human beings to change the technical coefficients that must be assumed to calculate carrying capacity. Cohen (1995) argued, nonetheless, that a useful indicator might be a set of surfaces that define human carrying capacity—maximum supportable population as a function of efficiency in natural resource production and level of consumption per capita.

But indicator of what? Human carrying capacity, like *I=PAT*, takes no account of the welfare implications of a given set of assumptions (MacKellar 1996). For example, what are the opportunity costs implicit in best practice estimates where it is assumed that demand for the natural resource is squeezed to the bare minimum and factors of production are poured into the natural resource sector? These opportunity costs are a function of prices and thus reflect individual preferences and values as mediated through market mechanisms. To know the relevant prices, we would need to solve an economic general equilibrium model of a level of sophistication unlikely to be attained anytime soon, if ever.

One reply from an ecological perspective would be that the assumptions embedded in carrying-capacity calculations can be made to reflect aspects of wise stewardship that cannot be left to the price system; that is, cannot be left up to individuals to work out in the marketplace. A good example is to be found in the Daily et al. (1994) estimate that the optimal world population is 1.5–2 billion persons; among the factors considered are that the population should be large enough to support urban centers, which provide a critical mass for the arts, yet small enough to allow indigenous cultures breathing space to live in isolation. However, this example in itself shows how carrying capacity is contingent on cultural norms and values: it is based on a particular way of seeing human beings, their needs and wants, as well as a given view human beings' ability or inability to mediate impacts on the environment through institutions.

To argue the irrelevance of human carrying capacity (save perhaps at the local level for populations living on the edge of subsistence) is by no means the same thing as to argue the irrelevance of ecology.

Moving deeper into the analysis, we can see that the population–consumption debate stands in the way of a more constructive discussion because it suggests that unidimensional policies hold the key to responding to climate change. The reductionist nature of the debate comes as no surprise because it is informed by a reductionist model. A much more constructive school of research has focused on extending the vicious circle model of high fertility, introduced above, to encompass the environment. In this way, attention is focused on the vulnerable populations in less industrialized countries who are most likely to be adversely affected by global climate change, and on how societies cope with environmental stress.

Population and the environment

This section looks at the neoclassical economic model of population and the environment, and then extends it to encompass poverty, and environmental fragility, and high fertility. No model exists in a vacuum and the resulting vicious circle model is informed by a characteristically neoclassical view of nature, of human nature, and fairness.

A neoclassical framework

The elements of a flexible model of population and the environment were enumerated by Duncan (1959, 1961) in the POET model: the human population (P), socioeconomic organization (O), the environment (E), and technology (T). Early human ecologists (e.g., Ogburn 1922) treated the natural environment, social organization and technology as exogenous; the human population adapted and there was an end to the matter. Over time, however, the tendency has been increasingly to view population as active. Today, population is viewed as acting not only upon the environment, but also on technology (Boserup 1965, 1981) and social structure and organizations (McNicoll 1990, 1993). This is, however, an inherently challenging research area, and little is known about how population affects path-dependent technology and institutions. The challenge is to learn more about how population facilitates and impedes institutions of all kinds, including but not limited to the market, as they seek to mediate environmental stress. How does population affect the ability of human institutions to react to the stress that population inevitably places on the environment?

A framework for considering two-way links between population and the environment is shown in Figure 2.2. In the box at the top left are variables describing the state of the population: its size, density, age and sex structure, and spatial distribution. These state variables reflect the operation of the underlying demographic processes of fertility, mortality, and migration. In the box at the lower right are variables describing the state of the environment: ambient concentrations of pollutants, biodiversity, soil fertility, and the like. These are caused by processes such as agricultural practices and industrial production.

Figure 2.2 shows proximate determinants, that is, factors that directly determine processes and through which other factors must work. The simplest example is fertility. The level of contraception is a proximate determinant of fertility. The level of socioeconomic development, which operates through contraception (as well as marriage rates and other proximate determinants), is an important influence on fertility, but it is not a proximate determinant. The same logic is applied in Figure 2.2 to environmental processes. A proximate determinant of deforestation is the clearing of new agricultural land; the rate of population growth and availability of alternative economic activities are more fundamental causes which work through this (and other) proximate determinants. Impacts upon proximate determinants are of two kinds: direct impacts, conveyed by the arrows at the top and the bottom of the diagram; and indirect impacts, which are mediated through what we have labelled the COST complex—cultural, organizational, socioeconomic, and technological factors.

Cultural values play an implicit role in models that seek to relate environmental impacts to population because many of the key concepts—such as environmental quality, security, population density—lie in the eye of the beholder. Perceptions are not static; they can shift over time. Whereas the natural scientific point of view privileges technological factors and often views technical coefficients as being fixed or rigid, the social scientific point of view privileges cultural, organizational, and socioeconomic processes which can either shift technical coefficients or promote adaptive attitudinal change when they cannot be changed. In economic analysis, the main mechanism of change is substitution in response to price signals.

The neoclassical economic model of population, natural resources, and the environment

Analysts and researchers use and extend basic economics tools to study the relationships among population, consumption, and environmental effects. Underlying these tools are certain assumptions about human behaviors, natural resources and their use for human consumption, what is fair and equitable, and how markets mediate all these relationships. This section provides an introduction to how economic analysis is applied to issues of people and nature.

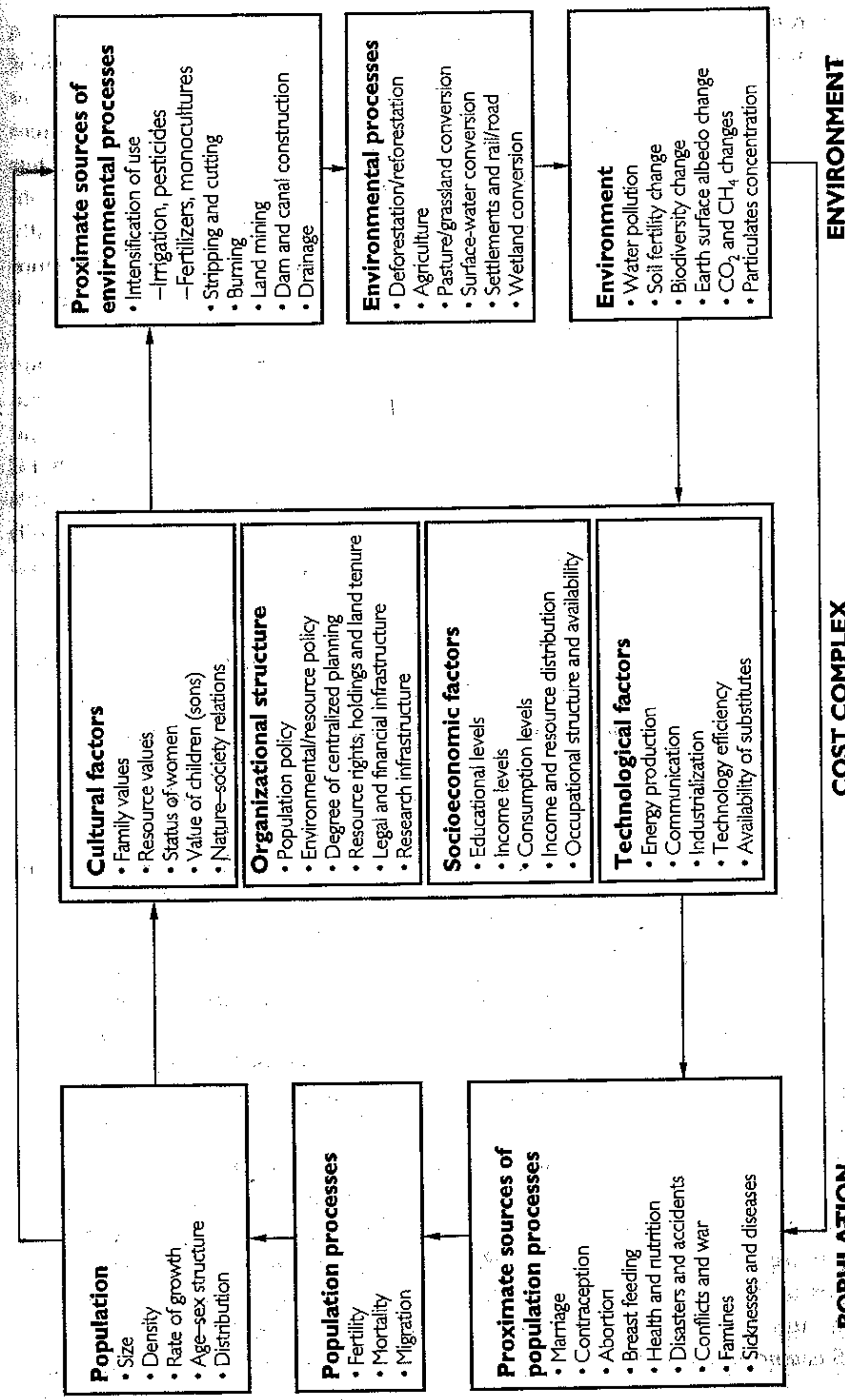

Figure 2.2 A conceptual framework for the study of population and environment.

Basic concepts

Economic analysis sees people as consumers who make consumption decisions based on their judgments of costs and benefits; judgments about the environment are made on this basis as well as decisions to purchase natural resources and man-made goods. Similarly, fairness, equity, and sustainability are interpreted through a cost–benefit lens. A well-functioning market, in which consumers have individually maximized utility and producers have individually maximized profits, gives rise to an economically efficient outcome. That is, since resources have been allocated over competing uses in such a way as to maximize total benefits minus total costs.

According to neoclassical economic theory, tradeoffs between population and quality of the environment may be understood in terms of the marginal economic costs and benefits (Kneese 1989, Cropper & Oates 1992). The survival of nature itself is not in question and nature is valued only to the extent that it is a source of utility to individuals. For example, if individuals derive more utility from highly developed national parks than from the existence of unspoilt wilderness areas, then it follows that existing wilderness should be developed for recreational purposes. At the limit of the neoclassical position lies Simon's (1981) critique of *The limits to growth* (Meadows et al. 1972) and *Global 2000* (CEQ 1980), and more recent work by Beckerman (1995). The term *exemptionalism* has been used (Dunlap 1983) to describe the view, implicit in the neoclassical model, that *Homo sapiens* is either exempt from ecological limits or, at least, is nowhere near having reached them.

Neoclassical economics has a distinctly unromantic view of human nature, focusing on how the individual gets ahead in material terms. At the heart of the neoclassical view is Adam Smith's celebrated invisible hand: individual self-interests give rise to a robust (in the sense of stable when disturbed) and efficient (in the sense of maximizing total output minus total inputs) equilibrium. The social system is permeated by the operation of an efficient marketplace in which price signals of scarcity are transmitted and appropriate responses are elicited. Some of this occurs within the economic sphere per se; for example, as copper becomes scarce and its price rises relative to other materials, producers turn to alternatives in manufacturing, investors allocate funds to exploring for and developing new copper sources (thereby profiting from the rising price), recycling becomes attractive, consumers substitute away from goods containing a great deal of copper, and so on. Other responses may be social and organizational in nature; for example, as income rises, demand for environmental quality rises and voters insist on policies and programs to achieve it. Shifting prices induce technical progress by alerting the research and development community to profitable avenues of technology development.

Sustainability is defined in terms of intergenerational transfers: fertility and

natural-resource consumption decisions in the present period are sustainable if the natural environment bequeathed to the next generation is not inferior in value to that inherited by the present generation. A less restrictive, hence less eco-friendly definition by Solow (1991) is that the value of the entire capital stock (natural, human, and man made) should not diminish in value over time. The key phrase is "in value," which opens the door to the expression of individual preferences via the marketplace. An intergenerational allocation of environmental assets may be ethically abominable and yet sustainable according to the strict neoclassical definition of the term (Dasgupta & Heal 1979).

The neoclassical definition of sustainability opens the door for discounting—the systematic devaluation of future costs and benefits by a factor that reflects preference for consumption now, as opposed to consumption later. Discounting is often assailed by critics of neoclassical economics, but many problems become analytically intractable without discounting. For example, without discounting, the value of the stream of future disbenefits arising from any environmental damage (however slight) in the present is infinite. Therefore, the debate over discounting is best limited to the rate of discount, not to the practice itself (Pearce et al. 1990).

Some neoclassical economists would argue that the discount rate employed to analyze the costs and benefits of public investment projects ought, in accordance with the principle of consumer sovereignty, to be identical to that of consumers. Outside the ranks of these hardliners, however, discomfort with the extension of consumer sovereignty to time preference has always been acute (Robinson 1990). The very founders of modern welfare economics, while universally accepting time preference as a fact of human nature, have described it as "impatient and greedy" (Marshall) and "a polite expression for rapacity and the conquest of reason by passion" (Harrod; see Robinson 1990 for citations and many more quotes). Others have referred to time preference as characteristic of "children," "laborers," and "savages." Pigou (1920: 29) spoke of "irrational discounting":

> It is the clear duty of Government, which is the trustee for unborn generations as well as for its present citizens, to watch over and, if need be, by legislative enactment, to defend, the exhaustible natural resources of the country from rash and reckless spoliation.

This is a lucid statement of the stewardship ethic prevalent among ecologists. Although the discount rate can be derived analytically from economic models, these attempts have failed to displace the more qualitative definition of the discount rate as an expression of society's subjective values: its concern for the well-being of future generations. If households' values lead them to discount the welfare of the next generation heavily, then the economically optimal consumption path will bear heavily on resources and the environment in the present.

The neoclassical model uses economic market concepts to describe the relationship between humans and their environment. Natural resources, in this model, are goods subject to market transactions and scarcity. Scarcity signals, in turn, will prompt various market responses, including technical improvements. Population plays a role, obviously, in what responses to scarcity are chosen; not so obviously, population growth may cause or contribute to market failures, although the research on this question does not provide clear answers. This section briefly explores each of these issues.

Scarcity signals

Natural resource supply and demand are mediated through markets, with prices providing the scarcity signals that elicit substitution, exploration and conservation behaviors. Partly because the share of primary goods (especially food) within the consumption basket falls as consumer income rises, the share of natural resources in economic output as a whole declines. Economic growth does not place pressure on the resource base because it generates a rising surplus (in the form of output and income outside the primary sector) which can be used to promote sustainability. That the surplus will be thus deployed is guaranteed by the fact that, as per capita income rises, so does demand for environmental quality.

The cornerstone of neoclassical natural resource and environmental economics is that all natural resource prices include a scarcity rent which grows exponentially at the financial rate of interest (if not, why would the owner not liquidate the resource stock and invest in bonds?). This reduces demand in the present period so as to conserve supplies for the future. The higher the discount rate, the lower the present price relative to the price in the future; hence, the more aggressively the resource is consumed.

The emphasis on prices reflects a fundamental assumption of neoclassical economics: scarcity is a relative concept, reflecting the ease with which one good can be substituted for another in production and, ultimately, in consumers' utility functions (Box 2.8). If scarcity is absolute—at least one good exists that has no substitute and the constraint is near enough to be relevant—then neoclassical economists would be the first to admit that their paradigm is inappropriate.

The key effect of population in the neoclassical model, absent market failure, is to drive up scarcity rent and raise the price of natural resources relative to the price of labor, thus shifting the distribution of income against resource consumers in favor of resource owners. In poor countries, redistribution of income from wages to profits may be (and probably is) distributionally vicious, but

Box 2.8 Ecological economics: an alternative

Ecological economics, which has emerged over the past quarter century based on the writings of economic mavericks such as Nicholas Georgescu-Roegen, Mancur Olson and Kenneth Boulding, combines elements of economics, ecology, and a deep concern with distributional issues. The theory tells a story of increasing scarcity with the threat of collapse. When the scale of total human activity—number of persons times per capita output or impact—was tiny relative to the size of the ecosystem, economic growth passed for progress and, based on the fact that each generation was better off than the last, appeared to offer a panacea for social ills. Now, the signs are multiplying that ecological limits have been exceeded (Goodland 1992). Total throughput of the natural system must be stabilized, or even better, reduced.

Because further growth is impossible, the theory holds, economic progress and, indeed, political security, can be achieved only by enhancing equity. Since equity is an explicitly normative concept, ecological economics is a self-professed postnormal science (Duchin 1994, Funtowicz & Ravetz 1994), driven by environmental values and combining advocacy with analysis. The advocacy element places ecological economics on the periphery of the economics discipline along with radical political economy.

Scale (and hence aggregate population size) is virtually irrelevant in neoclassical economics; it is absolutely crucial in ecological economics. The disagreement may be ascribed to fundamentally different pre-analytic visions of scarcity. Scarcity in neoclassical economics is relative—scarcity of good A relative to good B—which drives allocative decisions (e.g., allocation of investment resources between sectors A and B), which in turn balance out relative scarcities. Although the allocative focus implicitly recognizes that each individual human activity has an optimum scale (allocation of productive resources to agriculture versus industry, for example), there is no such thing as an overall optimum scale of human activity. By extension, there is no such thing as an optimum size for the human population.

The pre-analytic vision of scarcity in ecological economics is not relative, but generalized (e.g. Daly 1977), driven by growing scarcity of energy. Under conditions of relative scarcity, the potential to substitute abundant materials for scarce ones is practically infinite (Goeller & Weinberg 1976, Goeller & Zucker 1984). Under conditions of generalized scarcity, the price of virtually all goods would rise relative to the price of labor. Forced to allocate an ever-larger share of productive resources to eking food and materials from ever more costly sources (and cleaning up pollution), society would find itself caught in a vicious circle. Rapid population growth obviously worsens generalized scarcity, so ecological economists, in contrast to neoclassical economists, are deeply concerned by current population trends.

there is nothing economically inefficient about it. Governments are, in the event, free to tax winners and compensate losers if they so wish.

Technical progress

Population growth will also, by putting pressure on the natural resource base, give rise to technological innovation and progress which will permit that resource base to be used more intensively and more efficiently (Boserup 1965, 1981). According to Boserup's classic study, population pressure was responsible for the spread of the institutions that facilitated agricultural intensification and technological change in Europe. As population grew, more land was brought under cultivation and fallow periods decreased. Ultimately, fallow periods were abandoned altogether in favor of continuous cultivation. New methods were developed to replace the soil's capacity to regenerate naturally. These consisted, first, of increased labor input, followed by organic fertilizer and animal traction, followed by artificial fertilizer and mechanical power. Intensive agriculture both required and facilitated the development of infrastructure for marketing, transportation, and storage. Thus, population growth led first to agricultural extensification, then to intensification, resulting at first in reduced soil productivity, to which farmers responded by introducing technical change.

According to one line of thought, population growth is the single most important factor driving technical progress (Simon 1981). At least at the national level, population can also give rise to economies of scale (efficiencies as the level of production rises) and agglomeration economies (efficiencies that are gained when more than one firm is able to locate in the same place because of the size of the market).

Market failures

The question at the core of the neoclassical economic view of population, natural resources, and the environment is whether population factors give rise to market failures or worsen the effects of already existing ones. The most important of these market failures revolve around the impact of population on externalities, public goods, and the tragedy of the commons:

- Externalities are costs or benefits that arise from production or consumption decisions, but which are not borne by the decisionmaker. For example, eroded soil (and the chemicals it contains) inflicts damages downstream which are external to the farmer. The farmer will fail to take these damages into account when making profit-maximizing decisions; thus, the level of erosion, although economically optimal from the farmer's point of view, will be too high from the point of view of society as a whole.
- Public goods, such as existence of species and a stable global climate, are goods for which indivisibilities in consumption exist; that is, the amount consumed by person A does not diminish the amount consumed by person B. The definition of a public good is inherently cultural; for example, although police protection is regarded as public in more industrialized countries, private neighborhood militias are widespread in less industrialized countries. In other cases, most importantly climate and the quality of the atmosphere, technical factors make the good indisputably public. This gives rise to the free-rider problem: people with relatively low demand for public goods attempt to free-ride at the expense of people

with higher demand. Thus, the marketplace (and the election process) will lead to the production of a socially suboptimal supply of public goods.
- The tragedy of the commons has been a powerful metaphor since the publication of Hardin's (1972) much-cited article of that title. Although the tragedy of the commons is often associated with common-property natural resources, it is important to note that many resources (e.g., communal grazing lands in semi-arid regions), while held in common, are utilized only according to strictly enforced rules. Failure to control access, not common ownership, is the key. In fact, merely being a common-property resource is neither necessary nor sufficient for the tragedy of the commons: many tropical forest areas that are experiencing deforestation are, in theory, owned by the government, but the owner fails to restrict access.

In all three cases, research has concluded that the role of population is complex and/or heavily conditional on other factors:

- In the area of externalities, neoclassical economists frequently invoke the Coase theorem, according to which under suitable conditions (universality of property rights, absence of transactions costs, absence of wealth effects, and symmetric information), the pursuit of economic self-interest will give rise to bargaining and negotiation processes that will tend to eliminate externalities. Population might enter the Coase negotiation process in several ways. By giving rise to specialization and fragmentation of interests, population might raise transaction costs. If social and political institutions are better equipped to deal with moderate change than rapid change, then the Coase negotiation process might work better under conditions of slower demographic increase. If demographic factors lead to the emergence of an impoverished, disenfranchised subpopulation, then asymmetries of information would probably be worsened. However, imagining all of these problems arising on the national and subnational scale is easier than seeing them at the international level. On the international scale, rapid population growth may accelerate the Coase process by raising the stakes for all parties concerned.
- Population size and rate of growth do not alter the fundamentally public nature of goods such as the global climate, which arises from indivisibilities and the impossibility of limiting consumption. In other words, if supply of the public good is fixed, and if population grows, per capita consumption of the good remains as it was; its scarcity or abundance is unaffected. On the other hand, when supply of a public good is not fixed; for example, if the global climate can be stabilized by means of an ambitious investment program, then it is cheaper on a per capita basis to produce the public good in a large than in a small population. This point is

closely associated with economies of scale in supplying infrastructure, a theme developed by Simon (1981) and elsewhere. The same theme is important to installation of emissions-reducing equipment, provision of agricultural extension services, research and development, and other areas relevant to global climate change.

- Population size and, by extension, rate of growth exacerbate the tragedy of the commons by increasing the number of hands grabbing for a slice of the pie. Population pressures do not, however, give rise to common-property open-access problems where there were none before; on the contrary, they encourage privatization of formerly common-property resources and the evolution of rules limiting access to resources still held in common (Hayami & Ruttan 1991 for an example from the Philippines). This process may be distributionally troublesome, as elites may be able to lay exclusive claim to renewable natural resources that were formerly open to the poor (Jodha 1989 for the case of India) or provided an economic occupation of last resort (Stevenson 1989 for the case of wood fuel gathering in rural Haiti). Some writers (e.g., McNicoll 1984, 1990) have suggested that tenure systems are less likely to evolve toward sustainability under conditions of rapid population growth. The point is speculative, but plausible, and has become a standard feature in the literature. The US National Research Council (US NRC 1986) came close to saying the same thing when it stressed that slower demographic growth would give policymakers more breathing room in which to make politically difficult allocational decisions. Lee (1990b) has also identified a second tragedy of the commons (really an externality) as follows. Say a common property resource is optimally managed, meaning access is controlled and a user fee is charged. An additional birth raises the value of the resource and hence the user fee. The resource is still optimally managed, but now all couples—not just parents of the newborn—are paying the higher user fee.

On its face, an externality argument suggests that public programs to encourage lower fertility are a sound investment for climate-change mitigation (Box 2.9). On the other hand, the problems of estimating costs and benefits in climate change are notorious, a range of policies such as emission permits can also be used to correct the externality, and the greenhouse-related emissions externality is only one of the market failures in which population plays a (sometimes positive) role.

In summary, the neoclassical model suggests that, if markets and other social institutions work well, then a world of more rapid population growth will be one in which natural resources and environmental assets are more highly priced relative to other goods and services. If global climate change makes some natural resources, such as agricultural resources, scarcer and, what amounts to the

Box 2.9 Population and greenhouse-related emissions from a neoclassical economic point of view

Application of neoclassical model to the problem of population and greenhouse-related emissions would give rise to the following analysis. Leaving aside implications for the atmosphere, economists agree that no common-property or public-good problem affects the consumption of fossil fuels; in no other area are property rights more extensively elaborated or minutely assigned. The idea that the finiteness of fossil fuel supplies is a rationale for slower population growth has practically disappeared from the literature; in part because of the obvious fact that, on the assumption that the resource endowment is ultimately exhausted, total utilization is invariant to the rate of population growth (Dasgupta & Heal 1979). Whether a path in which many persons consume the resource now and few later (rapid population growth) is preferable to one in which few consume now but many later (slow population growth) is a question of the discount rate.

The heart of the matter lies, rather, in the public-good aspect of the global atmosphere, in the external cost imposed on other countries by within-country fossil-fuel combustion and land-use changes and in the external benefit of within-country emissions control and the elimination of subsidies on the combustion of coal. From the discussion here, it seems unlikely that population plays a major direct role in worsening or alleviating the market failures that give rise to the accumulation of greenhouse-related gases in the atmosphere. However, by adding urgency to resolution of the problem and strengthening the bargaining position of less industrialized countries ("Share with us your wealth or we will share with you our poverty . . ."), rapid population growth in less industrialized countries may have hastened the onset of negotiations.

Wexler (1996; see also Appendix 4.5 of MacKellar et al. 1996) evaluates the external costs an average newborn will place on society through its projected emissions of greenhouse-related gases. A serious global warming scenario under which the marginal damage from carbon emissions was valued at $180 per tonne, evaluated at a 2 percent discount rate yields a $20000 per birth cost in the more industrialized countries and a $13000 per birth cost in the less industrialized countries. A more optimistic scenario, assuming marginal damage costs of only $10 per tonne, evaluated at a 5 percent discount rate, yields a $620 per birth cost in the more industrialized countries and a $180 per birth cost in the less industrialized countries. To the external cost in the form of greenhouse gas emissions (and any other environmental externalities) must be added external costs, which arise from dilution of the available supply of public goods (such as schools). On the other hand, the birth gives rise to external benefits mediated through tax revenues, payments into the public pension system, and so on. Balancing out external costs and benefits is difficult and highly dependent on assumptions made, including the noneconomic external benefits of children. On its face, however, the externality argument makes a case for alleviating climate change through averting births.

same thing, raises the costs of burning fossil fuels, then these effects will be magnified under conditions of rapid demographic increase. Such effects can have distressing distributional consequences, but under the assumption of well-functioning markets, economic efficiency in the sense of allocating goods and services so as to maximize the present value of total costs minus total benefits will be unaffected. Dealing with the distributional consequences of more rapid population growth (and, for that matter, of climate change) is the task of political and social institutions and, ultimately, rests upon human values. It is impossible to say, on welfare-theoretic grounds, that one population scenario is preferable to another.

On the other hand, if markets do not work well, or if institutional arrangements impede response and the development of coping strategies, then rapid population growth is likely to exacerbate the effects of market failure. Under such conditions, and setting aside for the moment the strict standard imposed by welfare theory, slower population growth will be preferable to more rapid population growth. Moreover, the possibility must be considered that rapid population growth at the macro level and high fertility at the micro level may themselves impede the smooth functioning of markets and other institutions.

Population and renewable resources

Since the seminal US NRC (1986) study, researchers have placed special emphasis on links between population and renewable resources. The debate over population and agricultural resources mirrors the broader debate. The two polar positions are those of Thomas Malthus and Ester Boserup. Malthus proposed that a geometrically growing population tends to outrun an arithmetically growing food supply. Over the long run, population and agricultural resources remain in a state of equilibrium mediated by the available technology of food production and the prevailing living standard. The agricultural resource base is assumed to be fixed, and no allowance is made for technological change. Boserup (1965, 1981), on the other hand, argued that increasing population pressure itself induces technological change, leading to a more intensive use of land. A refinement on the Boserup model is Hayami & Ruttan's (1971, 1987, Ruttan & Hayami 1991) induced innovation model, according to which constraints imposed by an inelastic supply of labor are offset by advances in mechanical technologies, whereas constraints imposed by an inelastic supply of land are offset by biological technology. The examples of the first situation are typical of industrialized countries; examples of the second type are found in many less industrialized countries in general.

Boserup argued that opportunities for land extensification (i.e., rural to rural migration) are exhausted before intensification commences. Only when no more land is available do further increases in population density lead to substitution of more labor-intensive farming practices and modernization (such as mechanization and application of fertilizers and pesticides). The empirical evidence, however, is that land intensification does not necessarily wait for an exhaustion of land extensification opportunities. Pingali & Binswanger (1987)

argue that medium- and large-scale government-induced infrastructural investments, which facilitate land intensification at the farm level, become essential long before all potentially cultivable land is brought under the plow. They distinguish between farmer-based innovations and science- and technology-based innovations. The farmer-based innovations include changes in land use, land investments, development of organic fertilizer use, and the evolution of the tool systems. Science- and technology-based innovations include development of agricultural industry, science-based induced technological change, and development of agricultural research institutions. The authors argue that farmer-based innovations can only support slowly growing populations. In order to accommodate rapid population growth, science- and technology-based innovations are necessary as well.

Complicating the picture is the fact that the distribution of benefits from technical change is affected by policy interventions, such as export taxes and food consumer subsidies, of the sort almost universally applied in both highly industrialized (Alston et al. 1988) and less industrialized (Anania & McCalla 1995) countries. Some of these policy interventions are effectively endogenous; for example, rapid urbanization combined with failure of the agricultural sector to develop may lead almost inevitably to some form of consumer subsidy. Thus, there is a perhaps crucial, and unstudied, link between population growth and the impact of technical change. If population growth were to encourage policies that reduce the benefits of technical progress to those who must implement it, this would pose a serious obstacle to coping with demographic increase.

Theories and case studies of vicious and virtuous circles are derived from this debate over the role of population in resource use and the environment.

A vicious circle model

In this section we describe a vicious circle model, which combines the neoclassical model above with the fertility–poverty trap model which we discussed previously. Poverty, insecurity, and low status of women, although not market failures per se, give rise to similar problems. Much environmental damage in less industrialized countries occurs in disadvantaged local areas, which are characterized by acute deprivation: inequitable access to resources of all kinds, including land, credit to finance investments, and insurance to cover risks; insecurity; poor governance; and lack of opportunities for alternative economic activities or out-migration. The pernicious impact of poverty upon the operation of the price system was one of the major themes of the 1992 World Bank *World development report* focusing on environment and development, and the importance of market failures arising from poverty and insecurity has been explored by many researchers: a general framework is given by Bilsborrow (1987) and among case studies embodying the approach are Stonich (1989) and many others.

Women are more adversely affected than men across the board, and impoverished insecure households living at the margin of survival are likely to deplete surrounding natural resources and environmental assets with little heed for future consequences. Even if such households desired to safeguard their surroundings, however, their room for maneuver, in the form of the types of substitution, adaptation, and behavioral change that are at the heart of the neoclassical economic model, would be painfully restricted. For example, when poor households intensify agricultural production to cope with rapid population growth, they are unable to afford the investment and inputs necessary to conserve soil. The smooth neoclassical substitution mechanisms mediated through the market are unlikely to operate under such conditions. Thus, poverty, insecurity, and low status of women are not only morally wrong, they are barriers to neoclassical economic efficiency as well.

The most influential work in this area is the unified theory of fertility and the environment developed by Dasgupta (1993). In this model, population places pressure on the renewable resource base, say the supply of wood fuel. Poverty prevents substitution of alternative fuel sources; the low status of women and girls devalues the rising amount of time and effort that they must devote to daily wood gathering (Agarwal 1994, Sen 1994). As the value of hands around the house rises, fertility decline is impeded both directly (the value of child labor rises; for example, Feldman 1990) and indirectly (attitudinal change, which might occur through education of girls, is blocked because girls are kept home to help their mothers). The result is yet faster population growth, yet further degradation of the renewable resource base, and yet further erosion of women's position. Poverty, depletion of renewable natural resources, high fertility, and low status of women have combined in a vicious circle which, at best, forms a poverty trap and, at worst, may lead to local ecological breakdown.

But the key to the vicious circle is that it is contingent on the local historical, social, and cultural context. A range of research verifies the existence of virtuous circles as well, in which population pressure leads to environmentally benign intensification of renewable resource exploitation, development of alternative economic activities, and so on.

A virtuous circle model

Land intensification, properly implemented, is a virtuous process; it involves maximizing the productivity of existing land resources. Research in the Machakos district of Kenya (Tiffen & Mortimore 1992, Tiffen et al. 1994) and in semi-arid northern Nigeria (Mortimore 1993) has described the virtuous cycle in which population pressure gives rise to farm-level innovations, elicits policy responses in the form of agricultural extension services, stimulates the growth of nonagricultural activities and off-farm employment, and the like. Before the Second World War, when population growth in Machakos was slow, agricultural productivity was low and there was widespread land degradation in the district. But after the war, when the population of the district grew much more rapidly, this growth was accompanied with improved food production and considerable improvements in land degradation.

This virtuous circle model is almost directly opposed to the vicious circle model. The Machakos example has become so celebrated that it has been pointed out that not all types of soils are able to support such intensification. However, further evidence that demographic increase can stimulate productivity growth comes from the unlikely case of Bangladesh, where high-density rural districts had higher agricultural wages than low-density ones and, over time, the rate of population growth was positively correlated with the rate of change of real agricultural wages (Boyce 1989). The key question facing researchers is to identify the types of institutions that promote healthy response to environmental stress (Box 2.10).

Conclusion

The vicious circle model described here represents the state of the art in population–environment research related to global environmental change. It incorporates flexibility, in the form of neoclassical responses to scarcity; equity in the form of the recognition that poverty, insecurity, and low status of women impede healthy responses; and ecology, in the form of stressing the fragility of marginal environmental zones. As a basis for policy dialogue it is a great improvement over I=PAT, in that it focuses attention on response to climate change rather than on responsibility for avoiding climate change, which may be in significant degree unavoidable. It is an improvement over the basic neoclassical model in that it recognizes that markets must function in a possibly hostile social and historical context. It focuses attention on those populations that are simultaneously most likely to suffer consequences of climate change and least able to adapt. And finally, it focuses researchers' attention on the crucial question of what sorts of policies strengthen and erode the ability of institutions of all kinds to cope with environmental stress.

Figure 2.3 represents an attempt to distill some of the themes developed here while moving beyond a strictly economic framework. Economic, social, and

Box 2.10 Virtuous and vicious circles

When does virtuous Boserupian intensification *not* occur? This is the focus of work by Bilsborrow (1987) and many collaborators (Bilsborrow & Geores 1994, Bilsborrow & DeLargy 1991). Among the contextual factors on which intensification is contingent are the existing level of living, availability of potentially cultivable land, availability of off-farm employment opportunities, size and distribution of landholdings, potential for labor and technological intensification, rural fertility level, rural and urban population distribution, and existing crop structure. Crucial to the success of the virtuous cycle is the intervention of supportive and responsive institutions, especially in the public sector. Under pessimistic sociopolitical and institutional conditions, the result of population pressure will not be Boserupian intensification, but either predatory cultivation of existing land resources or a vicious extensification in which inequitable access to land causes poor families to crowd onto marginal lands whose low productivity exacerbates, in turn, the problem of poverty. Lele & Stone (1989) documented such outcomes in six sub-Saharan African countries, and pointed out that a major impediment to agricultural intensification is that, whereas the economic gains to large families are low, the social gains, in terms of community status and the like, are high. Cleaver & Schreiber (1993) described an African population, agriculture, and environment nexus which might be called Boserup in reverse: a vicious cycle of rapid population growth, agricultural stagnation, and environmental degradation. The conclusion is that a policy-led intensification is needed to supplement the demand-driven (autonomous) intensification suggested by Boserup. Case studies from Asia and Central America have illustrated the vicious combination of population pressure, poverty, and inequitable access to land which forces cultivators onto marginal lands (Cruz et al. 1992), and the UN Secretariat (1991) concluded that there is reason to question the relevance of the Boserup model for many less industrialized countries in the late twentieth century.

political institutions mediate pressures on the natural resource base and the conflicts to which they give rise. In line with the nature of the discussion above, most of the sources of stress shown in the figure have to do with market failure, but this is not the end of the story. Ideational shift and ecological surprises are other sources of stress. The functioning of institutions is informed by their perceived ethical legitimacy, in particular whether they are perceived to be fair (e.g., du Bois 1994 for equity in water management). By definition, populations cope in one way or another with environmental problems. They may cope in environmentally virtuous ways; they may become trapped in a vicious circle; they may use various strategies, a mixture of benign and destructive. The means of coping will, in turn, affect the nature of institutions. In the case of the strategies associated with the vicious circle model, this may amount to institutional fracture and atrophy; in the other cases, it may amount to institutional deepening and strengthening. The means of coping may also directly affect the ecosystem under consideration, and it may alleviate or worsen sources of stress.

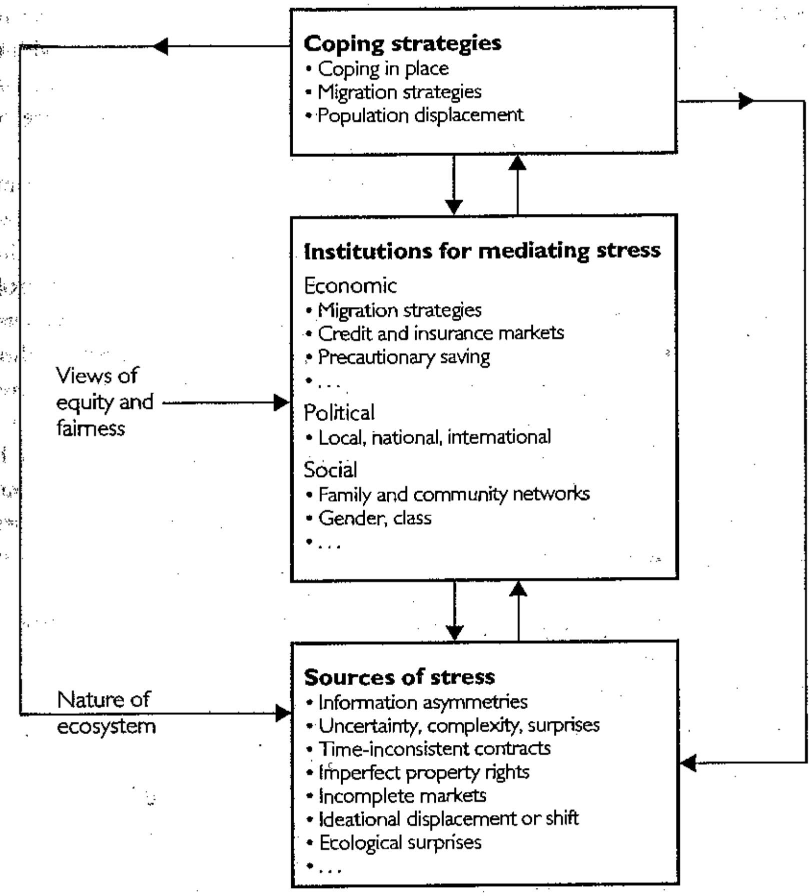

Figure 2.3 Environmental stress and institutional response.

Health

The previous sections have looked at the interactions between climate change and population issues as they relate to economic well-being and the state of the environment. Less well researched, but potentially important, are the possible impacts of climate change on human health.

The health profile of a human population is an outcome that integrates many inputs, some of which are outside human control and some of which, such as social and individual responses to disease, and perceptions of good health, depend on human behavior. Population is related to health in several ways:

- In societies marked by high and closely spaced fertility, the health of women and children tends to be impaired. Some evidence even suggests that the impact of family planning programs on women's health is greater than the impact on fertility.
- In rapidly growing populations, the scarce public health resources are strained. On the other hand, government health expenditures per capita are largely uncorrelated with health outcomes such as infant mortality and life expectancy. Dilution effects are a far less important policy problem than inefficiencies and inequities in the distribution of available health and education resources; for example, to urban-based curative hospital care at the expense of rural primary healthcare, to boys at the expense of girls, and so on (Jiminez 1989).
- In low fertility societies, population aging places special demands on the health system. It is cause for concern that, in both more and less industrialized countries, health systems will have to cope with any stresses arising from global climate change at the same time that they cope with the challenges posed by population aging.

The vicious circle paradigm is applicable to health insofar as good health and holistic well-being are fundamental human assets. Poverty is inimicable to health, and poor health is, in turn, a form of impoverishment. Poor health of rural workers, for example, is a significant barrier to rural development.

Global climate change: a new, fundamental, and complex health challenge

The sustained health of populations depends absolutely on maintaining climate variables within a range of tolerable extremes, protection from solar ultraviolet radiation, adequate supplies of food and fresh water, and (for various reasons) the continued existence of diverse species and their genes. Global climate change would pose a new, fundamental, and complex type of hazard to human health (Last 1993, McMichael 1993, Epstein 1995). As "new," "fundamental," and "complex" are words liable to overuse, this characterization is important to explore.

The hazard is new because, during two centuries of urbanization and industrialization, public health hazards have emerged primarily within geographically localized contexts, reflecting local demography, culture, technology, and wealth. Thus, patterns of infectious diseases, chemical pollutants, occupational exposures, and, more recently, the rise of affluent, risk-bearing behaviors (e.g. consumption of tobacco, alcohol, and processed foods; automobile transport) have mainly originated and been countered on a local scale. However, the

disruption of Earth's natural systems associated with global environmental change poses a new, supra-population scale of health hazard. The hazard is fundamental because these systems together comprise a general life-support system which underpins the long-term biological health of all species.

Complexity arises because forecasting these potential health impacts entails multiple uncertainties, nonlinearity, and a long time-horizon (McMichael & Martens 1995). The first two of these characteristics pose challenges to prevailing modes of scientific data assembly and analysis and, subsequently, to the process of scientific inference. The long time-horizon suggests that much of the research will not be amenable to conventional hypothesis testing (and certainly not within the timeframe of relevance to social decisionmaking). Because of the complexity of the ecological and geophysical disturbances attendant on climate change, we should expect some surprise outcomes (Levins 1995).

The hazard is new also because the extent and rate of some of the predicted changes would fall outside the range of recorded human experience. Conventional epidemiological research relies on collecting data that describe current or past experiences of populations or groups, calculating risks, and elaborating models which explain variations in risk. By extension, the conventional prediction of health risks (i.e., formal health risk assessment) entails applying empirically derived exposure–response relationships to current populations with a known or presumed exposure profile. Thus, both the exposure–response and population risk parameters are real, or at least realistic. However, assessment of the health impacts of global environmental change entails the prediction of future health risk from scenarios of future population exposures. Such exposures may be qualitatively different from past experience, because they will reflect changes in a range of background variables, such as changes in nutrition and the distribution of disease-bearing vectors (e.g. ticks, mosquitoes, and fleas). Few historical data directly encompass the projected exposure scenarios.

The risks are not merely more of the same—more heatwaves or more air pollution, for instance. Rather, they would arise substantially via indirect pathways; in particular, by disturbance of natural systems such as the ecology of infectious agents, food production, and freshwater supplies. Researchers have long been aware that global warming may have both direct and indirect effects on human health (WHO 1990). Nutritional status, disease incidence, and morbidity/mortality outcomes are, in turn, related by complex, incompletely understood processes (Murray 1994). Another indirect effect would arise if coping with impacts of global environmental change diverted public and private resources away from health. Difficult as direct effects are to model and predict, the challenge posed by indirect effects is greater, because these effects are contingent on a wider range of assumptions. The further the scenario moves from the empirical epidemiological record, the more tenuous the prediction and the greater the likelihood of surprises.

Because of these difficulties, the impact of global warming on human health is uncertain, at best, and perhaps, in part, unforeseeable. This difficulty is compounded by uncertainties about regional patterns of environmental change, and by variations in the vulnerability of populations in those different regions. However, the bulk of research has concluded that, although some changes are likely to be beneficial, the net impact of global warming on human health is likely to be negative (McMichael et al. 1996), with indirect effects being more significant than direct ones in the long term. In other words, most of the health impacts of global warming, especially those mediated by disturbances to ecological systems, would be adverse. Among these possible negative impacts on health may be the following:

- increased morbidity and mortality because of more extreme events, particularly heatwaves, fires, cyclones, and flooding
- changes in infectious disease epidemiology, particularly increases in the spread and activity of a variety of vector-borne diseases
- health impacts of changes in nutritional status arising from changes in agricultural productivity
- disruption of freshwater supply, and perhaps sanitation, because of sea level rise
- extensive population movements, some involving distress of the sort associated with the environmental refugee model discussed in the next section
- health impacts of social stresses associated with global environmental change and its impact on the economy.

In this section, we focus on two health impacts that are most likely to prove significant and which have been most intensively examined: the direct effects of increased frequency of thermal extremes, and indirect effects mediated through alteration of the distribution of vectors which transmit certain infectious diseases. Although the first is much better understood, the second is likely to involve the greater impacts, because of the greater size and vulnerability of the population exposed to heightened risk, and the more limited resources available for response and adaptation.

Background conditions

Just as a fairly typical transition from high to low fertility can be discerned in the historical record, so can an epidemiological or mortality transition be described. In more industrialized countries, this transition was marked first by

increased resistance to disease as a result of improved living conditions, then by mortality declines owing to improved sanitation, then by declines resulting from medical advancements such as vaccinations and antibiotics (McKeown 1988). The effect of these developments was to concentrate mortality into older ages where degenerative, rather than infectious and parasitic, diseases predominate. The most recent phase of the mortality transition has been reductions in some of these causes of death, such as cardiovascular disease and cancer. However, despite advances in high-technology, high-cost medical interventions, mortality rates in industrial countries are more closely associated with the equity of the income distribution than income level itself (Wilkinson 1994).

In less industrialized countries, the transition has been rather different, since modern medical technology became available before countries had undergone improvements in living conditions. Thus, as discussed in the early pages of this chapter, the mortality decline that took 200 or more years to occur in the industrialized countries has occurred in the less industrialized countries in 50 years. One result has been a gap within the Third World in the medical care available to the rich and the poor (World Bank 1993); for example, in countries where rural areas often lack basic maternal and child healthcare facilities or sanitation systems, the capital city may possess an up-to-date center for cardiac surgery. Although the urban/rural gap in healthcare is still the main concern, so is the gap between the urban middle class and poor, and between those elite workers with access to the public health system through membership in social security schemes and the rest of the population (McGreevey 1990). Good health is perhaps the most fundamental aspect of human capital, and reforming health systems to eliminate inequities and improve the health of the poor is one of the most promising opportunities for combating poverty (World Bank 1993). Steep health gradients across socioeconomic class are not, however, a concern limited to the Third World (Frank & Mustard 1994).

Health transition in rural areas of less industrialized countries must be placed in the context of continuing agricultural intensification. Growing use of machinery, fertilizers, and pesticides (often under conditions that would be considered unsafe in industrial countries), and the impacts of large dam projects are examples of factors that may affect health, as do more general agronomic practices (e.g., mosquito breeding is affected by how often ricefields are drained). One of the chief characteristics of health transition in urban areas is exposure to elevated levels of both traditional pollutants (e.g., particulates from woodfuel or charcoal burning, or sulfur dioxide and urban smog; Romieu et al. 1990, Pope et al. 1995) and of new pollutants, such as toxic substances. Rapid industrialization has not been accompanied by the development of institutions and regimes to ensure proper disposal of the harmful wastes generated by industries (Ludwig & Islam 1992 for Bangladesh, Asante-Duah & Sam 1995 for

West Africa). Marquette (1995) has written of the urgent need for improved information-gathering and planning mechanisms to cope with environmental health hazards in rapidly industrializing countries and in the transition economies, as well as of the need for a greater focus on the urban environment in a rapidly urbanizing world.

Several major components of the world health situation stand apart from the mortality transition model in its unadorned form. Recent years have seen a resurgence of infectious diseases and the emergence of new viruses (Morse 1991). Examples include the emergence of the human immunodeficiency virus (HIV), emergence of new vector-borne viral infections in the Americas, discovery of a new and spreading strain of cholera, the resurgence of diphtheria in Russia, and the emergence of various antibiotic-resistant microbes, including the malaria parasite (especially in Asia) and multidrug-resistant tuberculosis strains (among urban populations in the northeastern United States). Also well publicized is the upward ratchet in mortality in the transition economies of central and eastern Europe (Feachem 1994, Potrykowska & Clarke 1995). Some of these, such as the appearance of HIV, are classic surprises, whereas others, such as the development of antibiotic-resistant bacterial strains, fall within the range of experience and could have been predicted by models that accounted for the ecological complexity of disease.

The major deviation from the mortality transition model is, of course, the widespread increase in HIV infection and ensuing AIDS mortality. Studies discussed in Box 1.1 have concluded that the effect of AIDS mortality on population growth, although significant, is likely to be modest. On an individual and societal level, on the other hand, the AIDS epidemic is an epochal event, roughly on a scale with the 1918 influenza pandemic. In Africa, the social effects of AIDS are exacerbated by the fact that the persons at highest risk are in the prime productive years and belong, moreover, to skilled urban elites (Ainsworth & Over 1994). Thus, although other diseases such as tuberculosis and malaria account for more deaths, the economic impact of AIDS is greater. In all regions, AIDS is placing stress on public health budgets and, more generally, is increasing the share of total resources that must be devoted to health (e.g., placing claims on savings of affected families and raising insurance premiums).

Thermal extremes

The main thermal hazards of global warming would result from increased frequency and severity of heatwaves, defined often as five days in a row in which the daily ambient temperature exceeds the normal body temperature of 36°C (98.6°F). Prolonged heat stress can lead after several days to heat exhaus-

tion characterized by dizziness, weakness, and fatigue. More acutely, **heat stroke**, in which body temperature exceeds 41°C (106°F), may occur, often resulting in unconsciousness and sometimes death.

Minor changes in temperature and humidity evoke both physiological and behavioral responses. Healthy persons cope with moderate rises in ambient environmental temperature and, within certain limits, thermal comfort is thus maintained. Further physiological acclimatization develops after several days, thus minimizing heat stress. However, frail or ill individuals with lower physiological resilience adapt less well. Hence, heat stress is a greater health hazard in elderly persons, infants, and in persons suffering from cardiovascular or other disorders.

Higher summer temperatures and accompanying heatwaves would increase rates of heat-related illness and death in both temperate and tropical regions, but reliable dose–response estimates exist only for the first. Historical analogues may be found in events such as the extremely hot summers experienced in Missouri during the early 1980s, when temperatures were 2–3°C higher than normal, and heat-related deaths occurred at seven times their normal rate (Centers for Disease Control 1989). The pattern of deaths from all causes in relation to daily summer temperature in New York City indicates a nonlinear relationship with a threshold of approximately 33°C, above which overall death rates increase sharply (Kalkenstein 1993b). However, other studies in the United States indicate that 20–40 percent of such heat-related deaths during heatwaves represent a displacement or early harvesting effect; that is, deaths that would have occurred within several weeks under normal temperature conditions. From studies done in heat-sensitive northern US cities (those where heatwaves are infrequent) it has been estimated that, under climate scenarios accompanying a doubling of carbon dioxide concentration, heat-related deaths in such populations would increase by a factor of five or six (Kalkenstein & Smoyer 1993). Cities with naturally warmer weather would be less affected, because their inhabitants are better adapted to prolonged bouts of summer heat.

Excess mortality related to heatwaves is greatest in crowded inner urban environments, owing to the heat island effect, and in communities lacking air conditioning and proper ventilation. Before the advent of air conditioning in industrialized countries, excess mortality during heatwaves was much more pronounced than it is at present. Data from heatwaves of similar magnitude in Los Angeles in 1939, 1955, and 1963 indicate a sharp drop in excess mortality between the second and third episodes, probably because of the advent of residential air conditioning (Goldsmith 1986).

Just as global warming would be expected to increase heat-related mortality, it would, to some extent, reduce winter-time mortality by reducing the extent and frequency of extreme cold weather (Kalkenstein 1989, 1993a,b, Langford

& Bentham 1993). Excess winter mortality is predominantly attributable to influenza, other respiratory infections such as bronchitis and pneumonia, and coronary heat disease.

Temperature and other climatic variables affect the respiratory tract (Ayres 1990). Bronchitis and emphysema are typically exacerbated during winter, whereas asthma and hay fever tend to break out during summer, perhaps because of pollen release. Hot dry summer weather increases the pollen count, whereas summer rain stimulates the release of fungal spores. Thus, global warming may reduce winter bronchitis and pneumonia and increase summer asthma and hay fever.

Fossil fuel combustion, which is the principal cause of rising atmospheric carbon dioxide concentration, is accompanied by increases in the ambient concentration of other pollutants in the urban atmosphere, such as sulfur dioxide and nitrous oxides. The urban atmosphere in industrial countries has generally improved as a result of more effective environmental policies (OECD 1991); however, most less industrialized countries lack such policies. Higher summer temperatures would also stimulate the chemical reactions that give rise to photochemical smog. Bufalini et al. (1989) estimated that a 4°C increase in average summer temperature in the San Francisco Bay area would triple person-hours of exposure to concentrations of atmospheric ozone in excess of the current air quality standard. Exposure to such pollutants reduces lung function, thus increasing susceptibility to infection, heat stress, and chronic lung disease, with consequences for mortality and morbidity from a wide range of causes.

Some direct effects in addition to those mediated through thermal extremes also deserve mention. Disasters give rise to an entire class of public health problems (Gregg 1989), and to the extent that global climate change includes greater frequency of floods, storms, and other extreme weather events, the frequency of such problems will rise. Among these, in addition to direct weather-related mortality, are outbreaks of diarrhoeal disease when water sources are contaminated by fecal material, problems associated with runoff of toxic materials (Thurman et al. 1991, 1992), and increases in some vector-borne infectious diseases as a result of flood conditions (Hederra 1987, Cotton 1993). Even without flooding, increased rainfall and higher temperatures would also be favorable to the bacteria and protozoa that cause diarrhoeal diseases, including cholera.

Vector-borne diseases

Most infectious disease transmission mechanisms are affected one way or another by climatic factors (Bradley 1993), and the link to climate is especially close in the case of vector-borne infections. Most vector-borne diseases have at

least three, and usually four, components (Longstreth 1990): the infectious agent (e.g., to take the case of Rocky Mountain Spotted Fever, *Rickettsia ricketsii*), the vector (*Dermacentor variabilis*), an intermediate host (woodland birds and animals) and an ultimate host (humans). Changes in climate can affect any one of these components.

The maintenance of a vector-borne infectious disease agent requires an adequate population of the vector and favorable environmental conditions for both vector and parasite (Koopman et al. 1991, Shope 1991, Herrera-Basto et al. 1992, Bouma et al. 1994, Loevinsohn 1994). Slight changes in climate can affect the viability and geographical distribution of vectors. To take one example, and probably the most important one, the *Anopheles* mosquito, which transmits malaria, does not survive easily where the mean winter temperature drops below approximately 15°C, and it survives best where the mean temperature is 20–30°C and humidity exceeds 60 percent (Martens et al. 1995a). Higher temperatures accelerate the developmental cycle of the malaria parasite (Burgos et al. 1994). Further, the malarial parasite (*Plasmodium*) cannot survive below a critical temperature: around 14–16°C for *P. vivax* and 18–20°C for *P. falciparum*. By improving conditions for both vector and parasite, unusually hot and wet weather in endemic areas can cause a marked increase in malaria (Loevinsohn 1994). Many other vectors, parasites and microbes generally thrive in warmth and moisture (Gillet 1974 for parasites, Shope 1991, Nicholls 1993 for the case of rodents); thus, climate changes over the coming century could promote vector-borne and other infectious diseases. Although these cannot necessarily be ascribed to climate change, occurrences have already been noted of dengue fever in new areas and of malaria at higher latitudes than previously observed (Levins et al. 1994); these may arise from complex changes in regional climate, local ecological systems, and the distribution of the human population (Epstein 1995). Studies in Mexico have shown that incidence of dengue fever increases several-fold in years with rainy seasons of above-average warmth (Koopman et al. 1991).

A simple model, which related annual average temperature and rainfall to malaria incidence, predicted that incidence in Indonesia might increase 25 percent over 80 years as a result of climate change (Asian Development Bank 1994). Another model employing the same approach but worldwide found that five different climate change scenarios gave rise to increases ranging from 7 to 28 percent in the land area affected by malaria (Martin & Lefebvre 1995).

A detailed epidemiological model has been developed (Martens et al. 1994, 1995a,b) in which development, feeding frequency and longevity of the mosquito and the maturation period of the parasite within the mosquito are endogenous variables. The prevalence of public health control measures is exogenous; thus, the model's predictions refer only to potential alterations in the geographic range of transmission; their significance for alterations in disease incidence must be interpreted in relation to local conditions and public health control measures. Model simulations based on an assumed increase of 3°C in global temperature by 2100, holding population size and public health responses fixed, indicate a doubling of potential malaria incidence in tropical regions and a tenfold increase (from a very low base) in temperate regions.

A core finding of the study was that, although malaria would be worsened in all currently endemic regions, the effect would be more severe in currently low-endemicity areas, not in areas where prevalence is already elevated. Included among areas that might become endemic are highland urban areas, such as Nairobi and Harare, or parts of the Andes and mountainous western parts of China, which are currently situated above the mosquito line. The vulnerability of newly affected populations would initially lead to high case-fatality rates because of their lack of natural immunity. Worldwide, the model predicts a climate-induced increase of around 25 percent in malaria cases.

The re-emergence of malaria in formerly malarious areas, such as parts of the southern United States, is unlikely. Longstreth (1990), interpreting results of model simulations by Haille (1989) as well as other research, wrote that only a rather unlikely combination of events could lead to the re-emergence of malaria as a serious public health problem in the United States: a breakdown in the effectiveness of vector-control programs or establishment of a pesticide-resistant strain of *Anopheles*, plus establishment of a large infected human population that went untreated for an extended period of time.

Malaria is only one of many vector-borne diseases whose distribution may extend and whose intensity may be increased by warmer, more humid conditions (Rogers & Packer 1993). Others include trypanosomiasis (African sleeping sickness and American Chagas disease), filariasis (elephantiasis), onchocerciasis (river blindness), schistosomiasis (bilharzia), hookworm, guinea worm, and various tapeworms. Vector-borne viral infections such as dengue fever, yellow fever, and rodent-borne hantavirus are also affected by temperature and surface-water distribution (McMichael et al. 1996).

Climate change would also tend to increase various infectious diseases that are not vector borne, such as cholera, salmonellosis, other food- and water-related infections, and diseases caused by large parasites such as hookworm and roundworms. This would be most likely in tropical and subtropical regions, because of the effect of changes in water distribution and temperature upon micro-organism proliferation. Dobson & Carper (1992) have put it simply: parasites and disease will do well on a warmed Earth.

Conclusion

Assessing and countering these hazards is one of the main long-term challenges facing those concerned with the health of human populations (Powles 1992). Cost-effective public health responses can minimize the impacts described above. For example, in the case of malaria these would include surveillance, improved treatment, open-water management and applications of pesticides (although the acceleration of parasites' lifecycle allows quicker development of resistant strains). The range of measures available is broad: improved and extended medical care services, environmental management, protective technology (such as housing and water purification), public education directed at personal behaviors, and appropriate professional and research training. Bradley (1994) has classified responses in the case of tropical diseases as follows: pesticides, chemotherapy, vaccines, and environmental management. Better and larger-scale public health monitoring systems are also needed (Haines et al. 1993). Interventions need not be designed directly to reduce incidence of the disease, but rather to reduce its impact on the community. For example, where malaria eradication is infeasible, interventions designed to improve the nutritional status of an undernourished population may be more appropriate than vector-control interventions. As in the case of agriculture, the importance of local capacity and institutions must be stressed.

Most research has concluded that, given the possibility for response, the health impacts of climate change in more industrialized countries will probably be modest. In less industrialized countries, on the other hand, where populations tend to be more vulnerable (both socially and biologically) and public health spending is limited by available resources, mortality and morbidity conditions are likely to worsen as a result of global climate change. Both conclusions must be conditioned by the uncertainties and complexities discussed in the first paragraphs of this section.

Refugees, migration, and resource conflicts

The potent combination of poverty, natural resource scarcity, demographic pressure, ignorance, and ethnic hatred was evoked by Kaplan (1994) in a piece whose message was summed up by its title: "The coming anarchy." According to this school of thought, the pressure of impoverished populations against renewable natural resources is becoming one of the leading causes of population displacement, internal conflict between different ethnic and interest groups and, ultimately, international conflict (Homer-Dixon 1991, Homer-Dixon et al.

1993); if present trends continue, it will be one of the major international security problems of the next century.

The Kaplan scenario has some basis in economic theory: when renewable common property natural resources such as land, water, and forests, become more scarce, elites may claim them and thus worsen an already inequitable distribution. Much of the focus is on Africa, where drought and desertification have already exacted a heavy toll and where the situation might worsen under conditions of global climate change. South Asia, particularly sensitive border areas such as the territory between India and Bangladesh, is another area of concern. Jodha (1989) has documented such a process at work over the long term in India. Global climate change may be joined to the list of potential causes of conflicts. If land becomes uninhabitable or nonproductive, people will migrate to more desirable locations.

Environmental refugees

The term *environmental refugees* brings population–environment linkages forcefully home to policymakers, evoking images of human misery and social chaos. In the following paragraphs, by deflating some of the more expansive claims that have been made, we are able to focus more clearly on problems of environmental distress migration; that is, migration in which the deterioration of the natural resource base is a significant push factor. Such environmental migration can be dealt with in the much more familiar framework of international migration for economic reasons.

Minimalists versus maximalists

Although there is a substantial literature on the consequences of migration for the environment, there is much less research on the effects of environmental factors on migration. Yet two different and opposing perspectives can be identified. In one, the *minimalist* view, environmental change is a contextual variable that can contribute to migration, but analytic difficulties and empirical shortcomings make it difficult to draw reliable conclusions. The other perspective is a *maximalist* view, which holds that environmental deterioration is a direct cause of large-scale population displacements.

Minimalists (e.g., Bilsborrow 1987, Kritz 1990) are drawn principally from the ranks of economists, demographers, and geographers specializing in migration studies. A neoclassical strand of thought within the minimalist school considers the decision to migrate as the outcome of a cost–benefit calculation in which expected economic well-being is the variable of interest. A poor state of the environment, according to this model, is only one of many push variables; its effect is to reduce utility directly by making the environment less healthy, to reduce expected income by reducing the productivity of agricultural land, and to increase risk by raising the variance of agricultural yields. Costs of household production related to the renewable resource base—that is, gathering wood and fetching water—are increased as the resource base becomes less productive.

In a strict neoclassical interpretation, out-migration is seen as the result of a smoothly functioning response mechanism which offers the potential migrant a wide choice of options and strategies. In a neo-Marxist interpretation, however, decisions to move are made in the context of a powerful set of historical, institutional, and cultural factors that tilt the playing field against the potential migrant. Environmental deterioration, in this interpretation, is closely tied to poverty and exploitation; out-migration is best understood as an uprooting of households who are denied access to the resources that would allow them to ameliorate deteriorating environmental conditions.

In either of the minimalist interpretations, environmental change is not the simple direct cause of out-migration. Maximalists, by contrast, claim that substantial numbers of migrants in less industrialized countries represent households which have been directly displaced by deteriorating environmental conditions, and they forecast that the situation is bound to worsen. A seminal study in this vein stated, "All displaced persons can be described as environmental refugees, having been forced to leave their original habitat (or having left voluntarily) to protect themselves from harm and/or seek a better quality of life" (El Hinnawi 1984), and Myers (1994) offers a similarly broad definition of environmental refugees as people who can no longer earn a secure livelihood in their erstwhile homelands because of drought, soil erosion, desertification, and other environmental problems. Jacobson (1988) limited the definition to persons displaced by drought, flood, toxification, and rising sea level, but widened the umbrella by adding deforestation.

As a result of the expansive (practically, in the case of El-Hinnawi, all-inclusive) definition of the word "refugee", the numbers of people potentially involved are enormous. Westing (1992, 1994) estimated that there were 10–15 million displaced persons, mostly in Africa, and that the number is increasing by some 3 million per year. There being no discernible rise in warfare or persecution, he assigns the increase to environmental deterioration. Myers (1994) calculates that, by the year 2050, the number of environmental refugees may rise to 150 million people (89 million of them from China, India, Bangladesh and Egypt; some 1.5 percent of projected world population as opposed to the 0.2 percent that Myers estimates to currently qualify as environmental refugees).

Flexible definitions invite speculation at best and abuse at worst. To rehabilitate the term environmental refugee, we first return to the generally accepted definition of the term refugee and, second, situate the population displacements associated with environmental distress along a continuum, with refugee flight at one end and normal migration at the other. Refugees, in common sociological usage, flee involuntarily and in haste; they are powerless and vulnerable in their new place of residence. Although not in strict accordance with international law,[6] the term might reasonably be applied to persons displaced by a flood which was, in turn, exacerbated by environmental deterioration.

Migrants, by contrast, move of their own volition in response to a combination of disagreeable conditions (push factors) and in anticipation of a better life (pull factors); once installed in their new residence, they typically relate to the host society from a much stronger position than do refugees. The members of a household that relocates after months of struggling to cope with worsening environmental conditions are, by reasonable definition, environmental migrants, not environmental refugees. Similarly, the World Bank estimates that, from 1985, to 1995 80–90 million persons in less industrialized countries have been forced to move by infrastructural development projects, most involving either irrigation or transportation (Cernea 1995). Although they often suffer profound consequences, these displaced persons are not refugees.

A synthesis of the minimalist and maximalist lines of thought is possible along the following lines. Marginal deterioration of environmental conditions will, under normal circumstances, give rise to various responses, out-migration prominent among them. If conditions continue to deteriorate, and if households choose not to or are unable to alleviate the underlying environmental problem, then the importance of the out-migration response will grow. In the worst scenario, households do not address the problem of environmental deterioration and orderly out-migration is impeded; then pressure will build up until there is a classic ecological collapse and a resulting wave of environmental refugees. In the following section, we discuss responses and strategies likely to be invoked in order to avoid this extreme outcome.

Demographic and social responses to environmental stress

Since environmentally induced population movements are most pronounced in the rural areas of less industrialized countries, we may gain some insight by looking at the case of preindustrial Europe. The typical case examined is a run of bad harvests in an agricultural community. As summarized by Lee (1990a), among the responses that have been identified are the following. Vulnerable members of the population, particularly the aged, exhibit increased frailty and

6. According to the 1951 United Nations Convention on the Status of Refugees and Stateless Persons, to be considered a refugee, a person must be outside his or her country of origin for reasons of "persecution" based on "race, religion, nationality, membership of a particular social group or political opinion."

die as a result of normal morbidity conditions. Men may leave the community to seek work in adjoining agricultural regions or in the city; the ensuing spousal separation leads to a reduction in fertility. As financial assets are deployed to purchase food, marriages are delayed, reducing the number of first births. Fecundity may be somewhat reduced by poor diet and, more significantly, if there is a shortage of weaning supplements, infants will be breastfed more intensively for a longer period, with consequent reduction in fecundity. Davis (1963) long ago coined the term *multiphasic response* to refer to this dynamically complex demographic reaction to stress. Dyson (1991) found a proactive demographic response in South Asia, where famines were preceded by extended periods of worsening adversity, during which fertility declined.

When the harvest recovers, adaptation behaviors change. Children inherit land from those who died during the bad harvests, and young couples can thus marry. Returning male migrants are reunited with wives who have ceased breastfeeding infants conceived before the crisis and are fecund as a result. With the frailest members of the population having died, age-specific mortality rates may even be lower than normal. From beginning to end, the demographic response to a subnormal harvest requires about four years to run its course. This pattern, although first recognized for the case of preindustrial Europe, appears to be relevant to non-European populations. Lee (1990) discussed research findings from Bangladesh, China, India, Taiwan, and preindustrial Japan, all conforming to the pattern. Other studies have looked at a broader range of responses.

In drought-prone regions, seasonal or temporary migration of some household members may already be an established means of coping with periodic food shortages; when disaster strikes, households resort to the coping strategy with which they are most familiar. This was the case during the 1980s drought in the Sahel, during which Hill (1989) found that the most prevalent coping strategy was to move. Findley (1994) found that in Mali the drought did not cause an increase in migration per se, but led rather to a dramatic shortening of the periodicity of circular migration, concluding that the appropriate policy response is to facilitate the migration. Caldwell et al. (1986) looked at coping strategies employed by households in drought-prone south India during an especially severe episode. By far the most common response was eating less (to some extent in all households; to the point of hunger in one-third of households), followed by reductions in discretionary spending (a little under one-fifth of all households), followed at some distance by securing loans, selling assets and changing employment. Famine mortality in South Asia consists not of persons actually starving to death but of a massive expansion of normal seasonal mortality patterns, especially mortality caused by malaria (Dyson 1991). In northern Mali, an acutely drought-prone area, population expanded relatively smoothly throughout the twentieth century, despite periodic catastrophes (Pederson 1995).

As population pressure rises and the productivity of the renewable resource base declines, a bifurcation point is reached (Mortimore 1989, Tiffen et al. 1994). One branch corresponds to the environmental refugee scenario: worsening environmental deterioration, growing food scarcity, starvation and distress out-migration, dependence on international relief, and so on. The other branch, which shares the spirit, if not the particulars, of the Boserup model of agricultural intensification (Boserup 1965), is characterized by land-saving investment, adoption of improved agricultural practices, development of non-agricultural economic activities, and diversification of income sources. So, once again, we return to the theme of a vicious circle and a virtuous circle.

Which path is taken in response to environmental stress will depend in part on local conditions (e.g., the nature of land tenure rights) and on the enabling or impeding role of the state. The role of public policy is illustrated by Warrick's (1980) examination of the changing impact of recurrent droughts in the American Great Plains states. Great droughts in the 1890s and 1910s provoked large-scale out-migration; however, it was much less pronounced in the 1930s and 1950s, because public policies and programs were in force to encourage adaptation in place. International early warning systems and emergency assistance responses have improved over the years, but they remain unable to deal with situations in which civilian food supplies are destroyed or interdicted in the course of military conflict (Chen & Kates 1994).

Droughts, which tend to extend over several years and are periodic, give societies time to evolve a range of adaptive responses. Floods, being one-off events, are much more likely to provoke population dislocation. On the other hand, because floods are rare events, displaced populations are likely to re-implant themselves once the waters recede. Thus, although floods are more likely to produce environmental refugees than are droughts, their status as refugees will not necessarily be permanent or even long term. Although droughts cause less dislocation in the near term, they can cause more significant long-run social change because of their persistence.

Sea level rise

All estimates of the number of potential environmental refugees consist in part of persons displaced by rising sea level. Although the most dramatic effect of sea level rise is inundation, the loss of land area to the sea, sea level rise has a range of less profound impacts, such as intrusion of salt water into aquifers. These effects and possible responses are discussed extensively in Volume 2. Rising sea level lies midway between drought and floods, in that its effects are felt only over the long term, but when they are felt they take the form of more

frequent flooding of low-lying coastal areas. The severity of damage will depend more on local conditions than on the precise extent of sea level rise (Smil 1990). If coastal areas come under assault by the sea, and if countermeasures are not taken, then these areas will be gradually lost to human habitation. If countermeasures are taken, the effects of sea level rise can be in significant degree mitigated; the price will be forgone investment in other areas. The experience of low-lying countries such as the Netherlands is relevant, although the models that predict sea level rise also predict that it will occur much more rapidly than ever in historical experience.

Concern has been focused on the inundation of densely populated low-lying areas, such as the Nile Delta, and on coastal cities; in fact, because the value of land is so high in such regions, these are precisely the areas least likely to be abandoned to the sea. For example, the Nile Delta region is in no sense a natural delta in geophysical equilibrium; it has long been an area managed by ceaseless human intervention (Stanley & Warne 1993). The effect of sea level rise in areas of relatively low population density, by contrast, could be devastating to the populations affected. In a survey of South Pacific islands, Pernetta (1989) sorted countries into five categories, ranging from countries that might conceivably cease to exist (Kiribati being the most populous of these) to those where impacts would be only locally severe (Papua New Guinea, Guam, and Western Samoa among them). In the latter, planning responses could significantly ameliorate damages within existing social, demographic and agricultural structures. However, neither national nor international environmental policy communities seem to be reacting very effectively to the threat of sea level rise in the South Pacific (Pernetta 1992).

Some speculative damage estimates (e.g., Broadus 1993) have been made on the basis of land prices. Yohe et al. (1995) pointed out that, in a perfect world, sea level rise would be mediated through a forward-looking real-estate market in which prices are discounted to reflect hazards. (See the discussions in Vol. 2, Ch. 3 and Vol. 3, Ch. 1.) Taken to the limit, this logic would imply that sea level rise would be Pareto neutral (i.e., no one can become better off without making another worse off), with sellers of land losing while purchasers gain. Although extreme, the example serves to remind us that the real-estate market will serve a crucial function in defusing the economic costs of sea level rise. In California, for example, high real-estate prices in coastal neighborhoods, a function in part of rapid past population growth, have moved the focus of demographic increase to inland neighborhoods of coastal counties, that is, areas that would be less seriously affected by sea level rise (Van Arsdol et al. 1995). However, the real-estate market deals only with economic costs and benefits; for example, it will do nothing to mitigate the unambiguous loss that would occur if the cultural heritage of a small Pacific island were eradicated through sea level rise.

Some writers have stressed the enormity of the costs of sea level rise in low-lying coastal areas of developing countries; however, these calculations should be taken with a grain of salt. For example, Myers (1994) cited research indicating that engineering countermeasures in Bangladesh (which would not necessarily negate the problem altogether) would cost $10 billion. Since Bangladesh's total gross national product (GNP) is only on the order of $25 billion, this seems at first glance to be an impossible task. However, the capital investment requirement is a stock concept, whereas GNP is an annual flow. Assuming that total GNP remains fixed at $25 billion (which is exceedingly unlikely), a $10 billion investment project can be completed over 20 years by diverting 2 percent of GDP every year. On the other hand, once installed, public engineering works must be maintained; if the depreciation rate is 5 percent, further costs of $1 billion per year, again 2 percent of GNP, would be incurred. However, the diversion of 4 percent of GDP every year to investment in flood control, as opposed to other projects, would be a heavy blow; it would not spell the end of economic development in Bangladesh. The calculation errs, moreover, on the pessimistic side, because of the constant GNP assumption and because it takes no account of economic activity generated by the investment program.

International migration

If environmental conditions are regarded as an additional push factor encouraging migration, then environmental migration can be placed in the broader context of international economic migration. Although accurate data are hard to find because of the volume of illegal migration, there is little doubt that the volume of economic migration has risen and continues to rise (Böhning & Oishi 1995). International migration is a crucial variable in any global environmental change scenario because, depending on the policy regime, it either provides or is prevented from providing a means of adjustment to changing climatic conditions. A climatically changed world, which has effected adjustment in the institutional context of relatively free international movement of labor, is bound to be very different from one that has adjusted in the context of closed borders. The pessimistic scenario described above, in which a virtuous out-migration response is stifled, leading to environmental collapse at the local level, can easily be broadened to the national scale.

Refugees tend to move within countries or across neighboring borders; economic migrants tend to move either from less industrialized poor countries to highly industrialized rich countries, or into regional immigration poles such as Abidjan or Singapore. Immigration is everywhere a complex and emotional issue: it brings about global efficiency gains, but there are local winners and

losers; moreover, it involves social and cultural dislocations for receiving and sending regions, and perhaps most of all for migrants themselves. Neoclassical economic theory describes how, in a two-region world, there are aggregate welfare gains in both regions when factors are free to move from one to the other (Simon 1989, Layard et al. 1992). Unimpeded, labor will flow from the low-wage, labor-abundant region (i.e., the region characterized by a low capital-to-labor ratio) to the high-wage capital-abundant region, whereas capital will flow in the opposite direction. Economic scarcities are thus abated, with resulting increases in welfare in each region. The problem is that each region has winners and losers; the scarce factor loses and the abundant factor wins. The greater internal economic rigidities, the greater the imbalance. When the analysis moves to the macroeconomic level, there is less clarity; for example, a recent survey of US studies found no consensus on the burning political question of the fiscal impacts of immigration (Rothman & Espenshade 1992).

Thus, the policy debate over immigration has largely been driven by interest-group politics; for example, in the United States, organized labor has generally opposed free immigration, whereas the business community has generally favored it. The dispute cuts across other axes as well: socioeconomic class (unskilled workers lose from the import of cheap, unskilled labor; skilled workers may benefit), location (workers in border regions lose more than workers in further-flung regions from competition by cheaper labor). There is also a neglected generational aspect: older workers and retirees benefit economically from immigration because it strengthens the social security system; younger (typically less skilled) workers lose from competition in the labor market and from the fact that immigrants represent co-claimants on the social security system (as well as on public goods such as the school system). Assessing the net impact of immigration on younger persons is difficult, because without immigration, social security taxes would have to be higher to support pensioners, and this higher tax on labor would encourage employment of capital as opposed to labor. Even if younger people gain from immigration, however, clearly they do not gain as much as older workers and retirees.

On the other hand, international migration cannot be reduced to simple economics, because it is driven not only by economic disparities but also by more diffuse social and cultural factors. The diffusion of industrial culture raises the demand for an industrial lifestyle; the rise of individualism demands mobility. Similarly, opposition to immigration is not entirely a matter of economic interest-group politics; it also reflects a genuine fear that local cultural traditions will be eroded with the loss of homogeneity. All in all, it is likely that the social consequences of immigration are far greater than the economic consequences.

Several imbalances and inequities exist in the current international migration process. First, whereas intercontinental migration provided a major escape route from Europe during its period of rapid demographic expansion, people from less industrialized nations have so far benefited much less from migration (Emmer 1993). Second, whereas policy reforms since the mid-1970s have substantially reduced barriers to the flow of capital from industrialized countries to the South and to the East, the barriers to the flow of labor into industrialized countries have, if anything, increased (van de Kaa 1993). Policymakers in less industrialized countries, including the former socialist bloc, have put in place comprehensive policy regimes to facilitate capital inflows, whereas governments in industrialized countries have not yet adopted complementary policies in the area of immigration (Bade 1993 for the case of Germany).

Under conditions of climate change, if current research, which assigns the most serious agricultural and health impacts to developing countries, is correct, South–North migratory pressures will increase. To the extent that less industrialized countries are able to adjust smoothly to changing climate conditions, these pressures will be smaller, but perfect adjustment is an ideal that is unlikely to be attained. As in many other areas explored in this chapter, adjustment in the industrialized nations to these pressures can be either virtuous or vicious. In the latter case, immigration policy will remain essentially ad hoc, confusing, and inequitable, in which case the inevitable confusion is likely to bring about an increase in the number of illegal immigrants. Newcomers will not be integrated into host societies, and broader domestic policies that relate to problems such as structural unemployment will not be implemented, resulting in xenophobia and resentment. In the virtuous case, countries will elaborate comprehensive immigration policies, which respect national priorities while preserving equity and transparency, immigrants will be integrated into their destination, and societies and policies will be found to address the problems of vulnerable groups, such as unskilled workers.

Renewable natural resource wars

Since environmental change forces choices, which amount to the weighing and contesting of competing claims, conflict per se is essential to human adaptation and change (Stern et al. 1992). Violent conflict is only one of a range of means by which competing claims to scarce resources can be settled. Early research indicated, not surprisingly, that population pressure (density) was related to violent international conflict only by a complex chain of intervening causal variables (Choucri 1974). However, the model by which population pressure causes violence has received a new lease on life in the view that, if renewable natural resource systems are impaired by overuse in the context of global environmental change, risks of acute conflict and war will be increased (Westing 1986, Gleick 1989, Renner 1989).

Many of the root causes that make countries prone to violent conflict also make them prone to degradation of the renewable natural resource base, but this is not necessarily a simple cause–effect relationship. For example, Engleman & Leroy (1995) all but endorsed the hypothesis that recent violent internal conflicts in Rwanda, Somalia, Yemen, and Haiti are attributable in significant degree to food scarcity exacerbated by rapid population growth; in the first case, Bonneaux (1994) has blamed "demographic entrapment". Myers (1989, 1993) and Homer-Dixon et al. (1993) argued that competition for natural resources, worsened by demographic pressure, were to blame for the 1969 Soccer War between El Salvador and Honduras, and water scarcity has been the cause of small-scale regional conflicts in Central Asia (Smith 1995 for citations) and the Middle East (see Lonergan & Kavanaugh 1991 for citations). Competition for natural resources is often along ethnic lines (e.g., Hazarika 1993 for the case of Bangladesh and Assam). A series of case studies (Howard & Homer-Dixon 1995, Kelly & Homer-Dixon 1995, Percival & Homer-Dixon 1995) have broadened the application of the basic model of environmental scarcity and violent conflict. At the same time, the model has been subjected to a strong critique from within political science and international relations (Levy 1995a,b), and just as spiritedly defended (Homer-Dixon & Levy 1995).

If social and political institutions for conflict resolution, including the market, prove inadequate to the rising demands placed upon them, then regional environmental change associated with global climate change might increase the frequency of skirmishes over impaired renewable resource systems. However, a principal conclusion of Suhrke (1993) was that environmental degradation, at least to the extent that it gives rise to displacement of people, is more likely to lead to exploitation and structural low-level conflict than to acute conflict, let alone war. Although access to renewable resource systems spanning national boundaries will be an important component of any country's foreign policy, various options will be explored before a country resorts to war. Faced with the choice of obtaining food through trade or war, it is difficult to conceive of a country choosing the latter. Issues of national pride, as well as the pressures brought to bear on national policymakers by the local populations affected by resource scarcity, may be severe, and peace will stand or fall on the strength of conflict resolution mechanisms.

By far the largest body of research dealing with conflict over natural resources has dealt with water (Falkenmark 1989, Starr 1991, Anderson 1992, Gleick 1993, 1994). Gleick (1992) identified four factors that determine a country's vulnerability to disruption of shared water resources: scarcity of water, the extent to which water is shared, the degree of dependence on shared water, and the relative power of states that share rivers and other watercourses. In judging whether disruption is likely to lead to conflict, these considerations must be placed in a broader context of perceived interests, internal and external power relations, and so on. The possibility of relatively (at least with respect to war) low-cost internal adjustment mechanisms must not be forgotten. For example, Beaumont (1994) stressed the tremendous inefficiency with which water is employed in much of the Middle East and arrived at a conclusion captured parsimoniously in the title of his article, "The myth of Middle Eastern water wars." In a quite different reading of the evidence, however, Lonergan & Kavanaugh (1991: 281) forecast "desperate competition and conflict" in the near future. Indeed, so pessimistic was their view that they discounted the effects of climate change, which are long-term in nature.

When the costs of internal adjustment are too high, countries will have recourse to mechanisms for the international mediation of claims. The body of law regulating the interregional and international allocation of scarce water resources is simply massive, as is the body of accumulated experience (Biswas 1992, Chitale 1995). The relevant principles (Smith 1995) consist of three norms and three obligations. The three norms are equitable use, prevention of significant harm to other states and shared management of international rivers; the three obligations are to notify and inform, to share information and data, and to resolve disputes peacefully.

As yet, no international framework exists for resolution of water disputes, but work toward such a framework has begun (International Conference on Water and the Environment 1992). Mageed & White (1995) and Grover & Howarth (1991) review existing institutional arrangements. Regional organizations, such as the Interstate Coordinating Commission for Water Resources (ICCW) in Central Asia and the Middle East Water Commission (MWC) currently provide the natural institutional setting for the development of such regimes; some experts (Grover & Biswas 1993, Chitale 1995) have called for the constitution of an integrated World Water Council. The potential of water scarcity to serve as a focus of conflict cannot be denied, but neither can the distinct unlikelihood that violence will be casually resorted to.

Conclusion

The concept of environmental refugees has attracted wide interest precisely because it has been expansively and loosely used. A more careful reading indicates, however, that the term contains a grain of truth: rising environmental pressures are a push factor encouraging out-migration, and, if a virtuous out-migration response is stifled, then rapid environmental deterioration and resulting distress migration are possible. A similar observation applies to violent conflicts over natural resources: scarcity invariably gives rise to conflicts

between stakeholders; if these are not resolved by institutions, including the market, then violent conflict becomes a distinct possibility. However, it is premature to conclude that global environmental change is ushering a century of massive refugee movements and violent conflicts. A more sober reading is that the stresses associated with global change will intensify the pressures that already drive international migration, and that policymakers and societies will be forced to come to terms with these rising pressures, one way or another.

How will they do so? Environmental stress is mediated by institutions whose functioning is contingent on their perceived ethical legitimacy, in particular whether they are perceived to be fair. By definition, populations cope in one way or another with environmental problems. At one end of a continuum is successful coping-in-place; at the other is population displacement under highly distressed conditions; somewhere in the middle lies a wide and complex variety of migration strategies. The means of coping will, in turn, affect the nature of institutions. In the case of population displacement, this may amount to institutional fracture and atrophy; in the other cases, it may amount to institutional deepening and strengthening. The means of coping may also have a direct effect on the ecosystem under consideration, and it may alleviate or worsen sources of stress.

Finally, we need to develop a more flexible model of human security and the environment. Virtually all the key concepts in this area—security, poverty, displacement, equity, conflict, and even environmental deterioration itself—are open to differing views. Policies to promote response to environmental stresses associated with global change should acknowledge such ambiguities and recognize that such differing views can be complementary and the dialogue between them constructive.

Conclusion: population policy and global change

After a review of the world demographic situation and prospect, this chapter has concentrated on links between population, global climate change, and the possible effects of global climate change. In looking at the relationship between population and climate change, we stressed tradeoffs between policies to decelerate the rate of growth of population, on the one hand, and, on the other hand, policies impinging on the economy, technology, and the capacity of institutions to adapt to environmental stress. A recurring theme was the neoclassical economic tradeoff between children, the level of material consumption, and quality of the environment. Unidimensional models such as I=PAT act as if reducing environmental impacts were a strictly linear matter; in fact, the factors that give rise to environmental stress are interrelated in ways that are incompletely understood.

A second theme stressed was an institutionalist one. Population gives rise to scarcity of natural resources and environmental assets; it always has and it always will. Human society brings all of its institutions to bear on resolving conflict one way or the other. The resolution of one conflict, however, may simply engender another. The point is that resolution can be virtuous or vicious. We have tried to bring out that a key theme for research is how population pressure impedes or facilitates virtuous responses, and in what sorts of institutional contexts.

A third theme we have stressed is that population is more than simply a scale factor. In particular, it has an age distribution, and the difference between an aged and slowly growing population and a young and rapidly growing one is at least as important, socially speaking, as the difference between a small sparse population and a large dense one. It cannot be overstressed that global change includes global aging; the challenges of the next century will have to be met by a population that is older, with all that is implied for health systems, world savings, and so on.

The vicious circle model and the state of the art

We have come a long way since the population bomb literature of the 1960s. The chapter has revolved, in large part, around a vicious circle model, which represents the state of the art in research on the relationships among population, environment, and development. It incorporates flexibility, in the form of neoclassical responses; equity, in the form of recognizing the pernicious impacts of poverty, insecurity and low status of women; and ecology, in the form of recognizing the fragility of marginal environmental zones. It is constructive in that it focuses attention on response to climate change rather than responsibility for avoiding climate change. It is fair in that it focuses attention on those populations that are simultaneously most likely to suffer consequences and least able to adapt.

In the process leading up to the 1994 ICPD in Cairo, and in the conference itself, members of the public health orthodoxy defended the importance of family planning programs, orthodox neoclassical economists defended the virtues of overall socioeconomic development, and women's advocates challenged the policy community to make both family planning programs and socioeconomic development policies more relevant to women. What emerged was a women-first prescription for population policy which stressed its role in broadening opportunities for women (McIntosh & Finkle 1995, McNicoll 1995), as well as

children and the poor more generally. At the heart of this policy is the vicious circle model, both with and without its environmental component.

The rationale for slowing population growth

Many scholars and policymakers strongly affirm the desirability of slowing world population growth, consistent, of course, with human rights. But such assertions ought to be examined within a social science perspective, so we should ask the question: Why, in view of what we have learned in this chapter, deploy scarce public resources to slow population growth?

The list of rationales is limited:

- Parents in less industrialized countries really want fewer children but cannot achieve fertility targets; this rationale is based in altruism. But parents in less industrialized countries (and in more industrialized countries as well) want a great many things and cannot get them. Why should policy favor low fertility over, say, clean water?
- Parents' desire for many children reflects only private costs and benefits; parents do not consider the external costs imposed on society and the world as a whole. This is an empirical question: how important are externalities to childbearing? Is lowering fertility a better way of correcting the externality than other means, such as carbon taxes or emissions permits? Closely related to the externality question are matters related to inadequate information. Perhaps high fertility is even now placing ecological systems, even the world as a whole, at risk of catastrophic collapse. Whether this is so or not is, again, an empirical question, albeit one beset by complexities and uncertainties.
- High fertility changes the way in which social systems and institutions work in ways that are inimicable. For example, high fertility may give rise to market failures that would not have occurred with low fertility. Or it may limit the choice set over which preferences are defined. This is, in part, an area for empirical research: does high fertility really give rise to market failure? Does it really impede the functioning of institutions? Such questions rest on a normative foundation, namely, a value judgment as to the way systems and institutions ought to work. The Cairo ICPD reflected one value judgment, namely an individualistic approach to the welfare of women and children.
- Parents' desire to have many children is immoral. All empirical research shows that high fertility is inversely correlated with a range of welfare indicators for women and children. A utility theory argument might run that parents, including wives, know this and maximize utility nonetheless

by having many children, half of them destined to second-class status on account of their sex. But arguments based in utility theory can always be trumped by an ethical card—in this case, the conviction that behaviors inimical to the welfare of women and children (as perceived, of course, from the perspective of the moralist) are wrong.

Following the Cairo conference, it was sometimes said that the new "women-first" direction for population policy represented a consensus view. This is simply untrue: what was attained was a coalition between methodologically individualistic economists, concerned that high fertility limits the options of women, children and the poor; and moralists concerned with much more general issues of empowerment. This coalition replicates the international development policy orthodoxy, which stresses removing barriers that prevent the poor from participating in free-market based economic development.

The vicious circle model: what is left out

However, some parties are excluded from the Cairo coalition. Among these, and attracting the most attention, were religious traditionalists, whose idea of equity has nothing to do with freedom to maximize individual utility. Their influence has been waning; the Catholic Church is increasingly marginal in the population policy debate, and Muslim fundamentalism has done little to stem the rising practice of contraception among Muslim women. More important is the fact that, even within the Cairo coalition, empowerment issues have been subjected to a rather Procrustean reframing in neoclassical economic terms, and that the view that human population growth must be slowed at all costs to avoid global catastrophe has largely disappeared from population policy discourse.

Policies are shaped by models, so we look at these two matters, and others as well, in terms of the vicious circle model. The goal is not to invalidate the model, which is far better than others that have been proposed, but, first, to point out areas in which it can be strengthened, and second, to identify areas where further disputes in international population policymaking can be expected.

Equity according to whom?

Does the vicious circle model truly address equity concerns or merely co-opt them in neoclassical economic terms? An egalitarian view of human nature might hold that the fundamental human urge is not to maximize consumption but to belong to a nurturing community among whose members risks and burdens are shared equitably. (See Ch. 3 for a fuller discussion.) Prevailing institutions, economic arrangements and technology, according to this view, have

encouraged materialism at the expense of fairness, placing the ecosystem at risk in the process. Fairness, in turn, would be defined not in terms of process, as in economics, but in terms of the justice of the outcome. The definition of sustainability would be broadened to encompass not only the commitment to maintain the value of assets as they are passed from generation to generation, but a commitment to justice within each generation as well.

The vicious circle model only partly meets the concerns of this point of view, because poverty, insecurity, and women's status, all of which reflect values, have been couched in less ideational, more material terms. Insecurity has been interpreted in terms of the old-age security motive (Cain 1983, Nugent 1985 and Nugent & Anker 1990 for reviews of the literature) and also seen as representing a means of diversifying income sources or as a lottery process in which parents gamble that one son may be highly successful (Bledsoe 1994). If parents had adequate access to alternative forms of saving, insurance, and income, it is implied, high fertility would be unnecessary. Poverty is interpreted as an impediment to the smooth functioning of neoclassical economic substitution mechanisms; elevated fertility is seen as a survival strategy pursued by the poor because they have no other options (Birdsall & Griffin 1988, Ahlburg 1994). Low status of women consists either of unequal weighing of neoclassical costs and benefits that are specific to men and women (Lloyd 1994) or arises from intra-mural market failures such as information asymmetries between men and women (Palmer 1991).

The vicious circle model is so popular in part because it delivers the agreeable message that doing anything is better than doing nothing. Because the feedback effects in the model are so dense, any policy that improves the status of women, alleviates environmental stress, or reduces poverty is bound to have positive repercussions throughout the system. But the rather sanitized terms of reference above are some ways removed from the existential outrage with which many people view poverty and the exploitation of women. Jackson (n.d.), far from seeing the vicious circle model as serving women's interests, sees it as a means of co-opting women's legitimate gender interests in a way congenial to the established policy orthodoxy. Birdsall (1994) used the expression "win–win" in the context of fertility and poverty; the vicious circle model in current form extends this to win–win–win–win by adding women's status and the environment to the circle, but the fundamental question, "Win according to whose rules?", should not be overlooked.

For example, women's status and girls' education are treated as nearly equivalent, despite fact that women's status is a complex, multidimensional variable that cannot be adequately represented by a single proxy variable (Balk 1994). It is difficult to escape the conclusion that education of girls receives disproportionate attention because it can be so easily translated into targets and indicators—female literacy rate, female enrollment rates, and so on. A similar cautionary note was sounded by Wolf & Ying-Chang (1994) in the case of female labor for participation. In summarizing their finding that fertility in a district of rural Taiwan from 1905–80 did not vary according to women's agricultural labor force participation, they write, "It does not suffice for women to be involved in labor if they are involved only as laborers. Their fertility is only affected when women control or earn what they produce" (Wolf & Ying-Chang 1994: 433) Once again, attention seems to have been focused on an easily quantifiable variable, in this case, the female labor force participation rate.

The lack of reflexivity in the definition of equity applies also to a range of other variables as they are currently discussed. Security, poverty, displacement, equity, conflict, and even environmental deterioration itself are open to differing views. For example, equity may be interpreted in terms of priority, proportionality or strict equality (Young 1993; see the extended discussion in Ch. 4). In the area of population and the environment, views of fairness hinging on equality of opportunity in the present generation, equity of outcome in the present generation, and a just intergenerational distribution of risk have been identified (MacKellar 1997). Policies to promote response to environmental stresses associated with global change should acknowledge such ambiguities and recognize that such differing views can be complementary and the dialogue between them constructive.

How significant are individual causal effects within the vicious circle?
Is the sum really greater than the whole of the parts? Empirical research, limited as it is, has suggested that piecemeal causal effects, which comprise the vicious circle model (in particular, the deleterious effect of high fertility on children's well-being) are significant but nonetheless modest. The belief that these piecemeal effects add up, through synergy, to a whole that is greater than the sum of its parts is based as much on faith as empirical evidence. The empirical evidence (apart from correlation studies) that would lead policymakers to choose, say, female education over reforestation schemes, is thin. If female education is to be chosen over reforestation, it should be because it is an inherently good thing, and for no other reason.

How about the urban population and population aging?
One pressing need is for extension of vicious circle reasoning to the urban and industrial setting. An interesting contribution along this line (Hogan 1995) found that the workers who profited from highly paid industrial jobs in an intensely polluted city were often short-term migrants or long-distance commuters. The long-term resident impoverished population of the city lost more, in terms of impaired health and losses of public goods, than they gained in terms

of well-paid jobs. They formed the potential constituency for political pressure to alleviate pollution, but they were impoverished by pollution, just as rural women are impoverished by renewable resource degradation. Also neglected is the problem of impoverished rural aged persons living in environmentally fragile zones. When the young and healthy migrate out, the process of population aging is accelerated many times at the local level.

What about global ecological risk?
As mentioned in the opening pages of this chapter, the World Bank estimates that one-third of the population of less industrialized countries live in poverty and one-half of these live in environmentally fragile zones. The full vicious circle model applies, therefore, only to one-sixth of the population in less industrialized countries, less than one-seventh of the total world population. Even the half of that population in poverty represent only 40 percent of the world population. Policies to encourage fertility decline among these subpopulations are of limited impact in terms of stabilizing world population growth. If drastic actions to curb demographic increase are to be taken, a rationale beyond the vicious circle model will have to be found.

Post-Cairo population policy is decidedly oriented toward the welfare of the individual; it takes little stock of the concerns raised by modern, discontinuous, and complex ecology (Holling 1994). Neoclassical economics is based on smooth substitution mechanisms, which are expressed in classical Newtonian mechanics; ecologists, on the other hand, are trained to expect discontinuities. These are the stock in trade of statistical mechanics, according to which where you move next stands in no fixed relation to where you are now. In such dynamic systems, seemingly small alterations in the present period can have dramatic consequences in later periods. Thus, ecology is filled with examples of surprises, that is, events that fall outside the boundaries of prediction based on prior experience and theory.

Where economists see individuals making finely tuned tradeoffs between consumption, fertility, and the state of the environment, ecologists are more likely to see blind material and genetic overexuberance. Thus, instead of individual liberty to choose, the theme of prudent stewardship is most likely to be encountered in writings from the ecological school. So long as the human/nature balance is in local equilibrium, the *gradualist* model by which small changes in human impacts are predicted to lead to small changes in the state of the system will be valid. If these impacts are pushed too far—and the gradualist model is incapable of predicting what "too far" is—the system will experience a catastrophic collapse. Individuals and the policymakers who speak for them act as though they lived in a world consisting of only a few easily understood interdependencies. They fail to grasp the true underlying model, which is complex, uncertain and nonlinear; therefore, decisions that are rational according to the simple neoclassical calculus of the individual are irrational at the macro level (Boyden & Dovers 1992), and may give rise to ecological catastrophe (Catton 1982, 1984, Dunlap 1982). The only way to avoid disaster is to impose wise guidance on the individual or, what amounts to the same thing, ensure prudent stewardship of nature.

However, the ecological critique of neoclassical economics is not itself above criticism. Scale need not always be an exacerbating factor. Prevailing institutional arrangements, where much of the explanation for environmental trends is to be found, are in significant degree scale-dependent. Just as scale need not be exacerbating, prudence can cease to be a virtue when its opportunity cost is staggeringly high. Simply citing the possibility of (low probability) catastrophic events is not enough to convince policymakers to divert scarce resources from competing uses.

Where is the institutional dynamic?

The key aspect of the social coping process is that it is dynamic and path-dependent (McNicoll 1989). The vicious circle model, although providing a useful guide for policy interventions so far as it goes, recognizes only an economic–ecological dynamic at the local and household level; it takes little stock of the ability of institutions to adapt and change. The next step for research in this area is to examine the contextual variables that promote institutional robustness and evolution. For example, it is often asserted, quite plausibly but with no rigorous foundation, that rapid population growth impedes institutions' ability to react (US NRC 1986) or that population dynamics may reduce the capacity of the social system to adapt without violent conflict (Sirageldin 1994).

Closing thoughts

This chapter has been largely economic in orientation. The rise of rational actor models (especially at the household level, in the form of various economic models) in the field of population has, to be honest, been at some expense of research into the role of norms, values, and culture. "Demand," we learn in the first lecture of an undergraduate economics course, is a function of income, prices, and tastes. But "tastes" is a euphemism for values, which get short shrift in economic analysis (after the first lecture). The preceding analysis makes no claim to have gone much beyond a conventional economic analysis of population. But even within that orthodox paradigm, it emerges that population policy has too often been based on the easy, specious logic of "You would be happier if you had fewer children." Time and again in this chapter, we have found that this

assertion is difficult to back up with rigorous social scientific evidence. The real underlying logic has often been "I would happier if you had fewer children."

This simply represents a set of values. What sort of world population do we wish to see in the twenty-first century? Our choice set is limited because of population momentum, but then human choices made by our forebears brought us to where we are now, and human choices made in the present and future will determine where we end up, given the degrees of freedom available to us, so it all boils down to choice. The more frank and open the dialogue about human values, the more constructive the discussion will be and the more successfully we shall be able to attain the population future which we choose.

References

Agarwal, B. 1994. The gender and environment debate: lessons from India. In *Population and the environment: rethinking the debate*, L. Arizpe, M. Stone, D. Major (eds). Boulder, Colorado: Westview.

Agarwal, A. & S. Narain 1991. *Global warming in an unequal world: a case of environmental colonialism*. Delhi: Centre for Science and Environment.

Ahlburg, D. 1994. Population growth and poverty. In *Population and development: old debates, new conclusions*, R. Cassen (ed.). Washington DC: Overseas Development Council.

Ainsworth, M. & M. Over 1994. AIDS and African development. *The World Bank Research Observer* 9(2), 203–40.

Alston, J., G. Edwards, J. Freebairn 1988. Market distortions and benefits from research. *American Journal of Agricultural Economics* 70, 281–8.

Anania, G. & A. McCalla 1995. Assessing the impact of agricultural technology improvements in developing countries in the presence of policy distortions. *European Review of Agricultural Economics* 22, 5–24.

Anderson, E. 1992. The political and strategic significance of water. *Outlook on Agriculture* 21(4), 247–53.

Antle, J. & G. Heidebrink 1995. Environment and development: theory and international evidence. *Economic Development and Cultural Change* 43(3), 603–623.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C. Holling, B-O. Jansson, S. Levin, K-G. Mäler, C. Perrings, D. Pimentel 1995. Economic growth, carrying capacity, and the environment. *Science* 268, 520–21.

Asante-Duah, D. & P. Sam 1995. Assessment of waste management practices in sub-Saharan Africa. *International Journal of Environment and Pollution* 5(2/3), 224–42.

Asian Development Bank 1994. *Climate change in Asia: Indonesia country report*. Manila: Asian Development Bank.

Asselt, M. B. A. van, J. Rotmans, M. den Elzen, H. Hilderink 1995. *Uncertainty in integrated assessment modeling: a cultural perspective-based approach*. GLOBO Report Series 9 (no. 461502009), National Institute of Public Health and Environmental Protection [RIVM], Bilthoven, the Netherlands.

Ayres, J. 1990. Meteorology and respiratory disease. *Update 1990* 40, 596–605.

Ayres, R. 1995. Economic growth: politically necessary but not economically friendly. *Ecological Economics* 15, 97–9.

Bade, K. 1993. Immigration and integration. *European Review* 1(1), 75–9.

Balk, D. 1994. Individual and community aspects of women's status and fertility in rural Bangladesh. *Population Studies* 48(1), 21–45.
Bartiaux, F. & J-P. van Ypersele 1993. The role of population growth in global warming. In *Proceedings of the International Population Conference Montreal 1994* (vol. 4). Liège, Belgium: International Union for the Scientific Study of Population.
Beaumont, P. 1994. The myth of Middle Eastern water wars. *Water Resources Development* 10(1), 9–21.
Becker, G. 1981. *A treatise on the family*. Cambridge, Massachusetts: Harvard University Press.
Becker, G. & R. Barro 1988. Reformulating the economic theory of fertility. *Quarterly Journal of Economics* 103, 1–25.
Becker, G., K. Murphy, R. Tamura 1991. Human capital, fertility and economic growth. *Journal of Political Economy* 98(5), S12–37.
Beckerman, W. 1995. *Small is stupid: blowing the whistle on the Greens*. London: Duckworth.
Bilsborrow, R. 1987. Population pressures and agricultural development in developing countries: a conceptual framework and recent evidence. *World Development* 15(2), 182–203.
Bilsborrow, R. & M. Geores 1994. Population, land use and the environment in developing countries: what can we learn from cross-national data? In *The causes of tropical deforestation*, D. Pearce & K. Brown (eds). London: UCL Press.
Bilsborrow, R. & P. DeLargy 1991. Land use, migration and natural resource deterioration: the experience of Guatemala and the Sudan. In *Resources, environment and population*, K. Davis & M. Bernstam (eds). New York: Oxford University Press.
Birdsall, N. 1992. *Another look at population and global warming*. Working Paper WPS 1020, Population, Health and Nutrition Policy Research, World Bank, Washington DC.
——1994. Government, population, and poverty: a "win–win" tale. See Lindahl-Kiessling & Landberg (1994).
Birdsall, N. & C. Griffin 1988. Fertility and poverty. *Journal of Policy Modeling* 10(1), 29–55.
Biswas, A. 1992. Water for Third World development. *International Journal of Water Resources Development* 8(1), 3–9.
Bledsoe, C. 1994. "Children are like young bamboo trees": potentiality and reproduction in sub-Saharan Africa. See Lindahl-Kiessling & Landberg (1994).
Böhning, W. & N. Oishi 1995. Is international economic migration spreading? *International Migration Review* 29(3), 794–9.
Bois, F. du 1994. Water rights and the limits of environmental law. *Journal of Environmental Law* 6(1), 73–84.
Bongaarts, J. 1992. Population growth and global warming. *Population and Development Review* 18(2), 299–319.
——1996. Global trends in AIDS mortality. *Population and Development Review* 22(1), 21–45.
Bongaarts, J. & R. Potter 1982. *Fertility, behavior and biology*. New York: Academic Press.
Bonneaux, L. 1994. Rwanda: a case of demographic entrapment. *The Lancet* 344(December), 1689–90.
Boserup, E. 1965. *The conditions of agricultural growth*. Chicago: Aldine.
——1981. *Population and technological change: a study of long-term trends*. Chicago: University of Chicago Press.
Bouma, M. E., H. E. Sondorp, H. J. van der Kaay 1994. Climate change and periodic epidemic malaria. *The Lancet* 343, 1440.
Boyce, J. 1989. Population growth and real wages of agricultural labourers in Bangladesh. *Journal of Development Studies* 25(4), 467–85.
Boyden, S. & S. Dovers 1992. Natural resource consumption and its environmental impacts in the Western world: impacts of increasing per capita consumption. *Ambio* 21(1), 63–9.
Bradley, D. 1993. Human tropical diseases in a changing environment. *Ciba Foundation Symposium* 175, 146–62.
——1994. Agriculture and health. In *Health and sustainable agricultural development: perspectives on growth and constraints*, V. Ruttan (ed.). Boulder, Colorado: Westview.

Broadus, J. 1993. Possible impacts of, and adjustments to, sea level rise: the cases of Bangladesh and Egypt. In *Climate and sea level change: observations, projections and implications*, R. Warrick, E. Barrow, T. Wigley (eds). Cambridge: Cambridge University Press.
Bufalini, J., P. Finkelstein, E. Durman 1989. Air quality. In *The potential effects of global climate change on the United States*, J. Smith, & D. Tirpak (eds). Report EPA-230-05-89-050, Environmental Protection Agency, Washington DC.
Bumpass, L. 1990. What's happening to the family? Interactions between demographic and institutional change. *Demography* 27(4), 483–98.
Burgos, J., S. Curtos de Casas, R. Carcavallo, I. Galíndez Girón 1994. Global climate change influence in the distribution of some pathogenic complexes (malaria and Chagas disease) in Argentina. *Entomologia e Vectores* 1(2), 69–78.

Cain, M. 1983. Fertility as an adjustment to risk. *Population and Development Review* 7, 435–74.
Caldwell, J. C., P. H. Reddy, P. Caldwell 1986. Periodic high risk as a cause of fertility decline in a changing rural environment: survival strategies in the 1980–83 South Indian drought. *Economic Development and Cultural Change* 34(4), 677–701.
Caldwell, J. & P. Caldwell 1987. The cultural context of high fertility in sub-Saharan Africa. *Population and Development Review* 131(3), 409–37.
Catton, W. 1982. *Overshoot: the ecological basis of revolutionary change*. Urbana–Champaign: University of Illinois Press.
——1984. Probable collective response to ecological scarcity: how violent? *Sociological Perspectives* 27(1), 3–20.
Centers for Disease Control 1989. Heat related deaths—Missouri, 1979–1988. *Morbidity and Mortality Weekly Report* 38, 437–9.
CEQ [Council on Environmental Quality] 1980. *The Global 2000 report to the President*. Washington DC: US Government Printing Service.
Cernea, M. 1995. Social integration and population displacement: the contribution of social science. *International Social Science Journal* 143, 91–112.
Chen, R. & R. Kates 1994. World food security: prospects and trends. *Food Policy* 19(2), 192–208.
Chenery, H. & M. Syrquin 1975. *Patterns of development, 1950–70*. Oxford: Oxford University Press.
Chitale, M. 1995. Institutional characteristics for international cooperation in water resources. *Water Resources Development* 11(2), 113–23.
Choucri, N. 1974. *Population dynamics and international violence*. Lexington, Massachusetts: Lexington Books.
Clay, D. & J. Van der Haar 1993. Patterns of intergenerational support and childbearing in the Third World. *Population Studies* 47(1), 67–83.
Cleaver, K. & G. Schreiber 1993. *The population, agriculture and environment nexus in sub-Saharan Africa*. Washington DC: World Bank.
——1993. Equity, security and fertility: a reply to Thomas. *Population Studies* 47, 344–52.
——1996. A regional review of fertility trends in developing countries: 1960 to 1995. See Lutz (1996).
Cleland, J. & G. Rodriguez 1988. The effects of parental education on marital fertility. *Population Studies* 42(3), 419–42.
Cleland, J. & C. Wilson 1987. Demand theories of the fertility transition: an iconoclastic view. *Population Studies* 41(1), 5–30.
Cleland, J., J. F. Phillips, S. Amin, G. M. Kamal 1994. *The determinants of reproductive change in Bangladesh*. Washington DC: World Bank.
Coale, A. 1973. The demographic transition. In *Proceedings of the International Population Conference* (vol. 1). Liège, Belgium: International Union for the Scientific Study of Population.
Cochrane, S. 1979. *Fertility and education: what do we really know?* Baltimore: Johns Hopkins University Press.
Cohen, J. 1995. *How many people can the Earth support?* New York: W. W. Norton.

Commoner, B. 1971. *The closing circle*. New York: Knopf.

——1991. Rapid population growth and environmental stress. In *Consequences of rapid population growth in developing countries*, G. Tapinos, D. Blanchet, D. E. Horlacher (eds). New York: Taylor & Francis.

Concepcion, M. B. 1996. Population policies and family planning in Southeast Asia. See Lutz (1996).

Cotton, P. 1993. Health threat from mosquitoes rises as flood of century finally recedes. *Journal of the American Medical Association* **270**, 685–6.

Cropper, M. & W. Oates 1992. Environmental economics: a survey. *Journal of Economic Literature* **30**(2), 675–740.

Cropper, M. & C. Griffiths 1994. The interaction of population growth and environmental quality. *American Economic Review* **84**(2), 250–54.

Cruz, M. C., C. A. Meyer, R. Repetto, R. Woodward 1992. *Population growth, poverty, and environmental stress: frontier migration in the Philippines and Costa Rica*. Washington DC: World Resources Institute.

Cuddington, J., J. Hancock, C. Rogers 1994. A dynamic aggregative model of the AIDS epidemic with possible policy implications. *Journal of Policy Modeling* **16**(5), 473–96.

Daily, G., P. Ehrlich, A. Ehrlich 1994. Optimum human population size. *Population and Environment* **15**(6), 469–75.

Daly, H. 1977. *Steady state economics: the economics of biophysical equilibrium and moral growth*. San Francisco: W. H. Freeman.

Dasgupta, P. 1993. *An inquiry into well-being and destitution*. Oxford: Oxford University Press.

Dasgupta, P. & G. Heal 1979. *Economic theory and exhaustible resources*. Cambridge: Cambridge University Press.

Davis, K. 1954. The world demographic transition. *Annals of the American Academy of Political and Social Science* **237**, 1–11.

——1963. The theory of change and response in modern demographic history. *Population Index* **29**(4), 345–66.

——1991. Population and resources: fact and interpretation. In *Resources, environment and population: present knowledge*, K. Davis & M. Bernstam (eds). Oxford: Oxford University Press.

Degraaf, D. 1991. Increasing contraceptive use in Bangladesh: the role of demand and supply factors. *Demography* **28**(1), 65–81.

Dobson, A. & R. Carper 1992. Global warming and potential changes in host–parasite and disease–vector relationships. In *Global warming and biological diversity*, R. Peters & T. Lovejoy (eds). New Haven, Connecticut: Yale University Press.

Douglas, M. 1978. *Cultural bias*. Occasional Paper 35, Royal Anthropological Institute, London. [Reprinted in *In the active voice*, M. Douglas. London: Routledge, 1982.]

Duchin, F. 1994. Structural economics: toward a post-normal science of ecological economics. Paper presented at the Biennial Meeting of the International Society for Ecological Economics, San José, Costa Rica.

Duncan, O. D. 1959. Human ecology and population studies. In *The study of population*, P. M. Hauser & O. D. Duncan (eds). Chicago: University of Chicago Press.

——1961. From social system to ecosystem. *Social Inquiry* **31**, 140–49.

Dunlap, R. 1982. Ecological limits: societal and sociological implications. *Contemporary Sociology* **11**(2), 153–60.

——1983. Ecologist vs exemptionalist: the Ehrlich–Simon debate. *Social Science Quarterly* **64**, 201–203.

Durning, A. 1992. *How much is enough?* Washington DC: Worldwatch Institute.

Dyson, T. 1991. On the demography of South Asian famines, part II. *Population Studies* **45**(2), 279–97.

Ehrlich, P. & J. Holdren 1971. Impact of population growth. *Science* **171**, 1212–17.

Ehrlich, P. & A. Ehrlich 1990. *The population explosion*. New York: Simon & Schuster.

Ekins, P. 1991. The sustainable consumer society: a contradiction in terms? *International Environmental Affairs* **3**(4), 243–58.

El-Hinnawi, E. 1985. *Environmental refugees*. Nairobi: United Nations Environment Programme.

Emmer, P. 1993. Intercontinental migration as a world historical process. *European Review* **1**(1), 67–74.

Engleman, R. & P. LeRoy 1995. *Conserving land: population and sustainable food production*. Washington DC: Population Action International.

Epstein, P. 1995. Emerging diseases and ecosystem instability: new threats to public health. *American Journal of Public Health* **85**, 168–72.

Falkenmark, M. 1989. Middle Eastern hydropolitics: water scarcity and conflicts in the Middle East. *Ambio* **18**(6), 350–52.

Feacham, R. 1994. Health decline in Eastern Europe. *Nature* **367**, 313–14.

Feldman, A. 1990. *Environmental degradation and high fertility in sub-Saharan Africa*. Working Paper 36, Morrison Institute for Population and Resource Studies, Stanford University.

Findley, S. 1994. Does drought increase migration? A study of migration from rural Mali during the 1983–1985 drought. *International Migration Review* **28**(3), 539–53.

Frank, J. & J. Mustard 1994. The determinants of health from a historical perspective. *Daedalus* **123**(4), 1–19.

Funtowicz, S. & J. Ravetz 1994. Uncertainty, complexity and post-normal science. *Environmental Toxicology and Chemistry* **13**(12), 1–5.

Gilland, B. 1986. On resources and economic development. *Population and Development Review* **12**(2), 295–305.

Gillett, J. 1974. Direct and indirect influences of temperature on the transmission of parasites from insects to man. In *The effects of meteorological factors upon parasites*, A. Taylor & R. Muller (eds), 79–95. Oxford: Blackwell Scientific.

Gleick, P. 1989. Climate change and international politics: problems facing developing countries. *Ambio* **18**(6), 333–9.

——1992. Effects of climate change on shared freshwater resources. In *Confronting climate change: risks, implications, and responses*, I. Mintzer (ed.). Cambridge: Cambridge University Press.

——(ed.) 1993. *Water in crisis: a guide to the world's fresh water resources*. New York: Oxford University Press.

——1994. Water and conflict: fresh water resources and international security. *International Security* **18**(1), 79–112.

Goeller, H. E. & A. M. Weinberg 1976. The age of substitutability. *Science* **191**, 683.

Goeller, H. E. & A. Zucker 1984. Infinite resources: the ultimate strategy. *Science* **223**, 456–62.

Goldsmith, J. 1986. Three Los Angeles heat waves. In *Environmental epidemiology: epidemiological investigation of community environmental health problems*, J. Goldsmith (ed.), 73–81. Boca Raton, Florida: CRC Press.

Goodland, R. 1992. The case that the world has reached limits: more precisely that current throughput growth in the global economy cannot be sustained. *Population and Environment* **13**(3), 167–82.

Gore, A. 1992. *Earth in the balance: ecology and the human spirit*. Boston: Houghton Mifflin.

Gregg, M. B. 1989. *The public health consequences of disasters*. Atlanta, Georgia: US Center for Disease Control.

Grossman, G. & A. Krueger 1995. Economic growth and the environment. *Quarterly Journal of Economics* (May), 353–77.

Grover, B. & A. Biswas 1993. It's time for a World Water Council. *Water International* **18**, 81–3.

Grover, B. & D. Howarth 1991. Evolving international collaborative arrangements for water supply and sanitation. *Water International* **16**, 146–52.

Haille, D. G. 1989. Computer simulation of the effects of changes in weather patterns in vector-borne disease transmission. In *The potential effects of global climate change in the United States* (appendix G), J. B. Smith & D. Tirpak (eds). Washington DC: Environmental Protection Agency.
Haines, A., P. Epstein, A. McMichael 1993. Global health watch: monitoring the impacts of environmental change. *The Lancet* **342**, 1464–9.
Hardin, G. 1972. The tragedy of the commons. *Science* **162**, 1248.
——1991. Paramount positions in ecological economics. In *Ecological economics: the science and management of sustainability*, R. Costanza (ed.). New York: Columbia University Press.
Harrison, P. 1992. *The third revolution: environment, population and a sustainable world*. London: I. B. Tauris.
Hayami, Y. & V. Ruttan 1971. *Agricultural development: an international perspective*. Baltimore: Johns Hopkins University Press.
——1987. Rapid population growth and agricultural productivity. In *Population growth and economic development: issues and evidence*, D. G. Johnson & R. D. Lee (eds), 57–104. Madison: University of Wisconsin Press.
——1991. Rapid population growth and technical and institutional change. In *Consequences of rapid population growth in developing countries*, G. Tapinos, D. Blanchet, D. E. Horlacher (eds). New York: Taylor & Francis.
Hazarika, S. 1993. *Bangladesh and Assam: land pressures, migration and ethnic conflict*. Occasional Paper Series, Project on Environmental Change and Acute Conflict, American Academy of Arts and Sciences (Boston) and Peace and Conflict Studies Program, University of Toronto.
Hederra, R. 1987. Environmental sanitation and water supply during floods in Ecuador (1982–83). *Disasters* **11**, 113–16.
Herrera-Basto, E., D. Prevots, M. Zarate, J. Silva, J. Amor 1992. First reported outbreak of classical dengue fever at 1700 meters above sea level in Guerrero State, Mexico. *American Journal of Tropical Medicine* **46**, 649–53.
Hill, A. 1989. Demographic responses to food shortages in the Sahel. In *Rural development and populations: institutions and policy*, G. McNicoll & M. Cain (eds). New York: Oxford University Press. [Supplement to *Population and Development Review* **15**.]
Hogan, D. 1995. Population, poverty, and pollution in Cubatao, Brazil. See Potrykowska & Clarke (1995).
Holdren, J. 1991. Population and the energy problem. *Population and Environment* **12**(3), 231–55.
Holling, C. 1994. An ecologist view of the Malthusian conflict. See Lindahl-Kiessling & Landberg (1994).
Homer-Dixon, T. 1991. On the threshold: environmental changes as causes of acute conflict. *International Security* **16**, 2.
Homer-Dixon, T., J. Boutwell, G. Rathjens 1993. Environmental change and violent conflict. *Scientific American* **268**(February), 38–45.
Howard, P. & T. Homer-Dixon 1995. *Environmental scarcity and violent conflict: the case of Chiapas, Mexico*. Washington DC: American Association for the Advancement of Science.
Homer-Dixon, T. & M. Levy 1995. Correspondence: environment and security. *International Security* **30**(30), 1890–98.
Hynes, H. 1993. *Taking population out of the equation: reformulating I=PAT*. North Amherst, Massachusetts: Institute on Women and Technology.

International Conference on Water and the Environment 1992. *The Dublin statement on water and sustainable development*. Dublin: Conference Secretariat.

Jackson, C. n.d. Questioning synergism: win–win with women in population and environment policies? In *Environment and population change*, B. Zaba & J. Clarke (eds). Liège: Ordina.
Jacobson, J. 1988. *Environmental refugees: a yardstick of habitability*. Washington DC: Worldwatch Institute.
Jiminez, E. 1989. Social sector pricing policy revisited. *Proceedings of the World Bank Annual Conference on Development Economics 1989*. Washington DC: World Bank.
Jodha, N. 1989. Depletion of common-property resources in India: micro-level evidence: In *Rural development and populations: institutions and policy*, G. McNicoll & M. Cain (eds). New York: Oxford University Press. [Supplement to *Population and Development Review* **15**.]

Kaa, D. J. van de 1993. European migration at the end of history. *European Review* **1**(1), 87–108.
Kabeer, N. 1985. Do women gain from high fertility? In *Women, work and ideology in the Third World*, H. Afshar (ed.). London: Tavistock.
——1994. Re-examining the "demand for children" hypothesis in the context of fertility decline in Bangladesh. In *Poverty reduction and development cooperation: report from a conference*. Working Paper 94.6, Centre for Development Research, Copenhagen.
Kalkenstein, L. 1989. The impact of CO_2 and trace gas-induced climate change upon human mortality. Appendix G in *The potential effects of global climate change on the United States*, J. Smith & D. Tirpak (eds). Report EPA-230-05-89-057, Environmental Protection Agency, Washington DC.
——1993a. Global warming and human health. In *International implications of global warming*, L. Kalkenstein & J. Smith (eds). Cambridge: Cambridge University Press.
——1993b. Health and climate change: direct impacts in cities. *The Lancet* **342**, 1397–9.
Kalkenstein, L. & K. Smoyer 1993. The impact of climate change on human health: some international implications. *Experientia* **49**, 469–79.
Kaplan, R. 1994. The coming anarchy. *The Atlantic Monthly* (April), 44–76.
Kelly, K. & T. Homer-Dixon 1995. *Environmental scarcity and violent conflict: the case of Gaza*. Washington DC: American Association for the Advancement of Science.
Keyfitz, N. 1990. Population and development within the ecosphere: one view of the literature. *Population Index* **57**(1), 5–22.
——1992. Seven ways of making the less developed countries' population problem to disappear – in theory. *European Journal of Population* **8**, 149–67.
Kneese, A. 1989. The economics of natural resources. In *Population and resources in Western intellectual traditions*, M. Teitelbaum & J. Winter (eds). New York: Cambridge University Press.
Kolsrud, G. & B. Torrey 1992. The importance of population growth in future commercial energy consumption. In *Global climate change*, J. White (ed.). New York: Plenum Press.
Koopman, J., D. Prevots, M. Marin 1991. Determinants and predictors of dengue infection in Mexico. *American Journal of Epidemiology* **133**, 1168–78.
Kritz, M. 1990. Climate change and migration adaptations. Working Paper 2.16, Population and Development Program, Cornell University.

Langford, I. H. & G. Bentham 1993. *The potential effects of climate change on winter mortality in the UK*. Working paper GEC 93-25, Centre of Social and Economic Research on the Global Environment [CSERGE], University of East Anglia and University College London.
Lashof, D. & D. Tirpak (eds) 1990. *Policy options for stabilizing global climate (including technical appendix)*. Washington DC: Hemisphere.
Last, J. 1993. Global change: ozone depletion, greenhouse warming and public health. *Annual Review of Public Health* **14**, 115–36.
Layard, R., O. Blanchard, R. Dornbusch, P. Krugman 1992. *East–West migration: the alternatives*. Cambridge, Massachusetts: MIT Press.
Lee, R. 1990a. The demographic response to economic crisis in historical and contemporary populations. *Population Bulletin of the United Nations* **29**, 1–15.
——1990b. Comment: the second tragedy of the commons. *Population and Development Review* **16**, 315–22.
Lele, U. & S. W. Stone 1989. *Population pressure, the environment and agricultural intensification: variations on the Boserup hypothesis*. MADIA Discussion Paper 4, World Bank, Washington DC.
Lesthaeghe, R. 1983. A century of demographic and cultural change in western Europe; an exploration of underlying dimensions. *Population and Development Review* **9**(3), 411–35.
Lesthaeghe, R. & D. Meekers 1986. Value changes and the dimensions of familism in the

European community. *European Journal of Population* 2, 225–68.
Levins, R. 1995. Preparing for uncertainty. *Ecosystem Health* 1, 47–57.
Levins, R., T. Awerbuch, U. Brinkman, I. Eckhardt, P. R. Epstein, N. Makhoul, C. Albuquerque de Possas, C. Puccia, A. Spielman, M. E. Wilson 1994. The emergence of new diseases. *American Scientist* 82, 52–60.
Levy, M. 1995a. Time for a third wave of environment and security scholarship? Issue 1 (44–6), Environmental Change and Security Project Report, Woodrow Wilson Center, Princeton University.
——1995b. Is the environment a national security issue? *International Security* 20(2), 35–62.
Lindahl-Kiessling, K. & H. Landberg (eds) 1994. *Population, economic development, and the environment*. Oxford: Oxford University Press.
Lloyd, C. 1994. Investing in the next generation: the implications of high fertility at the level of the family. In *Population and development: old debates, new conclusions*, R. Cassen (ed.). Washington DC: Overseas Development Council.
Loevinsohn, M. 1994. Climate warming and increased malaria incidence in Rwanda. *The Lancet* 343, 714–18.
Lonergan, S. & B. Kavanaugh 1991. Climate change, water resources, and security in the Middle East. *Global Environmental Change* 1(4), 272–90.
Longstreth, J. D. 1990. Global warming: clues to potential health effects. *Environmental Carcinogenesis Reviews* C8(1), 139–69.
Ludwig, H. F. & A. Islam 1992. Environmental management of industrial wastes in developing countries: Bangladesh case study. *International Journal of Environment and Pollution* 2(1/2), 76–86.
Lutz, W. (ed.) 1996. *The future population of the world: what can we assume today?* London: Earthscan.
Lutz, W., C. Prinz, J. Langgassner 1993. World population projections and possible ecological feedbacks [POPNET 23 (Summer)]. Laxenburg, Austria: International Institute for Applied Systems Analysis.

MacArthur, R. H. & E. O. Wilson 1967. *The theory of island biogeography*. Princeton, New Jersey: Princeton University Press.
MacKellar, F. L. 1996. On human carrying capacity: a review essay on Joel Cohen's *How many people can the Earth support? Population and Development Review* 22(1), 145–56.
——1997. Population and fairness. *Population and Development Review* 23(2), 359–76.
MacKellar, F. L., W. Lutz, C. Prinz, A. Goujon 1995. Population, households, and CO_2 emissions. *Population and Development Review* 21(4), 849–65.
MacKellar, F. L., W. Lutz, L. Wexler, B. O'Neill 1996. *Population and global warming*. Unpublished paper, International Institute for Applied Systems Analysis, Laxenburg, Austria.
Maddison, J. M. 1989. *The world economy in the 20th century*. Paris: Organisation for Economic Cooperation and Development.
Mageed, Y. A. & G. F. White 1995. Critical analysis of existing institutional arrangements. *Water Resources Development* 11(2), 103–11.
Marden, P. G. & D. Hodgson 1975. *Population, environment, and the quality of life*. New York: AMS Press.
Marquette, C. M. 1995. Population and environment in industrialized regions: some general policy recommendations. See Potrykowska & Clarke (1995).
Martens, W. J. M., J. Rotmans, L. W. Niessen 1994. *Climate change and malaria risk: an integrated modelling approach*. GLOBO Report Series 3, Report 461502003, Global Dynamics and Sustainable Development Program, National Institute of Public Health and Environmental Protection [RIVM], Bilthoven, the Netherlands.
Martens, W. J. M., L. Niessen, J. Rotmans, T. H. Jetten, A. J. McMichael 1995a. Potential impact of global climate change on malaria risk. *Environmental Health Perspectives* 103, 458–64.
Martens, W. J. M., T. H. Jetten, J. Rotmans, L. W. Nielsson 1995b. Climate change and vector-

borne diseases: a global modelling perspective. *Global Environmental Change* 5(3), 195–209.
Martin, P. H. & M. G. Lefebvre 1995. Malaria and climate: sensitivity of malaria potential transmission to climate. *Ambio* 24(4), 200–7.
McGreevey, W. P. 1990. *Social security in Latin America*. Discussion Paper 110, World Bank, Washington DC.
McIntosh, A. & J. Finkle 1995. The Cairo Conference on Population and Development. *Population and Development Review* 21, 223–60.
McKeown, T. E. 1988. *The origins of disease*. Oxford: Basil Blackwell.
McMichael, A. J. 1993. Global environmental change and human population health: a conceptual and scientific challenge for epidemiology. *International Journal of Epidemiology* 22, 1–8.
McMichael, A. J. & W. J. M. Martens 1995. Assessing health impacts of global environmental change: grappling with scenarios, predictive models, and uncertainty. *Ecosystem Health* 1, 15–25.
McMichael, A. J., A. Haines, R. Sloof, S. Kovats (eds) 1996. *Climate change and human health*. Geneva: World Health Organisation.
McNicoll, G. 1984. Consequences of rapid population growth. *Population and Development Review* 10(2), 177–240.
——1990. Social organization and ecological stability under demographic stress. In *Rural development and population: institutions and policy*, G. McNicoll & M. Cain (eds). New York: Oxford University Press.
——1993. *Malthusian scenarios and demographic catastrophe*. Working Paper 49, Research Division, Population Council, New York.
——1995. On population and revisionism. *Population and Development Review* 21, 307–340.
Meadows, D. H., D. L. Meadows, J. Randers, W. W. Behrens III 1972. *The limits to growth*. New York: Universe.
Morse, S. S. 1991. Emerging viruses: defining the rules for viral traffic. *Perspectives in Biology and Medicine* 34(3), 387–409.
Mortimore, M. 1989. *Drought and drought response in the Sahel*. Background paper prepared for the Committee on Human Consequences of Global Change, National Research Council, Washington DC.
——1993. Northern Nigeria: land transformation under agricultural intensification. In *Population and land use in developing countries*, C. J. Jolly & B. B. Torrey (eds). Washington DC: National Academy Press.
Murphy, M. 1992. Economic models of fertility in post-war Britain – a conceptual and statistical reinterpretation. *Population Studies* 46(2), 235–58.
——1993. The contraceptive pill and women's employment as factors in fertility change in Britain 1963–1980: a challenge to the conventional view. *Population Studies* 47, 221–43.
Murray, J. 1994. Nutrition, disease and health. In *Health and sustainable agricultural development: perspectives on growth and constraints*, V. Ruttan (ed.). Boulder, Colorado: Westview.
Myers, N. 1989. Population, environment, and conflict. In *Resources, environment and population: present knowledge*, K. Davis & M. S. Bernstam (eds). Oxford: Oxford University Press.
——1993. Population, environment and development. *Environmental Conservation* 20(3), 205–16.
——1994. Environmental refugees in a globally warmed world. *BioScience* 43(11), 752–61.
Myrdal, G. 1944. *An American dilemma*. New York: Harper.

Nerlove, M., A. Razin, E. Sadka 1987. *Household and economy: welfare economics of endogenous fertility*. New York: Academic Press.
Nicholls, N. 1993. El Niño–Southern Oscillation and vector-borne disease. *The Lancet* 342, 1284–5.
Notestein, F. 1975. Population policy and development: a summary view. In *The population debate: dimensions and perspectives: papers of the World Population Conference, Bucharest, 1974*. New York: United Nations.

Nugent, J. B. 1985. The old age security motive and fertility. *Population and Development Review* 11, 75–97.

Nugent, J. B. & R. Anker 1990. *Old age support and fertility*. Working Paper 172, Population and Labor Policies, International Labour Organisation, Geneva.

OECD 1991. *The state of the environment*. Paris: Organisation for Economic Cooperation and Development.

Ogburn, W. F. 1922. *Social change: with respect to culture and original nature*. New York: Viking Press.

Palmer, I. 1991. *Gender and population in the adjustment of African economies: planning for change*. Geneva: International Labour Office.

Panayotou, T. 1993. *Empirical tests and policy analysis of environmental degradation at different stages of economic development*. Working Paper WEP 2-22/WP.238, World Employment Programme, International Labour Office, Geneva.

Pandit, K. & E. Cassetti 1989. The shifting patterns of sectoral labor allocation during development: developed versus developing countries. *Annals of the Association of American Geographers* 79(3), 329–44.

Pearce, D. W., E. Barbier, A. Markandya 1990. *Sustainable development: economics and environment in the Third World*. Cheltenham, England: Edward Elgar.

Pederson, J. 1995. Drought, migration and population growth in the Sahel: the case of the Malian Gourma: 1900–1991. *Population Studies* 49, 111–26.

Percival, V. & T. F. Homer-Dixon 1995. *Environmental scarcity and violent conflict: the case of South Africa*. Washington DC: American Association for the Advancement of Science.

Pernetta, J. C. 1989. Projected climate change and sea-level rise: a relative impact rating for the countries of the Pacific Basin. In *Implications of expected climate changes in the South Pacific: an overview*, J. C. Pernetta & P. J. Hughes (eds). Regional Seas Reports and Studies 128, United Nations Environment Programme, Nairobi.

——1992. Impacts of climate change and sea-level rise on small island states: national and international responses. *Global Environmental Change* 2(1), 19–31.

Pigou, A. 1960 (1920). *The economics of welfare* [reprint]. London: Macmillan.

Pingali, P. & H. Binswanger 1987. Population density and agricultural intensification: a study of the evolution of technologies in tropical agriculture. In *Population growth and economic development: issues and evidence*, D. G. Johnson & R. E. Lee (eds). Madison: University of Wisconsin Press.

Pope, C. A., D. V. Bates, M. E. Raizenne 1995. Health effects of particulate air pollution: time for reassessment. *Environmental Health Perspectives* 103, 472–80.

Potrykowska, A. & J. I. Clarke (eds) 1995. Population and environment in industrialized regions. *Geographica Polonica* 64 [special issue].

Powles, J. 1992. Changes in disease patterns and related social trends. *Social Science and Medicine* 35, 377–87.

Preston, S. 1994. Population and environment. From Rio to Cairo. IUSSP Distinguished Lecture on Population and Development, International Union for the Scientific Study of Population, Liège, Belgium.

Pritchett, L. 1994. Desired fertility and the impact of population policies. *Population and Development Review* 20(1), 1–55.

Rahman, A., N. Robins, A. Roncerel (eds) 1993. *Population versus consumption: which is the climate bomb?* Castle Cary, England: Castle Cary Press.

Raskin, P. D. 1995. Methods for estimating the population contribution to environmental change. *Ecological Economics* 15, 225–33.

Renner, M. 1989. *National security: the economic and environmental dimensions*. Worldwatch Paper 89, Worldwatch Institute, Washington DC.

Robinson, J. 1990. Philosophical origins of the social rate of discount in cost–benefit analysis.

Milbank Quarterly 682, 245–65.

Robinson, W. C. 1986. High fertility as risk assurance. *Population Studies* 40(2), 289–98.

Rogers, D. T. & M. J. Packer 1993. Vector-borne diseases, models and global change. *The Lancet* 342, 1282–4.

Romieu, I., H. Weitzenfeld, J. Finkelman 1990. Urban air pollution in Latin America and the Caribbean: health perspectives. *World Health Statistics Quarterly* 43, 153–67.

Rothman, E. S. & T. J. Espenshade 1992. Fiscal impacts of immigration to the United States. *Population Index* 58(3), 381–415.

Rowlands, I. H. 1992. North–South politics, environment, development and population: a post-Rio review. In *Environment and population change*, B. Zaba & J. Clarke (eds). Liège: Ordina.

Ruttan, V. W. 1971. Technology and the environment. *American Journal of Agricultural Economics* 53, 707–717.

Ruttan, V. W. & Y. Hayami 1991. Rapid population growth and technical and institutional change. In *Consequences of rapid population growth in developing countries*, G. Tapinos, D. Blanchet, D. E. Horlacher (eds). New York: Taylor & Francis.

Sen, G. 1994. Women, poverty and population: issues for the concerned environmentalist. In *Population and the environment: rethinking the debate*, L. Arizpe, M. P. Stone, D. C. Major (eds). Boulder, Colorado: Westview.

Serageldin, I. 1995. Water resources management: a new policy for a sustainable future. *Water Resources Development* 11(3), 221–2.

Shafik, N. & S. Bandyopadhyay 1992. *Economic growth and environmental quality: time series and cross-country evidence*. Policy Research Paper WPS 904, World Bank, Washington DC.

Shaw, P. 1993. Review of Harrison (1992). *Population and Development Review* 19(1), 189–92.

Shope, R. 1991. Global climate change and infectious diseases. *Environmental Health Perspectives* 96, 171–4.

Siddiqui, T. A. 1994. Implications for energy and climate-change policies of using purchasing-power-parity-based GDP. *Energy* 19(9), 975–81.

Simon, J. 1981. *The ultimate resource*. Princeton, New Jersey: Princeton University Press.

——1989. *The economic consequences of immigration*. Boston: Basil Blackwell.

Simons, J. 1986. Culture, economy and reproduction in contemporary Europe. In *The state of population theory: forward from Malthus*, D. Coleman & R. Schofield (eds). Oxford: Basil Blackwell.

Sirageldin, I. 1994. Population dynamics, environment and conflict. What are the connections? In *Population–environment–development interactions*, J. I. Clarke & L. Tabah (eds). Paris: Centre International de Recherche sur l'Environnement et la Développement [CIRED].

Smil, V. 1990. Planetary warming: realities and responses. *Population and Development Review* 16(1), 1–29.

Smith, D. R. 1995. Environmental security and shared water resources in post-Soviet Central Asia. *Post Soviet Geography* 36(6), 351–70.

Solow, R. 1991. *Sustainability: an economist's perspective*. Woods Hole, Massachusetts: Marine Policy Center.

Stanley, D. J. & A. G. Warne 1993. Nile Delta: recent geological evolution and human impact. *Science* 260(30 April), 628–34.

Starr, J. R. 1991. Water wars. *Foreign Policy* 70(2), 17–36.

Stern, P., O. Young, D. Druckman (eds) 1992. *Global environmental change: understanding the human dimensions*. Washington DC: National Academy Press.

Stevenson, G. 1989. The production, distribution and consumption of fuelwood in Haiti. *Journal of Developing Areas* 24(1), 59–76.

Stonich, S. C. 1989. The dynamics of social processes and environmental destruction: a Central American case study. *Population and Development Review* 15(2), 269–96.

Suhrke, A. 1993. *Pressure points: environmental degradation, migration and conflict*. Occasional

Paper Series on Environmental Change and Acute Conflict, Peace and Conflict Studies Program, University of Toronto.

Tabah, L. 1989. From one demographic transition to another. *Population Bulletin of the United Nations* **28**, 1–24.

Thomas, N. 1992. Review of UNFPA, *Population, resources, and the environment: the critical challenges*. *Population Studies* **46**(3), 559–60.

——1993. Economic security, culture and fertility: a reply to Cleland. *Population Studies* **47**, 353–9.

Thompson, M., R. Ellis, A. Wildavsky 1990. *Cultural theory*. Boulder, Colorado: Westview.

Thurman, E. M., D. A. Goolsby, M. T. Meyer, M. S. Mills, M. L. Pomes, D. W. Kolpin 1991. Herbicides in surface waters of the United States: the effect of spring flush. *Environmental Science and Technology* **25**, 1794–6.

——1992. A reconnaissance study of herbicides and their metabolites in surface water of the mid-western United States using immunoassay and gas chromatography/mass spectrometry. *Environmental Science and Technology* **26**, 2440–47.

Tiffen, M. & M. Mortimore 1992. Environment, population growth and productivity in Kenya. *Development Policy Review* **10**(4), 359–87.

Tiffen, M., M. Mortimore, F. N. Gichuki 1994. *More people, less erosion: environmental recovery in Kenya*. New York: John Wiley.

UN 1993. Synthesis of the Expert Group Meeting on Population, Environment, and Development. *United Nations Population Bulletin* **34/35**, 19–34.

United Nations Population Fund 1991. *Population, resources, and the environment: the challenges ahead*. New York: United Nations.

United Nations Secretariat 1991. Relationships between population and environment in rural areas of developing countries. *Population Bulletin of the United Nations* **46/47**, 52–69.

——1994. Population and environment: an overview. In *Population, environment and development: proceedings of the United Nations Expert Group meeting on population, environment and development*. New York: United Nations.

US NRC [US National Research Council] 1986. *Population growth and economic development: policy questions*. Washington DC: National Academy Press.

Van Arsdol, W. D., D. J. Sherman, A. Constable, J. Wang, L. Rollin 1995. Impacts of global sea level rise on California coastal population resources. In *Population–environment–development interactions*, J. I. Clarke & L. Tabah (eds). Paris: Comité International de Coopération dans les Recherches Nationales en Démographie.

Walle, E. van de 1992. Fertility transition, conscious choice and numeracy. *Demography* **29**(4), 487–502.

Warrick, R. 1980. Drought in the Great Plains: a case study of research on climate and society in the USA. In *Climatic constraints and human activities*, J. Ausabel & A. Biswas (eds). New York: Pergamon Press.

Weinberger, M. B. 1994. Recent trends in contraceptive use. *Population Bulletin of the United Nations* **36**, 55–80.

Westing, A. H. (ed.) 1986. *Global resources and international conflict: environmental factors in strategic policy and action*. New York: Oxford University Press.

——1992. Environmental refugees: a growing category of displaced persons. *Environmental Conservation* **19**, 201–207.

——1994. Population, desertification, and migration. *Environmental Conservation* **21**(2), 110–15.

Westoff, C. F. 1996a. The return to replacement fertility: a magnetic force? See Lutz (1996).

——1996b. Reproductive preferences and future fertility in developing countries. See Lutz (1996).

Wexler, L. 1996. *The greenhouse externality to childbearing*. Unpublished manuscript, International Institute for Applied Systems Analysis, Laxenburg, Austria.

WHO 1990. *Potential health effects of climate change: report of a WHO Task Group*. Geneva: World Health Organisation.

Wilkinson, R. G. 1994. The epidemiological transition: from material scarcity to social disadvantage? *Daedalus* **123**(4), 61–77.

Wolf, A. P. & C. Ying-Chang 1994. Fertility and women's labor: two negative (but instructive) findings. *Population Studies* **48**(3), 427–33.

World Bank 1992. *World development report 1992: development and environment*. Washington DC: World Bank.

——1993. *World development report 1993: investing in health*. Washington DC: World Bank.

World Resources Institute 1994. Natural resource consumption. In *World Resources 1994–95*. New York: Basic Books.

Yohe, G., J. Neuman, H. Ameden 1995. Assessing the economic cost of greenhouse-induced sea level rise: methods and application in support of a national survey. *Journal of Environmental Economics and Management* **29**, S78–S97.

Young, P. 1993. *Equity in theory and practice*. Princeton, New Jersey: Princeton University Press.