POPULATION, HOUSEHOLDS, AND CO_2 EMISSIONS

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The controversy over whether rapid population growth in the countries of the South or high consumption in those of the North is to be held responsible for global environmental problems is usually framed in terms of the I = PAT identity first introduced by Ehrlich and Holdren (1971). In a typical formulation, environmental impact (I) is seen as the product of three factors: population (P); affluence (A), which is measured by gross national product per person; and technological efficiency (T), which is expressed as impact per unit of GNP. This identity is useful and suggestive as a first approach, because it demonstrates that environmental impact is due, not to one factor alone, but to a combination of factors. However, I = PAT has serious limitations if taken as a basis for more rigorous scientific analysis.

The problems with I = PAT can be grouped into two broad categories: (1) the omission of interactions between the variables, and (2) questions related to the choice of variables:

(1) I = PAT cannot contribute much to resolving the population versus consumption debate because of differences of opinion concerning the interactions between the factors P, A, and T. The Malthusian view argues that population growth diminishes affluence and thereby impedes technical progress; the Boserupian view argues that population growth enhances technology and thereby increases affluence; and the modernization argument stresses that increasing affluence slows the rate of population growth and enhances technical progress, thus reducing impact per unit of GNP. Analysis along I = PAT lines cannot resolve these differences of opinion, because the controversial relationships are not explicit in the equation.[1]

(2) In some decomposition exercises, such as the decomposition of trends in the crude birth rate into age-structure and fertility-rate effects, the choice of variables is a straightforward matter of accounting. In the case of I = PAT the choice is much less self-evident. If the impact to be studied is, say, CO_2 emissions, why should the emitting unit be taken as the individual rather than, say, the household or the community? In other words, the choice of factors requires substantive justification and should not be taken for granted.

The following note concerns itself with the second (and less serious) problem, specifically, with the accounting implications of the fact that I = PAT selects the individual as the demographic unit. We illustrate the consequences of considering households (H) instead of individuals as the consuming unit (i.e., I = HAT instead of I = PAT). The substantive justification for this lies in the fact that for many goods, such as automobile transport and residential energy consumption, there are significant economies of scale: for example, a household of four persons will consume far less than twice as much as a household consisting of two persons.[2] For goods whose consumption is tied more closely to the hearth than to the individual, the size and rate of growth of population are of less concern than the number and rate of growth of households.

In the next section, we compare trends in the rate of growth of households to trends in the rate of growth of population and discuss the roles of changing age-specific household headship rates and changing population age structures. We then present an illustrative calculation in which growth of world primary energy demand from 1970 to 1990 is decomposed using the I = PAT and I = HAT identities. Because of the rapid growth over this period in the number of households in more developed regions, the two identities yield very different allocations of responsibility between demographic and economic factors. We then use the I = PAT and I = HAT models to calculate substantially different illustrative projections of CO_2 emissions from 1990 to 2100. The fundamental point of both exercises is that the decomposition approach contains an arbitrary element, depending as it does on the demographic unit of account.

Average household size: Historical trends and outlook

Average household size is the inverse of the average household headship rate, which is defined as the number of persons in the population who are heads of households divided by the population, expressed as a rate. Age-specific household headship rates are defined by the number of heads of households in a certain age group divided by the total number of persons in that age group. Changes in average household size result from the combined evolution of age-specific household headship rates and the age structure of the population.

Between 1950 and 1990, average household size in all of the more developed regions underwent a decline that, in proportional terms, can fairly be termed massive: on average, from 3.6 to 2.7 (see Table 1 and the Statistical Note for definition of regions and a description of estimation procedures). This decline was due more-or-less equally to changes in population age structure (mostly aging) and to increases in age-specific household headship rates; the former is an accounting effect while the latter reflects actual changes in behavior. Among these changes were young persons' moving away from home earlier, declining age-specific nuptiality rates (with a consequent increase in the mean age at marriage), and the growing tendency of the aged to live on their own rather than with their children.

The less developed regions, by contrast, present a mixed picture. Average household size declined in China and Hong Kong, Southeast Asia, and South America, while it increased in all other regions. For all less developed regions combined, household size remained practically unchanged, declining only from 5.0 in 1950 to 4.8 in 1990. In fact, if China is excluded, average household size in the less developed regions *increased* significantly.[3] The increase was most pronounced in South Asia and North Africa, where increases in average household size from 5.0 to 5.7 can be attributed, entirely in the first case and largely in the second, to reductions in age-specific headship rates. Of the three regions that experienced declines in average household size, only in the statistically uncertain case of China can the decline be attributed to an increase in age-specific household headship rates.

Further information can be gained by comparing changes in 1950–70 with changes in 1970–90 (see Table 1). During the first 20 years, in more developed regions, increases in age-specific household headship rates were a more important source of change than was shifting age structure. The situation was reversed during the last 20 years: the aging of populations drove changes in household size, and increases in age-specific household headship rates were relatively unimportant. In less developed regions, a similar reversal is observed. In 1950–70, the trend in age-specific household headship rates favored decline in average household size, but age-structure effects (i.e., the younger population age structure associated with mortality decline and unchanged fertility levels) were stronger in the opposite direction, resulting in an overall increase in average household size. In 1970–90, by contrast, fertility decline started to work its way through the age structure in most less developed countries, leading to an increase in the share of young adults in the population and consequent decline in average household size.

What does the future hold? Research on the decline of the extended family in more developed countries has identified three basic themes, one

TABLE 1 Average household size, world regions, 1950, 1970, and 1990

	1950	1970	1990
North Africa	5.0	5.3	5.7
Sub-Saharan Africa	4.6	4.9	5.1
Northern America	3.5	3.1	2.6
Central America	4.6	4.9	4.9
South America	5.0	5.0	4.4
West and Central Asia	5.0	5.3	5.1
South Asia	5.0	5.6	5.7
China and Hong Kong	5.0	4.7	4.1
Southeast Asia	5.2	5.3	4.8
Japan, Australia, and New Zealand	4.7	3.6	3.0
East Europe	3.7	3.3	2.9
West Europe	3.5	3.1	2.6
World	4.5	4.4	4.1
More developed regions	3.6	3.2	2.7
Less developed regions	5.0	5.1	4.8

	Change due to			
	Age distribution		Age-specific headship rates	
	1950–70	1970–90	1950–70	1970–90
North Africa	0.3	–0.2	0.0	0.6
Sub-Saharan Africa	0.2	0.1	0.1	0.1
Northern America	0.2	–0.5	–0.6	0.0
Central America	0.5	–0.6	–0.2	0.6
South America	0.1	–0.6	–0.1	0.0
West and Central Asia	0.2	–0.3	0.1	0.1
South Asia	0.2	–0.2	0.4	0.3
China and Hong Kong	0.7	–0.9	-1.0	0.3
Southeast Asia	0.3	–0.6	–0.2	0.1
Japan, Australia, and New Zealand	–0.7	–0.4	–0.4	–0.2
East Europe	–0.3	–0.4	–0.1	0.0
West Europe	–0.1	–0.2	–0.3	–0.3
World	0.2	–0.3	–0.3	0.0
More developed regions	–0.1	–0.4	–0.3	–0.1
Less developed regions	0.4	–0.4	–0.3	0.1

NOTE: See the Statistical Note for definition of more developed and less developed region aggregates. Totals in this and the following tables may not add due to rounding.

demographic, one sociological, and one economic.[4] The demographic view emphasizes that residence in an extended household unit must necessarily decline along with fertility for the simple reason that there are fewer kin (including siblings) to live with. The sociological view argues that there has been an exogenous shift in tastes toward privacy. The economic view concentrates on such factors as income and the price of housing. Bumpass (1990) and others have synthesized the three views to argue convincingly that no end is in sight to the shift toward more atomized living arrangements in more developed countries. The data in Table 1 indicate that increases in age-specific household headship rates contributed only –0.1 to the change in average household size in more developed regions in 1970–90, as opposed to –0.3 in 1950–70, so further behavioral change may have only modest impact. However, future declines in the proportion of the population aged under 15 and increases in the proportion aged 60 and older suggest that, even barring future individuation, average household size will continue to decline.

Research on household structure in less developed countries is limited by data availability. Foster (1993) finds that household structure in Bangladesh has been resistant to change, and cites consistent research results from elsewhere in South Asia. One might argue that the period covered by Foster (eight years) is insufficient for much change to occur and that Bangladesh is a stagnating economy. Reviewing 12 years of dynamic economic growth in Taiwan (1973–85), Weinstein et al. (1990) found that the proportion of couples living in nuclear households increased from 43 percent to 56 percent, leading the authors to have it both ways: they note the "gradual erosion of norms" sanctioning coresidence, but at the same time emphasize that nearly half of Taiwanese couples in 1985 were still living in extended units.

The traditional view, canonized by Goode (1963), is that the decline of the extended family is an inevitable accompaniment of what is indelicately termed "modernization." This gives rise to a "stages of development" interpretation according to which average household size in third world countries will decline as countries attain a higher material standard of living. One explanation might be that complex, extended household units are inherently less capable of allocating substantial resources harmoniously than are simple, nuclear ones. It might also be argued that with development comes the emergence of institutions, such as social security systems, to provide the insurance against risk that was formerly provided by the extended family. On the other hand, "stages of development" models lack rigorous microlevel foundations and postulate a rigid relationship between per-person income and various social indexes. For example, Yi et al. (1994) found that the mean age of leaving the parental home was about three years higher for young adults in China, Japan, and South Korea than in the United States, France, and Sweden. Japan, of course, is not a developing country, a fact that gives rise to two possible interpretations: either cultural factors are as important as "stage of development," or rapid economic development in Japan has not yet manifested itself in changing household structure, but will do so eventually. Moreover, differences between the United States and the two European countries were fairly substantial.

For purposes of forecasting average household size in the developing world, however, these issues are less important than might be thought. In fact, differences in age-specific household headship rates between more and less developed regions are significant only at the extremes of the age distribution; between ages 40 and 65, the age-specific rate schedules are practically indistinguishable. When 1990 age-specific household headship rates from less developed regions are applied to the 1990 population in more developed regions to calculate an age-standardized household headship rate, a striking fact emerges: the age-standardized rate in the less developed regions, 329 per thousand (average household size of 3.0) is only a little more than 10 percent lower than the age-standardized headship rate in the more developed regions, 366 per thousand (average household size of 2.7). It would thus seem that future changes in population age structure in less developed countries will have a much greater impact on average household size than will changes in age-specific headship rates. In other words, compositional effects will be more important than the less certain (and more controversial) behavioral changes in family formation and living arrangements that may arise in the context of "modernization." The age-structure changes that we have mentioned above in the case of more developed countries—a decline in the proportion at young ages, and an increase in the proportion who are elderly—will be more extreme for less developed countries because of the speed of fertility decline. Thus, even with no changes in age-specific headship rates, average household size in less developed countries will decline substantially.

Table 2 presents the results of four projections of average household size. "Central," "Low" and "High" scenarios correspond to IIASA population scenarios;[5] age-specific household headship rates are assumed to remain constant at 1990 levels, so differences in average household size between these variants are entirely due to differences in population age structure. The final variant, the "Modified Central" scenario, was calculated by applying the 1990 average age-specific headship rates in more developed regions to the Central scenario population projection for less developed regions; thus, differences between the Central and Modified Central scenarios apply only to less developed regions and are due entirely to differences in age-specific headship rates.[6]

Based on changes in the age structure alone, average household size in more developed regions is projected to decline modestly, from 2.7 to 2.5 in the Central scenario. Only in the High scenario, which combines high fertility (implying a high proportion of the population under 15) and high mortality (implying a small proportion of the population aged 60 and older), does it increase, and this insignificantly, from its current 2.7 to 2.8. Average household size in less developed regions, by contrast, is projected un-

TABLE 2 Average household size, 1990, and projected average household size in 2030 and 2100, according to four alternative scenarios, world regions

	Central scenario			Low scenario		High scenario		Modified Central scenario	
	1990	2030	2100	2030	2100	2030	2100	2030	2100
North Africa	5.7	4.1	2.9	3.7	2.5	4.5	3.3	3.6	2.6
Sub-Saharan Africa	5.1	4.2	2.6	3.8	2.4	4.6	2.8	4.3	2.7
Northern America	2.6	2.5	2.4	2.3	2.2	2.7	2.7	2.5	2.4
Central America	4.9	3.3	2.6	3.1	2.2	3.6	2.9	3.1	2.4
South America	4.4	3.3	2.8	3.0	2.5	3.5	3.1	3.0	2.6
West and Central Asia	5.1	3.8	2.8	3.5	2.4	4.1	3.1	3.3	2.5
South Asia	5.7	4.0	2.8	3.7	2.5	4.3	3.1	3.3	2.4
China and Hong Kong	4.1	3.1	2.8	2.8	2.5	3.3	3.1	2.7	2.4
Southeast Asia	4.8	3.3	2.7	3.1	2.4	3.6	2.9	3.0	2.5
Japan, Australia, and New Zealand	3.0	2.9	3.0	2.8	2.9	3.1	3.1	2.9	3.0
East Europe	2.9	2.6	2.6	2.4	2.3	2.8	3.0	2.6	2.6
West Europe	2.6	2.5	2.5	2.3	2.2	2.7	2.8	2.5	2.5
World	4.1	3.5	2.7	3.2	2.4	3.8	3.0	3.1	2.5
More developed regions	2.7	2.6	2.5	2.4	2.3	2.8	2.8	2.6	2.5
Less developed regions	4.8	3.7	2.7	3.4	2.4	4.0	3.0	3.3	2.5

NOTE: For description of the four scenarios see text. See also Note to Table 1.

der all three scenarios to undergo a decisive decline. Thus, age-structure changes alone are sufficient to ensure that, by the end of the next century, average household size in more developed and less developed regions will converge—to 2.5 and 2.7, respectively, in the Central scenario; 2.3 and 2.4 in the Low scenario; and 2.8 and 3.0 in the High scenario. This convergence mostly reflects declines in average household size in less developed regions.

The effect of imposing average more-developed-region age-specific headship rates on less developed regions is significant in the medium term—in 2030 the Modified Central scenario envisions an average household size of 3.3 in less developed regions, as opposed to 3.7 in the Central scenario—but in the long term, the differences between the Central and Modified Central scenarios are small; it is age structure that drives the convergence process.

Between 1950 and 1990, the population in less developed regions grew at an average rate of 2.2 percent per year and the number of households at 2.3 percent per year; in more developed regions, the corresponding rates of growth were 0.9 percent and 1.6 percent per year. Thus, whereas the "demographic growth gap" was 1.3 percentage points per year in terms of population, it was a much narrower 0.7 percentage point in terms of households. In the future, according to the projection results in Table 2, the gap will be broader, not narrower, for households than for population. In the Central scenario, population in more developed regions is projected to grow at an average rate of 0.3 percent per year between 1990 and 2100, and households at a roughly equal rate of 0.4 percent per year. In less developed regions, the corresponding growth rates are 0.9 percent per year and 1.4 percent per year, respectively. Thus the "demographic growth gap" of 0.6 percentage point per year in terms of population is projected to be a considerably wider 1.0 percentage point per year in terms of households. If age-specific household headship rates decline in less developed regions, as in the Modified Central scenario, the differences will be more pronounced.

I = PAT or I = HAT?

Despite its limitations, the I = PAT identity has become the model of choice in decomposing change in global environmental impacts into changes due to population growth and changes due to other factors. In this section, we illustrate differences that arise when the household, as opposed to the individual, is chosen as the demographic unit of account.

Let

$P(t)$ = Population
$y(t)$ = Gross National Product (GNP) per person
$I(t)$ = Impact (natural resource use or pollution generated)
$\alpha(t) = I(t)/y(t)$, impact per unit of GNP

all at time t. Then

$$I(t) = P(t)\, y(t)\, \alpha(t) \quad .$$

The I = PAT identity can be converted into an I = HAT—Impact-Households-Affluence-Technology—identity simply by substituting households, $H(t)$, for population and measuring affluence in terms of GNP per household, which we denote $x(t)$:

$$I(t) = H(t)\, x(t)\, \alpha(t) \quad .$$

Each of the two alternative identities is no more valid than the assumption that underlies it: impacts are considered as arising from activities undertaken either at the level of the household or at the level of the individual.

We will take impact as one and the same thing as consumption, $C(t)$, of a natural resource, on the understanding that generalization to cover emission of a pollutant is straightforward. Using G to denote growth rates, in growth-rate form the I = PAT model is

$$G_c = G_p + G_y + G_\alpha$$

and the I = HAT model is

$$G_c = G_H + G_x + G_\alpha \ .$$

An example: Growth of energy consumption, 1970–90

Tables 3, 4, and 5 display data on population and households, GNP, and primary commercial energy consumption that permit I = PAT and I = HAT decompositions of growth of world energy consumption in more developed and less developed regions over the period 1970–90; results are reported in Table 6. Increases in energy consumption accounted for by rise in income and by change in technology (the ratio of energy to GNP) are considered together. This reflects the assumption, referred to by many researchers (for example, MacKellar and Horlacher 1994; Preston 1994; Cropper and Griffiths 1994; World Bank 1992; Gilland 1986), that environmental impact per unit of GNP varies predictably with per-person (or per-household) income. The assumption that change in technology is accounted for

TABLE 3 Population and households, world regions, 1970 and 1990

	1970	1990
Less developed regions		
Persons (millions)	2,695	4,150
Average annual change 1970–90 (percent)		2.2
Crude headship rate (per 1000)	196	207
Households (millions)	529	861
Average annual change 1970–90 (percent)		2.5
Persons per household	5.1	4.8
More developed regions		
Persons (millions)	1,002	1,145
Average annual change 1970–90 (percent)		0.7
Crude headship rate (per 1000)	307	366
Households (millions)	308	419
Average annual change 1970–90 (percent)		1.6
Persons per household	3.2	2.7

SOURCES: Population: Lutz (1994); number of households calculated on the basis of household headship rate estimates discussed in text.

TABLE 4 Gross national product, world regions, 1970 and 1990

	1970	1990
Less developed regions		
Total (billions 1991 US$)	1,343	3,735
Average annual change 1970–90 (percent)		5.2
Per person (1991 US$)	498	900
Average annual change 1970–90 (percent)		3.0
Per household (1991 US$)	2,539	4,338
Average annual change 1970–90 (percent)		2.7
More developed regions		
Total (billions 1991 US$)	10,115	17,175
Average annual change 1970–90 (percent)		2.7
Per person (1991 US$)	10,095	15,000
Average annual change 1970–90 (percent)		2.0
Per household (1991 US$)	32,840	40,990
Average annual change 1970–90 (percent)		1.1

SOURCES: Per-person GNP and growth rate of per-person GNP 1970–90 estimated by authors from United Nations Development Programme (1994): Tables 2 and 27. Total GNP and per-household GNP calculated based on data in Table 3.

TABLE 5 Primary commercial energy consumption, world regions, 1970 and 1990

	1970	1990
Less developed regions		
Total (million tons oil equivalent)	624	2,283
Average annual change 1970–90 (percent)		6.7
Per-person (kg oil equivalent)	232	550
Average annual change 1970–90 (percent)		4.4
Per-household (kg oil equivalent)	1,179	2,651
Average annual change 1970–90 (percent)		4.1
More developed regions		
Total (million tons oil equivalent)	3,778	5,725
Average annual change 1970–90 (percent)		2.1
Per-person (kg oil equivalent)	3,770	5,000
Average annual change 1970–90 (percent)		1.4
Per-household (kg oil equivalent)	12,266	13,663
Average annual change 1970–90 (percent)		0.5

SOURCES: Per-person energy consumption and growth rate of total energy consumption 1970–90 estimated by authors from United Nations Development Programme (1994): Table 25. Total and per-household levels calculated using population and household data in Table 3.

TABLE 6 Sources of growth of energy consumption, world regions, 1970–90: Average annual percent change and, in parentheses, percent shares by world regions attributable to population growth or to growth in the number of households, and to the combined effect of changes in income and in technology

	I = PAT model			
		of which		
	Growth rate of energy consumption	Due to growth of population	Due to change in income per person	Due to change in technology
Less developed regions	6.7	2.2	3.0	1.5
	(100.0%)	(32.8%)	(67.2%)	
More developed regions	2.1	0.7	2.0	–0.6
	(100.0%)	(33.3%)	(66.7%)	
	I = HAT model			
		of which		
	Growth rate of energy consumption	**Due to growth of number of households**	**Due to change in income per household**	**Due to change in technology**
Less developed regions	6.7	2.5	2.7	1.5
	(100.0%)	(37.3%)	(62.7%)	
More developed regions	2.1	1.6	1.1	–0.6
	(100.0%)	(76.2%)	(23.8%)	

entirely by changes in the level of income is not strictly necessary to make the points that follow, but it does simplify matters by reducing the three-way I = PAT decomposition to a two-way one. If the reader prefers to consider the combined term to be "economic growth plus unexplained shifts in technology," nothing will be lost in terms of the point we wish to make.

According to the I = PAT identity, roughly one-third of the growth of energy consumption in both less developed and more developed regions over this period was accounted for by demographic growth—32.8 percent in the former and 33.3 percent in the latter (Table 6). Shifting to an I = HAT framework does not greatly alter the decomposition for less developed regions, but it completely changes the picture for more developed regions. Now, about three-quarters (76.2 percent) of the rate of growth of energy consumption is accounted for by demographic increase as measured by the rate of growth of the number of households. In Table 7, the same decomposition is performed in terms of absolute annual change in energy consumption, which allows the increase to be shared among more developed and less developed regions without worrying about the level of disaggregation at which the decomposition is done (Lutz, Prinz, and Lang-

TABLE 7 Sources of growth of energy consumption, world regions, 1970–90: Average annual absolute change (million tons oil equivalent) and, in parentheses, percent shares by world regions attributable to population growth or to growth in the number of households and to the combined effect of changes in income and in technology

	I = PAT model		
	Growth of population	Change in income and in technology	Total
Less developed regions	27.2	55.7	82.9
	(15.1%)	(30.9%)	(46.0%)
More developed regions	32.5	64.9	97.4
	(18.0%)	(36.0%)	(54.0%)
Total	59.7	120.6	180.3
	(33.1%)	(66.9%)	(100.0%)
	I = HAT model		
	Growth of number of households	**Change in income and in technology**	**Total**
Less developed regions	30.9	52.0	82.9
	(17.2%)	(28.8%)	(46.0%)
More developed regions	74.2	23.2	97.4
	(41.1%)	(12.9%)	(54.0%)
Total	105.1	75.2	180.3
	(58.3%)	(41.7%)	(100.0%)

gassner 1993). The I = PAT identity assigns 18.0 percent of the global annual increase in emissions to demographic growth in more developed regions; the I = HAT identity assigns 41.1 percent.

Based on such accounting exercises, one could argue that Western behavioral patterns, in the form of a tendency toward increasingly nucleated living arrangements, are an important contributor to rising energy consumption. This would be premature, however, as the story is not over. In Table 8, we expand the I = HAT decomposition to show the growth of the number of households that would have occurred holding age structure constant (that portion which reflects behavioral change) and the growth that resulted from shifts in age structure (holding age-specific headship rates constant). In the more developed regions, half the contribution of demographic effects arose from the rate of population growth and half from changes in age distribution; behavioral changes in the form of rising age-specific headship rates were a minor factor. An insight that emerges in the I = HAT framework is that the fertility decline which brings about deceleration in the rate of overall population growth, relieving pressure on the environment, contributes to population aging and the consequent rise in

TABLE 8 Sources of growth of energy consumption according to the I = HAT model, world regions, 1970–90: Average annual percent change and, in parentheses, percent shares by world regions attributable to four sources of that growth

		of which			
	Growth rate of energy consumption	Due to growth of population	Due to change in age structure	Due to change in age-specific headship rates	Due to other changes
Less developed regions	6.7	2.2	0.4	–0.1	4.2
	(100.0%)	(32.8%)	(6.0%)	(–1.5%)	(62.7%)
More developed regions	2.1	0.7	0.7	0.2	0.5
	(100.0%)	(33.3%)	(33.3%)	(9.5%)	(23.8%)

the proportion of the population in age groups characterized by high age-specific household headship rates, increasing pressure on the environment. Fertility decline will, of course, reduce the number of households 20 or 30 years hence, but in the longer run its impact on the number of households is limited by the age-structure change. In short, when environmental impact is considered to be at least in part related to the number of households as opposed to the number of individuals, and when account is taken of how changing age structure affects the number of households, the relationship between fertility decline and future environmental impacts is less straightforward than is commonly assumed.

Another example: Projected carbon dioxide emissions, 1990–2100

Like the historical decomposition exercise presented above, projections of future trends are also dependent on which model is chosen. Table 9 presents the results of the following illustrative exercise. Four alternative assumptions were made regarding CO_2 emissions. The first is that these remain constant in per-person terms, and the second is that these remain constant in per-household terms.[7] The third is that per-person emissions grow 1.0 percent per year in less developed regions and 0.4 percent per year in more developed regions. The fourth is that per-household emissions grow 1.0 percent per year in less developed regions and 0.4 percent in more developed regions. These four assumed emissions paths were then combined with the IIASA population projection and the Central scenario household projection presented in Table 2 to calculate global CO_2 emissions. As shown in Table 9, projections vary widely depending on which model is chosen. If the I = PAT model is selected and emissions are assumed to remain constant in per-person terms, an increase of 88 percent is projected between 1990 and 2100. If, by contrast, the I = HAT model is selected and emissions are assumed to remain constant in per-household

TABLE 9 Projected growth of total CO_2 emissions, world regions, under alternative assumptions, 1990–2100

	Average annual change (percent)		
	Less developed regions	More developed regions	Total emissions, 2100 (1990 = 100)
I = PAT model			
Constant per-person emissions	0.9	0.4	188
Growing per-person emissions	1.9	0.7	399
I = HAT model			
Constant per-household emissions	1.4	0.4	267
Growing per-household emissions	2.4	0.7	624

NOTE: For assumptions concerning per-person and per-household growth in emissions see text.

terms, the projected increase is 167 percent, almost exactly double. If the I = PAT model is selected and emissions are assumed to grow in per-person terms, a quadrupling of emissions is projected; if the I = HAT model is selected and emissions are assumed to grow at the same rate, but in per-household terms, an increase of over sixfold is projected.

The I = PAT and I = HAT models represent extreme formulations, the first assuming no household-level economies of scale whatsoever in the activities that generate CO_2, and the second assuming perfect economies of scale. If projections based on demographic trends, as opposed to projections based on economic trends or even some other "driver," are conceptually correct (which is not self-apparent), the truth will presumably lie somewhere in-between.[8] This would mean that, under the constant emissions assumption, an increase in total emissions of somewhere between 88 percent and 167 percent would be expected and, under the growing emissions assumption, an increase between four- and sixfold would be expected. This substantial range of variation can be narrowed only by research into the importance of household-level economies of scale in the activities that give rise to CO_2 emissions.

Conclusion

In both more developed and less developed regions, the proportion of the population aged under 15 is expected to decline and the proportion of the population aged over 60 is expected to rise. Even barring further increases in age-specific household headship rates in more developed regions, and even without taking into account weakening of the traditional extended family in the face of "modernization" in the less developed regions, the number of households will grow more rapidly than the number of people.

Decomposition exercises that seek to impute responsibility for environmental impacts such as CO_2 emissions, as well as forecasts of impacts, are sensitive to the demographic unit of account employed. Should this be the individual, the household, the community, or what? Until more is known about the nature of the activities that give rise to environmental impacts, the answer will not be clear. In the future, it might be possible to employ a model such as $I = C + a\text{PAT} = b\text{HAT}$, where C is a constant covering impacts that are not proportional to either demographic units or income (waste from military sources, for example) and a and b are the weights attached to impacts that are specific to individuals and households. The kind of model chosen should depend entirely on the nature of the specific environmental impact studied and the best information we have about its sources.

Meanwhile, it would be unwise to draw far-reaching conclusions about the impact of demographic variables on the environment from one specific choice of model without a substantive justification of that choice.

Statistical note

The More Developed Region aggregate consists of Northern America, Japan-Australia-New Zealand, West Europe, and East Europe (including the former Soviet Union except for the Central Asian republics). The Less Developed Region aggregate consists of all other regions. There is a slight inconsistency between demographic data from Lutz (1994) and the energy and GNP data from United Nations Development Programme (1994), in that the former classifies the Central Asian republics of the former Soviet Union as Less Developed while the latter classifies them as More Developed. The discrepancy is too small to affect results significantly.

Average household size for each of the 12 regions in each of the years 1950, 1960, 1970, 1980, and 1990 was approximated on the basis of incomplete country-specific household-size estimates taken from the UN *Demographic Yearbook* for 1991. For space reasons, the country-level data used to infer regional trends are not presented here, but are available from the authors. In some regions, data for major countries are unavailable; therefore, the size of the error in regional estimates varies from year to year and from region to region. The data appear sufficient, however, to estimate overall trends fairly accurately, with the important exception of China.

Age-specific household headship rates for each of the 12 regions for around 1985 were also estimated on the basis of country-specific rates; these data are also not presented here but are available from the authors. In this case, the data were taken from the 1987 UN *Demographic Yearbook*. Again, available data are incomplete; however, differences between regions are slight, and the regional estimates are likely to be fairly accurate.

Decomposition of household-size changes between 1950 and 1990 was done in the following way: in a first step, age- and region-specific household headship rates around 1985 (estimated as described above) were assumed to remain constant over time throughout the period 1950–90. Household-size estimates for 1950, 1970, and 1980 were calculated by applying the constant rates to changing age distributions. Changes over time in these estimates, then, can be assumed to be the result purely of changes in the age structure of the population. Effects of changes in age-specific household headship rates are calculated as a residual; they are the difference between the household-size estimates assuming constant age-specific headship rates and the average household size estimated on the basis of data in the 1991 UN *Demographic Yearbook*.

Notes

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1 The literature that questions the massive ceteris paribus assumptions underlying I = PAT is scattered, but Shaw (1993), Preston (1994), and MacKellar and Horlacher (1994) are representative. Harrison (1992) exemplifies the sort of application of I = PAT that has drawn fire, but it is only one of many.

2 US energy data from the end of the 1980s give an idea of the significance of such effects (Wexler 1995). 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. Household vehicles and residential energy combined account for roughly one-third of total US energy consumption.

3 The figures given for China must be interpreted with caution. Data on average household size were available only for the years 1982 and 1984. While they imply a decline, mostly as a consequence of declining fertility, they give no indication of the long-term trend since 1950.

4 The literature on household and family demography is vast, and no attempt is made here to do it justice. Among the better compilations of international data on average household size from the 1950s to the 1970s is Kuznets (1982).

5 In the Central scenario, central mortality and fertility assumptions are used; the High scenario, which might be termed "slow demographic transition," combines high fertility assumptions with high mortality assumptions; the Low scenario, which might be termed "rapid demographic transition," assumes rapid fertility decline and rapid improvements in life expectancy. The assumptions and results are discussed in Lutz (1994).

6 Making an explicit assumption on how rapidly age-specific headship rates in developing regions converge on the averages for more developed regions would be an obvious refinement, but it makes little difference in results.

7 Since the rate of growth of population and that of households differ, the constant per-person and constant per-household scenarios implicitly define two different scenarios for emissions per unit of GNP, as do the two scenarios in which emissions per demographic unit are assumed to grow.

8 Some might argue that demographic factors should be suppressed entirely and impacts considered solely relative to the level of economic activity. But this just raises a new set of issues. Should we be looking at impact per unit of GNP, impact per unit of gross output (including exported goods, the impact of whose production should reasonably be imputed to someone else's domestic absorption; and excluding imported goods, the impact of whose production should reasonably be imputed to own-domestic absorption), impact per unit of domestic absorption (in which case impacts arising from imports will be weighted averages of impacts per unit of production in trading partners), or something else? Empirical difficulties aside, even the conceptual issues are not easily resolved.

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