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Population, Households and CO_2 Emissions

F. Landis MacKellar
Wolfgang Lutz
Christopher Prinz
Anne Goujon

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IIASA International Institute for Applied Systems Analysis ☐ A-2361 Laxenburg Austria
Telephone: +43 2236 807 ☐ e-mail: info@iiasa.ac.at ☐ Telefax: +43 2236 71313

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ABOUT THE AUTHORS

F. Landis MacKellar, Wolfgang Lutz and Anne Goujon are members of the IIASA Population Project.

Christopher Prinz is from the European Center, Berggasse 17, A-1090 Vienna, Austria.

ABSTRACT

In this paper, the Income-Population-Affluence-Technology, or I=PAT, model is reformulated in terms of households (i.e., I=HAT) as opposed to persons. Such an approach is preferable in the case of environmental impacts, such as CO_2 emissions, which are caused by activities such as residential heating and automobile transport, for which there exist significant household-level economies of scale.

Because of historical changes in average household size, the IHAT identity gives rise to a very different decomposition of the sources of growth in environmental impacts than does the IPAT identity. Taking growth in commercial energy consumption as an example, we find that the IPAT identity attributes 18.2% of the annual increase (in absolute terms) over the period 1970-90 to industrialized-country demographic increase, whereas the IHAT model attributes 41.5% because of the significant decrease of mean household sizes. The difference between the two decompositions is simply that, in the first, it is the individual who is the demographic unit of account, whereas in the latter, it is the household.

Based on the IIASA world population projections and derived projections of households, the IPAT and IHAT identities are employed to project the level of CO_2 emissions in the year 2100. In the case where the level of emissions per demographic unit is assumed to remain constant at 1990 levels, the IHAT projection for 2100 is over 40% higher than the IPAT projection; in the case where emissions per demographic unit are projected to increase over time, the IHAT projection is over 80% higher.

We conclude that decomposition and projection exercises are very sensitive to the unit of account chosen. Should the unit of analysis be the individual, the household, the community, or what? Until more is known about the nature of the many activities which give rise to environmental impacts -- specifically, the role of economies of scale -- it is unwise to draw far-reaching conclusions from one specific choice of model without a substantive justification of that choice.

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INTRODUCTION

The controversy over whether rapid population growth in the South or high consumption in the North is to blame for anticipated future changes in world climate is almost invariably framed in terms of the simple identity I=PAT. Environmental impact (I) is seen as the product of the three factors population (P), affluence (A) which is measured by GNP/person, and technological efficiency (T) which may be captured by impact per unit of GNP. This identity is useful and suggestive as a first approach to the issue, because it demonstrates that environmental impact is due, not to one factor alone, but to a combination of several factors. However, IPAT has serious limitations if taken as a basis for more rigorous scientific analysis.

The problems with choosing IPAT as the basis for analysis can be grouped into two broad categories: (1) questions related to the choice of variables, and (2) the omission of interactions between the variables:

(1) 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 IPAT the choice is much less self-evident. If the impact to be studied is, say, CO_2 emissions, why should the emitting unit be the individual rather than the engine or fireplace that is ultimately responsible, or, as we will develop in the following paper, the household that operates the emitting units? The choice of factors requires substantive justification and may not be taken for granted.

(2) IPAT cannot really contribute much to the resolution of the population versus consumption debate because the differences of opinion mostly concern the interactions between the P, A and T factors. The Malthusian view argues that population growth diminishes affluence and thereby impedes technical progress, while the Boserupian view argues that population growth enhances technology and thereby increases affluence, while the modernization argument stresses that increasing affluence and technical progress combine to reduce the rate of population growth. Analysis along the simple IPAT approach can do nothing to resolve these controversies empirically, because the controversial relationships are not explicit in the equation.

The following paper concerns itself with the first problem, specifically, with the accounting implications of the fact that IPAT selects the individual as the demographic unit. We illustrate the consequences of considering households (H) instead of individuals as the consuming unit (i.e., IHAT instead of IPAT). 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. For goods whose consumption is tied more closely to the household than the individual, the size and rate of growth of population is of less concern than the number and rate of growth of households.

The organization of the paper is as follows. In the next section, trends in the rate of growth of households are compared to trends in the rate of growth of population and the roles of changing age-specific household headship rates and changing population age structures are discussed. In the third section, an illustrative simulation is presented in which growth in world energy demand from 1970 to 1990 is decomposed using the IPAT and IHAT identities. Because of the rapid growth over this period in the number of households in developed countries, the IPAT and IHAT identities result in very different allocations of responsibility between demographic and economic factors, on the one hand, and between the North and the South. The IPAT and IHAT models are then used to calculate substantially different projections of CO_2 emissions from 1990-2100. The fundamental point of both simulation exercises is that the entire decomposition approach is rather arbitrary, 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 headship rate, which is defined as the number of persons in the population who are heads of household divided by the population, expressed as a rate per 1000. Age-specific 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. The average headship rate can therefore be expressed as a weighted average of age-specific headship rates, the weights being the proportion of the population in each age group. The observed patterns of average household size and average headship rates result from a combination of these two effects.

Between 1950 and 1990, average household size in presently developed countries underwent a decline which, in proportional terms, can fairly be termed massive: from 3.6 to 2.7 (see Table 1 for regional trends and the Statistical Note for a description of estimation procedures followed). This decline was due more-or-less equally to changes in population age structure (mostly ageing) and to increases in age-specific 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 consequent increase in mean age at marriage), and the growing tendency of the aged to live on their own rather than with their children.

Table 1. Changes in household size from 1950 to 1990.

	Average household size		Changes due to:	
	1950	1990	Age distribution	Age-specific headship rates
North Africa	5.0	5.7	0.1	0.6
Sub-Saharan Africa	4.6	5.1	0.3	0.2
North America	3.5	2.6	-0.3	-0.6
Central America	4.6	4.9	-0.1	0.4
South America	5.0	4.4	-0.5	-0.1
West & Central Asia	5.0	5.1	-0.1	0.2
South Asia	5.0	5.7	0.0	0.7
China & Hong Kong	5.0	4.1	-0.2	-0.7
Southeast Asia	5.2	4.8	-0.3	-0.1
Japan & Australia & New Zealand	4.7	3.0	-1.1	-0.6
East Europe	3.7	2.9	-0.6	-0.2
West Europe	3.5	2.6	-0.3	-0.6
World	4.5	4.1	-0.1	-0.2
More Developed Countries	3.6	2.7	-0.5	-0.4
Less Developed Countries	5.0	4.8	0.0	-0.2

In presently developing countries, by contrast, average 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 developing regions *increased* significantly.[1] The increase was most pronounced in South Asia, where reductions in age-specific headship rates caused average household size to rise from 5.0 to 5.7. Even in South America, where average household size declined from 5.0 to 4.4, the decline was accounted for almost entirely by age-structure effects; age-specific headship rates remained practically constant.

Further information can be gained by dividing the post-war period in two and comparing changes in 1950-70 with changes in 1970-90 (see Table 2). During the first twenty years, in industrialized countries, increases in age-specific headship rates were the most important source of change, with age-structure changes playing a secondary role. The situation was reversed during the last twenty years: population ageing was the driving force, and changes in age-specific headship rates were relatively unimportant. In developing countries, a similar reversal is observed. In 1950-70, age-specific headship rates actually increased significantly, but age-structure effects (i.e., the young population age structure associated with mortality decline and unchanged fertility levels) favored large households. In 1970-90, by contrast, fertility decline started to work its way through the age structure in most regions, leading to an increase in the share of young adults in the population and consequent decline in average household size. Age-specific headship rates declined marginally, except in North Africa and Central America.

What does the future hold? Research on the decline of the extended family in presently developed countries has identified three basic themes, one demographic, one sociological and one economic.[2] The demographic view (Kuznets 1978) emphasizes that residence in an extended household unit must necessarily decline along with fertility for a simple demographic reason: there are fewer kin (including siblings) to live with. The sociological view argues that there has been an exogenous shift in tastes towards privacy (Beresford and Rivlin 1966). The economic view (Smith et al. 1984; Santi 1990; Skaburskis 1994) concentrates on factors such as income and the price of housing. Bumpass (1990) and many others have synthesized the three views to argue convincingly that no end is in sight to the shift towards more atomized living arrangements in industrial countries. The data in Table 2 indicate that increases in age-specific headship rates contributed only -0.1 to the change in average household size in developed countries in 1970-90, as opposed to -0.3 in 1950-70. However, future declines in the proportion of the population aged under 15 and increases in the proportion aged 60 and over suggest that, even barring future individuation, average household size will continue to decline.

Research on household structure in presently developing countries is somewhat limited by data availability. Foster (1993, pp. 104-105) finds that household structure in Bangladesh has been surprisingly resistant to change, and cites consistent research results from elsewhere in South Asia. It might be argued, first, that the period covered by Foster (eight years) is insufficient for much change to occur, and second, that Bangladesh is a stagnating economy. Over 12 years of extraordinarily dynamic economic growth in Taiwan (1973-85), Weinstein et al. (1990) found that the proportion of couples living in nuclear households increased from 43% to 56%, leading the authors to have it both

[1] 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 little indication of the long-term trend since 1950.

[2] 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).

ways: they note the "gradual erosion of norms" sanctioning co-residence, but at the same time emphasize that nearly half of Taiwanese couples in 1985 were still living in extended units.

Table 2. Changes in household size from 1950 to 1970 and from 1970 to 1990.

	Average household size		Changes due to:	
	1950	1970	Age distribution	Age-specific headship rates
North Africa	5.0	5.3	0.3	0.0
Sub-Saharan Africa	4.6	4.9	0.2	0.1
North America	3.5	3.1	0.2	-0.6
Central America	4.6	4.9	0.5	-0.2
South America	5.0	5.0	0.1	-0.1
West & Central Asia	5.0	5.3	0.2	0.1
South Asia	5.0	5.6	0.2	0.4
China & Hong Kong	5.0	4.7	0.7	-1.0
Southeast Asia	5.2	5.3	0.3	-0.2
Japan & Australia & New Zealand	4.7	3.6	-0.7	-0.4
East Europe	3.7	3.3	-0.3	-0.1
West Europe	3.5	3.1	-0.1	-0.3
World	4.5	4.4	0.2	-0.3
More Developed Countries	3.6	3.2	-0.1	-0.3
Less Developed Countries	5.0	5.1	0.4	-0.3

	Average household size		Changes due to:	
	1970	1990	Age distribution	Age-specific headship rates
North Africa	5.3	5.7	-0.2	0.6
Sub-Saharan Africa	4.9	5.1	0.1	0.1
North America	3.1	2.6	-0.5	0.0
Central America	4.9	4.9	-0.6	0.6
South America	5.0	4.4	-0.6	0.0
West & Central Asia	5.3	5.1	-0.3	0.1
South Asia	5.6	5.7	-0.2	0.3
China & Hong Kong	4.7	4.1	-0.9	0.3
Southeast Asia	5.3	4.8	-0.6	0.1
Japan & Australia & New Zealand	3.6	3.0	-0.4	-0.2
East Europe	3.3	2.9	-0.4	0.0
West Europe	3.1	2.6	-0.2	-0.3
World	4.4	4.1	-0.3	0.0
More Developed Countries	3.2	2.7	-0.4	-0.1
Less Developed Countries	5.1	4.8	-0.4	0.1

Goode (1963) proposed that the decline of the traditional extended family was an inevitable accompaniment of industrialization and what is indelicately termed "modernization." This gives rise to a "stages of development" interpretation according to which age-specific headship rates 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 the extended households provide insurance against risk (on the downside) which is no longer necessary once income is tolerably above the subsistence level. On the other hand, "stages of development" models have been criticized by many for lacking rigorous micro-level foundations and for postulating a rigid relationship between per person income and various social indices. For example, Yi et al. (1994) found that the mean age of leaving the parental home was about 3 years higher for young adults in China, Japan and South Korea than in the U.S., France and Sweden. Japan is, of course, not a developing country, which 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. Moreover, differences between the U.S. and the two European countries were fairly substantial.

For purposes of forecasting the course of average household size in developing countries, an understanding of the causal mechanisms behind the long-term decline in age-specific headship rates is less important than might be thought. A comparison of estimated age-specific headship rates by region in about 1980 reveals a striking fact: differences between ages 40 and 65 are almost negligible (see Table 3). Under age 40 and over age 65, headship rates in developing countries are naturally lower because of the greater force of the extended family. However, if age-specific rates are applied to the 1990 population in developed countries to calculate an age-standardized headship rate, a striking fact emerges: the age-standardized rate in developed countries, 367 (average household size of 2.7) is only about 10% higher than the age-standardized headship rate in developing countries, 329 (average household size of 3.0).

It would thus seem that future changes in population age structure in developing countries will have a greater impact on average household size than will changes in age-specific headship rates. In other words, compositional effects are likely to be more important than the less certain (and more controversial) behavioral changes in family formation and living arrangements which may arise in the context of "modernization." The age-structure changes which have been mentioned above in the case of presently developed regions -- decline in the proportion at young ages, increase in the proportion who are elderly -- will be more extreme for presently developing countries because of the speed of fertility decline. Thus, even with no changes in age-specific headship rates, it is likely that average household size in presently developing regions will decline substantially.

Table 4 presents the results of four projections of average household size. "Central," "Low" and "High" Scenarios correspond to IIASA population scenarios[3]; age-specific headship rates are assumed to remain constant at 1990 levels (see Table 3), 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 average developed-region age-specific headship rates for 1990 to the Central Scenario population projection for developing regions; thus, differences in the outlook for developing regions in the Central and Modified Central Scenarios are due entirely to differences in age-specific headship rates.[4]

[3] 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 detail in Lutz (1994).

[4] Making an explicit assumption on how rapidly age-specific headship rates in developing regions converge on the developed-region average would be an obvious refinement, but makes little difference in results.

Table 3. Headship rates by age and region. These headship rates have been estimated by aggregation, analysis and comparison of available country headship rates. Year of reference varies from country to country. Source: UN 1987.

	[0-14]	[15-19]	[20-24]	[25-29]	[30-34]	[35-39]	[40-44]	[45-49]	[50-54]	[55-59]	[60-64]	[65-69]	[70-74]	[75+]
N. Africa	0.2	2.2	12.0	28.0	37.0	45.0	49.0	54.0	56.0	58.0	58.5	57.0	55.0	53.0
S.S. Africa	0.4	4.4	20.3	38.5	45.6	49.6	53.0	56.9	59.3	62.4	63.8	64.0	61.8	59.6
N. America	0.0	2.3	24.6	45.7	52.4	55.8	55.7	56.2	56.3	58.6	58.8	65.0	65.2	69.9
C. America	0.0	1.4	12.0	30.3	39.1	46.4	50.7	53.8	55.9	57.7	59.0	59.9	60.5	57.6
S. America	0.0	1.4	14.9	32.6	40.9	47.0	50.9	53.7	55.5	57.4	57.9	58.1	57.0	50.5
W&C Asia	0.0	1.5	11.0	28.0	37.0	45.0	49.0	53.0	56.0	57.0	58.0	58.5	56.0	53.0
S. Asia	0.2	1.9	9.2	22.3	33.1	42.2	46.8	52.3	54.1	56.1	55.9	54.8	53.4	50.9
China&HK	0.0	1.1	11.0	29.0	40.9	47.0	50.9	53.7	55.5	57.4	57.0	54.0	49.0	42.0
S.E. Asia	0.0	1.1	11.2	29.4	41.8	48.0	52.2	54.8	58.1	59.6	58.4	55.5	50.6	43.7
Jap& Aus&N	0.0	7.4	27.0	33.0	40.8	46.5	49.5	52.4	54.2	52.6	51.9	50.4	45.1	32.7
E. Europe	0.0	2.6	18.0	39.1	47.6	50.7	52.8	54.3	55.8	57.5	59.5	60.6	59.5	56.1
W. Europe	0.0	1.2	14.8	37.8	46.7	49.6	50.8	51.9	53.7	55.9	58.0	61.1	63.2	60.8
World	0.1	2.0	13.2	30.8	41.1	47.2	50.6	53.7	55.6	57.3	57.7	57.7	55.8	53.6
Less Dev. C.	0.1	1.8	11.8	28.4	39.0	45.9	50.0	53.7	55.9	57.7	57.6	56.0	52.8	47.9
More Dev C.	0.0	2.8	19.6	39.7	47.9	51.2	52.4	53.7	55.0	56.5	57.9	60.6	60.5	58.8

Table 4. Average household size, 1990, 2030 and 2100.

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

Based on changes in the age structure alone, average household size in presently developed countries is likely to decline moderately. 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 over), does it increase, and this only marginally, from its current 2.7 to 2.8. Average household size in presently developing countries, by contrast, is projected to decline significantly under all three scenarios. Thus, on the assumption that age-specific headship rates remain constant, the age-structure changes in the IIASA population projections imply that, by the end of the next century, average household size in developed and developing 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 will reflect essentially declines in average household size in developing regions, with average household size in developed regions remaining relatively constant.

The effect of imposing average developed-region age-specific headship rates on developing regions is significant in the medium-term -- in 2030 the Modified Central Scenario envisions average household size of 3.3 in developing 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 which matters the most.

Between 1950 and 1990, population in developing regions grew at an average rate of 2.2% and the number of households at 2.3%; in developed regions, the corresponding rates of growth were 0.9% and 1.6% per year. Thus, whereas the "demographic growth gap" was 1.3% per year in terms of population, it was a much narrower 0.7% in terms of households. In the future, according to the projection results in Table 4, the gap will be broader, not narrower, for households than for population. In the Central Scenario, population in developed regions is projected to grow at an average rate of 0.3% per year between 1990 and 2100, and households at a roughly equal rate of 0.4% per year. In developing regions, the corresponding growth rates are 0.9% per year and 1.4% per year, respectively. Thus the "demographic growth gap" of 0.6% per year in terms of population is projected to be a much wider 1.0% per year in terms of households. If age-specific headship rates decline in developing regions, as for example in the Modified Central Scenario, the differences will be even more dramatic.

IPAT or IHAT?

Despite the limitations indicated in the introduction, the IPAT identity has become the model of choice, or at least the model of first resort, in decomposing change in global environmental impacts into changes due to population growth and changes due to per person income growth.[5] In this section, we illustrate differences which arise when the household, as opposed to the individual, is chosen as the demographic unit of account.

Let

$P(t)$	=	Population at time t
$y(t)$	=	Gross Domestic Product (GDP) per person
$I(t)$	=	Impact (resources utilized or pollution generated)
$\alpha(t)$	=	$I(t)/Y(t)$, impact *per* unit GDP

[5] The large literature on the IPAT model is reviewed by MacKellar (1995), who concludes that the *ceteris paribus* assumptions which underlie the model are "simply massive." Harrison (1992) is a good example of the sort of decomposition presented below and Shaw (1993) of the sharp criticisms which have been levelled at such exercises.

all at time t. Then

$$I(t) = P(t)\ y(t)\ \alpha(t)$$

The IPAT identity can be converted into an "IHAT" -- Impact-Households-Affluence-Technology -- identity simply by substituting households H(t) for population and measuring affluence in terms of income per household, which we will denote x(t):

$$I(t) = H(t)\ x(t)\ \alpha(t)$$

Each of the two alternative identities is no more valid than the assumption which underlies it: either impacts are considered as arising at the level of the household or at the level of the individual; there is no in-between assumption. The IPAT and IHAT models are entirely different; comparing them is like comparing apples and oranges! Or, to quote the immortal American expression, you pays your money and you takes your choice.

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

$$G_C = G_P + G_y + G_\alpha$$

and the IHAT model is

$$G_C = G_H + G_x + G_\alpha$$

An Example: Growth in Energy Consumption, 1970-90

Tables 5, 6 and 7 display population and household, GDP and energy consumption data which permit IPAT / IHAT decompositions of growth in world energy consumption in developed and developing countries over the period 1970-90; results are reported in Table 8. In the latter table, increase in energy demand accounted for by the rise in per person income and by the change in "technology" -- the ratio of energy to GDP -- are bracketed. This reflects the theme, developed by many researchers (Gilland 1986 for energy; MacKellar and Horlacher 1994a and 1994b for references from the energy literature; World Bank 1992a for references to concerning pollutants; Preston 1994 for pollutants; Cropper and Griffiths 1994 for deforestation) that environmental impact *per* unit of GDP varies predictably with per person (or per household) income. The assumption that change in technology is accounted for entirely by changes in the level of income is not strictly necessary to make the points which follow, but it does simplify matters by reducing the three-way IPAT decomposition to a two-way one. If the reader prefers to consider the bracketed term to be "economic growth plus unexplained shifts in technology," he or she will lose nothing.

According to the IPAT identity (see Table 8), roughly half of growth in energy consumption in both developing and developed countries over this period was accounted for by demographic growth -- 43.1% in the first case, 50.0% in the latter. Shifting to an IHAT framework does not drastically alter the decomposition for developing regions, but it completely changes the picture for developed countries. Now, the rate of growth of impacts is entirely accounted for; indeed, more than accounted for, by the rate of growth in the number of households. In Table 9, the same decomposition is done in terms of absolute annual change in energy consumption, which allows blame to be shared out among developed and developing regions without worrying about the level of disaggregation at which the decomposition is done (Lutz et al. 1993). The IPAT identity assigns 18.2% of the annual increase to developed-country demographic increase; the IHAT identity assigns 41.5%.

Table 5. Population and households, 1970 and 1990. Source: Authors' estimates based on World Bank 1993 (population) and headship rate estimates discussed in text. Age-standardized rates calculated on basis of 1990 developed country population.

	1970	1990
Developing countries		
Persons (millions)	2,929	4,528
Average annual % change		2.2
Crude headship rate (per 1000)	196	208
Age-standardized headship rate (per 1000)		329
Households (millions)	574	943
Average annual % change		2.5
Persons per household	5.1	4.8
Developed countries		
Persons (millions)	711	822
Average annual % change		0.7
Crude headship rate (per 1000)	312	367
Age-standardized headship rate (per 1000)		367
Households (millions)	222	304
Average annual % change		1.6
Persons per household	3.2	2.7

Table 6. Gross national income, 1970 and 1990. Source: Authors' estimates based on World Bank 1992b.

	1970	1990
Developing countries		
Total (millions 1987 US $)	1,347,340	3,214,880
Average annual % change		4.4
Per person (1987 US $)	460	710
Average annual % change		2.2
Per household (1987 US $)	2,347	3,409
Average annual % change		1.9
Developed countries		
Total (million 1987 US $)	7,927,650	14,072,640
Average annual % change		2.9
Per person (1987 US$)	11,150	17,120
Average annual % change		2.2
Per household (1987 US$)	35,710	46,292
Average annual % change		1.3

Table 7. Commercial energy consumption, 1970 and 1990. Source: Authors' estimates based on World Bank 1993.

	1970	1990
Developing countries		
Total (million kcal oil equivalent)	1,060,298	2,857,168
Average annual % change		5.1
Per person (kcal oil equivalent)	362	631
Average annual % change		2.8
Per household (kcal oil equivalent)	1,847	3,030
Average annual % change		2.5
Per unit GDP	0.787	0.889
Developed countries		
Total (million kcal oil equivalent)	3,173,193	4,197,132
Average annual % change		1.4
Per person (kcal oil equivalent)	4,463	5,106
Average annual % change		0.7
Per household (kcal oil equivalent)	14,294	13,806
Average annual % change		-0.2
Per unit GDP	0.400	0.298

Table 8. Sources of growth in energy consumption, 1970-1990: IPAT versus IHAT Model, growth rate form.

IPAT Model

	Growth rate of energy consumption (% per year)	Due to growth of population	Due to growth of income per person	Due to change in technology
Developing	5.1	2.2	2.2	0.7
		(43.1%)	(56.9%)	
Developed	1.4	0.7	2.2	-1.5
		(50.0%)	(50.0%)	

IHAT Model

	Growth rate of energy consumption (% per year)	Due to growth of number of households	Due to growth in income per household	Due to change in technology
Developing	5.1	2.5	1.9	0.7
		(49.0%)	(51.0%)	
Developed	1.4	1.6	1.3	-1.5
		(114.3%)	(-14.3%)	

Table 9. Average annual change in energy consumption, 1970-1990 (million kcal oil equivalent).

	IPAT Model		
	Due to growth in population	Other	Total
Developing countries	38,756 (27.5%)	51,087 (36.2%)	89,843 (63.7%)
Developed countries	25,599 (18.2%)	25,599 (18.2%)	51,198 (36.4%)
Total	64,355 (45.6%)	76,686 (54.4%)	141,041 (100.0%)

	IHAT Model		
	Due to growth in number of households	Other	Total
Developing countries	46,143 (32.7%)	43,700 (31.0%)	89,843 (63.7%)
Developed countries	58,511 (41.5%)	-7,315 (-5.2%)	51,197 (36.3%)
Total	104,654 (74.2%)	36,385 (25.8%)	141,040 (100.0%)

Table 10. The IHAT Model again: Population growth, changing age structure, and changing age-specific headship rates.

	IHAT Model				
	Growth rate of energy consumption (% per year)	Due to growth of population	Due to change in age structure	Due to change in age-specific headship rates	Other
Developing	5.1	2.2 (43.1%)	0.4 (7.8%)	-0.1 (-2.0%)	2.6 (51.0%)
Developed	1.4	0.7 (50.0%)	0.7 (50.0%)	0.2 (14.3%)	-0.2 (-14.3%)

Based on such estimates, an argument could be constructed that Western behavioral patterns, in the form of a tendency towards increasingly atomized living arrangements, bear a heavy burden of blame for rising energy consumption. This would be premature, however, as the story is not over. Recall from the discussion above the impact of shifts in population age structure. In Table 10, we expand the IHAT decomposition to show the growth in the number of households which would have occurred holding age-structure constant (that portion which reflects behavioral change) and the growth which resulted from shifts in age-structure (holding age-specific headship rates constant). In the case of developed countries, half the contribution of demographic effects arose from the rate of population growth and half from changes in age distribution. A striking fact which emerges in the IHAT framework is that the fertility decline which brings about deceleration in the rate of overall population growth, presumably relieving pressure on the environment, contributes to population ageing and the consequent rise in the proportion of the population in age groups characterized by high age-specific headship rates. Fertility decline will, of course, reduce the number of households twenty or thirty 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 might be imagined.

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 11 presents the results of the following 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. The third is that per person emissions grow 1.0% per year in developing countries and 0.4% per year in developed countries; this is the central scenario elaborated by the Inter-governmental Panel on Climate Change (Houghton et al. 1992). The fourth is that per household emissions grow 1.0% per year in developing countries and 0.4% in developed countries. These four assumed emissions paths were then combined with the IIASA population projection and the Central household projection presented in Table 4 to calculate total global CO_2 emissions. As shown in Table 11, projections vary widely depending on which model is chosen. If the IPAT model is selected and emissions are assumed to remain constant in per person terms, an increase of 88% is projected between 1990 and 2100. If, by contrast, the IHAT model is selected and emissions are assumed to remain constant in per household terms, the projected increase is 167%, almost exactly double. If the IPAT model is selected and emissions are assumed to grow in per person terms, a quadrupling of emissions is projected; if the IHAT model is selected and emissions are assumed to grow at the same rate, but in per household terms, an increase of over six-fold is projected.

Table 11. Projected growth in total CO_2 emissions, 1990-2100.

	Average annual % change, by region, 1990-2100		Total emissions, 2100 (1990 : 100)
	LDC	MDC	
IPAT Model			
Constant per person emissions	0.9	0.4	188
Growing per person emissions	1.9	0.7	399
IHAT Model			
Constant per household emissions	1.4	0.4	267
Growing per household emissions	2.4	0.7	624

The IPAT and IHAT models represent extreme positions, the first assuming no household-level economies of scale whatsoever in the activities which generate CO_2, and the second assuming perfect economies of scale. Presumably, the truth lies somewhere in between, meaning that, under the constant emissions assumption, an increase in total emissions of somewhere between 88% and 167% would be expected and, under the growing emissions assumption, an increase between four- and six-fold would be expected. These substantial ranges of variation can be narrowed down only by research into the importance of household-level economies of scale in the activities which emit CO_2.

CONCLUSION

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

Decomposition exercises which seek to assign blame for environmental impacts, as well as forecasts of impacts such as CO_2 emissions, 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 which give rise to environmental impacts, the answer will not be clear. In the future, it might be possible to employ a model such as $I = C + aPAT + bHAT$, 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 to impacts which 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 and the kinds of agents that produce it.

Meanwhile, it would be very 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

Average household size for each of the twelve 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 will vary from year to year and from region to region. The data appear sufficient, however, to estimate overall trends fairly accurately.

Age-specific headship rates for each of the twelve regions for around 1985 were also estimated on the basis of country-specific age-specific headship rates. In this case, the data were taken from the 1987 *Demographic Yearbook*. Again, available data are incomplete. Since Table 3 reveals only slight differences between regions, however, the regional estimates are likely to be fairly accurate.

Disaggregation of household-size changes between 1950 and 1990 was done the following way: in a first step, age- and region-specific headship rates in around 1985 (estimated as described above) were assumed to remain constant over time throughout the period 1950-1990. 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 headship rates are calculated as a residual; they are just the difference between the household size estimates assuming constant headship rates and the average household size estimated on the basis of data in the 1991 *Demographic Yearbook*.

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