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Another Look at Population and Global Warming

Nancy Birdsall

There is little basis for the view that the South could contribute to major reductions in global warming by taking new and stronger steps to reduce its population. But cost analysis suggests that it makes sense for developed countries *in their own interests* to spend money to reduce rates of population growth in developing countries as part of any optimal carbon reduction strategy.

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Birdsall addresses two questions: First, how much could feasible reductions in projected rates of population growth in the developing countries help reduce greenhouse gas emissions? Second, how much would it cost to ensure such reductions in population growth, compared with other options for reducing emissions?

The answer to the first question is that reductions in population growth would matter, but not much. Based on current econometric estimates linking population growth to deforestation, feasible reductions in population growth could reduce emissions from deforestation (relative to what they otherwise would be) by 8 percent over the next 35 years. Feasible reductions in population growth rates could reduce fossil fuel emissions by about 10 percent. The percentage reductions, though substantial, are small relative to projections of a tripling or more in emissions under any baseline scenario in the next 50 years.

Thus there is little basis for the view that the South could contribute to major reductions in global warming by taking new and stronger steps to reduce its population.

The answer to the second question is that reducing population growth is cost-effective compared with other options to reduce emissions. Birdsall estimates the costs of reducing carbon emissions by reducing births through increased spending on family planning at between $6 and $12 per ton; and by educating girls at between $4 and $8 per ton. These compare to a marginal cost of $20 per ton to reduce current emissions by 10 percent, using a carbon tax. Discounting reduces the cost advantage of the population reduction strategies over the tax, but does not eliminate them as a critical part of an overall global strategy to reduce emissions.

The implication of the cost analysis is simple: The global negative externality represented by rapid population growth in developing countries provides a strong, new rationale for developed countries, in their own interests, to finance programs that would reduce population growth in developing countries. This is true even though feasible reductions in population growth would represent only a modest contribution to reducing greenhouse gas emissions. Spending to reduce rates of population growth in developing countries makes sense as part of any optimal carbon reduction strategy.

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Comments welcome

ANOTHER LOOK AT POPULATION AND GLOBAL WARMING

Nancy Birdsall*

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Table of Contents

Introduction and Summary

There is considerable popular concern that world population growth is a critical contributor to the emissions of greenhouse gases and thus to the potential for global warming. The accumulated stock of greenhouse gases now in the atmosphere is almost wholly the responsibility of developed countries, where increases in emissions have been associated largely with industrialization and income growth, and not with population growth, which has been low in the last few decades. However, annual flows of emissions are increasing more slowly now in the developed countries, whereas in developing countries annual flows are increasing rapidly and are likely to continue to increase at a rapid rate, due to the combination of expected per capita income growth with continuing high rates of population growth.

This paper addresses two questions: First, how much could feasible reductions in projected rates of population growth in the developing countries contribute to reductions in greenhouse gas emissions? Second, what would be the cost of ensuring such reductions in population growth, relative to the cost of other options for reducing emissions?

The answer to the first question is that reductions in population growth would matter -- but could not be key to achieving a levelling off of emissions, let alone a reduction in them. Feasible reductions in population growth rates could reduce fossil fuel emissions by about 10 percent by the year 2050. Based on econometric estimates linking population growth to deforestation, feasible reductions in population growth could reduce emissions from deforestation (relative to what they otherwise would be) by about 6 percent over the next 35 years. The percentage reductions, though substantial, are small relative to projections of a tripling of emissions in the next 50 years under any baseline scenario.

This conclusion will appear surprising in the light of analyses such as Bongaarts (1992), who concludes: "The role of population growth as a determinant of the projected rise in CO_2 emissions appears to be substantial. It accounts for 35 percent of the global increase and for 48 percent of the growth in LDCs between 1985 and 2100." (pp. 11-12) However, the apparent difference lies only in the starting point. Bongaarts estimates the amount of future emissions to be accounted for by all of projected future population growth. The question in this paper is not what difference elimination of all future population growth would make, but what difference feasible reductions from current projections of population growth would make.[1]

There is, therefore, only a limited basis for adding the specter of global warming to the arguments in favor of reducing rapid population growth rates in developing countries[2], and there is little basis for the view that the south could contribute to major reductions in global warming by taking new and stronger steps to reduce its population growth.

The second question, regarding costs, arises for the following reason. The effects of more people on global greenhouse gas emissions are probably the most obvious example of a case where rapid population growth in developing countries may represent a negative externality at the global level, that is rapid population growth in one country or set of countries may impose costs on other countries beyond any costs it imposes on the countries where it is occurring. This externality could provide a new and important rationale for developed countries, in their own interests, to finance programs that might reduce population growth in developing countries -- independent of such traditional rationales as improving the welfare of the poor in developing countries, or improving the likelihood of more rapid economic growth in developing countries so as to ensure for developed

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[1] As explained below, zero population growth in developing countries is not demographically possible for at least 50 years, even were fertility to fall immediately to replacement level (itself also a virtual impossibility).

[2] There are in any event other more compelling reasons for concern with rapid population growth in developing countries, in particular the likelihood that high fertility among the poor deepens and prolongs the battle against poverty, and the possibility that rapid population growth, particularly in poor countries, exacerbates local environmental problems.

countries more stable and reliable trading partners. Such financing makes sense if programs to reduce population growth are cost-effective in terms of the specific goal of reduced global emissions, compared with alternative approaches to reducing such emissions over the next 50 to 100 years.[3]

Estimates of the costs of reducing emissions through lower population growth come from evidence on the effects of educating girls on their subsequent fertility, and on the effects of family planning services on fertility. These estimates -- in the range of $3 to $11 per ton of reduced carbon emissions -- suggest that the costs are well worth the benefits. This is so even though the benefits are relatively small, simply because the cost of comparable reductions in emissions via, for example, carbon taxes, is higher.

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In Section 1, the two mechanisms through which population growth in developing countries contributes to greenhouse gas emissions, namely fossil fuel emissions and deforestation, are set out. Available information is summarized on the flow of emissions and on the accumulated stock of emissions, distinguishing between developing and developed countries. In Section 2, the effects of feasible lower rates of population growth in reducing fossil fuel emissions and deforestation are estimated. For fossil fuel emissions, a reference or "business-as-usual" path of emissions is compared to a path of emissions based on lower rates of population growth in developing countries, using alternative World Bank population projections. An estimate of the effects of the alternative projections of reduced population growth on reduced deforestation is also presented, based on estimated elasticities from selected within-country studies. In Section 3, estimates of the cost of

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[3] Whether such expenditures are cost-effective for reducing emissions or not, there would obviously continue to be other rationales for financing population programs. Insofar as such programs improve welfare in developing countries at low cost, local as well as international financing is obviously justified. Birdsall and Griffin, 1991, make the point that irrespective of the motive for financing population programs, the content of such programs must be welfare-enhancing for the poor in developing countries, if the programs are to be effective in reducing fertility.

reducing emissions are presented and compared to the likely costs of reducing emissions through spending on family planning and on educating girls. A concluding section summarizes the findings.

Section 1. Population Growth and Greenhouse Gas Emissions in Developing Countries

There are two principal mechanisms by which population growth in developing countries contributes to the potential for global warming. The first is through the effect of a larger population at a given per capita income on fossil fuel emissions, as a result of increased demand for energy for power, industry, and transport. I refer here to a simple arithmetic effect of more people, holding constant per capita income. (It is possible of course that population growth affects per capita income; recent cross-country analysis indicates that higher population growth is associated with lower per capita income growth in the 1980-85 period, with a greater negative relation for low-income countries.[4] But for simplicity and given that the effect of higher per capita income on per capita emissions itself varies by income level, as will be seen below, this complication is ignored in the computations below.[5])

The second mechanism by which rapid population growth may contribute to greenhouse gas emissions is through whatever effect such growth has on deforestation with its associated emissions of carbon. The empirical evidence on how population growth in developing countries affects deforestation, either independently or by interacting with and exacerbating the effects of poverty, poor land security, and poor government policies, is available only for a few settings over a few time

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[4] Brander and Dowrick (1991); Bloom and Freeman (1987). The negative relation is not found in earlier (postwar) periods, probably because per capita income growth was associated with rapid mortality decline as well as rapid fertility decline. With overall mortality levels relatively low now in most countries, the negative relationship between income growth and population growth may now more closely reflect a negative relationship of income growth to fertility.

[5] Despite the evidence for a simple bivariate negative association, the literature on the effects of rapid population growth on economic growth and development remains controversial. For extensive reviews, see Birdsall 1988; Birdsall, 1989; Kelley, 1988; Simon, 1989; National Research Council, 1987.

periods, and can only be aggregated at the level of developing countries as a group using strong and rather crude assumptions.[6] The attempt set out below should be regarded as a first effort, done primarily to provide some basis for comparing the potential benefits of reduced population growth via reduction of fossil fuel emission vs. reductions in the rate of deforestation.

Table 1 shows shares of population, GDP and estimated shares in annual flows of carbon emissions for various groups of countries in 1988.[7] The current share of developing countries in annual flows of fossil-fuel based carbon emissions is about 20 percent,[8] and in carbon emissions due to deforestation is about 95 percent. Fossil fuel burning to meet increased energy demand accounts for almost 80 percent of carbon emissions[9]; because deforestation contributes much less to total emissions than fossil fuel emissions, the combined total share of developing countries in annual emission flows is low despite the deforestation phenomenon, about 33 percent. With only about 15 percent of total world population, the developed countries (excluding the Soviet Union and Eastern

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[6] For a recent review of the effects of population pressure on deforestation, including case studies in four developing countries, see Cruz, 1991.

[7] Most available data and projections of emissions deal with carbon only, and so the discussion in Section 2 is based on carbon emissions only. Carbon emissions comprise about 50 percent of current emissions of all greenhouse gases, and this percent is likely to increase as emissions of CFCs are controlled. Ogawa, 1991, cites EPA data in stating that CO_2 is estimated to have been responsible for 66 percent of the incremental greenhouse effect between 1880 and 1980, and 49 percent during the 1980s.

[8] This is also the figure used by Ogawa (1991, Table 1). He estimated it on the basis of energy consumption data published by the International Energy Agency and British Petroleum Company.

[9] This number is based on total emissions of 5.9 billion tons from fossil fuels (Table 2) plus emissions of 1.6 billion tons from deforestation. The latter figure is based on unpublished estimates developed by Robert Schneider of the World Bank. He revised 1987 estimates of Houghton, published in Worldwatch Institute State of the World, using more recent 1989 estimates of Houghton on deforestation and adjusting Houghton's 1989 estimate to take into account 1990 data showing reduced deforestation rates in Brazil (a major contributor among all developing countries to emission from deforestation). See World Bank, 1991 (by Schneider) regarding the latest Brazil data.

Europe) account for more than 55 percent of annual flows of total carbon emissions,[10] with the remaining 12 percent accounted for by Eastern Europe and the Soviet Union. However, the share of developed countries in annual flows has declined since 1960, while the shares of the two other groups have increased (not shown).[11]

Table 2 shows annual flows of fossil-fuel based carbon emissions for selected countries in absolute and per capita amounts (1960 and 1988), and in amounts per dollar of GNP (1987). The country data show that the large overall share of the developed countries shown in Table 1 is due to higher GNP and higher per capita emissions. The reasons for the declining share of developed countries are apparent. First, per capita emissions are rising faster in developing countries, which is not surprising since the base is much lower. Second, population growth has been more rapid in developing countries (about 2 percent over the period compared with less than 1 percent in developed countries); even if per capita emissions had not changed in either group, absolute emissions would be rising faster in developing countries.

Third, as shown in Table 2 (last column), the "emissions-intensity" of GNP in the developed countries is lower than in developing countries. Emissions intensities have also been declining in developed countries. In 1987, fossil fuel carbon emissions were over 2,000 grams per dollar of GNP in China[12], 655 in India and 609 in Mexico, compared with 276 grams in the U.S., 223 in (West)

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[10] The computation is as follows: (.52), the share of developed countries in total flows of 5.9 billion tons due to fossil fuel emissions (see Table 2) plus (.05), the share of developed countries in total flows of 1.6 billion tons due to deforestation equals .553, the total share of developed countries in annual flows of total global carbon emissions.

[11] The share of fossil fuel emissions of the United States, greater Germany, United Kingdom, France, Japan, and Italy fell from 54 percent in 1960 to 39 percent in 1988 (Boden et al., 1990).

[12] Income per capita in China would be much higher (perhaps three times) compared to industrialized countries, and higher also compared to other developing countries, if estimated on the basis of purchasing power parity rather than using conventional exchange rates (which fail to take into account the lower costs of services and other nontradables in low-income countries). The appropriate correction would make China look much less profligate in emissions per dollar of GNP -

Germany and 156 in Japan. High emissions per dollar of GNP in developing countries is the result of a combination of factors. Developing countries are at an earlier stage of development, in which the shift from agriculture to industry implies increasing use of energy per unit of value added; in comparison the shift in developed countries from industry to services may imply decreasing use of energy. Within the envelope of energy used, developing countries have shifted less away from coal to cleaner but higher-cost fuels, because they are less able to incur the higher costs and are less concerned with local air pollution. Within the envelope of fuels used, developing countries are less likely to use new clean technologies to reduce emissions, given lower levels of resources and of new investments. Finally, developing countries are not as "efficient" in their use of energy as developed countries, i.e. they are more likely to be using more energy than is optimal from an allocative point of view, due to underpricing of energy itself and of capital in general, lack of competition among major users of energy due to trade barriers and the monopolistic protection that state enterprises enjoy, insufficient incentives at the firm level to invest in cleaner technologies and so on.[13]

What matters for potential global warming is the accumulated stock, not the annual flows, since greenhouse gases are retained in the atmosphere for long periods and current annual emissions contribute relatively little to that stock.[14] Over the last 30 years, the total contribution of the developing countries to fossil fuel carbon emissions is certainly lower than the 1988 estimated

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- particularly compared to India with its warmer climate -- though still at double the levels in the U.S.

[13] For a useful discussion of differences in fuel use and of the distortions that may lead to inefficiency in energy use in developing countries, including underpricing, lack of competition because of trade barriers and because many producers and users of energy are state enterprises, see Bates, 1991.

[14] Eckaus, 1991, points this out and notes that when stock matters and accumulates slowly, the conventional procedure of computing present discounted values to assess the significance of a future event makes little sense.

contribution of 20 percent, since emissions have been growing in absolute terms faster in developing than developed countries.

The implications are clear. Though the developing countries contribute and have contributed relatively little to emissions, especially given their larger share in world population, they are also the likely source of a substantial part of future growth in fossil fuel emissions, for the same reasons that have caused their share in total emissions to rise in the last several decades. Their per capita fossil fuel emissions are still low but are likely to rise with increasing income. Their emissions per dollar of GNP are relatively high; for various reasons noted above they are still on the steep portion of the curve that describes the relation between per capita income and emissions. (Lower emissions per dollar of GNP for developed countries suggests this curve rises at a declining rate, and may even fall above some level of income.) Finally, they have had and will continue to have higher rates of population growth.

Table 3 shows estimates of annual deforestation for the major countries in terms of absolute amounts of deforestation, and associated estimates of carbon emissions from two sources. (The differences in the two sources provide an indication of the state of understanding and of data.) As with fossil fuel emissions, it seems likely that emissions due to deforestation will increase for the next several decades in developing countries. However, the absolute contribution of deforestation to greenhouse gas emissions cannot increase indefinitely, simply because the forest base is being reduced, and thus the share of global emissions due to deforestation is likely to decline in the long run.

Section 2. Effects of Slower Population Growth on Fossil Fuel Emissions and on Deforestation

Fossil Fuel Emissions

To examine the effects of feasible reductions in population growth rates on reductions in fossil fuel emissions, I use alternative population projections of the World Bank. These are referred to below as the "standard" projections and the "rapid" projections, where the latter builds in more rapid fertility decline.[15]

Table 4 shows for all developing countries (including China, excluding Eastern Europe and the Soviet Union) the differences in population growth rates and in total fertility rates that underlie projected population growth under the two scenarios, and the resulting projections of total population. In the standard scenario (which is similar to the "medium" projections of the United Nations), the total fertility rate declines from 3.62 for the period 1995-2000 to 2.4 for the period 2025-2050.[16] Fertility declines to replacement level (a total fertility rate slightly above two) in most developing countries in the first decade or two of the next century; the transition to replacement level fertility is virtually complete in all developing countries by the year 2050.

In the rapid fertility decline (hereafter rapid) scenario, fertility decline begins in 1990 in all countries,[17] and declines more rapidly -- at a rate roughly equivalent to 90 percent of the rate of

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[15] The basis for these projections is explained in detail in Bos and Bulatao (1990) and in Bos (1991). The numbers used in this paper are based on preliminary projections (as of September, 1991). These may change slightly before they are published in 1992.

[16] The assumption is that in all countries where fertility is already declining it will continue to do so at the average rate experienced in the past for all developing countries (0.6 reduction in the total fertility rate every 5 years). In countries where fertility decline has not occurred, but where life expectancy exceeds 50, fertility decline is also assumed to start in 1990, initially at a somewhat slower pace than in the first set of countries. In countries where life expectancy is below 50, fertility does not decline until that point in the future when life expectancy is projected to reach 50; then decline follows the standard pattern.

[17] Fertility decline begins in 1990 in the "rapid" scenario even in countries where current life expectancy is below 50 years.

decline in a set of countries where fertility decline has been rapid in certain periods between 1950 and the present. (For example, declines in the total fertility rate of almost 0.2 per year have occurred over 10-year periods in Colombia, Singapore, Korea and Thailand.) In other words, the assumption is built in that all developing countries can achieve a rate of decline in fertility almost as rapid as that already achieved by a select group in the past.

In the standard scenario, the population of all developing countries is projected to grow from about 4 billion today (3.67 billion in 1985, the baseline year for the projections) to 10.6 billion in the year 2100, and to stabilize by the year 2150 at 11 billion. The increase of more than 6 billion between now and the year 2100 occurs despite the assumption built into these standard projections that fertility will continue to decline in all developing countries (in the case of those countries, largely in Africa, where no decline is yet discernible, the assumption is that fertility will begin to decline before the year 2000). Under the scenario of rapid fertility decline, the population of developing countries would still increase by almost 5 billion, going from 3.67 billion today to about 8.4 billion in the year 2100, and would stabilize at a projected 8.67 billion by the year 2150.

Even with rapid fertility decline, the increase alone in population size in developing countries over the next 100 years is expected to be substantial, exceeding in absolute terms current population size. In fact, the increases in population under both projection scenarios dwarf the differences between them; by the year 2100, the difference in projected total population size for developing countries between the two projections would be about 2.2 billion -- in absolute terms a large number, but a relatively small number compared to the 5 billion increase projected even with rapid fertility decline.

In Table 5, the percentage differences between the two projections are shown for selected countries and regions,[18] and the regions' corresponding shares of total population reductions. More

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[18] See the appendix table for the underlying population numbers by year and region.

than one-half of the total difference in the years 2050 and 2100 is accounted for by the projected difference in Sub-Saharan Africa. Almost all of the remaining difference is accounted for by the countries of North Africa and the Middle East. The difference between the two projections in the total population of China in 2150 is only 29 million -- about 1 percent of the total difference of more than 2 billion. The reason is clear: fertility rates in China are already relatively low, and the difference that more rapid fertility decline would make is small.

What difference would these alternative projections make to future flows of carbon emissions from fossil fuels in developing countries? To address this question requires first that a baseline, or reference path of emissions for developing countries be set out. Table 6 shows emissions from three different baseline or business-as-usual paths (labelled "SPP" in the table, i.e. under the World Bank's standard population projection): those of the International Panel on Climate Change (IPCC, 1991); of the U.S. Environmental Protection Agency (EPA, 1990) and a third prepared by this author.[19] The first two reference paths are based on projections of energy consumption in each of the regions, based on projected future population and income, and taking into account global energy supply. These two reference paths build in substantial improvements in energy efficiency. The third path is based on a simpler projection of emissions in developing countries, based solely on the assumption

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[19] Projected emissions are simulated using the assumption that per capita income will increase at an annual rate of 2 percent per year in all developing countries over the period 1990 to 2100, and using the results of a regression of per capita emissions on per capita income, i.e.

$$\begin{array}{c}\text{LnPCE} = \text{constant} + \text{lnPCY} + \text{lnPCY2}\\ -12.11 + 1.89 - .05\\ (-33)\quad(18.8)\quad(-7.7)\end{array}$$

where lnPCE is the natural logarithm (ln) of per capita emissions and lnPCY and lnPCY2 refer to ln of per capita income and of per capita income squared. The regression was run on data for the period 1960 through 1987 for a sample of 150 developing and developed countries, with the results shown (t- statistics in parentheses). (I am grateful to Nemat Shafik, who constructed this data set, for making it available, and to Sushenjit Bandyopadhyay and Anita Schwartz for programming.)

that per capita emissions in developing countries will grow as a function of increases in per capita income; per capita income is assumed to grow at 2 percent per year.[20]

Under the baseline scenarios, total emissions from fossil fuels are projected to nearly double by the year 2000, and to increase between seven-fold (EPA) and more than 20-fold (author's simulation) by the year 2050. The difference in the baseline scenarios illustrates the possible range of effects of technological change; none of the baseline scenarios allows for any policy change at all.

Table 6 also shows, for each region, the lower emissions in future years associated with the lower population growth under the rapid fertility decline population projection. (These reduced emissions are shown in the columns labelled "RFD" in the table.)

The results can be summarized simply (Table 7). In the year 2050, the difference in projected total emissions of developing countries between the two population projections is 780 million tons (EPA baseline) and 5 billion (econometrically based) metric tons. On the one hand, these numbers are large -- 780 million tons is two-thirds of the total estimated emissions of all developing countries today, and 5 billion tons is close to today's world total emissions. On the other hand, for both scenarios these differences amount to just 9 percent of the total emissions of developing countries

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[20] As noted above, this computation does not take into account the possibility that lower population growth would induce greater per capita income growth -- except to the extent that a steady rate of annual per capita income growth as high as 2 percent is itself unlikely without the projected declines in population growth.

projected in 2050.[21] Even with lower population growth, emissions would have increased almost six-fold in developing countries using the EPA baseline.[22]

In short, policies to reduce population growth in developing countries and thus reduce world population size would contribute relatively little to reductions in fossil fuel emissions. There are at least three reasons.

First, differences in projections of population growth on a global scale are not that great. Demographic momentum assures that the population of the developing countries will grow dramatically even with "rapid fertility decline", because of the momentum created by the high fertility and declining mortality of the past three decades. Past high fertility and falling mortality mean women entering childbearing age now constitute a large proportion of the total population in these countries. Because in most developing countries, the next generation of women will outnumber the previous one, even if the number of births per woman declines rapidly, the birth rate can stay high and the total number of births can continue to rise. (Only dramatic increases in mortality as a result of war or worldwide natural catastrophe would alter this conclusion. Obviously concern with global environmental damage arises because of a global interest in avoiding catastrophic increases in

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[21] Note, moreover that in the third scenario, the same regression coefficients are applied to all countries -- so differences in shares arise only due to differences in projected per capita income and in population. If anything, this exaggerates the effects of population change, since it leads to an understatement of China's predicted emissions and an overstatement of Africa's. Adjustments were made to the constant to bring the "projection" for 1989 into line with available data on emissions across regions. These are available from the author.

[22] It is worth noting that given there may be important nonlinearities (referred to often as cliffs in the environment literature), a 9 percent reduction could be important. It could be the margin that makes a critical difference in whether the polar ice caps disintegrate, Bangladesh is submerged, etc.

mortality or other major reductions in human welfare, so an increase in mortality could hardly be viewed as a solution to the fundamental problem.[23])

For example, because of demographic momentum, the populations of most developing countries would almost double in size before stabilizing, even were fertility rates to drop instantaneously to replacement level (about two children per woman). In contrast, the population of most developed countries under this situation would increase by 10 percent (Germany and Sweden) to at most 40 percent (the United States).

Is this result due to the huge projected total emissions in the baseline scenarios? No. Let us assume that by the year 2100 developing countries as a group had emissions per capita similar to the current world average of 1.2 metric tons -- i.e. well above their current average of about .4, but still below per capita emissions in most industrialized countries and below that projected using the approach above; and that the developed countries had reduced their emissions to 1.2 metric tons per capita. Then total annual global emissions from fossil fuels under the rapid fertility decline scenario would be 12.0 billion rather than 14.4 billion tons -- compared to a figure of 5.9 billion tons in 1988 -- still a doubling of total emissions.

Second, the potential for affecting future population size is greatest in those countries of the developing world where per capita emissions are currently lowest. As noted above (Table 5), the greatest potential reductions in population size between the two scenarios are in Africa and the Middle East. In contrast, the potential percentage declines for China are small. Yet Africa has low emissions per capita while China, with about 29 percent of the developing world's population, had emissions in 1988 that accounted for 42 percent of the emissions for all developing countries -- due in part to China's heavy use of its abundant coal (Table 2). Using the EPA estimates in Table 6 for

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[23] The AIDS epidemic could take a major toll in mortality in Africa and Asia during the next century (see Armstrong, 1991). Since Africa has low per capita carbon emissions, the effect on global emissions would be minimal.

the year 2050, we can calculate that Africa and the Middle East together would account for about 66 percent of the reduction in emissions with lower population growth (Table 7).[24] Yet this large share in absolute terms is small -- about 5 percent of expected total emissions under the standard scenario in 2050.

Third, it is likely that for given per capita income (which we are assuming), a smaller population will produce somewhat higher per capita emissions, due to substitution of energy for labor in production. To the extent this is the case, the difference in total emissions with more rapid fertility decline would be overstated.[25] In addition, if lower population growth in fact causes higher per capita income growth (contrary to the simplifying assumption made in the projections of carbon emissions), the effect of fewer people in reducing emissions could be offset -- on the assumption that greater income raises emissions, at least at the lower level of income in regions where population growth might be cut.

Deforestation

Deforestation currently accounts for estimated carbon emissions on the order of 1.4 billion tons per year, compared to 5.6 billion tons attributable to fossil fuel burning (Table 2). Thus tropical

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[24] The question arises: Why not, as part of a global carbon emissions reduction strategy, try to reduce population growth in the industrialized countries, where per capita emissions are 10 to 20 times as high as in Africa? Ideally, the feasibility and costs of such population reductions in developed countries would also be considered. Though feasible reductions in projected population growth would be much lower, since fertility rates are already close to replacement or, in parts of Europe, even below replacement, the cost per birth averted could be 10 to 20 times as high and would still compare favorably to costs in developing countries -- at least for as long as the current ratio of emissions per capita in the industrialized countries relative to Africa prevails. Moreover, women in industrialized countries still report that many births are "unwanted" -- and presumably would be averted were the full costs of contraception (and abortion) lower than they currently are.

[25] I am grateful to Charles Blitzer for pointing this out to me.

forests are currently contributing about 20 percent of the buildup of carbon dioxide in the atmosphere, which in turn accounts for about 50 percent of the total buildup from all gases.[26]

Major underlying causes of deforestation in developing countries include clearing of forests for agriculture and use of forests as a source of woodfuel; both are closely associated with population growth. Most analysts agree that logging for forest products also contributes, as do government programs and policies such as road-building, fiscal incentives to exploit frontier areas, and colonization and resettlement schemes (in Indonesia and Brazil -- see, for example, Schneider 1991, on Brazil).

Population growth could affect deforestation by increasing the demand for agricultural products and thus the return to land clearing, and by increasing the demand for woodfuels, particularly in small urban areas. Cross-section analysis of Southgate (1989, for cantons of Ecuador) links deforestation to the size of agricultural populations; analysis across countries of Latin America (Southgate et al., 1991) links agricultural land growth to rates of population growth. Allen and Barnes (1985) find, for a cross-section of developing countries, that population growth rates in the 1970s are associated with higher rates of deforestation; the relationship is stronger for Africa and Asia than for Latin America, presumably because land clearing to extend agriculture and use of woodfuel are both more likely at lower average levels of income.[27] They also find that across countries total wood use (the sum of wood use and wood exports) is associated with higher rates of deforestation. Rudel (1989), using a similar approach, reports similar findings.[28]

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[26] Deforestation probably accounts for a higher proportion of the buildup of methane and other greenhouse gases, and thus accounts for between 15 and 20 percent of all greenhouse gas emissions. (Myers, 1989).

[27] They regress rates of deforestation on rates of population growth, controlling for GNP per capita and extent of forest cover.

[28] Rudel regresses the natural logarithm (ln) of changes in forest coverage (1976-80) on the ln of the change in population growth, 1960-75, with controls for GNP per capita and forest area at the beginning of the period. Bilsborrow (1992) and Bilsborrow and Geores (1992) review Rudel and other studies.

None of these analyses demonstrates an inevitable relationship between population growth and deforestation. An estimated 90 percent of increases in agricultural production in the last two decades is the result of higher yields on existing lands, not the extension of agriculture to new lands (World Bank, 1992); and consumption of woodfuels (and thus deforestation for that purpose) declines consistently and universally with household income and city size (Barnes and Qian, 1991), implying that continued income growth and urban growth will reduce this source of pressure on forests. (A rough estimate of the income elasticity of woodfuel consumption is zero, based on the range of estimates reported by Hyde and Newman, 1991).

However, it is reasonable to assume that barring dramatic policy changes (e.g. in fuel or agricultural taxes and subsidies), the current association of population growth with deforestation will persist, particularly in the poorer countries of Africa and Asia. Such an assumption is consistent with the observation that worldwide rates of deforestation have continued to increase in the last decade (a possible exception is Brazil, where rates of forest loss have declined since a peak in 1987) despite income growth (outside of Africa) and growth in city size. It is also consistent with the observation that deforestation in developing countries is closely associated with poverty -- be it of the small farmer who migrates to new lands and clears forests, or of the poor urbanite who uses woodfuel -- and that even with modest income growth in developing countries, the problem of poverty will not be quickly resolved.[29] Given this assumption, to what extent would differences in future population growth alter rates of deforestation and thus rates of emissions of greenhouse gases?

The econometric analyses referred to above suggest roughly that a one percentage point difference in the rate of population growth would reduce annual rates of deforestation in all developing countries by between one-third and one-half percentage point, and by somewhat more than that in Africa and Asia (e.g. Allen and Barnes, 1985). (Annual rates of deforestation reported

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[29] Myers, 1989, makes a similar point.

by Myers, 1989, range widely. In West Africa they are high, e.g. 14 percent in Nigeria and 15 percent in Cote d'Ivoire; in Zaire, with the great bulk of Africa's existing forests, the rate is 0.4 percent. In Brazil and Indonesia, which along with Zaire account for almost 50 percent of all global forest cover, Myers' estimated rates in the late 1980s were 2.3 and 1.4 percent respectively.) For simplicity, let us assume a 0.5 response elasticity of the rate of deforestation to reductions in the rate of population growth, implying for example that a 50 percent reduction in the rate of population growth would reduce the rate of deforestation by 25 percent. The critical period for analyzing the effect is between now and about the year 2025. Beyond the year 2025, the payoff of lower population growth in terms of reduced emissions of greenhouse gases from deforestation declines quickly, both because the forest base is lower and because the difference in the two population projections between rates of population growth drops so rapidly. The difference in the population growth rate between the standard and rapid fertility decline projections for this critical period between now and 2025 is almost 60 percent for Africa, and is about 8 percent for Brazil and Indonesia. At 0.5 elasticity, this implies that with rapid fertility decline over the next 25-35 years, rates of deforestation for Africa as a whole would decline from roughly 2 percent (one-half of all Africa's forest cover is in Zaire, where the rate of deforestation is relatively low compared to West Africa), to about 1.4 percent over the period; rates in Brazil from 2.3 to 2.2 percent; and rates in Indonesia from 1.4 to 1.34 percent. These declines would reduce forest loss by perhaps 410,000 square kilometers over the entire period (an average of 12,000 square kilometers per year -- compared to annual current estimated losses reported by Myers, 1989, of 140,000 square kilometers).

The bulk of the reduction occurs in Africa, because that is where the great difference occurs in population growth between the two projections. The total (global) reduction in deforestation is relatively low because Africa accounts for a relatively small proportion of existing global forest cover.

At 10,000 tons of carbon released per square kilometer,[30] the total reduction in carbon releases over the 35-year period associated with the lower rate of population growth would be about 4.1 billion tons, and the average annual reduction about 117 million tons, compared to current annual carbon releases associated with deforestation of 1.4 billion tons. This implies about an 8 percent reduction in carbon emissions due to deforestation and a 2 percent reduction in total carbon emissions.

Section 3. Economic Costs of Reducing CO_2 Emissions

In this section I compare the economic costs of reducing CO_2 emissions in two ways: with population growth as given, but energy consumption reduced or made more efficient or less carbon intensive, e.g. through technological change (the "tax" route); and with per capita emissions as given, but a reduction in total emissions via lower increases in population (labelled hereafter the "population" route). The cost of attaining lower population growth is discussed in terms of the costs of educating women (given the evidence that educated women have fewer births) and the costs of family planning programs, i.e. greater provision of modern contraceptives (given the evidence that family planning programs reduce fertility over and above the effects of household income, parents' education and so on.[31])

Ideally, the comparison of the costs of reducing emissions via the two routes above would be made in terms of economic costs, i.e. the actual resource costs to the economy of reducing emissions under the two alternative approaches. In fact the cost of the population reduction strategies is

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[30] This is also a crude estimate, based on the observation that Myers estimates carbon releases from deforestation in 1989 to be 1.4 billion tons, and reports an estimated 142,000 square kilometers of (tropical) forest loss, i.e. about 10,000 tons of carbon per square kilometer of deforestation.

[31] For reviews of the evidence on the determinants of fertility, see Birdsall, 1988 and World Bank, 1984.

measured in terms of direct costs to government or donors, and does not take into account any efficiency costs due to the associated additional taxation, while the cost of the carbon tax is measured in terms of foregone efficiency. Nor does the comparison does not take into account such externalities (generally positive, but negative externalities are also possible) as the possible benefits a tax might bring via reduced emissions of other pollutants besides greenhouse gases[32], or via incentive effects on development of new cleaner technologies, nor the economic productivity effects of greater education for women or the health benefits of family planning. Finally, the costs discussed below do not take into account any benefits of reduced global warming.

The effect of discounting on the relative costs of the tax vs. population strategies is explored briefly below, after presentation of the initial cost estimates. To take fully into account the streams of costs and benefits of the various carbon reduction strategies would require more detailed analysis than is presented here.

Carbon taxes. Various approaches have been used to estimate the costs of reducing CO_2 emissions. Nordhaus (1991) reports on estimates from econometric (or elasticity) studies and from mathematical programming or optimizing models. The costs in these estimates assume an economically efficient reduction strategy.[33] In econometric analyses, the impact of various policies, such as carbon taxes on consumption or production, is estimated, in the context of behaviorally based models of the supply and demand for energy. The underlying models use various assumptions about

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[32] Shah and Larsen (1992) assess the case for carbon taxes in terms of the potential local environmental benefits and revenue benefits, noting that currently fossil fuel prices are subsidized globally -- in an amount in excess of $230 billion (evaluated at end-user prices), equivalent to a negative global carbon tax of $40 per ton of carbon. They conclude that Indonesia, India and Indonesia could benefit from a carbon tax based solely on the health benefits to reducing local pollution.

[33] I.e. assuming competitive markets. These estimates also do not take into account any externalities (such as welfare empowerment due to slower global warming).

interfuel substitution, technological change, and the elasticity of energy supply. Optimizing models are conceptually similar.[34]

Nordhaus uses the cost estimates from about 10 such studies as the basis for fitting an equation that thus constitutes a kind of summary "cost-reduction schedule" of the marginal cost of reducing emissions. As a function of the percentage reduction from a baseline path, the relationship of emissions reductions to marginal costs summarized in this schedule is identical to the relationship between a uniform carbon tax and the CO_2 reduction; in other words, the necessary tax to reduce emissions at each margin provides a summary measure of the marginal cost. The estimates used to fit his equation generally allow factors of production to adjust fully, and therefore are estimates of long-run marginal costs -- short-run costs would be much higher.

The cost reduction schedule (and in effect the underlying estimates that it summarizes) indicates that the marginal cost of a 10 percent reduction in carbon emissions would be about $20 a ton.[35] The average cost of a 10 percent reduction from a baseline path would be about $10 a ton; with current global emissions of about 6 billion tons, a 10 percent reduction would cost about $6 billion annually. This cost is relatively low -- under one-tenth of 1 percent of annual world output.

However, the schedule also shows that costs of further reductions rise rapidly. A 20 percent reduction would require a tax of over $50 a ton and a 50 percent reduction a tax of $130 a ton. Nordhaus elsewhere (1990) concludes that given current understanding of the likely costs of climate change, a tax that reduced current emissions by 10 percent would be reasonable. (He estimates that

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[34] To estimate marginal costs of CO_2 reduction, alternative constraints of total emissions are imposed, and efficiency pricing and energy production under different constraints is derived. The shadow prices associated with the alternative constraints are equivalent to the tax rates that would induce the constraints; thus the marginal costs of reducing emissions by particular amounts can be summarized in p

[50] Wheeler, 1985.

a lower tax, of about $5, would be sufficient to reduce total emissions of all greenhouse gases by 10%, because initial CFC emissions reductions are relatively cheap.)

Averting a birth through greater public spending on family planning. How do these costs of reducing emissions from a baseline path in which population increases are given compare to the costs of reducing emissions by reducing population increases, with per capita emissions given?

Increasing the availability of modern contraceptives is one approach to reducing the rate of increase in population growth. Estimates of the costs of averting births through contraceptive services or family planning programs require estimates of the costs of delivering services to users and of the effects of such services in reducing fertility -- from what it might otherwise have been even in the absence of contraceptive services.[36]

The most careful single estimate of the cost of averting a birth I could find is provided in a recent paper of Cochrane and Sai (1991). They first calculate the costs of a couple year of protection, on the basis of information at the country level on users and methods. These costs vary from about $3 for female sterilization in Indonesia to about $25 for pill use in Morocco and Honduras. To translate costs per couple year of protection into costs of a birth averted they assume that the foregone fertility of users is equal to the actual fertility of all women of the same age in the particular country. In a mechanical sense this underestimates births averted since the comparator group includes contraceptive users[37] However, in a behavioral sense, it may overstate births averted due to contraception, since many users might have found other ways to control their fertility.[38]

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[36] Note that fertility can and historically has been controlled in many societies by abstinence, withdrawal, the rhythm method, lactation, separation of spouses, and probably most important, by low rates of marriage and late age of marriage.

[37] Cochrane and Zachariah (1983) provided two estimates, including a lower one for costs of births averted, by reducing the comparator age-specific fertility rates to take into account the effects on those rates of the inclusion of contraceptive users.

[38] See footnote 36 above.

Cochrane and Sai note that the resulting estimated costs per birth averted vary across countries as a function of the number of women who state in surveys that they want no more children -- at the rate of $4.60 decline for every 1 percent increase in those who want no more children. Using available country data on costs per year of couple protection and on proportions of women across countries who want no more children, they estimate three costs per birth averted for three types of countries: $259 (1987 dollars) per birth averted in high mortality countries where about 20 percent of women report wanting no more children (typical of Africa and some countries of the Middle East); $213 in high mortality countries where about 30 percent of women report wanting no more children (India, Bangladesh); and $144 in low mortality countries where about 45 percent of women report wanting no more children (Colombia, Mexico, much of Latin America).

For the comparisons below, I assume a cost per birth averted of $240, since about 80 percent of the feasible reductions in population increase (Table 5) would come from Africa and the Middle East, and another 10 percent from India and other high-fertility countries of Asia.

An estimate of emissions averted for each birth averted is also needed. For the set of countries where fertility could be reduced (primarily Africa and the Middle East) I estimate that annual per capita emissions of carbon are currently 0.35 tons.[39] For lifetimes of 60 years, this implies lifetime per capita emissions of 21 tons, and with a 2 percent annual increase in emissions per capita, of 40 tons. This per capita figure does not take into account current carbon emissions associated with deforestation (which in Sub-Saharan Africa were almost one ton per capita in 1980[40], but which on

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[39] 0.35 tons is the weighted average of current fossil fuel-based per capita emissions of Sub-Saharan Africa, the Middle East/North Africa, South Asia and Latin America, where the weights represent the proportions of all expected reduced births (from Table 5) and annual per capita emissions for these regions are, respectively (from Table 2); 0.1, 0.8, 0.2 and 0.4 tons per capita.

[40] United Nations Environment Program, 1991, Table 1.3.

a per capita basis cannot continue at the same level); the estimate of 0.35 tons is thus a conservative one.

With these assumptions, the cost of reducing carbon emissions via family planning programs would be between $6 and $12 per ton ($240/$40 and $240/$21) -- see Figure 1. These costs compare favorably with the marginal cost of $20 a ton to reduce carbon emissions by 10 percent using a carbon tax.

Is it reasonable to assume that $240 per birth averted is the marginal cost of averting births in a comparable range of carbon reduction? Yes. To achieve an eventual reduction of current emissions by 10 percent, i.e., 600 million tons, would require that between 15 and 29 million additional births be averted (600/40 tons of lifetime per capita emissions and 600/21 tons), at a cost of between $3.6 billion and $7 billion.[41] Twenty-nine million births would represent less than one-third of the difference in population size between the two population projections discussed above in the year 2000 (Table 5) and less than 5 percent of the difference in Africa alone in the year 2050. In fact, the marginal costs of family planning services to avert an additional 29 million births may actually be lower than current estimated average costs, and in low income countries are likely to decline over time. It is true that marginal costs could increase in settings where family planning services have already realized economies of scale (such as Indonesia or Thailand) and where average number of children is already low (China, the United States)--though even in these settings,

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[41] Additional spending of such amounts over and above current estimated spending of between $3 and $5 billion would be large but not unreasonable. Estimates from various studies and sources shown in Cochrane et al., 1990 (Table 8) are that the annual cost in the year 2000 of services sufficient to ensure the fertility decline associated with the United Nation's medium population projection, will be between $3.6 and $8 billion (including private spending) in developing countries. The UN medium projection is similar to the World Bank's standard projection. To reduce births more, in line with the rapid fertility decline projection, would cost more.

improvements in contraceptive technology could drive down costs.[42] However, where family planning services are still limited and average number of children high (Africa and the Middle East), marginal (and average) costs are likely to decline; as the three figures for the three types of countries cited above indicate, the cost of averting a birth appears to decline as desired fertility declines and more women in a population say they want no more children.[43]

Averting births by educating girls. Summers (1992) notes that one additional year of female schooling reduces fertility by between 5 and 10 percent, on the basis of econometric studies at the country level of the effects of female education on fertility. The effect is probably closer to 10 percent where fertility is relatively high.[44] In Kenya, for example, where the total fertility rate is 6.5, a woman with secondary education has one fewer child than a woman with five to eight years of education; in Colombia in 1976 a woman with one to three years of education had almost seven births, compared to six births for a woman with four to six years of education.[45] I assume below that in the low-income countries, each additional year of girls' schooling would result in 0.3 fewer births, a conservative assumption.

World Bank estimates of the average annual recurrent cost of one year of primary schooling in low income countries are about $36 per student. Using an assumed annual recurrent cost of

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[42] Reductions in the cost of abortion, including in the industrialized countries, would have the same effect--for example, more widespread use of RU-486, an abortifacient the use of which eliminates the need for any surgical procedure.

[43] Decline in desired family size are in turn dependent on continuing increases in educational attainment of women, urbanization, and so on, in these regions and continuing declines in infant mortality. These are built in already in the population projections of the World Bank as trends that are assumed to follow patterns set in the past.

[44] de Tray (1972) reports an elasticity of fertility with respect to education of -0.3 in Pakistan, implying at 3 years of education a 10 percent reduction in fertility, or 0.7 fewer births given a total fertility rate of 7.

[45] For Kenya, Schafgans, 1991, cited by Summers. For Colombia, World Bank, 1984, based on Casterline et al., 1983.

double that for a year of secondary school, i.e. $72, the annual cost of raising female enrollment in all low-income countries to that in high income countries would be almost $6 billion ($560 million for 14 million additional years of primary schooling and $5.3 billion for 98 million additional years of secondary schooling).[46] Thus in low-income countries, spending $6 billion on girls' schooling could be associated with an additional 112 million years of education -- at the implied ratio of additional primary to additional secondary education, an average cost of $52 per year of additional education. This implies a cost per birth averted of $173 (at 0.3 fewer births per year of additional education).

Assuming that each birth averted is associated with a reduction in lifetime emissions of 21 tons (as discussed above), the implied marginal cost per ton of emissions averted is between $4 and $8 (the former if we assume a 2 percent annual increase in per capita emissions) - see Figure 2.

Of course, as in the case of family planning, these estimates do not take into account the lag in the benefits of reduced births associated with schooling of girls. The lag would be longer than it is for the tax or for family planning services.

<u>Discounting</u>. The benefits of spending on family planning and of educating girls should be discounted to take into account the fact that costs but not benefits are immediate. In the case of family planning, birth reductions are immediate but benefits in terms of reduced emissions accrue slowly over the would-be lifetimes of those not born. In the case of educating girls, benefits begin only when those girls reach reproductive age, and then accrue slowly over their years of reproductive age.

One or two examples can help illustrate the effect of discounting.[47] In the case of family planning, where the effect of reduced births begins immediately but the benefits accrue gradually,

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[46] Summers, 1991.

[47] I am grateful to Bjorn Larsen and Anwar Shah for useful comments on this and the following sections.

consider a discount rate of 2 percent. It would just offset the assumed 2 percent growth rate of per capita emissions, so that the discounted tons of emissions would be 21 tons, and the cost per ton about $12 (240/21). With a 2 percent discount rate, and no increase in per capita emissions over time, and assuming uniform reductions in emissions over lifetimes, the discounted carbon emissions would be about 12 tons and the cost per ton would rise to $20 (240/12). With a 5 percent discount rate, the cost per ton would rise to $39 (240/6.6 tons). In the case of educating girls, an additional assumption is required. Assume a gap of 15 years between the additional year of education and the year when a birth is averted (e.g. between age 10 and age 25). Assuming not only a 2 percent discount rate but a 2 percent annual growth in emissions, averted tons continue to be 21, and the marginal cost per ton is $8. Without the assumption that per capita emissions are increasing, and taking into account the 15-year lag, the discounted tons of emissions averted would be 9.3 tons at a 2 percent discount rate and 3.2 tons at a 5 percent discount rate, so that marginal costs per ton are, respectively, $19 and $54.

The marginal cost of a carbon tax should also be discounted. The short-run reduction in emissions associated with a $20 tax (or a $20 marginal cost) would be much lower than the long run reduction, because of the difficulty of changing the capital stock and adapting new technologies in the short run. Assuming a long run period of 20 years for the tax, and a 2 percent discount rate, the discounted tons reduced would decline by about 20 percent, implying an increase in the marginal cost of a tax to about $24. At a 5 percent discount rate, the discounted tons reduced would decline by 56 percent, implying an increase in the marginal cost of the tax to $31.

The costs across the different strategies of attaining a 10 percent reduction of carbon emissions (from fossil fuel burning alone) under the various strategies and with different discount rates are summarized in Table 9.

Thus depending on assumptions regarding expected increases in emissions in developing countries, the appropriate discount rate, and the appropriate period of discounting, the relative costs of the tax and the family planning strategies shift. The greater the expected increase in per capita emissions in developing countries (as discussed above, increases are likely given the current low base), the lower the discount rate, and the longer it takes for adjustments of the capital stock and of technology in response to a tax, the more cost-effective the family planning strategy is compared to the tax. Between family planning and educating girls, the latter is more attractive the lower the discount rate and the steeper are expected increases over time in per capita emissions.[48]

An optimal carbon reduction strategy. In fact, an optimal strategy would almost certainly exploit some combination of a carbon tax and population reduction. We can use the Nordhaus cost reduction schedule to illustrate the point. Figure 3 shows the Nordhaus marginal cost curve of a carbon tax (MC_t), and the \$12 per ton cost of reducing population through family planning, (MC_{FP}) shown as constant until point A, and then increasing. (The same point could be made using the estimated cost of reducing emissions by educating girls.) As the figure indicates, at a \$12 marginal cost of reducing emissions by a tax, current emissions would decline from their baseline path by 8.35 percent.[49] If this percentage reduction is sufficient, the optimal strategy is to rely solely on the \$12 tax. However, to achieve any greater decline, it makes sense to combine a \$12 tax with additional spending on family planning (or educating girls). Combining population reduction with a tax is

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[48] To fully take into account the stream of costs and benefits for the tax, family planning and education of girls would require more than simple application of a uniform discount rate. For example, note that the benefits of averting births accumulate across generations; the costs in the second generation of averting the births that might have occurred to persons never born in the first generation are zero. This is true of educating girls as well as of family planning, since there is strong evidence that education of mothers positively affects education of children (and to a greater extent than education of fathers), i.e., there is an echo in a second generation of the benefits of educating girls (King and Lillard, 1987 and King and Bellew, 1989).

[49] Calculation is based on Nordhaus' (1991) regression estimate, which provides the basis for his cost curve: $\ln(1-R) = -.0223 - .0054\,(MC)$.

optimal as long as the marginal costs of the former are lower than those of the tax within the range of the targeted reduction. Thus in Figure 3, relying on the population reduction strategy continues to make sense beyond point A, up to whatever percentage reduction is targeted, as long as its marginal cost remains below the marginal costs of a tax (which, of course, may not hold beyond some point).

Discounting the benefits of the population reduction strategies would raise the point at which these strategies should kick in. With a relatively low targeted reduction, and a relatively high discount rate (and depending on expected growth in per capita emissions), there may be a point at which population reduction would not be part of a cost-effective strategy. But given targeted reductions in the range of 10 percent, and the range of plausible costs set out above, it appears that population reduction in fact would be part of any cost-effective strategy.

To illustrate the point differently, suppose a global constraint was set on the costs of reducing carbon emissions, of $6 billion per year. Recall that a tax of $20 per ton would imply costs to the economy of $6 billion annually and would reduce current carbon emissions by about 10 percent or 600 million tons. How much would $6 billion reduce emissions if spent on a combination of a tax and population reduction? At a rate of $12 per ton, the total cost of the tax would be about $3 billion and emissions would be reduced by 500 million tons. Spending of the remaining $3 billion on family planning would avert an additional 12.5 million births (at $240 per birth averted), implying an eventual reduction of another 263 million tons of carbon emissions (at 21 tons of emissions over a lifetime). Thus, the total effect of spending of $6 billion would be to reduce current emissions by 763 million tons, i.e., by 12.7 percent--compared to a reduction of 10 percent using the tax alone.

Conclusion

The costs of reducing carbon emissions by spending to reduce births compare favorably with the costs of a carbon tax; at $12 per ton, the costs of reducing births by spending on family planning are equivalent or lower than the $20 marginal cost of a tax that would reduce emissions by 10 percent. Discounting at 2 percent implies costs of $20 a ton, in the range of our estimate of $24 a ton for equivalent discounted reductions via a tax. The undiscounted costs of reducing births by educating girls, at $8 per ton, are similar to the costs of family planning; discounting at 2 percent, and taking into account the longer lag before the benefits of girls' education begin, costs rise to $19 a ton. In fact, other evidence shows that the marginal effects of both family planning services and female education on births increase as a function of increases in the other, i.e. there is a strong interaction between the two.[50] Thus the marginal costs of some combination of spending on the two population reduction strategies might actually be lower than their costs estimated separately.

The implication of the cost analysis for the overall conclusion is simple: The global negative externality represented by rapid population growth in developing countries provides a strong, new rationale for developed countries, in their own interests, to finance programs that would reduce population growth in developing countries. This is true even though feasible reductions in population growth would represent at best a modest contribution to reducing greenhouse gas emissions. Spending to reduce population growth cannot alone solve the potential problem of global warming. However, it seems clear that some combination of spending on family planning and girls' education in low income countries should be a central part of any optimal carbon reduction strategy.[51]

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[50] Wheeler, 1985.

[51] Cline (1992), using a different approach, similarly concludes that reducing population growth makes sense as part of any strategy to reduce global warming, in terms of its relative costs and benefits.

Table 1. Shares in World Population, GDP, and Carbon Emissions, Country Groups, 1988

	Population	GDP	Fossil Fuel Carbon Emissions	Deforestation Carbon Emissions[d]	Total Carbon Emissions
Developed Countries[a]	15	87	52	5	ca. 55
Eastern Europe and USSR[b]	9	N/A	28		ca. 12
Developing Countries[c]	76	18	20	95	ca. 33

Sources: World Bank, 1990 (population and GDP); Boden et al., 1990 (fossil fuel carbon emissions); Houghton, 1990; Schneider, 1991.

[a] OECD
[b] Including then East Germany
[c] Including China
[d] 1990

Table 2. Fossil Fuel Carbon Emissions, Selected Countries and Regions

	Total Emissions (millions of metric tons)		Per Capita Emissions (metric tons)		Emissions Per Million Dollars of GDP (tons of carbon)
	1960	1988	1960	1988	1989
United States	800	1,310	4.40	5.30	259
United Kingdom	161	153	3.10	2.70	185
West Germany	149	183	2.70	3.00	147
China	215	609	0.33	0.56	1,547
India	33	164	0.10	0.20	670
Brazil	13	55	0.20	0.40	
Latin America and the Caribbean					278
South Korea	4	56	0.10	1.30	
East Asia and the Pacific					934
TOTAL GLOBAL	2,586	5,893	0.90	1.20	
Sub-Saharan Africa		61[a]		0.13[b]	376
Middle East and North Africa		189[a]		0.76[b]	516

Sources: Top Panel (excluding column 5): Boden et al. (total per capita emissions). Boden et al. do not cover all countries, but the top 20 in terms of emissions, comprising an estimated 95% of all emissions.
Bottom panel and column 5: World Development Report, 1992.

[a] 1989 data, expressed in millions of tons of carbon
[b] 1989 data, expressed in tons of carbon

Table 3. Carbon Emissions from Deforestation, by Country

	Annual Deforestation (1989) source: Myers (square kilometers)	Estimated Carbon Emissions source: Myers[a] (millions metric tons)	Estimated Carbon Emissions source: Choucri based on Houghton (millions metric tons)
Brazil	50,000	500	336
Indonesia	12,000	120	192
Colombia	6,500	65	123
Cote d'Ivoire	2,500	25	101
Nigeria	4,000	40	60
Zaire	4,000	40	--
TOTAL, including all other countries	138,600		1,659

[a] Based on assumption that deforestation of one square kilometer of forest emits 10,000 tons of carbon.

Table 4. Population Growth Rates, Total Fertility Rates, and Population Projections,[a] All Developing Countries[b]

Population Growth Rates

	1985-2000	2025-2050	2075-2100	2125-2150
Standard	1.99	.90	.22	.05
Rapid	1.86	.64	.13	.04

Total Fertility Rates

Standard	3.62	2.241	2.063	2.054
Rapid	3.40	2.110	2.063	2.055

Population Projections (billions)

	1985	2000	2050	2100	2150
All Developing Countries					
Standard	3.67	4.95	8.95	10.60	11.03
Rapid	3.67	4.85	7.60	8.39	8.67

[a] These numbers reflect preliminary runs (September 1991) and may change slightly before they are published in 1992.

[b] Including China, excluding Eastern Europe and the Soviet Union

Source: Preliminary World Bank projections (1991)

Table 5: Percentage Reduction, Rapid Fertility Decline vs. Standard, and Shares of Total Reduction, by Regions

	Percentage Reduction			Share of Total Reduction	
	2000	2050	2100	2050	2100
China	0.7	1.3	1.5	1.7	1.3
India	1.5	6.6	7.9	7.7	6.4
Sub-Saharan Africa	4.4	34.6	43.4	51.2	53.9
Latin America	1.9	8.1	7.3	5.1	3.1
Other Asia	1.6	5.1	6.4	4.9	4.2
Mid. East & N. Africa	3.9	28.8	38.1	29.4	31.3
TOTAL	2.0	15.3	20.9	100	100

Table 6. Alternative Projections, Fossil Fuel Carbon Emissions, Developing Country Regions

Intergovernmental Panel on Climate Change

	1985 Est.	2000 SPP[a]	2000 RFD[b][c]
Africa	0.17	0.28	.27
Centrally Planned Asia	0.54	0.88	.87
Latin America	0.22	0.31	.30
Middle East	0.13	0.31	.30
S. & E. Asia	0.27	0.56	.55
TOTAL	1.33	2.35	2.30

Environmental Protection Agency

	1985 Est.	2000 SPP[a]	2000 RFD[b][c]	2050 SPP[a]	2050 RFD[b][c]	2100 SPP[a]	2100 RFD[b][c]
Africa	0.1	0.3	.29	0.9	.59	1.4	.79
Centrally Planned Asia	0.6	1.0	.99	3.6	3.55	4.9	4.83
Latin America	0.2	0.3	.29	1.4	1.29	1.8	1.67
Middle East	0.1	0.2	.19	0.7	.50	1.0	.62
S. & E. Asia	0.3	0.5	.49	2.1	1.99	4.1	3.84
TOTAL	1.3	2.3	2.25	8.7	7.92	13.2	11.75

Econometrically-Based[d]

	2000 SPP[a]	2000 RFD[b][c]	2050 SPP[a]	2050 RFD[b][c]	2100 SPP[a]	2100 RFD[b][c]
Africa (Sub-Saharan)	0.2	.19	3.3	2.16	26.3	14.89
China	1.9	1.89	15.1	14.90	93.3	91.9
Latin America	0.8	.79	7.8	7.17	50.4	46.72
Middle East/ N. Africa	0.6	.58	8.6	6.12	66.0	40.85
India	0.3	.30	2.6	2.43	17.1	15.75
Other Asia	0.8	.79	8.1	7.69	52.5	49.14
TOTAL[e]	4.64	4.56	45.5	40.4	305.7	259.3

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[a] Standard Population Projection

[b] Rapid Fertility Decline Population Projection

[c] The figures shown in the RFD columns are derived by applying the percentage declines in population shown in Table 5 to the figures in the "standard" column for the same year. Unfortunately, there is not a one-to-one correspondence between regional population projections of the World Bank and the regions modelled in the IPCC and EPA carbon emission projections. The percentage declines in population (Table 5) are applied as follows: for Africa, Sub-Saharan Africa; for Centrally Planned Asia, China; for Middle East, Middle East and North Africa; for South and East Asia, Other Asia.

[d] Regression results available from author.

[e] Columns may not add due to rounding.

Table 7. Effect of Slower Population Growth on Fossil Fuel Emissions, 2050

REGIONS	Difference in population size (millions)	Resulting reduction in emissions (EPA scenario, millions of tons)	Percent difference from baseline scenario	Shares in total reduction from baseline scenario
Africa	699	310	34	40
Centrally Planned Asia	23	50	1.4	6
Latin America	69	110	8	14
Middle East	401	200	8.5	26
South and East Asia	67	110	5	14
TOTAL	1,259	780	9	100

Sources: Appendix Table and Table 6. See notes to Table 6.

Table 8: Effects of Slower Population Growth on Reduced Deforestation, 2025

	Brazil	Indonesia	Zaire	Other Africa	TOTAL
Difference in population growth rate, in 2025	8%	8%	60%		
Current Annual Rate of Deforestation	2.3%	1.4%	2%		
Annual Rate of Deforestation with Slower Population Growth Rate[a]	2.2%	1.34%	1.4%		
Resulting Reduction in Deforestation (sq. kilometers) over 35 years	77,000	18,060	210,000	105,000	410,060
Resulting Reduction in Carbon Emissions @ 10,000 tons per sq. kilometer (in millions of tons)	770	181	2,100	1,050	4,100
Annualized reduction from current emissions from deforestation (in millions of tons)	22	5	60	30	117

NOTE: Reduction by 117 million is equal to about 8 percent of current emissions due to deforestation.

[a] Using assumption that the elasticity of deforestation rate with respect to population growth rate is 0.5.

Table 9. Costs of a 10% Carbon Reduction (Emissions from Fossil Fuels) under Various Reduction Strategies[a]

	Carbon Tax			Family Planning			Educating Girls		
	No Discount	2%[c]	5%[c]	No Discount	2%	5%	No Discount	2%	5%
Marginal Cost	20	24	31	12	20	39	8	19	54
Total Cost[b] ($ billion)	6	7.2	9	7.2	12.0	23.4	4.8	11.4	32.4

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[a] Using a baseline in which there are no annual increases in per capita emissions. To the extent there are such increases, due for example to income growth, the relative costs of the family planning and girls' education strategies would be lower.

Note that if the carbon tax and population control strategies are pursued simultaneously, the relative cost of population control increases because the carbon tax will make per capita emissions lower and thereby reduce the cost-effectiveness of population control policies. The magnitude of this effect increases with the size of the carbon tax.

[b] For the population reduction strategies, I assume constant marginal costs in the relevant range. For the carbon tax, marginal costs are increasing.

[c] Assuming a long run period of 20 years for the full effects of the tax to take hold.

Figure 1
Family Planning to Reduce Carbon Emissions

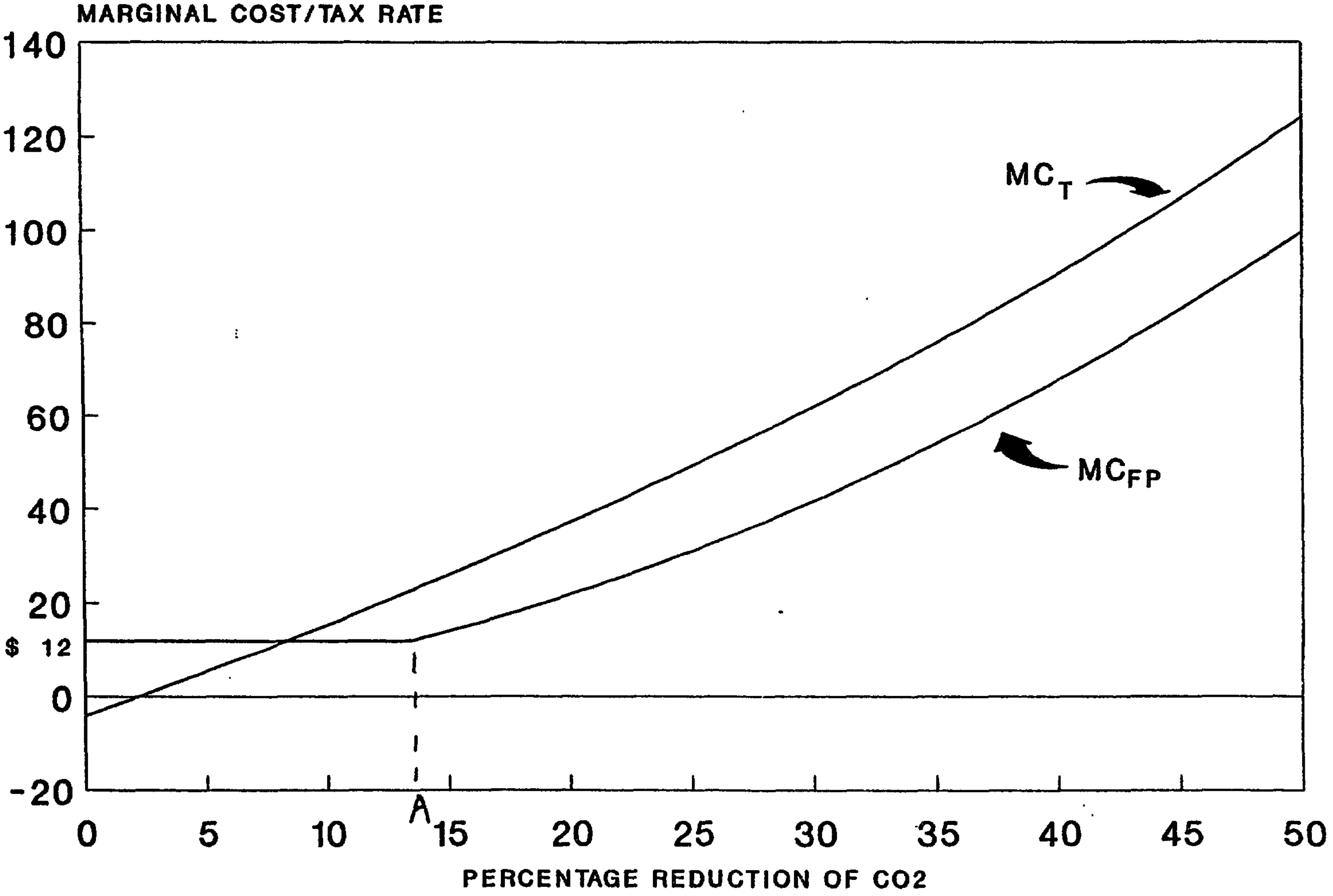
Estimated cost per birth averted:	$240
Estimated annual expected per capita emissions (of births averted[a]):	0.35 tons
Times 60 years (lifetime)	21 tons
With 2% annual increase	40 tons
Cost per ton of emissions:	Between $6 (240/40) and $12 (240/21)

Figure 2
Educating Girls to Reduce Carbon Emissions

Estimated cost for an additional year of girls' schooling	$52
Assumed reduction in births for each year of schooling	0.3
Cost per birth averted	$173
0.35 tons times 60 years (lifetime)	21 tons
With 2% annual increase	40 tons
Cost per ton of resulting reduced emissions	Between $4 (173/40) and $8 (173/21)

[a] I.e. weighted average of current emissions per capita by region, where weights correspond to proportions of all expected reduced births.

FIGURE 3
MARGINAL COSTS OF CO2 REDUCTION: CARBON TAX AND SPENDING ON FAMILY PLANNING



Appendix Table: Population Projections for Selected Countries, Regions and Years

	1985	2000	Difference	2050	Difference	2100	Difference	2150	Difference
China									
Standard	1,048	1,294	9	1,764	23	1,854	28	1,886	29
Rapid		1,285		1,741		1,826		1,857	
India									
Standard	765	1,007	15	1,600	105	1,791	142	1,856	149
Rapid		992		1,495		1,649		1,707	
Sub-Saharan Africa									
Standard	455	724	32	2,020	699	2,751	1,194	2,923	1,277
Rapid		692		1,321		1,557		1,646	
Latin America									
Standard	400	526	10	849	69	930	68	950	70
Rapid		516		780		862		880	
Other Asia									
Standard	624	820	13	1,308	67	1,447	92	1,493	95
Rapid		807		1,241		1,355		1,398	
Middle East/ N. Africa									
Standard	372	570	22	1,390	401	1,817	693	1,901	736
Rapid		548		989		1,124		1,165	
TOTAL	3,664		101		1,364		2,217		2,356

Note: Difference is standard minus rapid.

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