Population and Environment

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Abstract

The past fifty years have witnessed two simultaneous and accelerating trends: an explosive growth in population and a steep increase in resource depletion and environmental degradation. These trends have fueled the debate on the link between population and environment that began 150 years earlier, when Malthus voiced his concern about the ability of the earth and its finite resources to feed an exponentially growing population.

The purpose of this study is to review the literature on population and environment and to identify the main strands of thought and the assumptions that lie behind them. The author begins with a review of the historical perspective. He then reviews and assesses the evidence on the relationship between population and environment, focusing on selected natural and environmental resources: land use, water use, local pollution, deforestation and climate change. The author also reviews selected recent macro and micro perspectives. The new macro perspective introduces the environment-income relationship and examines the role of population growth and density in mediating this relationship. The new micro perspective introduces the close relationship between poverty and environmental degradation, also examining the roles of gender in decision-making and the role of children as economic assets in fertility decisions. Finally, the author carries out a comparative assessment of the approaches and methods employed in the literature to explain the wide variation in findings and predictions.

This literature review demonstrates that there is little agreement on the relationship between population and growth, and even whether any relationship exists at all. Empirical research has been unable to resolve the issue because of limited data, divergent methodologies, and varying levels of analysis.

Keywords: Population, Environment, Economic Growth

JEL Classification Codes: J10, O13, Q20

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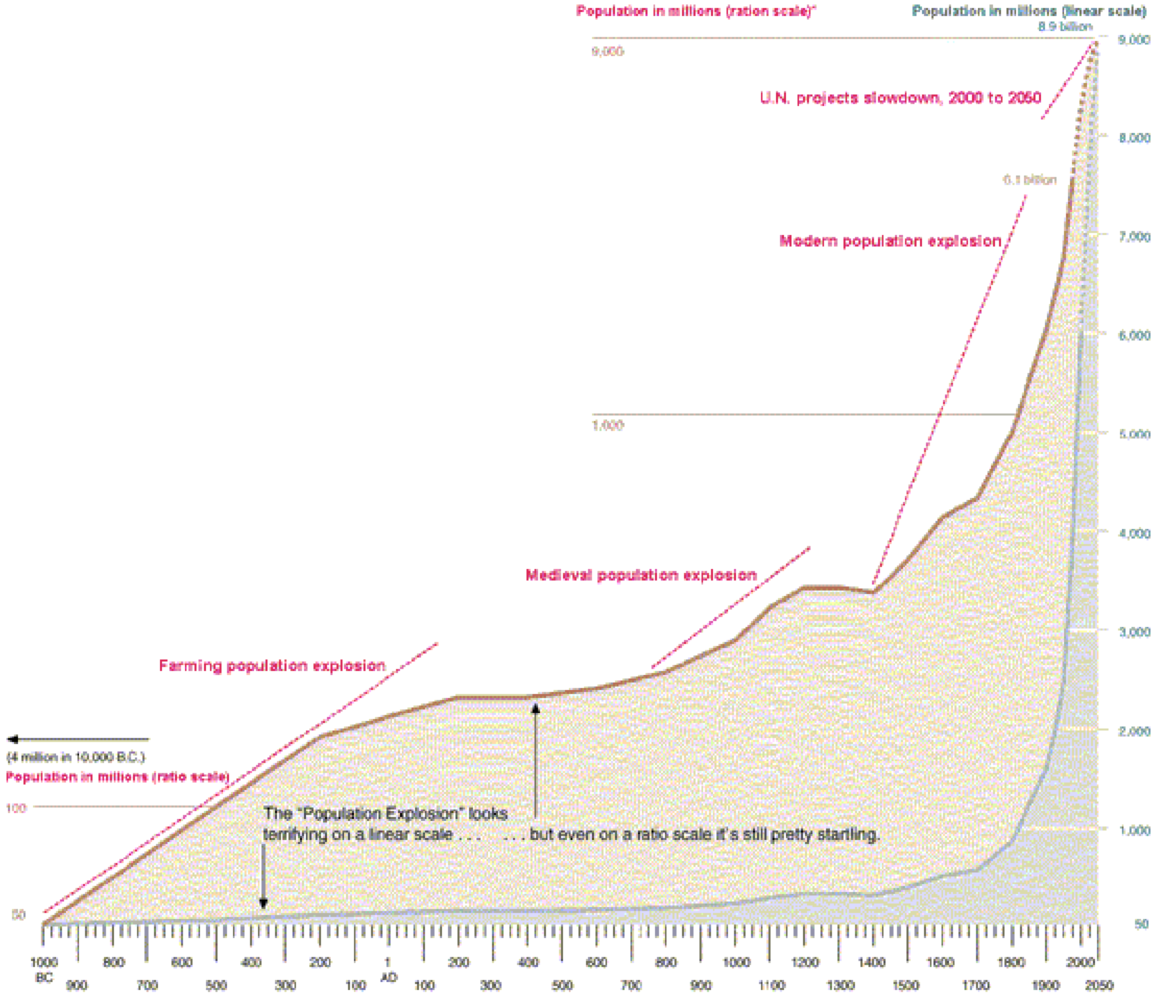
1. Introduction

The past two hundred years have witnessed two exploding trends: rapid population growth following the decline in mortality due to both the medical revolution and the improvement in living conditions and a steep increase of resource depletion and environmental degradation following the industrial and agricultural revolutions. Both of these trends have accelerated over the past 50 years, fueling the debate on the linkages between population and environment that began 150 years earlier with Malthus' concern about the capacity of fixed land to feed an exponentially growing population. While population grew at rates beyond Malthus' imagination (see Figure 1), food production expanded even faster, and the debate has shifted to concerns about the role of population growth in the depletion of other natural resources, such as fossil fuels and minerals; in the degradation of renewable resources, such as forests, fisheries and biodiversity; and in the despoliation of local environment and the global climate.

The analysis and debate have been carried out on two distinct levels: the macro level, involving large units of analysis, such as the nation, the region or the globe; and the micro level, involving small units of analysis, such as the household, the family and the community. Some studies are content with establishing simple correlations, while others involve sophisticated econometric analysis, attempting to ascertain the existence and direction of causality. Yet other studies involve complex systems with feedback loops or large simulation models with scenario analysis. Inevitably, they reach different conclusions even when they analyze the same body of data because of differences in perspectives, levels of aggregation and methods of analysis.

Another critical difference is the degree to which the studies take into account the relevant context and which intervening, mediating or interacting variables have been included in the analysis. For example, technology, market failures, international trade,

Figure 1. World Population Growth: Linear Scale vs. Ratio Scale



*Ratio scale shows constant percentage rate as a straight, upward-sloping line; linear scale shows absolute increases, so steady percentage growth rate appears to curve up.

Sources: Colin McEvedy and Richard Jones, Atlas of World Population History; U.N. Secretariat, World Population Prospects: The 1998 Revision; Census Bureau. Figure obtained from http://www.forbes.com/forbes/99/01/25/6302058chart1.htm.

economic growth, poverty and mobility are some of the factors that influence population-environment interactions, but are not consistently brought into the analytical frameworks and the empirical investigations of these studies. Left-out variables bias the results in one or the other direction, creating confusion for the reader. Ultimately, it is the attempt to understand and explain along disciplinary lines phenomena that span several disciplines, such as demography, ecology, sociology, anthropology, political economy, and economics, which is at the root of the disparity of perspectives, findings and policy prescriptions.

The purpose of this study is to review the literature on population and environment to identify the main strands of thought and the salient features and assumptions that lie behind them, and to guide the reader through what is a very diverse and confusing, yet rapidly expanding, field of study. We begin with a review of the historical perspective from Malthus and his capitalist and socialist critics, through Boserup's thesis and other neoclassical economists, to the recent ideological war between the "neo-Malthusians" and the "cornucopians." In section three, we review and assess the evidence on interaction between population and environment focusing on selected natural and environmental resources: land use, water use, local pollution, deforestation and climate change. The following two sections review selected recent macro and micro perspectives. The new macro perspective introduces the environment-income relationship (known also as the Environmental Kuznets Curve) and examines the role of population growth and density in mediating this relationship. The new micro perspective introduces the feedbacks between population growth, poverty and environmental degradation and examines the role of gender in decision-making and the role played by children as economic assets in fertility decisions in a world of market and policy failures. Finally, in section six, we carry out a comparative assessment of predictions, approaches and methods employed in the literature to explain the wide variation in findings and predictions. The study closes with concluding remarks.

2. Historical Perspective

The relationship between population and environment has a long history, although in different times it may have been expressed in somewhat different contexts, such as the relationship of population growth to governance (Plato and Aristotle), to food production (Malthus), to agricultural growth (Boserup), to resource availability (Neoclassical economists, Simon), to pollution (Meadows), and to land degradation (Blaikie and Moore). Development economists have long been concerned about the impact of population growth and related demographic transition on the rate of economic growth, while neoclassical economists sought to redress the classical economists' concern of whether it is possible to maintain an increasing or even steady standard of living in the face of finite resources and a growing population. In more recent years, questions have been raised regarding the effect of population growth on climate change and on biodiversity loss. In addition to the effects of population growth on global resource availability, on the global environment and on the prospects for continued growth of the world economy, there are also serious concerns as to the effects of population growth on local resources such as soil, water, forest, fisheries, pastures and the urban environment.

In what follows, we will first review the historical perspective leading up to the modern debate on population and environment, from the utopians through the Malthusians and neo-Malthusians to the cornucopians.

2.1 The Utopians

The utopians have their roots in ancient Greece where the need to balance population with resources was taken for granted and pursued through a policy of progressive colonization of new areas. The utopian view of zero population growth was recommended by Plato in his Republic; Aristotle viewed a populous city as too hard to govern. The modern population debate began in 1761 with Robert Wallace, who in his *Various Prospects of Mankind, Nature and Providence*, wrote about an egalitarian utopia that would self-destruct through overpopulation. Wallace's argument was that an egalitarian society, while otherwise desirable, would lead to a decline in infant mortality (as children are better cared for in such a society), leading to growth of population beyond the earth's capacity to support it. Wallace did not expect population to be controlled by famines, but by violence and war, caused by conflict over socially intolerable rules to control population growth. William Godwin in 1793 responded to Wallace through his *Inquiry Concerning Political Justice* by arguing that "The number of inhabitants in a country will perhaps never be found in the ordinary course of affairs, greatly to increase beyond the facility of subsistence." Even if it did, he argued, the earth could support increasing populations for many centuries; he saw no reason to "conceive discouragements for so distant a contingency." To the contrary, he saw a progressive weakening of people's "eagerness for the gratification of the senses" and propagation, and the end of selfishness, injustice, crime and war. Godwin's utopian optimism provoked the response of Thomas Malthus, five years later (1798), in his *Essay on the Principle of Population.*

2.2 Malthus and Ricardo

Malthus argued that population grows geometrically, while food production can only grow arithmetically. Therefore, population growth will ultimately outstrip the ability of the economy to meet the demand for food. Since food is essential to survival, the shortage of food would keep a check on further population growth, through disease and death of excess members among the lower classes, and late marriage or no marrying at all by the middle class. To understand Malthus' dire prediction, it is important to consider (a) his cynicism about human beings, which he viewed as "inert, sluggish, and averse from labor, unless compelled by necessity," and (b) his social status as a son of landowners, writing from a position of threatened privilege on the heels of the French Revolution and growing demands for radical reform in Britain. His theorem was meant to prove the impossibility of all schemes to improve the lot of workers or to redistribute income. He concluded that inequality (indeed poverty) was inevitable and useful, as an incentive for work by the poor and benevolence by the rich.

Five years later, in a second edition, Malthus virtually reversed his views, stressing the power of self-control among all classes and arguing that, if this is practiced, population growth need not outpace food supply, in effect anticipating family planning. Furthermore, he argued that "an increase in population, where it follows its natural order, is both a great positive good in itself and is absolutely necessary to a further increase in annual production of the land and labor of any country", in effect anticipating (and endorsing) the cornucopian view of almost two centuries later.

However, it is his earlier views, as appeared in the first edition, that are remembered and have become the Malthusian school of thought on population. Following Malthus, the classical economists stressed the difficulty of sustaining a rising (or even steady) standard of living with finite resources and a growing population. In 1817, Ricardo, in *The Principle of Political Economy and Taxation*, advanced the "iron law of wages" according to which, wages can never rise above (or fall below) the minimal level required for the subsistence of workers and the children needed to replace them.

2.3 The Socialist and Capitalist Critique: From Karl Marx to Henry George

The Malthusian view, as expressed in Malthus' first edition of his essay on population, was heavily criticized by both socialists and capitalists, for different reasons. Karl Marx called Malthus' essay a "libel on the human race," and argued that "overpopulation" was the outcome of the laws of capitalism, not the laws of nature. It was not a true overpopulation, but a surplus of unemployed laborers created by capitalism's investment in machinery. Engels wrote that "the pressure of population is not upon the means of subsistence but upon the means of employment; mankind could multiply more rapidly than is compatible with modern bourgeois society."

Henry George, on the other hand, in his *Progress and Poverty* (1879), saw population growth as a source of wealth and overpopulation not as a cause but a consequence of poverty. The real causes of poverty are unjust laws, warfare, excessive rents, and insecure land tenure, which condemn people to be poor in the midst of wealth and to have more children than the rich. He attributed famines to oppressive governments and extortion by landlords, rather than any imbalance between population and food production.

According to Henry George, population growth and population density are catalysts of wealth through increased cooperation and specialization: extra labor results in extra productivity of land and this results in extra food, more than sufficient to feed the extra population; hence the Malthusian prediction of overpopulation and famines does not occur as long as there are no distortions that prevent the productive application of the extra labor to land.

Of course, as an American, Henry George had a different perspective than the European writers: land abundance versus severe land scarcity. Ricardo and other classical economists were concerned that the law of diminishing marginal productivity would inevitably result in decline in per capita incomes, as successive increases of labor applied to a fixed factor (land) result in the marginal product of labor falling below the average product. George, writing from the perspective of a land-abundant, labor-scarce environment, saw population growth as a source of economies of scale and specialization, rather than as a source of diminishing marginal productivity.

2.4 The Boserup Thesis of Induced Innovation

Almost a century later, George's ideas found fertile ground in Ester Boserup's seminal book *The Conditions of Agricultural Growth*, which turned Malthus on his head by suggesting that it is not the growth of agriculture (food) that determines population growth but the reverse: population growth determines agricultural growth. Boserup (1965, 1976, 1980) discussed how, in response to greater population density and lower yields, farmers, who began as shifting cultivators, reduced their fallow periods and began to use the plow, manure, crop-rotation, irrigation, and multiple cropping to maintain and increase crop yields (see Table 1). These developments, which help keep food production apace with population growth, would not have taken place without the pressure of population growth: all of them involved more labor, and people would not have used more labor if they were not compelled by population growth. She argued that communities with sustained population growth have a better chance for genuine economic development through technological innovation and substitution than communities with small and stagnant populations, which are unlikely to advance much beyond primitive agriculture. Boserup recognized that land degradation may take place as fallow periods are excessively shortened or hills are cultivated but she argued that terracing, fertilizer, and other technological advances could limit the damage.

Table 1. Boserup: Agricultural Systems and Population Density

System	**Description**	Population Density (Persons/km^2)
1. Gathering/ Pastoralism	Wild plants, roots, fruits and nuts gathered Possibly domestic animals	0-4
2. Forest-fallow	1 or 2 crops followed by 15-25 years fallow	0-4
3. Bush-fallow	2 or more crops followed by 8-10 years fallow	4-64
4. Short-fallow	1-2 crops followed by 1-2 years fallow	16-64
5. Annual Cropping	1 crop each year with few months fallow	64-256
6. Multi-cropping	2 or more crops in same fields with no fallow	>256

Source: Boserup, 1981, p. 9, Table 3.2, p. 19 and Table 3.7, p. 23.

2.5 The Neoclassical Economists

The Boserup thesis was subsequently extended to the industrial revolution (Boserup 1980), and formed the backbone of the neoclassical approach to population growth and development. Neoclassical economists (like the classical economists) are concerned with whether economy can sustain a rising (or even steady) standard of living, given finite resources and a growing population. But unlike their predecessors, the neoclassical economists, in order to determine whether output growth can keep pace with population growth, examine the extent to which technological progress and substitution of scarce factors with more abundant ones can offset diminishing marginal productivity resulting from fixed factors. As land resources become increasingly scarce, land prices will rise and incentives will thus, increase for people to (a) substitute more abundant resources such as labor, fertilizer and irrigation for land; and (b) to develop new technologies (such as high yield crop varieties) to increase yields from existing land (intensification), as well as to farm previously unused land (extensification). The key assumption here is that markets are well-functioning, in the sense that neither market failures (insecure property rights; pervasive externalities) nor policy distortions (e.g. taxes on intensification inputs) constrain efficient response. Furthermore, the public-good aspects of new agricultural technologies[1] call for a certain level of public sector involvement in or subsidization of the development and dissemination of new agricultural technologies in response to a growing land scarcity.

Under the neoclassical paradigm, population growth may lead to land degradation and retard agricultural growth, if markets are inefficient or distorted and/or the technological and substitution responses lagged significantly behind population growth. For example, artificially low producer prices and insecure land tenure rob the farmers of the incentives to practice soil conservation or to intensify agricultural production, while subsidies for forest land clearing has made it (artificially) profitable for people to settle in the Amazon or on Indonesia's outer islands where agricultural production is not sustainable. Removal of policy failures without concurrent correction of market failures may not reduce environmental degradation; for example, removal of kerosene or fertilizer

[1] Some new agricultural technologies (e.g. seed selection, biological pest control, etc.) may be regarded as private rather than public goods. See Umali and Schwartz (1994).

subsidies may accelerate deforestation if the relevant externalities are not also internalized. Even if markets are not distorted, it takes time for farmers and governments first to perceive and then to react to growing land scarcities by developing or adopting more efficient and sustainable technologies: lagged response to population-induced resource scarcities in this case results in land degradation rather than in land improvement and intensification.

2.6 The neo-Malthusians

The neo-Malthusian school of thought was launched in 1968 with the publication of *The Population Bomb* by American ecologist Paul Ehrlich. He termed over-population as the biggest threat to terrestrial life that the planet faces, short of a thermo-nuclear war, and predicted vast famines sometime between 1970 and 1985; he supported compulsory measures to control population and opposed food aid to poor and populous countries such as India where "the unbalance between food and population is hopeless."

Under conditions of high infant mortality, ensuring that a child is alive to provide care and sustenance when the parents are old raises the demand for children above the number dictated by the "children as ends" motive. Considering further that in many societies daughters are considered a net drain on household resources, or, in any case, insufficient security for old age, the strive for sons results in a larger number of children being desired than otherwise. May and Heer (1968) estimated that in the 1960s, an Indian couple needed to have 6.3 children to have a virtual certainty that a surviving son would be available as a source of old age security, when the father reaches 68.

Ehrlich's apocalyptic views were richer in rhetoric than in evidence. *The Limits to Growth*, published four years later by Dennis Meadows and his fellow Club of Rome members attempted to provide the evidence that Ehrlich (1968) lacked. They used a systems dynamics computer model with feedback loops to simulate likely futures of the world economy in terms of population, resource use, food, industrial output and pollution. They predicted that, under a business as usual scenario, there will be a dramatic shortage of mineral and land resources early in the 21st century leading to a catastrophic collapse of the population by the year 2025 and a dismal existence of any survivors. Alternatively, more optimistic scenarios did not fare much better: the growth of population and output always overshot the earth's carry capacity either in terms of resource availability or in terms of assimilative capacity for waste. With growing population against fixed land resource, it is a matter of time (a few decades) before the limits of arable land are reached and agricultural production per capita declines leading to famines. Even if, somehow, food yields are raised, the rise of industrial output will exhaust energy and mineral resources leading again to a collapse; and even if this is somehow avoided expanded industrial production would generate pollution levels beyond the earth's assimilative capacity, leading again to a collapse, within a century.

The dire predictions of the *Limits to Growth* is the direct consequence of the assumptions that went into the model: (a) fixed carrying capacity in terms of resource availability and assimilative capacity for waste; (b) exponentially growing population; (c) no technological change; (d) no substitutability of more abundant resources for more scarce ones; (e) no prices that rise with scarcity and induce substitution and technological innovation; and (f) no income effects and structural changes and related feedback systems. As a consequence of these assumptions, there is no smooth transition, no gradual slowing down of resource use as scarcity increases; the world consumes successively larger amounts of depletable resources until they are all gone. Under these assumptions, their doomsday prediction was mathematically inevitable. Only one avenue of escape was left open: stabilization of population at 1970 levels (a virtual impossibility given the demographic momentum), a massive reduction of resource use and pollution per unit of output, de-industrialization of the world economy, a shift to solar energy and recycling of all wastes including sewage. The authors did not attempt to assess the political feasibility and economic and the social costs of the heavy-handed government intervention needed to bring about such a scenario of survival. Twenty years later, in a sequel to the 1972 book, Donella Meadows' *Beyond the Limits* attempts to correct some of the deficiencies of the *Limits to Growth* by allowing for technological progress and limited negative feedback loops from the economic to the natural system. However, the dominance of the positive feedback loops coupled with fixed limits on essential resources and exponential population growth and leads to the same doomsday predictions even somewhat modified in nature and timing.

2.7 The Cornucopians

Partly in reaction to the neo-Malthusians doomsday prediction, Herman Kahn and associates presented an alternative vision in their 1976 book *The Next 200 Years: A Scenario for America and the World*. The central thrust of this vision is the continuing evolution of technological progress and its ability to push back the resource limits until they are no longer constraining economic growth. They postulated an S-shaped logistic curve for population growth with the point of inflection around the mid-1970s. Looking backward from the mid-seventies one sees exponential population growth but looking forward one should expect a continuing but steadily declining population growth. They expect population to level off by the middle of the 22nd century at around 15 billion people and average world income per capita to rise to $20,000 in 1975 constant dollars by the year 2176, implying an almost hundred-fold increase in world gross national product (GNP) from its mid-seventies levels. This contrast with the *Limits to Growth* prediction that continued economic growth is not only infeasible but it would lead to disaster and called for immediate limits to population and cessation of economic growth.

Two factors account for these widely diverging visions of the future. First, Khan and associates dispense with the idea of exponential population growth as a myopic extrapolation of recent trends. Second, they introduce technological progress that responds to approaching resource limits: as a certain limit is reached a new technology is introduced that either permanently removes the limit or buys time until a future technology can remove it. The supply of food is not constrained by fixed arable land, as in the case of the *Limits to Growth* model; instead, the availability of physical resources expands through better farming techniques, new higher yielding seeds, irrigation systems, and ultimately hydroponics, a farming process that uses no soil. Similarly, energy is ultimately derived from clear and inexhaustible solar power, once the limits of more conventional sources are approached to justify it economically. It is thus the replacement of the positive feedback loops of the *Limits to Growth* model by the negative feedback loops of *The Next 200 Years* model that largely accounts for the reversal of the results.

Khan and associates argue that in light of their vision it is both unnecessary and unethical to put any restrictions on either population or economic growth, condemning developing countries to poverty. Continued economic growth is possible and would benefit all, especially the poor.

Julian Simon, in his 1981 book *The Ultimate Resource* and the follow-up book on the *Theory of Population and Economic Growth* (1986), established the ultimate feedback loop between population size and human ingenuity that brings about technological progress in response to scarcity. According to Simon, human ingenuity is the ultimate resource; more people means more brains devising solutions to emerging problems. More people means more ideas, bigger markets, economies of scale, more specialization and easier communications and ultimately, more resources. Simon marshaled evidence showing that the real costs of non-renewable resources fell over time both in terms of wages and consumer prices, signaling increased rather than reduced resource availability. The same is true of agricultural land while pollution control measures are tightened over time as wealth brings about demands for a cleaner environment. It is not that shortages do not occur, but when they do, they are temporary and unleash human incentives that develops new superior substitutes and improved methods of production that leaves us better off after the shortage than before it. Thus, population growth provides both the incentive (higher costs of existing resources and promising benefits from substitutes) and the means (additional brains and ingenuity) for advancement that continuously pushes back resource limits and creates wealth. Simon went further to argue that more people are desirable not only from a production standpoint but also from a consumption perspective. Other things being equal (e.g. per capita consumption), the more people, the better. According to Simon, population growth permits us to achieve the greatest good for the greatest amount of human beings both existing and possible, thus extending Bentham's welfare rule[2] to those unborn.

The views of Herman Khan and Julian Simon are so optimistic that they came to be known as "cornucopia" and the extreme antithesis of the Malthusian and neo-Malthusian doomsday predictions. A third view, represented by Susan George, Piers Blaikie and Frances Moore Lappé, exonerates population growth from being a cause to being a symptom of deeper rooted problems of exploitation, expropriation, inequality and

[2] Jeremy Bentham founded the utilitarian school of moral philosophy, which considers the highest good to be the greatest happiness for the greatest number.

injustice perpetrated by colonialism, imperialism and multinational companies that conspire to keep poor people in perpetual poverty. The poor are forced to have large families so that the children can work and supplement the family income and support their parents in their old age. But since poor people are left with only small and marginal pieces of land, they are forced to overexploit them and to encroach on forest lands to supplement their income. Under these conditions, population growth, which is greater among the poor, results in deforestation and land degradation.

2.8 The Theory of Optimum Population

Yet another strand of thought postulates the existence of an optimum population. As population grows, two opposing forces are put into action: a) marginal and average labor productivity diminish as each person has a smaller share of land and natural resources to work with, and b) division of labor, specialization, cooperation and scale economies expand with a larger population. The optimum population is reached when these opposing forces exactly cancel each other. Optimum population is a dynamic, not a static concept, constantly being shifted by technology. As Wicksell (1920) put it: "The profusion of new discoveries and the growth of technical knowledge will most often, if not always, displace it." Cannan (1928 p. 61) was even more explicit about the dynamics of optimum population theory: "We have to treat the ideal or optimum in regard to population as being the right movement (i.e. increase or decrease) of population rather than define it in reference to particular point in time. The right movement is that which will give the largest returns to industry in the long-run, the interests of the people of all generations being taken into account."

Historically, the concept of optimum population dates back to the works of Plato and Aristotle, who postulated the existence of an ideal city size. John Stuart Mill (1848), Wagner (1893), Julius Wolf (1901, 1908), and Schmoller (1919) along with others have discussed the concept prior to Wicksell (1910) and Cannan (1928) who are credited with originating the concept independently.

Theoretically, the concept of optimum population has played an important role in models of economic growth. Earlier models, such as Dasgupta (1969), Meade (1955) and Lane (1977) treated population change as exogenous. More recent models, such as

Dasgupta (1984) and Nerlove, Razin and Sadka (1987), Schmitt-Rink (1989) endogenize population growth and dismiss population policy. Following the seminal contribution of Becker (1960, there has been a proliferation of microeconomic models of endogenous fertility and family size. In these models, different population sizes are optimal depending on what is being maximized: life expectancy, gross domestic product, income per capita or sustainable consumption (total or per capita). For example, Singer (1971) argued that there exists an optimal population size that maximizes income per capita. In practical terms, the concept has played a significant role in the discussion of the effects of population growth on land productivity. The concepts of over-population and under-population as applied to specific countries are derived from an implicit notion that there is (or must be) a population size that is optimal in the sense that it maximizes well-being or minimizes environmental impact and the like.

3. Population and Environment: Evidence of Interaction

Since there is no single satisfactory index of the state of the environment, the relationship between population and environment is usually analyzed in terms of individual resources or dimensions of environmental quality. The earlier debate from Malthus to Boserup was conducted in terms of food availability to feed a growing population. The debate of the neo-Malthusians versus the cornucopians centered on the availability of non-renewable resources such as minerals and fuels and the environmental quality threatened by industrial pollution. At present, the degradation of the global biodiversity and climate are receiving most of the attention. In what follows, we examine the evidence of interaction between population on the one hand and selected resources and pollutants on the other.

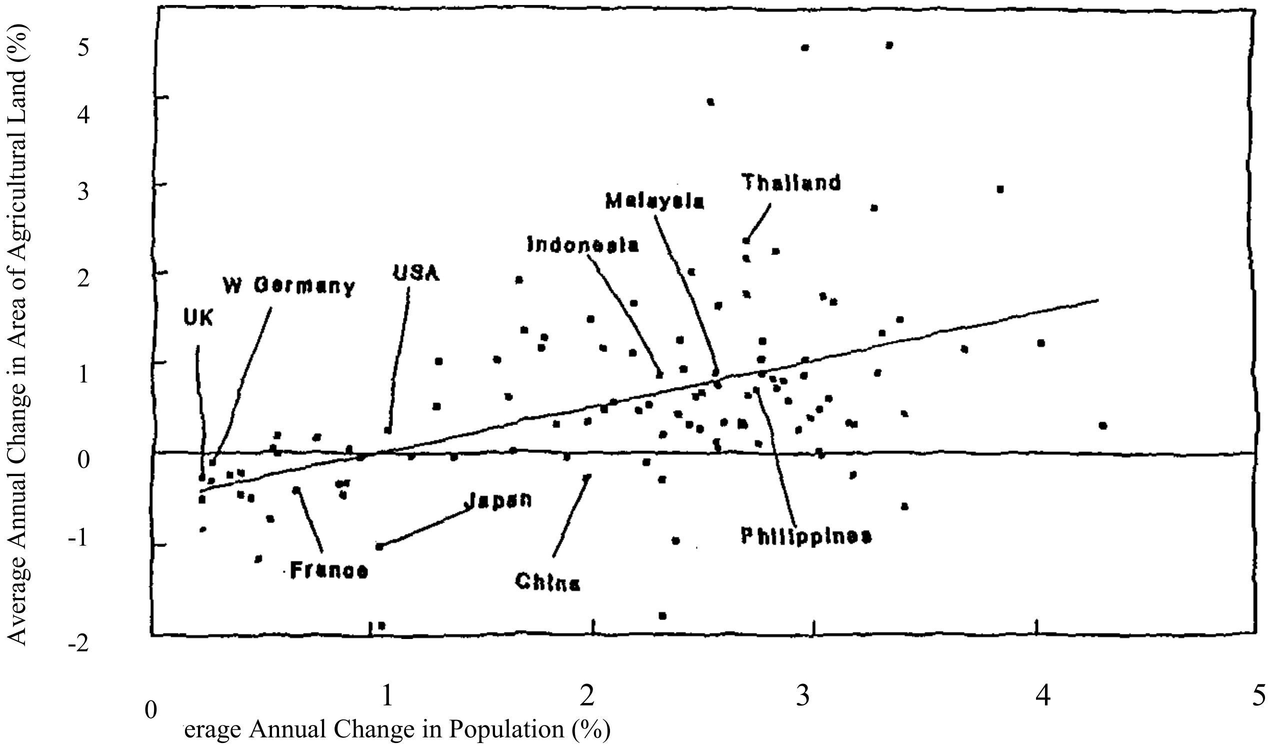
3.1 Population and Land Use

Population growth affects land use mainly through extensification and intensification of agricultural production. There is both historical and empirical evidence that different population densities and different population growth rates produce different land use patterns and changes over time. Analytically, more people need more food, which can come only from either expansion of agriculture into new lands, or use of existing agricultural land more intensively, or a combination of the two depending on relative costs, themselves a function of technological, institutional and ecological factors. Wolman (1983) presents historical evidence that land use patterns over the past 6,000 years are associated with the growth of human population. Until most recently, the increase in agricultural production needed to meet the needs of expanded population took place through the expansion of land under cultivation, the shortening of fallow periods and the application of more labor. Dramatic increases in agricultural productivity during the past 50 years have come from new biological and chemical technologies (fertilizers and new crop varieties), as well as from new mechanical technologies in land-abundant, labor-scarce countries (Hayami and Ruttan 1985). Technology has provided both the means to reduce land extensification and the capacity of man to alter the landscape, which has accelerated land use change (Burringh and Dudal, 1987).

Bilsborrow and Geores (1993) present cross-sectional evidence of a positive relationship between a country's population density and the percentage of the country's arable land that is used for agricultural production. Panayotou (1993) presents time series evidence of association between population growth and land use change over three decades (1960-1990) in Thailand. Evanson (1993) presents evidence from India that shows how population growth induced people to cultivate additional land as well as to use existing land more productively. Mink (1993) found some association between the average annual change in population and average annual change in the agricultural land area (see Figure 2). Tiffen et al (1994) and Tiffen (1995), using data on long-term trends in population and soil erosion in the Machakos district in Kenya, show that population density was the driving force in soil conservation and environmental recovery in the area. In the 1980s and 1990s, the district was sparsely populated and the inhabited area was treeless and "characterized by widespread erosion and degraded communal lands, leading to increasing poverty and frequent need for famine relief" (Tiffen 1995, p. 42). Between 1932 and 1989, there was a fivefold increase in the district's population; average density rose from 18/km2 in 1932 to 106/km2 in 1989. By 1990, all pasture land was privately owned and degraded; communal grazing lands were converted to arable land and terraced and trees were planted to shelter houses, to demarcate boundaries and to produce timber and fuel. "Photographs taken in 1937 and 1990 attest to the transformation of eroded, unproductive land into a manicured farm landscape" (Tiffen 1995).

However, while population growth almost certainly affects land use, population growth is only one of many factors that do so. Domestic and world markets for agricultural products also influence land use patterns, as do ecological and technological changes, land tenure systems, capital markets, government regulations, and tax policies. It is often the interaction of population growth with these factors, especially insecure land tenure, poor soil quality and vulnerable ecology that results in land degradation. In much of Africa, it is land held in common and without rules governing access, that is most adversely impacted by population growth. Yet Mortimore (1993) shows that even under such conditions, farmers in northern Nigeria adapted well to the doubling of their population. In the general case, however, clearly defined property rights and efficient labor and capital markets are key to translating expanding markets for agricultural products (whether driven by population growth or trade expansion) into incentives and measures for land improvement and soil conservation, that allows production growth without land degradation (Larson and Bromley 1990, Migot-Adholla et al 1993, and Jolly and Torrey 1993).

Figure 2. Agricultural Land and Population (Average Annual Change: 1961-87)



Source: Mink, S.D. (1993), "Poverty, Population, and the Environment," *World Bank Discussion Papers*, p. 25.

Much remains to be learned about the dynamic relationship between population growth and land use. Neither the research on resource limits nor studies that rely on cross-sectional data can capture the dynamics between population growth and land use change. Long-time series at the appropriate time and space scales are limited, and most time series analyses have established correlations rather than causality. For causality, it would be necessary to have both a more explicit theory of how population growth induces land use change, and to empirically control for all other factors that affect land use. Adequate attention needs to be paid to interactions (multiplicative rather than additive effects), time lags, and technical issues of endogeneity. For example, if land use change has significant income effects, it might result in changes in population growth rates, through changes in migration or fertility rates. Also better measures of land use change are needed, as well as more carefully constructed time series on land use variables. In recent years, remote sensing and geographic information systems (GIS) have dramatically improved our ability to monitor and quantify land use changes and construct appropriate time series for dynamic analysis of the relationship between population growth and land use.

While all land use changes constitute changes of the environment of the landscapes in which they take place, many such changes constitute welfare improvement as new uses produce a greater economic value than the ones they replace. From an anthropocentric point of view, land use change constitutes a welfare-reducing environmental change when (a) inferior land uses replace superior ones as it is likely to happen under conditions of open access e.g. tropical forests; (b) there are significant off-site externalities such as sedimentation of water bodies due to soil erosion or water contamination due to excessive or inappropriate use of agrochemicals; (c) land use change involves the loss of environmental services that are not accounted for, such as watershed protection, wildlife habitat or the increased vulnerability to natural disasters such as pest outbreaks, floods etc.; (d) future consequences of current land use change are discounted more heavily by private markets than it is socially optimal, such as the loss of biodiversity and the release of greenhouse gasses resulting from land use change or the emergence of more virulent strains of pests resulting from the increased use of chemical pesticides; and (e) the social justification that led to land use change have disappeared but land use cannot technically or economically be reversed (irreversibility).

It should be noted, however, that population growth, while a trigger of land use change, is not the root cause of the resulting environmental consequences. The root cause is to be found in market failures that prevent the full costs of land use change to register in the private economic calculus. Under conditions of inefficient or distorted markets any trigger (e.g. trade liberalization, technological change, increased export demand) would result in land use changes with environmental implications that are social welfare reducing.

Tracing out the contribution of human actions to environmental change arising from land use change is further complicated by long lags, the effects of natural (non-anthropogenic) processes and shocks, and the dynamism of landscape evolution. According to Wolman (1993) "the sequence of changes following disturbance and the duration of an apparently stable configuration are difficult to predict. As these disturbances interact with human activities, isolation of the significance of the one or the other influence is particularly difficult" (p. 25). Two other key concepts on which little information is available are the resilience (rebound) and recovery (reversal) of ecological systems following a change, whether anthropogenic or natural. While it is easy to establish the lack of resilience and recovery, and hence the irreversibility of erosion and soil loss on steep slopes as a result of farming without terracing, it is difficult to ascertain more subtle ecological changes brought about by land use change and to assess the likelihood of reversal.

To sum up, the historical record indicates that human population has significantly altered the natural landscape over much of the globe. Furthermore, there is evidence that land use change and demographic changes are correlated, but causality is more difficult to establish conclusively. The environmental consequences of past land use change (to the extent that they can be ascertained) have been significant but have not thus far diminished the capacity of land, aided by technology, to produce food at a rate faster than population growth, contrary to Malthusian and neo-Malthusian predictions. Sub-Saharan Africa has been the one region of the world where food production has not kept pace with population growth. The reasons are many and complex, including geography, history, economic policy, civil wars, but also characteristically environmental degradation and low levels of agricultural technology. However, even for the regions of the world that have fared well in the past, past experience cannot easily be extrapolated into the future for several reasons. First, the environmental consequences of past land use changes, such as possible climate change, may not have fully unfolded. Second, while population growth is slowing down, the magnitudes involved in absolute numbers of people are unprecedented in history: despite dropping fertility rates, a billion people were added to world population from 1987 to 1999--an increase equal to the total world population in 1804 (UN 1999). According to Wolman (1990), “Today the human capacity to alter the environment is on a scale equivalent to the forces of nature, a situation that did not prevail in the past.”

3.2 Population and Water Use

With over a billion people lacking access to clean water today, further population growth at the low UN population projection, would put additional pressure on accessible water resources and reduce the per capita availability of clean water and increase the numbers of those without access. This is particularly so because 90 percent of the projected population increase is expected to take place in poor developing countries where only two thirds of the population have access to clean water and the capital resources for further water development and distribution are scarce. Furthermore, in poor countries, where half the population is lacking sanitation and sewage facilities, water supplies are contaminated by disease-bearing human waste, as well as agricultural and industrial pollution. Use of polluted water spreads diseases and results in high mortality and morbidity. WRI (1995) reports that 1 billion people a year suffer from water-born diseases. Under these conditions population growth in these countries without significant investments in water supply and sanitation would not only reduce per capita water availability, it would also increase the contamination of existing water supplies and raise the cost of providing even the current level of access and quality. As surface waters become increasingly polluted, people are turning to groundwater aquifers, some of which are being drawn at rates faster than they can be replenished. Population growth will accelerate the depletion of aquifers both because of increased demand for water and because of further contamination of surface waters.

Additional quantities of water are also needed for crop irrigation and livestock to produce the additional food needed to supply a growing population. According to Falkenmark (1992), "A desired yield increase from 1 ton/ha to 4 tons/ha might well correspond with an increase in the return flow of water to the atmosphere from 1000 m^3/ha (100mm) to 4000 m^3/ha (400 mm) for a given crop. The question then is *whether the desired amount of water is indeed available.*" (p. 50). Most of the poorest countries where the largest increases in population are expected over the next 50 years (e.g. Africa and South Asia) are located in agro-climatic zones where part of the year is dry or where drought years are part of the climate. These areas also experience high rates of evaporation and low efficiency of rainfall and irrigation because of a dry and warm atmosphere; as a result they have a short growing season and suffer recurrent droughts imply a persistent crop failure risk. Growing population in these regions results in increasing withdrawals from surface sources with significant environmental consequences for in-stream uses and ecological functions and/or in pumping of ground water at unsustainable rates.

To the extent that population growth results in the clearing of forests, especially tropical moist forests, that serve as water catching areas, the hydrological cycle may be disrupted, rainfall diminished, usable water supply reduced, and destructive flash-floods increased. For example, Salati (1985) estimates that about 75% of the annual rainfall in the Amazon Basin is returned from the forest to the atmosphere; the loss of forest could reduce future rainfall. Mebar Homji (1985), based on a vegetation-rainfall study covering 29 stations for over 100 years, found that the number of indicators showing decreasing rainfall was association with the size of the area of deforestation. Somanathan (1991) attributes the increase of flooding in the Indian state of Uhar Pradesh, from 17,000 sq. km. in 1953-65 to 41,000 sq.km in 1976-78, to deforestation in the Himalayas. Vohra (1987) finds a strong correlation between upstream soil erosion and downstream flooding. Thus, land degradation, whether induced by population growth or not, may exacerbate water scarcity and other water-related problems, making it more difficult to meet the water needs of a growing population.

Not all water shortages are due to genuine physical scarcity of water. Indeed, countries with plentiful rainfall and surface water bodies such as Thailand, Indonesia and parts of China and India face severe and growing water shortages and inter-sectoral water-use conflicts. The cause of these problems is not population growth but mismanagement and wasteful use. In much of the developing world, free or heavily subsidized irrigation water destroys market signals, encouraging farmers to use water beyond its economic and agronomic optimum. Under-priced water stifles incentives to invest in maintaining and improving water systems, which are often plagued by poor drainage and inefficient distribution. For example, revenues from irrigation water charges in Bangladesh and Thailand cover only 10-20 percent of total costs of supplying water to farms (Rogers 1985).

Cheap water often becomes a substitute for other inputs, such as land improvement and soil conservation; over-irrigation, in turn, leads to water-logging, salinization and alkalization of soil. The Food and Agriculture Organization (FAO) estimates that fifty percent of all irrigated lands have been damaged by over-irrigation, which results in both on-site economic losses in terms of reduced fertility of irrigated areas and off-site environmental damages in terms of increased salt loading of return flow and aquifers. Furthermore, the irrigable area is reduced by water use inefficiencies. For example, it is estimated that a 10 percent improvement of irrigation system efficiency in Panama could save enough water to irrigate another two million hectares (WRI 1987). However, as long as farmers do not bear the true cost of water, they are unlikely to appreciate its scarcity or recognize the problems that arise from overuse. Until they receive clear market signals indicating otherwise, they will continue to use water wastefully. Where water is so wasted, there would be less room to accommodate more people, and any population growth would result in amplified water resource needs and magnified environmental consequences. While the correction of these market and policy failures is the first-best solution, when there are multiple distortions but only some (not all) can be corrected; we are in a second-best world, and direct control of population growth may be the best feasible possible policy alternative for dealing with the problem.

3.3 Population and Pollution

Other things equal, a growth of population results in growth of air and water pollution and solid waste. Some pollutants rise in direct proportion to population growth and others more slowly. The association between population growth and pollutant load is exemplified by New York City, where the population grew from 3 million in 1880 to 14.2 million in 1980. Waterborne discharges of organic carbon, nitrogen and phosphorus from human waste rose in direct proportion to population. Yet other developments, such as industrialization, large-scale agriculture development, and introduction of new products both complicate the picture and overshadow the effects of population growth. For example, phosphate-based detergents, introduced in the 1950s, were contributing by 1980 substantially more phosphorus to the New York region's surface water than human waste (Tarr and Ayres 1990).

Cole et al. (1993), in a study of 42 rivers found a close correlation between the level of marine pollution from nitrates and the level of population in the watershed and predicted a 55 percent increase in nitrate levels as a result of doubling population. While correlation does not imply causation, these results are fully consistent with the hypothesis that in the absence of effective mechanisms of internalization of externalities, population growth leads to increased waste generation. Given the absence of effective mechanisms to internalize the environmental costs of fertilizer use, sewage discharge and watershed disturbance and the direct and indirect subsidization of those activities, in many instances, it is not surprising that the larger the population, the larger the nitrate pollution. Yet the level of development, the structure of the economy and the strictness of environmental regulations do play a role (see below).

Further evidence of the population-pollution connection is provided by Mink (1993) who found that the growth in the use of nitrogen parallels worldwide population growth, although there are significant variations by country depending on land availability and quality, dietary habits and level of development. Since as much as 50 percent of applied nitrogen ends up in freshwater bodies and the sea, the author projects proportional increase in related water pollution problem with projected population growth into the foreseeable future. However, the fact that 50 percent of applied nitrogen leaches into water bodies and application efficiency is very low, suggests that there is enormous scope for increased efficiency and reduced application and related pollution problems. With full-cost pricing, proper application and related land use management, the growth of agricultural production, whether population driven or not, can be de-coupled from increased fertilizer use, which in turn can be de-coupled from increased nitrogen leaching and loading on water systems. This indeed happened in Japan, where application of nitrogen between 1960 and 1980 were reduced by 10 percent while agricultural production increased significantly (Smil 1991), and where ground water has not been affected by one of the world's highest fertilization rates, due to improved efficiency in fertilizer application and land-use management..

3.4 Population and Deforestation

The relationship between expanding human populations and receding forests, especially in the tropics, has received considerable attention, since forests play a key role in water and soil conservation, wildlife habitat, biodiversity protection and the carbon cycle, as well as being a source of raw material for the timber industry and livelihood for local communities. Each year, 70 million people are added to world population, mostly in developing countries and 15 million square kilometers of forests disappear. This led many people to postulate a simple displacement-model of "more people, fewer forests" (Allen and Barnes 1985, Myers 1987, Ehrlich and Ehrlich 1990, and Rudel 1991), but deforestation is a complex and dynamic process in which the role of population growth is neither static nor monotonic. In what follows, we critically review selected studies of the empirical relationship between population growth and deforestation and conclude that much more empirical research, with more sophisticated models, is necessary before we can fully understand the role of population dynamics (density, growth, distribution and composition) on deforestation in different socioeconomic contexts.

Southgate (1994) analyzed data from 24 Latin American countries to determine the causes of agricultural frontier expansion and hence of forest clearance. He found that the expansion of the agricultural frontier was positively correlated with both population growth and agricultural export growth and negatively related to the growth of agricultural yields. Cropper and Griffith (1994) used panel data for Asia, Africa and Latin America over the period 1961-88 to determine the causes of deforestation. The authors find an inverted u-relationship between deforestation and income and a positive relationship between deforestation and population growth and rural population density, but the latter relationship is not highly significant. Barbier (1996) analyzed pooled cross-section and time series for 21 countries in Latin America over the period 1980-85 to identify the key influences on forest clearance. He found that rural population density, along with roundwood production and agricultural yields, explained about half the variation in deforestation. However, the population elasticity of deforestation was relatively small: a ten percent increase in rural population density was found to result in a 0.36 percent increase in the annual forest area cleared. A proportionate (10%) increase in agricultural yields (reflecting largely technological change) results in three times as high reduction in deforestation (1.16%), suggesting that a plausible increase in yields can offset the effect of population growth on forest clearance. However, rising yields might not slow down deforestation if poor households are cultivating marginal lands that experience degradation and yield decline. Indeed, the positive relationship between rural population density and deforestation probably reflects the forest encroachment activities of migrating poor rural households in much of Latin America.

In a similar study of the causes of deforestation in Thailand's poorest region, the Northeast, during the period 1973-82, Panayotou and Sungsuwan (1992) found that population density was the most important factor leading to deforestation; other factors were poverty, wood price and agricultural yields. The dominance of population growth as a cause of deforestation should be expected in Thailand's poorest and most populous region. Both population density and population growth are relatively high, soil fertility is poor, most agricultural land is insecurely held, and non-farm activities are scarce. Forest encroachment for conversion to agriculture and progressive shortening of the fallow cycle from 10-15 years down to 4-6 years are two channels through which increasing population density leads to deforestation and reduced forest regeneration. Two other factors, artificially high fertilizer and kerosene prices, further exacerbated the effect of high population density on deforestation by acting as "taxes" on agricultural intensification and fuel substitution, respectively. A second study, Tongpan and Panayotou (1990), that extended the study period to 1988, found similar results: a ten percent increase in the rate of population growth was associated with a 3.3 percent increase in deforestation.

While it is tempting to conclude that at least in the case of Northeast Thailand, "population drives deforestation," the context must be kept in mind: open access forest resources, insecurely held agricultural land, lack of access to credit, scarcity of off-farm employment opportunities and low levels of education, all combine to prevent people from responding to growing population density, according to what Boserup (1981) would have expected. A more complete analysis should incorporate these factors and their interaction with population growth. This is illustrated by the results of a study of forty tropical countries (Panayotou 1993), which found that it is the strong interaction between population density and income per capita that determines deforestation rather than simply population density, suggesting that population density affects the environment differently at different stages of economic development. Indeed, a rerun of the models with the addition of 27 developed countries reduced substantially both the magnitude and the significance of the extent to which population density accounts for deforestation.

Table 2 below summarizes the results of selected deforestation studies that examined the role of population density and growth in deforestation. Most, but not all, find a positive relationship, some stronger than others. Westoby (1968) and Palo et al. (1987), however, found zero correlation, while Burgess (1991, 1992) found a negative relationship between population growth and deforestation. Inevitably, all these studies have their limitations. Palo et al., using a systems approach, argued that population as a causal factor of deforestation has to be analyzed within the relevant socioeconomic context, a point made earlier in relation to Northeast Thailand.

Table 2. Summary of Selected Deforestation Studies

Study	Unit of Analysis	Dependent variables	Independent variables	Methodology sample size
1. Lugo, Schmidt & Brown (1981)	Nation (regional)	% Forest Cover (% FC)	-0.001 population (pop), +0.001 energy use	C.S., Linear Regression 30
2. Allen & Barnes (1985)	Nation (global)	Deforestation rate (D.R.)	+ pop increase, + increase in farmland, +wood-use, -0.05 wood export in 1968	C.S., Linear Regression 39 Units from Africa, Asia and L.A.
3. Grainger (1986)	Nation (global)	D.R.	+pop increase, +area logged	C.S., Linear Regression 43
4. Palo, Salami and Geradol (1987)	Nation (global)	%FC	-pop density	C.S. Linear Regression 60
5. Rudel (1989)	Nation (global)	D.R.	+pop increase, +availability of capital	C.S. Linear Regression 36
6. Panayotou and Sungsuwan (1992)	Province (Nation)	%FC	-pop density, wood price	C.S. Linear Regression, 64
7. Scotti (1990)	Nation (global)	%FC	-pop density	C.S. Linear Regression, 47
8. Reis and Margulis (1990)	Municipality (Brazil)	%Deforestation	+pop density, +road density, +crop area	C.S. Linear Regression, 474
9. Burgess (1991)	Nation (global)	Level of deforestation	+pop growth, +GDP per capita, +debt service ratio as % of exports, +total roundwood production, food production per capita	C.S. Linear Regression, 44
10. Burgess (1992)	Nation (global)	Change in closed forest area	-pop density, real GNP per capita in 1980, -roundwood production per capita	C.S. Linear Regression, 44
11. Kahn and McDonald (1994)	Nation (global)	Deforested area	-pop, +forested land area, +annual change in public external debt	C.S., 2 Stage Linear Regression model, 54
12. Capistrano (1994)	Nation (global)	Depletion of broadleaf forests	+pop, +GNP per capita, -debt service ratio	C.S. Linear Regression, 45
13. Kummer and Sham (1994)	Province (Philippines)	Area deforested	-population, -road density	C.S. Linear Regression, 68
14. Chakraborty (1994)	Nation (India)	Reserved forest area	-livestock unit, -per capita income, -net rate return, -fuelwood and charcoal production	T.S., Linear Regression

Notes: C.S. = Cross section, T.S. = Time series, Nation (global) means unit of analysis is a nation, while the sample intends to cover deforestation on global scale.

Source: Saxena, A.K. and J.C. Nautiyal (1997). "Analyzing Deforestation: A Systems Dynamic Approach," *Journal of Sustainable Forestry*, Vol. 5, No. 3/4.

Kummer and Sham (1994) criticized earlier studies for failing to distinguish between the determinants of forest cover and deforestation, and to include initial conditions in the analysis. Other limitations pertaining to most of these studies is the use of static and linear specifications to analyze what is intrinsically a dynamic problem, involving non-linear interaction between factors and dynamic feedbacks. Saxena and Nautiyal use a systems approach to construct a dynamic model of deforestation. They find that both the number of people and their socioeconomic conditions have a significant impact on deforestation and conclude that "population has to be considered as a causal factor only in context of other factors and … that the role of the interactions among the factors of the system is crucial in driving the deforestation process" (p. 34).

3.5 Population and Climate Change

According to an expert panel convened by the National Academy of Sciences to consider the implications of climate change in 1992, "The more people there are in the world, the greater is the demand put on resources to provide food, energy, clothing and shelter for them. All these activities necessarily involve emissions of greenhouse gases" (NAS 1992). Newell and Marcus found a 99.8 percent correlation between world population growth and growing concentration of carbon dioxide in the atmosphere during the period 1958-83 and called it the "nearly perfect" correlation.

Figure 3 depicts a very close association between CO_2 emissions and population during the past 130 years. However, even a nearly perfect correlation does not imply causation. Otherwise, we would expect countries with large population such as China and India to have the highest greenhouse gas emissions, yet the US, with only 4% of the world's population, accounts for 23% of the world's total greenhouse gas emissions.

Clearly, per capita resource consumption, which is a function of per capita income, is another major determinant of greenhouse gas emissions, but there is little agreement among analysts as to the relative importance of population growth and economic growth. Moreover, many other factors, such as climate, geographic location *vis a vis* the coast, socioeconomic systems, energy prices, degree of urbanization, domestic energy endowments and many other factors influence a country's level of CO_2 emissions.

To apportion the contribution of population growth to greenhouse gas emissions, Holdren (1991) used a simple mathematical formula:

$$I = P \times A \times T$$

where I = environmental impact, in this case CO_2 emissions

P = population

A = affluence or per capita consumption level (consumption/population)

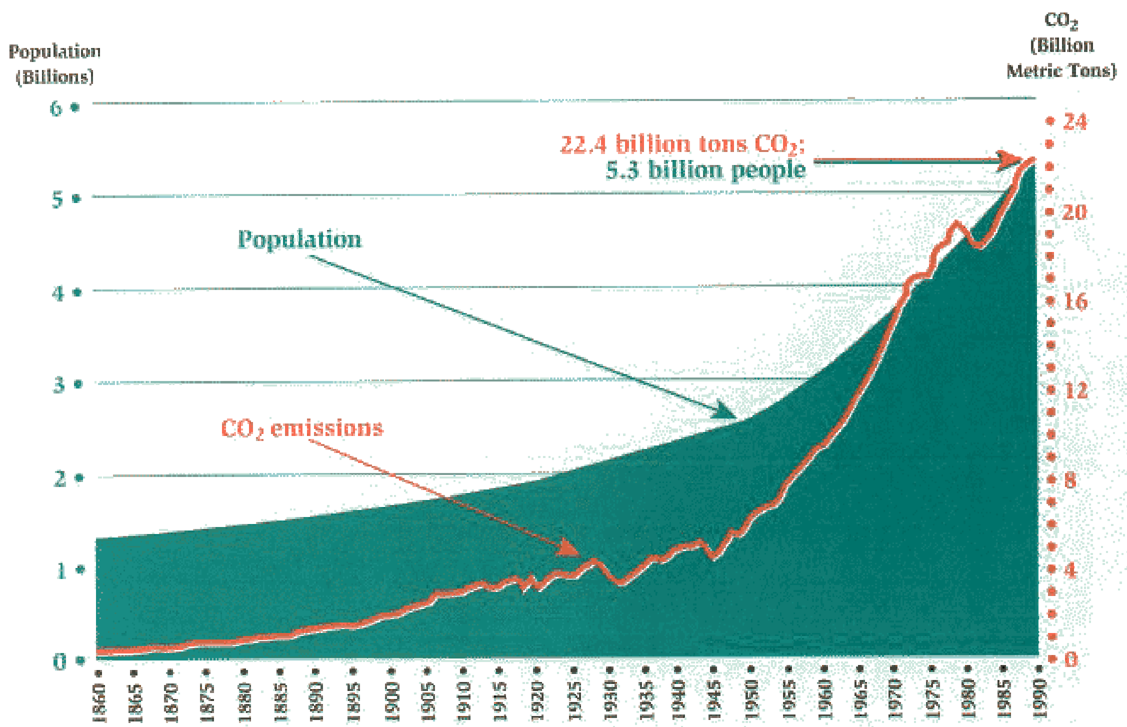
T = per capita pollution produced by the technology use in that consumption (emissions/consumption)

Holdren calculated that over the past two centuries, population growth was responsible for 40 percent of the increase in energy consumption, including traditional fuels. Harisson (1994), using the same methodology, attributed 36 percent of the annual emissions growth between 1965 and 1989 to population growth and 64 percent to per capita consumption of energy, while technology helped offset part of the emissions growth.

Birdsall (1992) analyzed the relative costs of mitigating CO_2 emissions by various means including carbon taxes to reduce fossil fuel consumption in developed countries. She concluded that developed countries can more cost-effectively reduce global CO_2 emissions by helping developing countries reduce their population growth through "family planning and girls' education."

Lutz (1993), on the other hand, taking into account regional differences in population growth, energy consumption and deforestation found a smaller role for population growth in the total growth of industrial CO_2 emissions and a larger role for population growth for CO_2 and methane emissions from land use changes. Others have argued that, regardless of the relative role of population growth in the growth of greenhouse gas emissions, any policy to slow down climate change must focus on consumption patterns rather than population control, because the "demographics dynamics are subject to greater inertial forces than consumption and production patterns" (Rahman et al 1993).

Figure 3. World Population and Carbon Dioxide Emissions 1860-1990



Source: Population Action International, "Considering Population's Role," http://www.cnie.org/pop/CO2/consider.htm.

The I = PAT equation approach to climate change analysis is subject to many limitations, pointed out by Lutz (1992,1993), Engelman (1998) and others. First, since the trends of population and consumption varied widely over time, the results are very sensitive to the selection of the starting and ending dates of analysis. Second, the right-hand side variables (population, consumption and technology) interact in complex ways that are not captured by the equation. More importantly, the equation lacks behavioral context and is prone to inappropriate aggregation of diverse behaviors. Projections forward ignore underlying structural changes and compound the uncertainty inherent in the three multiplicative factors.

Bongaarts (1992) made an effort to take into account the structure of the economy and the energy mix; in addition to population size and income per capita, he also included carbon emitted from net deforestation (net of carbon sequestration by growing forests):

$$T = P \times G \times E \times C + D$$

where T = total annual carbon emissions

P = population size

G = GDP per capita

E = energy intensity of GDP (per unit of GDP)

C = carbon intensity of energy use (per unit of energy)

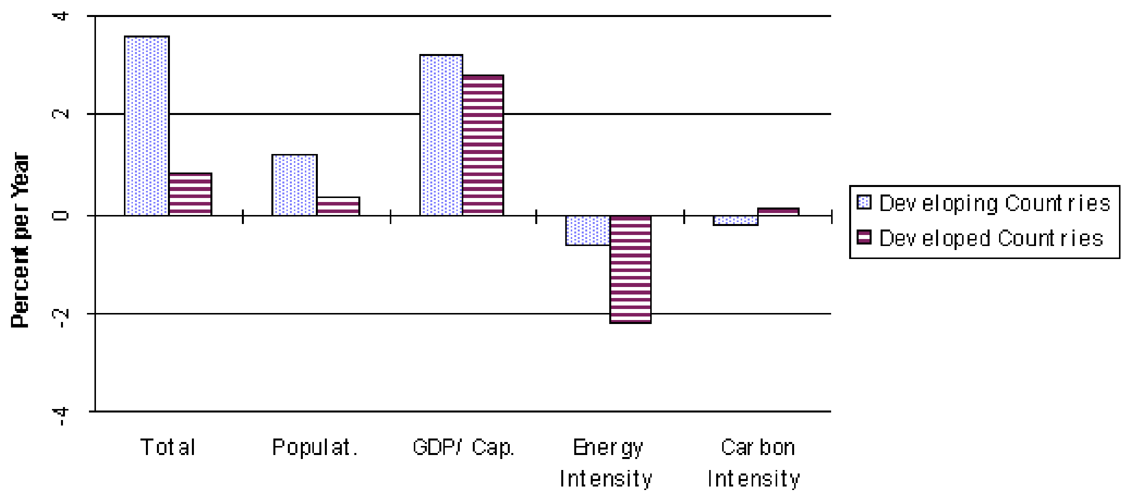
D = carbon emitted from deforestation

Based on projected world population growth from 4.8 billion in 1985 to 10.5 billion by the year 2000, GDP per capita growth from $3,000 to $36,000, energy intensity decline by 50%, global carbon intensity constant and a decline in carbon emissions due to deforestation from 12% to 3% by the year 2100, he projected a 7-fold increase in total CO_2 for developing countries and a 3-fold increase for developed countries. The relative contributions of the different factors are shown in Figure 4. Population growth, which accounts for about a third of the overall global increase in emissions between 1985 and 2100, is far more important in developing countries, where it is projected to contribute

53% of CO_2 emissions, while in developed countries its contribution is only 16%. In terms of policy, the author includes population control as part of a policy package to control climate change but he also recognizes the "demographic inertia" and emphasizes the rapid transfer of low-carbon technologies from developed to developing countries.

Econometric studies aiming to explain variations in CO_2 emissions over time and across countries have generally assumed that CO_2 emissions are proportional to population and have sought to understand the relationship between emissions per capita and GDP per capita, while controlling for country and time fixed effects (Schmalensee, Stoker and Judson 1998, Holtz-Eakin and Selden 1995, Galeotti and Lanza 1999 and Panayotou, Sachs and Peterson 1999). These studies have found an inverted U-shaped relationship between CO_2 emissions per capita and GDP per capita (usually in purchasing power parity terms), and use the coefficients so obtained to forecast total emissions by projecting GDP growth and using the UN population projections. We know of no studies that have attempted to estimate the population elasticity of CO_2 emissions, but some preliminary estimates by this author suggest that this elasticity may differ between developed and developing countries (1.0 versus 1.3). This might be due to population-induced structural changes in energy use or urbanization that more than offset any scale economies, or may be just simply due to left-out variables. This is an area that warrants further research.

Figure 4. Determinants of growth of CO_2 emission from fossil fuels



Source: Tonalee Carlson Key, "The Effect of Population on Global Climate Change," http://www.cnie.org/pop/intros/globalclimate2.htm.
McEvedy C. and R. Jones (199) Atlas of the world population history; UN Secretariat, *World Population Prospects: The 1998 Revision*; Census Bureau. Figure obtained from http://www.forbes.com/forbes/99/01/25/6302058chart1.htm

4. New Macro Perspectives and the Environmental Kuznets Curve

The 1990s have seen the advent of the Environmental Kuznets Curve (EKC) hypothesis and an explosion of studies that tested it for a variety of pollutants. The EKC hypothesis postulates that environmental quality deteriorates with income growth in earlier stages of development, reaches its lowest point at an intermediate level of per capita income and improves at higher income levels. Expressed as a relationship between environmental degradation or emissions (SO_2, PM, CO_2, etc.) and income per capita is also known as the inverted U-shaped environmental-income relationship. The reasons behind this non-monotonic relationship have to do with structural changes in the economy (from agriculture, to industry, to services) along the course of economic development. Furthermore, economic growth brings along two opposing forces: a larger scale of economic activity that increases pollution levels, and growth in incomes that raises the demand for environmental quality and the willingness to pay to bring it about. Population growth and/or population density is included in some of the studies that aim to test the environment-income relationship, either as a control variable or in order to examine its interaction with income in influencing emission or environmental quality. We will first review the main EKC studies and then examine more closely those that include population variables.

Grossman and Krueger (1994) estimated EKCs for SO_2, dark matter (smoke) and suspended particles using GEMS (Global Environmental Monitoring System) data for 52 cities in 32 countries during the period 1977-88, and in per capita GDP data in purchasing power parity (PPP) terms. For SO_2 and dark matter, they found turning points at \$4000-\$5000 per capita; suspended particles continually declined at even low-income levels. However, at income levels over \$10,000-\$15,000 all three pollutants began to increase again, a finding which may be an artifact of the cubic equation used in the estimation and the limited number of observations at high-income levels.

Shafik and Bandyopadhyay (1992) estimated EKCs for 10 different indicators for environmental degradation, including lack of clean water and sanitation, deforestation, municipal waste, and sulfur oxides and carbon emissions. Their sample includes observations for up to 149 countries during 1960-90 and their functional specification log-linear, log-quadratic and logarithmic cubic polynomial functional forms. They found that lack of clean water and sanitation declined uniformly with increasing incomes and over time; water pollution, municipal waste and carbon emissions increase; and deforestation is independent of income levels. In contrast, air pollutants conform to the EKC hypothesis with turning points at income levels between $300 and $4000. Selden and Song (1994) also found that three air pollutants, SO_2, NOx and SPM conform with the EKC hypothesis, with turning points at income levels in the range of $8,700 to $11,200 per capita (in PPP terms). Panayotou (1993), using cross section data and a translog specification, found similar results for these pollutants, with turning points at income levels ranging from $3000 to $5000. (The lower figures are due to the use of official exchange rates rather than PPP rates). Panayotou also found that deforestation also conforms to the EKC hypothesis, with a turning point around $800 per capita. Cropper and Griffiths (1994), on the other hand, using panel data, obtained a turning point for deforestation in Africa and Latin America between $4700 and $5400 (in PPP terms). Finally, Cole et. al. (1997) have examined the existence of EKC for a wide range of environmental indicators and concluded that "meaningful EKCs exist only for local air pollutants, whilst indicators with a more global, more indirect, environmental impact either increase with income or else have high turning points with large standard errors."

EKC studies attempt to control for other influences on environmental quality, either by direct inclusion of other variables in the reduced-form equation or by employing country (or country and time) fixed-effect estimators. Here, we will briefly review the role played by the population variable in influencing environmental quality along the path of economic development in selected EKC studies. Panayotou (1993) found that higher population density delays the turning point at which further income growth slows down deforestation, while Panayotou (1997) found that population density raises the height of the EKC for SO_2 at every level of income. In the latter study, the relationship between population density and SO_2 emissions was found to be highly non-linear, with higher impacts at low and high densities.

Vincent (1997), in a study that tested and rejected the EKC for total suspended particulates (TSP) in a single country (Malaysia), found that the net impact of population density on TSP concentration was positive, which he attributed to the fact that "household activities like cooking and heating, rubbish disposal and transportation are important sources of particulate concentrations" (p.425). Vincent also found a negative interaction term between population density and time, indicating a downward pressure on population-driven TSP concentrations by the mere passage of time, which he attributes to increasingly effective anti-pollution regulations. The same study found analogous results for water quality: holding income constant, higher population densities were associated with worse water quality as measured by biological oxygen demand (BOD), and ammoniacal nitrogen (which reflect the growth of sewage discharge) and better quality as measured by suspended solids (which probably reflects the movement of people out of rural areas). The interaction between population density and time was again negative for the first two pollutants, reflecting more effective regulations over time pertaining to BOD discharges by palm-oil mills and reduction of the percentage of population without access to sanitary facilities.

Selden and Song (1994) have also tested the relationship between population density and airborne emissions while holding income constant. They found a negative relationship, which they attribute to the likelihood that in countries with low population densities, there will be less pressure to adopt stringent environmental standards; moreover, emissions due to transportation are likely to be higher. Their econometric results suggest that an additional resident per hectare would lower per capita SO_2 by 12-15 kgs, SPM by 3-5 kgs and CO by 10.3-16.2 kgs (per person). This density effect tends to partially affect the scale effect of population growth. Indeed, with the exception of SPM, their models with population density forecast global emissions to peak and turn down earlier and at significantly lower levels than models without population density. For example, SO_2 emissions (in the fixed-effects baseline) are projected to peak by the year 2046 at 144% above 1986 levels, when growing population density is considered, rather than in the year 2085 at 354% above 1986 levels, when population density is not considered. Population density, however, changes along the course of socioeconomic development. As Stern et al. (1996) pointed out, societies tend to go through a process of increasing and then falling urban population densities as they develop." This trend may result in redistribution of pollution with ambient concentrations falling, even while emissions may continue to rise.

A word of caution is in order. Most EKC studies analyze cross-sectional data to obtain results that are interpreted as if they are obtained from a time-series analysis; that is, as if they revealed what happens to the environment as income is increased in a representative country. This involves a certain leap of faith that dictates caution in the use of these results.

5. New Micro Perspectives of Population Growth, Poverty, and Environmental Degradation

The new micro perspective focuses on people in rural communities in the poorest regions of the world, such as Sub-Saharan Africa and the Indian sub-continent, and identifies situations in which population growth, poverty and environmental degradation are entangled in a mutually reinforcing vicious circle. It begins with the "new economic demography," which regards population growth as endogenous and seeks to identify the determinants of fertility behavior by focusing on the decisions made by individual households and their motivations. In contrast to those that argued that the high fertility in the world's poorest regions is the consequence of an unmet need for modern birth-control devices (e.g. Robey, Rutstein and Morris 1993), the new economic demography postulates that parental demand for children can best explain reproductive behavior (Schultz, 1993). However, this new approach, which has its roots in the seminal contribution by (Baker 1960) has been criticized as incomplete by Easterlin (1975, 1978), Easterlin et al (1980) and Dasgupta (1995). According to Easterlin and Easterlin et al, reproductive behavior depends not only on the demand for children but also on potential family size and the costs of fertility regulation. Potential family size is considered a function of demographic as well as socioeconomic factors. Fertility control depends on the excess of potential family size over desired family size and on the costs of fertility regulation. While this approach gives a more complete description of actual fertility behavior than the demand for children alone favored by the new economic demography, its empirical testing is constrained by the lack of adequate data. Perhaps more central to our subject matter, the population-environment nexus, is the critique by Dasgupta (1995). First, he argues that the new economic demography treats the household as a monolithic unit, having a unitary view of wellbeing and making choices to maximize its welfare, while there is ample evidence of gender iniquities within rural poor household affecting the allocation of education, food, healthcare and other household resources. Second, the new household economics, which lies at the heart of the new approach, ignores the possibility that the individual optimizing decisions of a large number of households may result in collective failure, since the private benefits and costs of having children may differ significantly from their social benefits and costs.

The demand for children is determined by the benefits and costs of having children. However, if not all the costs and benefits of decisions are borne by the decision-maker, the decision may not be optimal. With regard to gender inequality within poor households, women bear a disproportionate share of the cost of having children (pregnancy, breast-feeding, daily care and risk of maternal mortality); yet in many traditional societies men are the decision-makers with regard to the desired number of children. These inequalities, reinforced and perpetuated by high rates of female illiteracy and low share of paid employment, lead to the similarity of women's professed demand for children to that of men's, despite substantial differences in the respective reproductive costs (Mason and Taj 1987). Dasgupta (1995), after surveying the evidence, concludes that "differences between the genders in the net benefits of having children are a key ingredient in the population problem facing both the Indian subcontinent and the Sub-Saharan Africa" (p. 1891).

Further evidence of the dependence of population growth on the net demand for children (rather than the available family planning services) was provided by Pritchett (1994) who regressed actual fertility on fertility desired, based on a sample of 43 countries from Asia, Africa and Latin America. Differences in desired fertility explained 90% of cross-country variations in total fertility rates.

Gender inequalities aside, what are the determinants of the demand for children and how does this demand affect the local natural resource base of the household and the community? Dasgupta (1995) proposed two hypotheses: children as ends and children as productive assets. The motive for having children as ends in themselves arises from the positive value that parents assign to children, e.g. reproducing the lineage, deriving direct utility, and obeying social or religious norms. Originally, such norms prescribing high fertility had a social purpose, when population densities were low and mortality was high.

Inertia, low educational level and imitative behavior may perpetuate high fertility rates even when mortality rates have dropped and the original rationale for the social norm has disappeared (Dasgupta 1993).

The motive for having children as productive assets has at least two dimensions. First is old age security in circumstances where old-age pension and social security are absent. Second, but equally important, is the role that children play in poor countries as income-earning assets. In much of rural South Asia and Sub-Saharan Africa and other poor areas of the developing world, households derive a good part of their livelihood from common property resources. Households do not have access to domestic energy and tap water. Fuelwood must be obtained from receding forests and water from distant and often dwindling water sources.

A variety of foods and other non-timber forest products, fish and fodder for livestock are also obtained from commonly-held resources. These activities are time consuming and require much labor. With little or no capital available and with receding natural resources, labor productivity is low, competition is strong and increasing effort is called for on a daily basis to ensure survival. Children are the main source of this labor. Once they are old enough (usually over 5) children would tend domestic animals, look after younger siblings, fetch water, fuelwood and fodder, help with land clearing and collect a variety of naturally occurring products (e.g. herbs, mushrooms, and medicinal plants) essential to the household's sustenance. According to the Centre for Science and Environment (1990), children between the ages of 10 and 15 work 50 percent more hours than adults in these activities, more than defraying the costs of their upkeep by the time they are 12 (Cain 1987). This role of children as productive assets has two critical implications. First, appropriation by capture makes the number of children the decisive instrument in the hands of the household: the household's share of open-access resources depends on the number of hands it employs to convert common property into private property. This is not unlike the case of common pasture, where each household's share depends on the number of animals it grazes. The rule of capture puts a premium on the deployment of as large a number of human hands (and animal mouths) as possible, to appropriate open-access resources before others do. In this context, children are a primary vehicle of resource capture and a major asset rather than a liability for the household. On the one hand, the availability of unappropriated resources open to capture raises the benefits of having children; on the other hand, the strong kinship support system of many traditional societies spreads the costs of raising children beyond the decision-making household, further increasing the net benefits from having them and raising the demand for larger families (Dasgupta 1995, Panayotou 1995).

The second implication of children as income-earning assets has to do with the social consequences of this household welfare maximizing demand for children. While having a large number of children exploiting the commons is optimal from the individual household's perspective given the open access regime, socially it is not optimal, and in the long run it is devastating for the resource, the community and eventually the individual household. Entry into common-access resources continues until excessive capture costs and damage to the resource dissipate all rents. In the approach toward this lower-level equilibrium, households may in fact respond by adding more hands to offset the declining labor productivity (Panayotou 1995, 1996). But since everyone is doing the same without consideration of the effects of one's increased effort on the average return of effort and the sustainability of the resource, degradation accelerates and people are trapped in rising poverty. This is not to imply that commonly-held resources were always a source of destructive competition; traditionally communities relied on social norms to protect their commons from over-exploitation, but economic and social change--including interference from the outside--have eroded traditional controls (see Ostrom 1991). Under these conditions, fertility, poverty and environmental degradation reinforce each other in a positive feedback that creates a vicious circle of growing population and deteriorating social and environmental conditions (Dasgupta 1995). Indeed, Cleaver and Schreiber (1992) found evidence of this happening in Sub-Saharan Africa, where poverty, fertility and environmental degradation are positively correlated.

It is tempting to conclude that having a large number of children (and hence population growth) is the cause of over-population and degradation of resources. However, there is clearly a question here of cause and effect. The decision to have an extra child is dependent on the expected benefits, a major part of which is the capture and the appropriation of open-access resources for the household. Hence, the availability of unappropriated open-access resources as well as the advancing poverty as these resources become depleted may be thought of as causes of the demand for large families and hence of high fertility rates. However, even if we assume that population growth is not endogenous, there are many ways in which a household can accommodate extra members. It can intensify agricultural production by investing in land improvement, soil conservation, irrigation and other productivity-enhancing inputs (such as fertilizers), as the Boserup (1965) expected would happen. However, given the rural household's limited cash resources, such a response is predicated on the availability of and access to credit. But credit is often scarce due to interest rate ceilings, excessively costly due to high cost of monitoring and information,[3] and unavailable to small rural borrowers with inadequate collateral, especially when land is insecurely held. Repetto (1986) reports that lack of rural credit in Java has prevented upland farmers from undertaking investments and adopting technologies with long payback periods, such as stump clearance, land leveling, terracing, irrigation drainage and tree cropping. Cleaver and Schreiber (1994) report that government policies in Sub-Saharan Africa have kept food and fuelwood prices low, thereby reducing the incentives for the intensification of food and wood production. Bilsborrow (1979) has summarized the multiphasic responses to resource pressure and their determinants, as shown in Table 4.

To break the vicious circle of poverty, fertility and environmental degradation, a number of policies need to be implemented concurrently. Enhancement of education and employment opportunities for women would raise the opportunity cost of having large families as well as help break the "self-sustaining mode of behavior, characterized by very high fertility and low education attainment" (Dasgupta 1995). Providing affordable fuel and potable water will reduce the need for extra hands. Accessible family planning services for those who demand them will also be helpful. Finally, removing policy distortions that prevent an efficient household and community response to population growth and resource depletion is needed if population growth is to become a source of innovation and economic growth. The vicious circle may also be broken by policies that reduce the credit constraint, e.g. by promoting micro-credit schemes or creating off-farm employment opportunities.

[3] The high costs of rural credit may be also due to the high covariance in yield risk and in timing of depositing and borrowing (Binswanger and Rosenzweig 1986).

Table 4. Bilsborrow's (1979) Multiphasic Responses to Resource Pressure

<table>
<tr><th>Type of Possible Responses</th><th>Response</th><th>Determinants of Response</th></tr>
<tr><td>Demographic</td><td>Change in nuptiality
Decline in fertility</td><td rowspan="3">Level of Agricultural Technology
Social and Cultural Practices
Infrastructure and Development
Institutional Factors
Natural Resource Endowments
Policy and Political Factors</td></tr>
<tr><td>Economic</td><td>Intensification of Agriculture</td></tr>
<tr><td>Demographic-Economic</td><td>Out-migration</td></tr>
</table>

Source: Bilsborrow, 1979, p. 5 and 1992, p. 131.

6. Population-Environment Relationships: A Comparative Assessment of Predictions, Approaches, and Methods

6.1 Perspectives and Predictions

Our review of the population-environment debate and analysis reveals a tremendous variation in findings and their interpretation. One source of the variation is undoubtedly the different historical perspective or vantage point of the various writers. Clearly, Malthus (1798, 1803) did not foresee the technological advances of the last two hundred years, because he formulated his theory before the industrial and agricultural revolutions. Like classical writers and contemporaries, he assumed that land productivity was fixed. He also assumed that population would continue to grow exponentially at a constant rate, foreseeing neither the drop in mortality that attended the medical/public health revolution, nor the decline in fertility and demographic transition attending economic development. Given his perspective and assumptions, his conclusions follow: an exponentially growing population would eventually hit an absolute limit, the earth's capacity to produce food.

In contrast, Boserup (1965, 1976 and 1981), writing after both the agricultural and industrial revolutions, not only makes technological change central to her thesis, but she makes it endogenous and largely driven by population growth. Under this formulation, there is no possibility of famine, since technology advances in response to population growth, allowing food production to keep pace with population growth. The resource limits are constantly moving out and the Malthusian "carrying capacity" is no longer fixed but a moving target. Under the Boserup hypothesis, the only way that a Malthusian outcome can be obtained is by blocking all avenues of response or by assuming long leads between population growth and technological response. Indeed, the Neoclassical formulation of the problem, that extended Boserup's thesis to the industrial revolution, focuses on the existence of policy distortions and market failures as barriers to efficient response to emerging relative resource scarcities. A Malthusian outcome can be obtained from the neoclassical model if relative resource prices are prevented by market and/or policy failures to reflect the relative resource scarcities. In a dynamic formulation, a lagged response to population-induced scarcities can lead to the same outcome, which neoclassical economists would likely attribute to institutional rigidities and the failure of the public sector to internalize scientific and technological externalities.

It is more difficult to provide a "historical" explanation for the diametrically opposing "findings" of neo-Malthusians and the "cornucopians;" they are largely contemporaries analyzing the same body of evidence, yet they reach vastly different conclusions. The agricultural and industrial revolutions and the demographic trends attending both the medical revolution and economic development are part of the historical records for both schools of thought, but their interpretations differ. The neo-Malthusians focus on quantities; the cornucopians focus on prices. The former see growing populations, rising natural resource use and mounting pollution levels leading to eventual collapse; they see only positive feedbacks. The latter see advancing resource-saving technology (through both efficiency improvement and substitution), falling relative resource prices and improving living standards; they see only negative feedbacks. The selective use of evidence gives rise to outcomes that range from the most pessimistic to the most optimistic. The truth is somewhere in between. The neo-Malthusians largely ignore markets and underestimate the role of prices; the cornucopians ignore market failures and underestimate the necessary investments in personal development to make a growing population a positive resource. To quote Dasgupta (1995):

> In this background [of the vicious circle of population growth, poverty and environmental degradation] it is hard to make sense of the oft-expressed suggestion (e.g. Simon 1981) that there are cumulative benefits to be enjoyed from increases in population size even in poor countries; that human beings are a valuable resource. To be sure, they are potentially valuable as doers of things and originators of ideas, but for this they require the means of personal development. Moreover, historical evidence on the way pressure of population led to changes in the organization of production, property rights….does not seem to speak to the population problem as it exists today in Sub-Saharan Africa and the Indian subcontinent (p. 1898).

Yet barring Sub-Saharan Africa, neo-Malthusian predictions failed equally roundly. Income per capita has grown in all other poor regions of the world; world food production since 1960 grew annually by 0.6 percent faster than the world's population and literacy improved substantially, even in societies where population grew much faster than in the past. As for resource scarcity, resource prices have been steadily declining, signaling diminishing economic scarcity (Barnett and Morse 1963, Nordhaus 1974). The only exception has been tropical timber prices that grew at an annual rate of about 1 percent. The situation with environmental quality is mixed: with regard to local and regional pollutants, there has been a marked improvement in high- and middle-income countries and continued deterioration in low-income and newly-industrialized countries. With regard to global pollutants, CO_2 and other greenhouse gases and the global commons, especially biodiversity, there is continued deterioration. But even here, there seems to be an endogenous institutional response, albeit a slow and "tortuous" one, as evidenced by the relative success of implementing the Montreal Protocol for controlling ozone-depleting substances and negotiating the Kyoto Protocol for controlling greenhouse gases.

6.2 Approaches and Methods of Analysis[4]

A second source of variation among the studies analyzing the population and environment relationship is the diversity of approaches and methods of analysis. Some are linear and static, others are non-linear and dynamic; some allow for feedbacks, others do not; some are "bottom up" or micro, while others are "top down" or macro. Marquette and Bilsborrow (1997) identified the commonality and differences of the various approaches and classified them into a few categories. They identified five such groups of approaches, summarized in Figure 5 and discussed briefly below:

[4] This section draws heavily on Marquette and Bilsborrow (1997).

Figure 5. Some Conceptual Approaches to Population and Environment Relationships

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(a) Linear perspectives

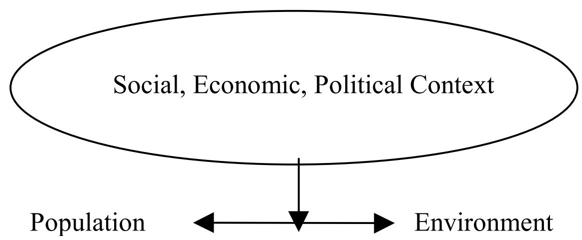
Malthus: Population ⟷ Environment

Boserup: Population ⟷ Technology ⟷ Environment

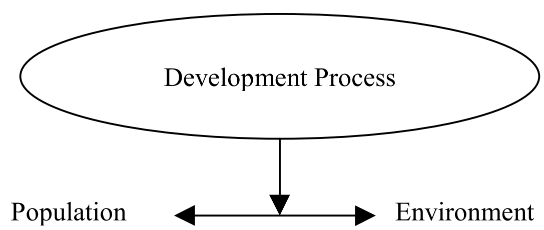
(b) Multiplicative perspective

Environment Impacts = (Population size) {Affluence or per capita consumption) {Level of Technology)

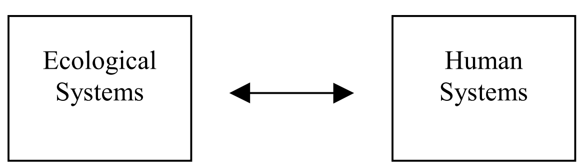
(c) Mediating perspective



(d) Development-dependency perspective



(e) Complex systems perspective



Source: Marquette and Bilshorrow (1997)

(a) The *linear approach* postulates a direct linear and reciprocal relationship between population and the environment. Malthus, Boserup and Simon, despite their widely divergent historical and ideological perspectives, employ the same linear approach. They differ, however, in the factors they considered and the feedbacks they allow for. Malthus, having failed to anticipate technological change, postulates a direct linear and reciprocal relationship (land use and food production); population growth limits per capita food availability, which in turn limits population through increased famine and mortality. Neo-Malthusians combined demographic and ecological trends along similar linear reciprocal relationships to devise concepts such as the carrying capacity (e.g. Hardin 1968; Ehrlich and Holdren 1971) and to construct mathematical and simulation models (e.g. Meadows 1972, 1992 and Cohen 1995).

Boserup introduces a two-stage linear reciprocal relationship: the pressure of high population density brought about by population growth induces technological change (new inputs such as fertilizers, and new institutions such as property rights), which allows food production from fixed land to keep pace with population growth (hence no famine and no environmental degradation). Simon, like Boserup, introduces negative feedbacks between population and environment via technology, but the operating concepts are human ingenuity and market incentives, rather than the compulsion of necessity arising from population pressure.

(b) The *multiplicative approach* obtains the environmental impacts as the product of population size with the level of affluence or per capita consumption and the level of technology in the form of the now-familiar I=PAT equation. It is, thus, the interaction of population with consumption and technology that determines environmental change. In this construction, the environment remains unchanged if population growth is offset by a corresponding reduction in consumption per capita or improvements in technology that reduce waste per unit of consumption. This approach, as we have seen, has been used by Holdren (1991), Harisson (1994) and Bongaarts (1992) in attributing and projecting CO_2 emissions, as well as by Commoner (1991, 1992) in analyzing the environmental impacts of population and development. While in the I=PAT formulation the three factors are equally weighted, Shaw (1989a,b,c) sought to qualitatively differentiate between them by identifying consumption and technology as the ultimate causes of environmental degradation, with population as an aggravating factor.

(c) The *mediating-factor approach* postulates that not only the magnitude but also the direction (sign) of the effect of population on the environment is determined by other factors, such as poverty, market demands, government policies, and social and cultural factors. These conditions and factors determine whether population growth would lead to technological innovation or to environmental degradation or out-migration (Marquette and Bilsborrow 1997, Bilsborrow 1992a, 1992b, McNicoll 1990, Hogan 1990, Schmink 1994). The poverty-fertility-environment vicious circle fits best in this approach.

(d) The *development-dependency approach* advocates that it is the development process that mediates the population-environment interface. In particular, the dependency of the South or the North on export markets for natural resources, technology, foreign investment and a variety of other international economic and political dependencies shape both the observed demographic and environmental outcomes (Jolly 1991, Martine 1992, 1993). In this approach, population growth and environmental degradation are spuriously (rather than causally) related, both being driven by a third factor, the South-North development dependency.

(e) The *systems approach* to the population-environment relationship combines ecological, socioeconomic and demographic systems into a web of inter-relationships of which the population-environment nexus is only one. In such complex, integrated systems, structural changes along a country's development path cause non-marginal shifts in population-environment dynamics. The systems approach has been employed both at the macro level (e.g. Gallopin et al. 1988, Hawley 1986, and Cleaver and Schreiber 1992) and at the micro or household and community level (e.g. Bennett 1969, Fricke 1993, Wilk 1991, and Viazzo 1989).

Studies also differ in the dimensions of population and environment they focus on. Most studies focus on population growth or population density. Few consider the spatial distribution of population and migration or issues related to health and education and the demography of the household, such as family size and age, gender and power structure. With regard to the environment, the studies vary from those which focus on a particular dimension (deforestation, land use, water, pollution, climate change) to those that use general but vague concepts of resource depletion and environmental degradation. This is important since the environment has many dimensions, some not easily quantifiable. Focusing on one dimension avoids difficult issues of valuation and aggregation, but also ignores spillovers between environments, intermedia substitution and shifting pressures from one resource or environment to another (e.g. from the rural resource base to the urban environment through migration). In this regard, the shifting of population pressures from the local environment to the environment of other countries or the global environment through international trade and globalization has received less attention than either local studies abstracting from spillover effects or global studies treating the world as a single unit.

This brings us to the final dimension of diversity: the level of analysis. Here, there are two categories: top-down (or macro) studies, and bottom-up (or micro) studies. Macro-level studies use highly aggregate data on population and environment and units of analysis that are countries, regions or the globe, while micro-level studies use highly disaggregated data and units of analysis that are households and communities. As such, micro studies are closer to the level where decisions are made and hence they have much more behavioral content than macro studies. Also, micro-level studies can incorporate more easily the socio-cultural and institutional context into the analysis and are best suited for analyzing cause and effect linkages between population and environment (Blaikie and Brookfield 1987, Zaba and Clarke 1994, Bilsborrow and Geores 1994, Marquette and Bilsborrow 1994, and Jacobson and Price 1990, among others).

Macro-level studies, on the other hand, are national or global assessments and predictions of the likely environmental outcomes of broad demographic and economic trends (e.g. Ridker 1979, Simon 1981, 1990, Bongaarts 1992, Meadows 1972 and 1992). Such studies are useful in the formulation of national and global policies and the identification of general hypotheses for testing at lower geographical levels (Marquette and Bilsborrow 1994). While both micro- and macro-level studies generate valuable and often complementary insights into the population and environment interface (albeit in different contexts), the wide conceptual gap that exists between the two approaches produces seemingly contradictory results. For example, micro studies may find significant adverse effects of population pressures on the local environment, while macro studies identify no resource constraints at the national or global level (or vice versa). To bridge the gap between the two, Marquette and Bilsborrow advocate more emphasis on "middle-range theory and research, which explains as well as possible a limited phenomena in a specific context" (p. 8). Another approach to bridging the gap is to use the macro approach to identify hypotheses for testing at the micro level; the result of such tests would then be used to modify the specification of the population-environment relationship at the macro level. Ultimately, macro studies must be based on more solid micro formulations than has been the case in the past, and micro studies must seek to provide input into the answers of a wider set of policy questions faced by an increasingly open and interdependent world.

7. Conclusions

The objective of this paper was to review analytically and critically the literature on the population-environment interface. The literature, beginning with Malthus 150 years ago, is vast and steadily growing. We tried to be selective, yet cover all the major schools of thought and strands of research. Inevitable, some important contributions may have been omitted. There is little agreement on the relationship between population and environment, not only on the magnitude but also on the direction (sign). Some even dispute whether such a relationship exists at all. Empirical research has not been able to resolve the issue because of limited data and divergent methodologies and levels of analysis. Any attempt to summarize the paper is tantamount to reproducing it. Nor do we offer any conclusions. This is a task we gladly leave to the reader.

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