The Interaction of Population Growth and Environmental Quality

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The study of interactions between population growth and the environment has a long history. According to Malthus, a growing population exerts pressure on agricultural land, forcing the cultivation of land of poorer and poorer quality. This environmental degradation (broadly defined) lowers the marginal product of labor and, through its effect on income, reduces the rate of population growth. The result is an equilibrium population that enjoys low levels of both income and environmental quality.

The modern statement of this view replaces agricultural land with nonrenewable resources. In this model, natural resources impose a limit to economic growth, with population pressures reducing the marginal product of labor as scarce natural resources are exploited more intensively.

A more recent theme in discussions of population growth and the environment is the importance of environmental quality per se, where environmental quality is measured by the stock of forests or by the absence of air and water pollution. In this view the environment is seen not as a factor that limits productivity as population expands, but as a good whose quality is degraded by a growing population. Population pressures, for example, are frequently cited as a cause of deforestation: population growth, by increasing the need for arable land, encourages the conversion of forest land to other uses. Population growth, because it places increased pressure on the assimilative capacity of the environment, is also viewed as a major cause of air, water, and solid-waste pollution. To some, the logical conclusion of these arguments is that population control is an important means of improving environmental quality.

While there is no question that population growth contributes to environmental degradation, its effects can be modified by economic growth and modern technology. Consider, for example, two countries with rapid population growth and significant forest resources but with different levels of per capita income. The country with the higher income is likely to be deforesting less rapidly. As income grows, people will switch to energy sources other than firewood and will use modern agricultural techniques that reduce the demand for agricultural land. Similar effects are likely to be felt regarding pollution. As income grows, sanitation and waste-water treatment will improve, and pollution will be less of a problem at any level of population density.

An important question for policy is whether, holding constant per capita income and other relevant factors, population pressures have a significant effect on environmental degradation. To the best of our knowledge there is little empirical evidence on this point. In this paper we take a first step toward providing such evidence. Specifically, we examine the effect of population pressures on deforestation in 64 developing countries.

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Previous research in environmental economics has uncovered a relationship between environmental quality, measured by ambient concentrations of SO_2 or particulates, and per capita income (Gene M. Grossman and Alan B. Krueger, 1991). This so-called environmental Kuznets curve shows environmental quality worsening up until about \$5,000 of per capita income (using Robert Summers and Alan Heston [1991] purchasing-power-parity income measures) and improving thereafter. Below, we find a similar relationship for the rate of deforestation in Latin America and Africa. We estimate this relationship using pooled cross-section and time-series data for each continent for the period 1961–1988, including country dummies to capture factors that change slowly over time, such as the proximity of forests to cities or rivers.

To capture the effects of population pressures we include rural population density and the rate of population growth in the equation as well. These variables thus shift the Kuznets curve for deforestation. It is thus possible for a country that is beyond the level of per capita GDP at which environmental quality begins to improve to have a higher rate of deforestation than a country that has not yet reached this level of GDP but faces lower population pressures. This is a simple point, but one that deserves emphasis: the vertical intercept of environmental Kuznets curves is just as important as the level of per capita GDP at which the curve peaks.

I. Causes of Deforestation

In the literature of deforestation, three reasons are highlighted for the destruction of tropical forests: the desire to convert forest and woodland areas to pasture and cropland, the harvesting of logs, and the gathering of fuelwood. Population pressures are emphasized as an underlying cause of all three sources of deforestation. Population growth, by increasing the demand for arable land, encourages the conversion of forests to agriculture. Since it is people living in rural areas who turn to agriculture as a livelihood, one would expect deforestation to increase with rural population density. Population growth also increases the demand for wood, both for timber and for fuelwood.

The links between population pressures and deforestation are thought to be so strong that, in a recent assessment of deforestation in tropical countries, the United Nations Food and Agriculture Organization (FAO) estimated deforestation rates using a model of population pressures (FAO, 1993a), Specifically, the FAO assumed that the ratio of forest area to total land area is a logistic function of population density. This model, estimated using data for a sample of countries at the subnational level, was used to predict national rates of deforestation for countries outside the sample.[1]

The FAO model implies (after some manipulation) that the percentage change in forest area depends on the percentage change in population (the rate of population growth), as well as on population density. This relationship, however, will be modified by a country's stage of economic development. The relationship between population pressures and deforestation to create arable land is clearly affected by the use of modern agricultural technology, which reduces land requirements. It is also affected by the pace of industrialization, which means that labor will be hired in nonagricultural sectors. Logging is also likely to be linked to income, interpreted as a proxy for the stage of development. It is likely to grow as a country develops, especially as the ability to process logs develops, but may wane as industrialization takes over. The demand for fuelwood as an energy source is also a function of income. It may initially rise with income, but is eventually likely to fall with income as more modern sources of energy are used.

The previous discussion motivates the importance of income and population growth

[1]We emphasize that this is not the source of the data used in our analysis.

as factors underlying the rate of deforestation. Other variables that may influence the rate of deforestation are the rate of growth in per capita income (which is correlated with the rate of urbanization) and the prices of forest products, especially logs.

Letting F_{it} represent forest area in country i in year t, the equation below specifies a possible form for the relationship between the rate of deforestation (minus the percentage change in forest area) and the factors discussed above:

$$\frac{F_{i,t-1} - F_{it}}{F_{i,t-1}}$$
$$= a_{0,i} + a_1(\text{RPD})_{it} + a_2(\Delta\,\text{POP})_{it} + a_3(\text{TP}) + a_4(\Delta\,\text{PCGDP})_{it} + a_5(\text{PCGDP})_{it} + a_6(\text{PCGDP})^2 + u_{it}$$

where RPD = rural population density, ΔPOP = percentage change in population, TP = timber price, ΔPCGDP = percentage change in per capita GDP, PCGDP is per capita GDP, and u_{it} is an error term.

The reason for assuming a quadratic relationship between deforestation and per capita GDP is that logging and fuelwood uses of the forest are likely at first to increase with income. Agricultural and fuelwood motives for deforestation, however, are eventually likely to decline with per capita GDP, causing an inverted U-shaped relationship.

The intercept of the equation is allowed to vary across countries to capture factors affecting the rate of deforestation that change slowly over time. Deforestation, for example, is more likely to take place the closer forests are to cities and rivers. The size and distribution of forests can also affect the rate of deforestation: forest area that is clustered is likely to be less vulnerable to deforestation than fragmented forest —forest that is interspersed with agricultural and other land uses. The density of trees likewise affects the profitability of logging. It is these factors that the fixed effects are intended to capture.

II. The Data

The source of our deforestation data is the Food and Agriculture Organization's *Production Yearbook* (FAO, 1993b), which provides data on forests and woodland area.[2] This is a very broad definition of forest land. It includes both closed and open forest, plantations, and land from which forests have been cleared but which will be replanted in the foreseeable future. This is an acceptable definition of forest from an economic perspective; however, it is too broad a definition to be useful for studying habitat destruction or the loss of biodiversity.

Because deforestation is primarily a problem of developing countries, we have limited our study to non-OECD countries in Africa, Asia, and Central and South America (hereafter referred to collectively as Latin America) roughly in the tropical belt and containing forest area of over 1,000,000 hectares. Separate versions of the equation are estimated for each continent. The parameters of the equation may vary across continents because the nature of forests varies significantly from one continent to another. Moist tropical forests comprise half of the forest cover in Latin America, for example, but only 17 percent of the forest cover in Africa.

Data on population and per capita GDP come from Summers and Heston (1991). It is the availability of these data that limits the size of our sample: the Summers-Heston data are available for only 64 countries for which deforestation data exist, and are available only through 1988. Since some years are missing for some countries, we have an unbalanced panel. Data on the price of tropical logs are from the FAO (1981, 1990), which reports international prices for forest products. These prices were adjusted by the average mid-year market exchange rate for each country, as pub-

[2]The 1993 AGROSTAT tapes provide a consistent time series for forests and woodlands from 1961 to 1991, using data published in the FAO *Production Yearbook*. It is those data that are used here.

TABLE 1—A FIXED-EFFECTS MODEL OF TROPICAL DEFORESTATION

Independent variable	Africa	Latin America	Asia
Per capita income ($millions)	3.90	6.03	−13.33
	(2.60)	(1.93)	(−0.71)
Per capita income squared	−410.05	−556.29	1,386.77
	(−1.68)	(−1.54)	(0.53)
Percentage change in per capita income	-5.95×10^{-3}	-1.23×10^{-2}	7.28×10^{-3}
	(−2.46)	(−3.23)	(0.20)
Price of tropical logs ($1,000's)	-1.00×10^{-5}	1.92×10^{-4}	-8.70×10^{-5}
	(−0.40)	(2.41)	(−0.20)
Percentage change in population	8.33×10^{-3}	1.96×10^{-2}	1.35×10^{-1}
	(0.13)	(0.39)	(0.20)
Rural population density	3.26×10^{-2}	3.63×10^{-2}	-2.09×10^{-3}
	(3.79)	(1.08)	(−0.21)
Time trend	1.84×10^{-5}	-6.30×10^{-6}	3.60×10^{-4}
	(0.34)	(−0.05)	(0.79)
Number of observations:	862	450	364
R^2:	0.63	0.47	0.13
Turning point:	$4.760	$5,420	—

Notes: The dependent variable is the annual rate of deforestation. Equations for Africa and Latin America were estimated using the Prais-Winsten technique to correct for autocorrelation. Numbers below coefficients in parentheses are *t* statistics.

lished by the IMF, to obtain the price faced by domestic wood producers.

To compute rural population density we obtained the percentage of total population living in rural areas from the World Bank and used this number to adjust total population figures from the Summers-Heston data.

III. Results

Table 1 reports the results of estimating our equation for Africa, Latin America, and Asia. Only results for Africa and Latin America are statistically significant at conventional levels. They suggest, first, that a hump-shaped relationship exists between per capita income and deforestation; and second, that, for Africa, rural population density shifts this relationship upward.

There is, however, a disquieting feature of the quadratic relationship between deforestation and per capita income. The levels of income at which rates of deforestation peak ($4,760 for Africa and $5,420 for Latin America) are such that most of our observations fall to the left of the peak. It would therefore be more accurate to say that the increase in the rate of deforestation levels off as income increases.

The coefficient on average rural population density is positive and significant in Africa, giving the expected result that rural population density increases deforestation. The magnitude of this coefficient, which is roughly similar for both continents, implies that an increase in rural population density of 100 persons per 1,000 hectares raises the rate of deforestation by 0.33 percentage points in Africa.

The rate of growth in per capita income also has a significant negative impact on deforestation, although the magnitude of this effect is small. In Latin America, for example, increasing the rate of growth in per capita income by 8 percentage points reduces the rate of deforestation by only one-tenth of a percentage point. The price of tropical logs is statistically significant in Latin America but not in Africa, a reasonable result given that logging occurs on a much larger scale in Latin America than in Africa.

The clear anomaly in Table 1 is Asia: none of the variables in our equation is statistically significant for this continent. Breaking the region into South Asia versus East Asia does nothing to improve the results. A possible explanation for this finding concerns the importance of forest plantations in Asia. The FAO has estimated that, in 1990, natural forest area in Asia decreased by 3.9 million hectares; however, an additional 2.1 million hectares were planted, implying that the decrease in forest and woodland area would amount to only 1.8 million hectares (FAO, 1993). The factors influencing the destruction of natural forests are, however, likely to differ from the factors influencing the growth of plantations. An increase in the price of tropical logs, for example, is likely to increase both, implying that it might have no measurable effect on the sum of forest area plus plantations. We suspect that, were we able to decompose the change in forest and woodland area into these two components, we would find a relationship similar to that for Africa and Latin America for deforestation of natural forests in Asia.

IV. Implications

Macroeconomic relationships of the type reported in Table 1 are sometimes misinterpreted as indicating that income growth, if fast enough, will solve environmental problems. This is clearly not the case for deforestation in Latin America or Africa.

For a country in Latin America with an intercept that is zero, the rate of deforestation at the peak of the curve is 1.63 percent per annum. Even at a per capita income of $8,000, the rate of deforestation is 1.26 percent—surely not an indication that economic growth will solve the problems of deforestation!

In Africa, the situation is yet more grim. Rural population density shifts the relationship between income and deforestation upward, so that a country with a rural population density equal to that of Kenya (0.3 persons per hectare) has a peak deforestation rate of 1.91 percent per year, while a country with the rural population density of Malawi (0.7 persons per hectare) has a peak deforestation rate of 3.21 per year.

The implied trade-off between per capita income and rural population density is large: at a per capita income of $4,760, a country with a rural population density of 0.1 persons per hectare (the average for the African countries in our sample) has a peak deforestation rate of 1.26 percent per year. A country with a population density of 0.7 persons per hectare requires an income of $11,650 per year to achieve the same rate of deforestation!

In spite of these grim predictions, it would be inappropriate to conclude that reducing the rate of population growth is necessarily the best method of reducing the rate of deforestation. Deforestation in developing countries is very much a problem of market failure. Because property rights are often not defined or not enforced, the private cost of deforestation is effectively zero. Put somewhat differently, because people have no right of ownership in the land, they have no incentive to make efficient land-use decisions. It is this problem that must be addressed, as well as the problems of poverty and population growth.

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