ECONOMIC GROWTH AND THE RISE OF FORESTS*

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Although forests have diminished globally over the past 400 years, forest cover has increased in some areas, including India in the last two decades. Aggregate time-series evidence on forest growth rates and income growth across countries and within India and a newly assembled data set that combines national household survey data, census data, and satellite images of land use in rural India at the village level over a 29-year period are used to explore the hypothesis that increases in the demand for forest products associated with income and population growth lead to forest growth. The evidence is consistent with this hypothesis, which also shows that neither the expansion of agricultural productivity nor rising wages in India increased local forest cover.

I. INTRODUCTION

In the last 350 years, increases in worldwide per capita incomes have been accompanied by substantial declines in forest cover. In the United States, for example, which today accounts for 10 percent of the world's forests, forest coverage is estimated to be 70 percent of what it was in 1630 [USDA Forest Service 2001]. And between 1980 and 1990, forest area decreased at a rate of 0.9 percent per year in the developing world, with annual rates of deforestation averaging 1.2 percent in Asia [World Bank 1992].

Concern about the phenomena of global warming and declining biodiversity has led to an increase in attention paid to the link between the disappearance of the world's forests and economic growth. A particular focus of this debate has been whether there is an "environmental Kuznets curve" (EKC) for forests, analogous to that found for air and water quality [Grossman and Krueger 1995], in which afforestation occurs at higher levels of economic prosperity. The extent of such a relationship is of considerable interest to policy makers: it has been argued on the one hand that policies directed at economic growth such as the promotion of markets and increasing openness to trade will lead eventually to increases in forest cover and on the other that forest cover will continue to decline as economic growth takes place in the absence of policies that directly promote forest growth and conservation [Arrow et al. 1995].

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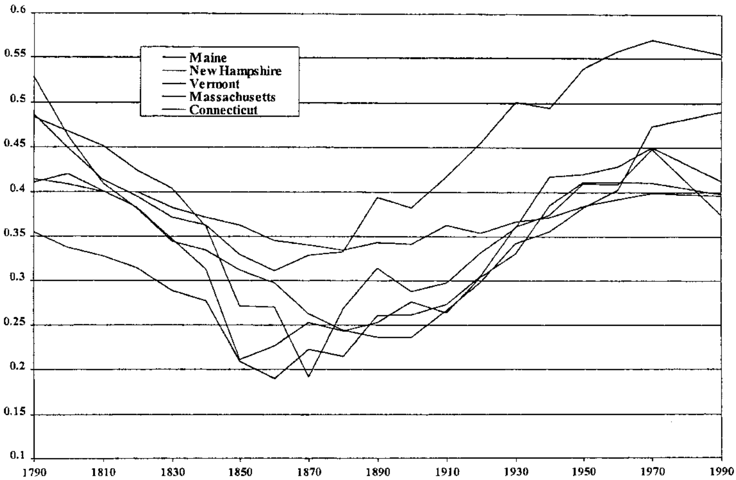

FIGURE I
Proportion of Total Land Forested, by State, U. S. New England States 1790–1990

Existing evidence on the forest EKC is mixed. Two cross-country regression studies [Cropper and Griffiths 1994; Panayotou 1995] find no positive relationship between income and forest growth at any feasible level of per capita income, and one finds a positive relationship for a level of per capita GDP above $1200 based on cross-country data [Antle and Heidebrink 1995]. But cross-country regressions based on one time period cannot, in any case, necessarily be used to infer that increases in income will eventually lead to an increase in forest cover. Although we are unaware of systematic cross-country studies over multiple periods, there are two prominent within-country examples of a positive relationship between income growth and forest cover at higher levels of income. Figure I depicts the proportion of land forested in five New England states between 1790 and 1990 based on data compiled in Foster [1992]. As can be seen, forest cover in New England fell to half of what it was in 1790. By 1990, however, the levels of forest cover exceeded those in 1790, with forests substituting for lower-value pastureland. Less well-known is the fact that India has also experienced an increase in forests after many decades of forest decline. Figure II displays the trends in forest area and forest cover from 1880 through 1999. Estimates of forest cover between 1880 and 1950, from Richards and Flint [1994], indicate that forest cover declined from 20 percent of total

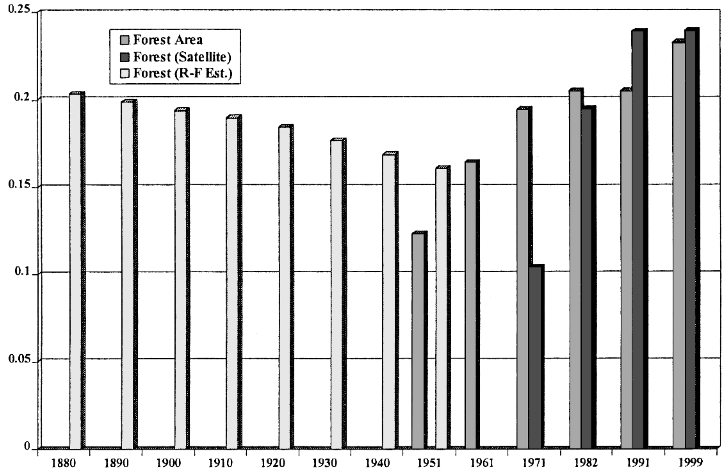

FIGURE II

Proportion of Total Land Area Classified as Forest (Government Statistics) and Proportion of Land Forested (Richards and Flint Estimates and Satellite Data for Survey Villages), India 1880–1999

land in India in 1880 to about 16 percent in 1950.[1] Figure II also shows, however, that the proportion of land designated by the Indian government as forest land [Anon 1997; FAO 2001] increased from 12.3 percent in 1951 to over 23 percent in 1999. It is possible that these increases do not reflect tree growth. However, we have assembled an aggregate time-series of tree coverage for India based on satellite imagery for a national sample of Indian villages starting in 1971 when satellite data first became available.[2] These data, described below, indicate that the increase in officially designated forest land has been accompanied, with a lag, by increases in the proportion of land covered by forests, from just over 10 percent in 1971 to over 24 percent in 1999.

Per capita incomes in both New England and India grew during the period in which forest area was increasing, thus establishing both that economic growth is not inconsistent with afforestation and that deforestation can be reversed even at fairly low levels of national income. What is less understood are the

1. Richards and Flint [1994] provide estimates of forest cover for 1880, 1920, 1950. The intervening years are interpolated in the graph.

2. The information on land use prior to 1999 is from Anon [1997, pp. 90–91] and from the Food and Agricultural Organization for 2001. The earliest satellite images are actually for 1972. The construction of the measures of forest growth is discussed below.

mechanisms by which economic growth leads to afforestation. One possibility is that income growth leads to a greater demand for environmental amenities and direct efforts to conserve resources such as trees. The recycling of paper in the United States and Europe is motivated in part by tree "conservation." For example, one U. S. environmental organization promoting recycling provides the estimate that there will be a four-pound reduction in carbon dioxide for every pound of paper recycled [Environmental Defense 2001]. This implies that saving paper increases trees. An alternative view is that economic growth leads to an increase in the demand for forest products and that, like other renewable resources, this leads to a shift in land use toward trees. If this is the case, then efforts to conserve paper would curtail forest growth not promote it. Thus, an improved understanding of the linkages between economic growth and forest change has important implications for environmental policies in all countries.

Evidence on the linkages between forests and human activity, particularly in low-income countries, is scant. Much of the economic literature has emphasized the importance of local-level processes such as agricultural encroachment and product extraction through firewood collection and animal grazing. The primary difficulty with this approach, with its emphasis on tree management, is that it neglects factors determining the demand for forest products and does not allow for the possibility that forest area will be importantly determined by the relative returns to forest and other uses of land. Recent work based on household survey data has focused on the relationship between household income and the demand for fuelwood, a major component of forest-product extraction in South Asia [Bardhan et al. 2001; Chaudhuri and Pfaff 2002]. These studies, however, do not connect fuelwood consumption to actual forest area, and thus they do not shed light on the key issue of whether increases in the demand for forest products increase or decrease the size of forests.

In this paper we utilize new cross-country time-series data for developing countries on forest and income growth rates for the period 1980–1995 and a variety of data sources for India, including aggregate times-series on total forest-product consumption and the price of fuelwood, household survey data on wood consumption, and another newly assembled data set that combines at the village level longitudinal household survey data, Census data and satellite images of land use that cover a wide area of rural India over a 29-year period to investigate the linkages between income change and forest growth. We carry out our empirical analysis within the context of a general-equilibrium framework in which land use is shaped by the relative returns to agricultural and wood-product production. A key feature of this framework is that increases in the demand for forest products lead to increases in forests, given costs of wood extraction, inclusive of the opportunity cost of forest land and labor. The principal empirical challenge to assessing this implication is that if the markets for forest products are spatially extensive, there is not necessarily any relationship between local forest-product demand and local forests even at the national level. In this respect, India is a particularly useful context to assess the role of demand factors in forest growth, for two reasons. First, India is a closed economy with, in particular, high import tariffs on wood products. At the national level therefore domestic demand for wood must be met by wood supplied from Indian forests. Second, most of the demand for wood in India is for fuel. Fuelwood markets are limited geographically so that within India there is a relationship between changes in local forest-product demand induced by local income and population growth and local forest growth. Spatially disaggregated time-series data on forests in India along with information on factors affecting wood demand and forest costs can thus be used to assess the determinants of forest growth.

We show that the aggregate rise in forests in India that has occurred since 1961 has been accompanied by a substantial increase in the domestic consumption of forest products. One possible source of this increase would be a supply-driven reduction in the price of forest products. However, we also show that during this period the price of fuelwood, the major component of forest-product consumption in India, has risen relative to the price of other consumption commodities, which is inconsistent with the supply-driven model. We also show that at the world level there is a positive relationship among developing countries between rates of growth in incomes and forests among closed economies but not among countries with extensive trade. These findings are inconsistent with the view that income growth induces forest growth because of direct demand for forest amenities, but are consistent with a product-demand-driven explanation for forest growth.

Prior studies of forest growth have focused not on changes in forest product demand as the causes of afforestation but on the effects of agricultural technical change and changes in the value of labor. The World Bank, in a recent report on Indian forests [Kumar et al. 2000], speculates the "green revolution," the substantial increase in crop productivity experienced by India over the past 30 years, was a major positive force in abating the decline in forests by relieving pressures for extensive cultivation that lead to the destruction of forests that arise from population and income growth. This alternative explanation is important because a major factor determining income growth in India was the growth in agricultural productivity. We use our village-level panel data set, exploiting the fact that agricultural technical change in India was spatially uneven, to show that, contrary to this view but consistent with our framework in which forest area reflects the relative returns to producing forest products, increases in crop productivity decreased forest growth where these increases were strongest.[3]

Sedjo [1995] suggests that afforestation in New England was due to a decrease in the returns to agriculture that reflected the changing costs of labor, an important input in forest extraction. We exploit the fact that in India wages are determined in local markets to show using the village-level data that changes in the value of time had a minimal impact on forests in India. We find using the same data, however, that increases in local fuel expenditures are associated with increases in local forest area and density. We show that this evidence, combined with estimates from Indian household survey data indicating that, for given prices, the household demand for wood-intensive fuel (and furniture and paper) is significantly and positively associated with household income, is only consistent with the hypothesis that increases in the demand for fuel, driven by income growth, induced forest growth. Our empirical findings thus indicate that the principal factors leading to the reversal of deforestation in India were neither increases in agricultural productivity associated with the green revolution nor increases in the price of time. Both factors raised the opportunity costs of land and labor, two inputs to forest production, and decreased land under forests. Rather, increases in aggregate demand propelled by income and population growth for such forest products as fuelwood, furniture, and paper appear to be the main forces leading to afforestation in India.

3. Moreover, the terms of trade with respect to agriculture rose in India between 1982 and 1999, and green revolution seed varieties yield less stems and husks [Saxena 1997], leading to increased demand for forest products as fodder.

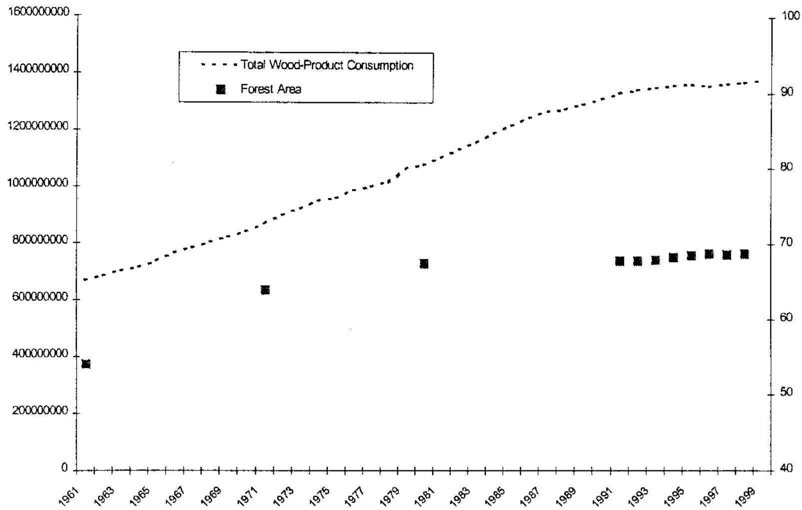

FIGURE III
Total Domestic Wood-Product Consumption (Metric Tons) and Forest Area (Million Ha's), India 1961–1999

II. FOREST-PRODUCT DEMAND AND FOREST GROWTH: AGGREGATE EVIDENCE

India has been a closed economy since its independence, with the sum of imports and exports accounting for less than 17 percent of total domestic product in 1980 according to the data in Summers and Heston [1995]. Indeed, because of high tariffs on imported lumber and because of the relative nontradability of fuelwood, imports make up less than 1 percent of total domestic consumption of wood products in India. Such products thus must be supplied from domestic forests, and changes in the demand for forest products will have direct effects on Indian forests. From 1961 to 1999, as income has risen in India, the domestic consumption of wood has also risen—by 2.8 percent per year on average. Figure III plots the rise in domestic wood-product consumption—aggregate domestic production plus imports less exports (both of which are an insignificant part of the total)—in metric tons from 1961 through 1999 along with the estimates of forest area over the same period. These all-India figures indicate that the rise in demand for wood products that accompanies economic growth is not inconsistent with a rise in forests even when all domestic consumption must be met through local wood production.

One alternative explanation for the relationship in Figure III

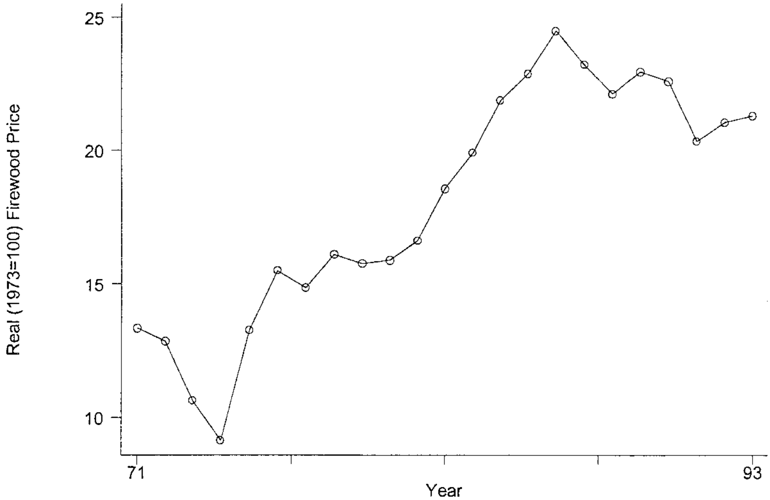

FIGURE IV
The Real Price of Fuelwood, 1971–1993: All India

is that income growth has increased the demand for forests in India because of a general increase in demand for environmental amenities, leading to a reduction in the price of forest products and thus increased consumption. However, as seen in Figure IV, the real (relative to the rural consumer price index) price of a major component of wood consumption, fuelwood, has also risen during this period, ruling out a supply-driven explanation [Özler, Datt, and Ravallion 1996].

Another way to assess to what extent the rise in forests accompanying growth is due to increases in the direct demand for trees as environmental goods or to the derived demand for trees via the demand for forest products is to perform the counterfactual experiment of opening the economy to trade. With non-Indian suppliers of wood free to sell to Indian consumers and in the absence of a strong and increasing demand for forests as amenities, the relationship between domestic demand growth and Indian forests should be reduced. However, although India has relaxed constraints on lumber trade in recent years, the effects on imports are as of yet too small to discern an effect on forests.

In the absence of the Indian counterfactual, we can attempt to rule out the environmental amenities hypothesis by examining the relationship between economic growth and forest growth across countries classified by their openness. For closed economies we should expect to observe a strong relationship between income change and forests, because domestic forests are the major source of wood products. For open economies, unless the demand for trees as amenities is substantially income-elastic, the relationship between economic growth and forest growth should be weak. To carry out this analysis, we combined three sources of country-level data. First, we obtained data from 1980 and 1995 on forest area in developing countries from Gardner-Outlaw and Engelman [1999]. These data are compiled from FAO sources and are designed to provide consistent estimates of the extent of forest area, inclusive of both natural and plantation forests, in developing countries.[4] Although 129 developing countries were included in the original FAO studies, only 103 of these countries provide consistent data for both 1980 and 1995.[5] We then linked the forest data to information on "openness" (exports + imports/GDP) and real GDP from the International Comparisons Project [Summers and Heston 1995, version 5.6] and to information on country-specific total area from CIA [1999]. Twelve of the 103 countries did not have ICP data in 1980 (e.g., Afghanistan, Laos, North Korea) and an additional 33 did not have ICP data for 1995. These countries were dropped from the analysis yielding 58.

Figure V plots the relationship between domestic income growth and forest growth over the period 1980 through 1995 for the 35 developing countries classified as open, using as the criterion that the openness measure in 1980 be greater than 50 percent. As can be seen, there is a small and insignificantly negative relationship between forest growth and income growth for these countries, as confirmed by the regression line also plotted in the figure. There is thus little evidence that income growth leads to a rise in forests in countries in which there is no necessary relationship between domestic wood-product demand and domestic supply. In contrast, for the 23 closed economies in the

4. Comparable data are unavailable over this interval for developed countries because of inconsistencies in the classification of the FAO forest area over time and space. In the early 1980s developed country forest measures considered forest measures relevant only to temperate climates while those for developing countries could be compared across both temperate and tropical areas. These differences have been reconciled in recent years through the use of a consistent series of definitions, but published reports from developed countries are not sufficiently disaggregated to permit reconstruction of a consistent series [WRI 1998].

5. Data from countries that divided between 1980 and 1995 such as Czechoslovakia were aggregated in 1995 to maintain consistent geographical coverage over time.

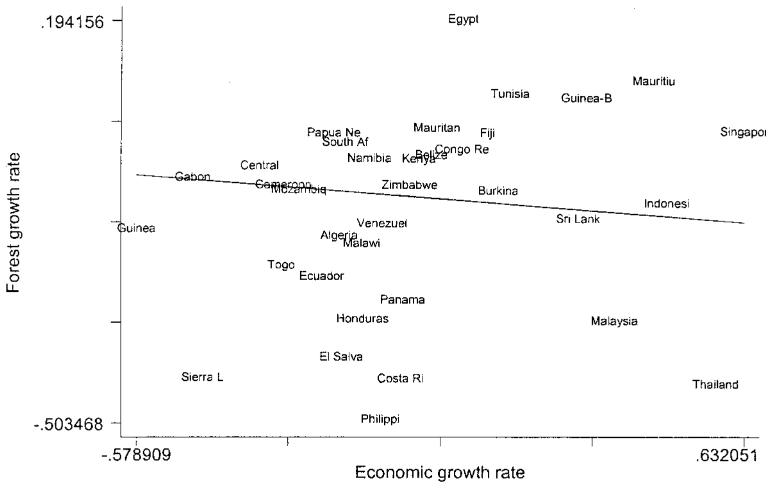

FIGURE V
Economic Growth and Forest Growth, 1980–1995: Open Economies

data set in which the demand for wood products must be reflected in domestic forests, the association between economic growth and forests is positive and statistically significant, as seen in Figure VI.[6] Unless only populations in closed economies care about forest amenities as income grows, this evidence suggests that the supply of trees responds positively to increased demand for tree products.

III. IDENTIFYING DEMAND AND COST FACTORS USING DISAGGREGATED DATA: EMPIRICAL FRAMEWORK

Although the bivariate relationships between forest growth, the growth in wood-product consumption, and the price of fuelwood at the national level for India are consistent with a demand-driven explanation for the rise in forests, other factors associated with income growth may be masked by the aggregate relationships, in particular the growth in agricultural productivity and the rise in the value of labor that may have direct effects on the

6. Appendix 2 provides the relevant regression coefficients for each subsample and for the combined sample. In the latter, the difference in the slope coefficients across the sets of closed and open countries is statistically significant. Appendix 3 provides the data.

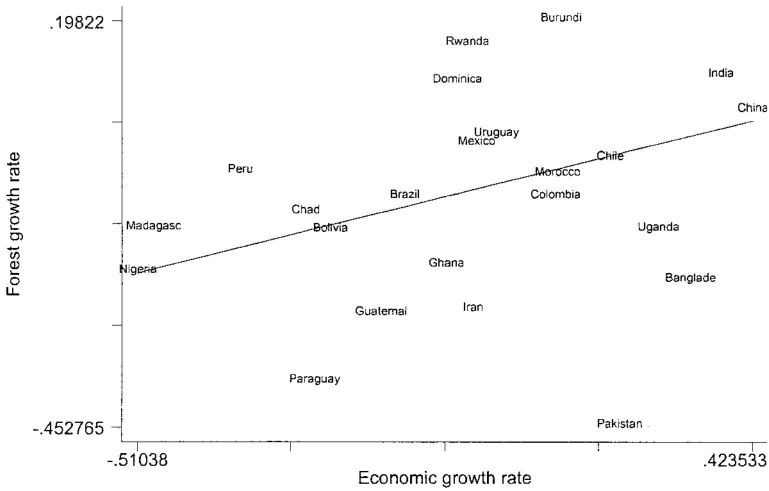

FIGURE VI
Economic Growth and Forest Growth, 1980–1995: Closed Economies

exploitation and growth of forests. In this section we describe the multidimensional framework we employ to assess the roles of changes in both the demand for forest products and the opportunity costs of land and labor in determining the growth in forest resources that arise from agricultural technical progress, rural infrastructural development and population growth using disaggregated, village-level data for India.

The model encompasses three sectors—agriculture, forestry, and industry—with two factors of production—land and labor. As noted, we need to specify precisely which factors are mobile in order to assess how data describing changes over time and across villages in India can be used to identify the development factors affecting forest growth. In particular, consistent with most studies, we assume that rural India can be characterized as an economy composed of subeconomies (villages) across which there is little mobility of labor or of an important set of forest products—firewood and fodder [FAO 1987]. However, manufactured goods—including goods making use of forest resources (e.g., newspapers and furniture)—and agricultural products are traded across villages, and labor is freely mobile across sectors within villages. Given that land is also immobile, wage rates and the prices of locally produced forest products and land are thus locally determined.[7]

We consider three sources of economic growth and productivity variation in the three sectors that affect the supply and demand for resources in each village: changes in technology in the agricultural sector that vary across areas due to differentials in the suitability of and constraints on the adoption of high-yielding variety crops associated with naturally varying local environment variables (e.g., rainfall, temperature, soil quality), and variation in variables affecting labor productivity in the manufacturing sector (e.g., the availability of infrastructure). How these exogenous factors and population growth affect the land allocated to forests will depend importantly on the preferences of households, the nature of agricultural technology change, and the institutional structure governing resource allocation. We make no special assumptions about preferences except that households derive utility from forest products but not directly from the presence of forests. We specify agricultural technology change as factor-neutral, reflecting the advance in seed productivity that was the hallmark of the Indian green revolution. We also assume that property rights are well defined and that all labor allocations can be monitored so that either all land is privately held or public lands are allocated efficiently by the relevant governing body.

We make the complete markets assumption for two reasons. First, the assumption leads to a tractable model that captures the idea that forest area will be importantly determined by the returns to alternative uses of land, by pressures on wage rates and by income change. Second, we believe that this assumption captures in part the forest management reforms introduced by the Indian government in the post-1970 period to which our data refer and during which forest growth occurred.[8] It should be emphasized that the approach does not necessarily assume that forest land is privately held. The market solution emerges if

7. We have assumed that traded forest products are manufactured and use wood from forests outside of the villages considered. This is consistent with our set of sample villages, in which less than 4 percent had any wood industry in 1999.

8. We set out the model described here formally in Foster, Rosenzweig, and Behrman [2001]. We also show that if forest labor use is unmonitorable, then even when a social planner allocates resources optimally, given the prevailing wage and land rental rate and the marginal products of land and labor in forests, there is too little forest land and too much extraction of forest resources per unit land compared with the competitive case. Improvements in labor monitoring/enforcement thus increase forest area and create a positive association between the demand for forest products and forested area.

forests are commonly owned as long as both the area and usage of these forests are first-best efficiently chosen and managed.

Households maximize utility and in each period choose allocations of land to forest and agricultural production, allocations of labor to forest-product extraction, agriculture, manufacturing, and the labor market, and the consumption of local and imported forest and nonforest goods. Solving the first-order conditions determining the allocation of labor and land along with the equilibrium conditions for labor markets and forest products yields reduced-form expressions for how forest area as well as the opportunity costs of forest-product inputs—wages and land rent—are influenced by agricultural technology improvements, changes in infrastructure, endowment income, and population density. An important feature of this simple framework[9] is that there is a positive association between the demand for local forest products and the amount of land under forest. However, agricultural technical change, population growth, and rural industrialization have different effects on forest survival, even if they have similar effects on income growth, because they differentially affect the opportunity costs of the two main forest inputs, land and labor.

The reduced-form effects of improvements in (factor-neutral) agricultural technology on land rents and wages in this framework are straightforward—both increase as agricultural productivity rises. Conversely, an increase in the total population lowers wages but increases the price of land as long as production scale economies are negligible. Improvements in infrastructure that attract local industry or improve industrial productivity also raise wages, but the effects on the land price are ambiguous, depending on the land intensity of manufacturing.

Despite the fact that the effects of agricultural technical change and population growth have predictable effects on the two components of the opportunity costs of forest land use, it is not possible even in this simple framework to derive a prediction as to how in the reduced-form changes in agricultural technology, population growth, or the conditions that promote the expansion of the manufacturing sector affect forests. The complexity arises largely from the fact that forest area is importantly linked in the model to the local demand for forest products, which depends on income and price. The framework can be used however, to derive

9. We are assuming for simplicity that households are identical and that time periods are of sufficient length such that the extraction of forest resources in one period does not influence the output of forest products in subsequent periods.

an estimable equilibrium equation relating changes in technology, the endogenously determined wage and income, and the population variables to the optimal forest allocation. This equation yields testable implications.

In particular, it can be shown that, in equilibrium, increases in agricultural technology, given wage rates and income, will reduce the land devoted to forests unless accompanied by sufficient declines in the price of the traded agricultural good. Given that the terms of trade between agriculture and manufacturing goods have actually increased in favor of agriculture over the last 30 years in India, the model thus suggests that the green revolution could not have been a proximate cause of the growth of forests, and likely was a deterrent, net of its effects on income and wages. Moreover, it is not necessarily true that increases in the value of time will lead to increases in forests in rural areas. The model suggests that the effect of an increase in the wage on forest area, brought about by increased labor demand in the manufacturing sector, depends on the relative labor intensity of forest-product production. If forests are more labor-intensive than agriculture (as seems plausible), an increase in the wage will increase the relative costs of local forest products and thus decrease forest area. Finally, the effect of an increase in income on forests, given wages and the price of the traded wood product, is the same sign as the effect of income change on the household demand for locally produced forest products. Thus, increases in income will increase local forest area if local forest goods are a normal good and conversely if they are inferior. However, because increases in income raise the local price of the nontraded forest good, the aggregate relationship between income and forest area at the local level will always underestimate in absolute value the true (price-constant) income effect.

IV. The Village Panel Data Set

Based on the theory, we have assembled a village-level panel data set for India including approximately 250 villages and covering the period 1971–1999. The data set combines survey- and census-based information on household demographic characteristics, land use, incomes, agricultural output, and prices with governmental statistics on weather and satellite-based information on locale-specific changes in the density of forests. The data from which many of the village-level variables are constructed are from surveys designed to provide information representative of the entire rural population of India in sixteen major states. In particular, the constructed data set comes from six sources: (i) the 1970–1971 National Council of Applied Economic Research (NCAER) Additional Rural Incomes Survey (ARIS), (ii) the 1981–1982 NCAER Rural Economic Development Survey (REDS), (iii) the 1991 Indian Census, (iv) the 1999 NCAER Village REDS, (v) the National Climate Data Center monthly global Surface data, and (vi) satellite spectral images for India from 1972–1980, 1992, and 1999.

The absence of nationwide ground-level censuses of trees in India for the relevant period covered by the surveys means that in order to obtain a measure of the changes in actual forest or tree cover for the specific "micro" regions surrounding each of the survey villages it is necessary to employ satellite images. Satellite images based on specific light-frequencies enable the construction of indices that measure reasonably accurately area vegetation for relatively small geographic areas. The index we use is the normalized differentiated vegetation index (NDVI) [Rouse et al. 1974], which is the ratio of the difference in reflectance in the near infrared and red bands in the light spectrum to the sum of these reflectances. This index correlates well with the presence of plant matter because vegetation tends to reflect infrared light and absorb red light. It is among the most commonly used measures of vegetative cover because it is simple to compute and filters out topographic effects, variations in the illumination angle of the sun, and other atmospheric elements such as haze. The NDVI is bounded between -1 and 1, with vegetation associated with trees achieving values of .2 or greater.[10]

To match the satellite and survey data we geo-coded the surveyed villages based on maps from the district-level volumes of the 1971 and 1981 Indian censuses. Measurement of forest cover for each of the sample villages that could be linked to the

10. Although the NDVI is thought to be a good measure of photosynthetic activity, the relationship between this measure and characteristics of forest cover such as biomass, carbon content, or leaf area is not completely straightforward [Wulder 1998]. It has been established, for example, that the top layer of leaves effectively masks the presence of leaves at lower levels thus yielding a nonlinear relationship between the NDVI and leaf area. Moreover, it is sometimes difficult to distinguish forest area from agricultural crops. To address this issue, we chose time periods in which standing crops were not present. No single measure clearly dominates the NDVI in terms of being able to provide a robust measure of forest area across a wide variety of areas and climatic conditions given the type of remote sensing data available for the study period. Note that area-specific errors associated with the use of NDVI to measure forest cover that are fixed over time will not importantly influence our results when we examine the determinants of differential changes in the NDVI across regions.

corresponding time periods involved accessing three distinct sources: Multispectral Scanner (MSS) images from Landsats 1–3 for the period 1971–1982; Advanced Very High Resolution Radiometer (AVHRR) NDVI data from 1992 compiled by the USGS; and Extended Thematic Mapper Plus (ETM+) images from Landsat 7 for 1999. The two primary summary measures used for the distributions of NDVI within a 10km radius of each sampled village were the proportion of pixels with an NDVI > 0.2 (NDP) and the mean NDVI of those areas with an NDVI exceeding 0.2. The product of these two measures was also constructed as a measure of overall biomass attributable to forests (NDT).

Because the first Landsat satellite, Landsat 1, was not launched until late in 1972 and available satellite-based data for India in late 1980s are incomplete, we could not precisely match satellite scenes to survey dates. However, 96 percent of the scenes corresponding to the ARIS survey came from late 1972 and early 1973, with the scenes corresponding to the REDS survey distributed between years 1977 and 1980.[11] In addition, 81 percent of the selected scenes came from January and February, when there are few standing crops that could be confused with tree cover, and the level of cloud cover for the selected scenes never exceeds 2 on a 0–7 scale, with 0 denoting complete absence of clouds and 7 complete cloud cover. The selected Landsat 7 images were collected between November 1998 and April 1999 and had cloud cover of less than 20 percent. Due to the limited availability and high cost of Landsat images for the South Asian region during the 1980s and early 1990s, we obtained NDVI images compiled by the USGS based on data collected from the AVHRR satellite in 1992. Because these images have a lower resolution (1.1 kilometer) than the Landsat images and because measures of vegetative cover may be importantly affected by the resolution used, we resampled these images to a higher resolution based on the content of the 1999 images.

To construct a measure of agricultural technology for the 1971, 1982, and 1999 survey rounds, information from each of the surveys on crop outputs and acreage planted by crop, type of land, and seed variety (high-yielding (HYV) or not) was used to construct a Laspeyres index of HYV crop yields on irrigated lands combining four HYV crops (corn, rice, sorghum, and wheat) using

11. The average number of years between these scenes across path-row combinations is 5.1, with 75 percent of the observations spanning the interval between 4 and 7 years.

constant 1971 prices for each of the villages for the three survey years.

The Indian Census provides data for every village in India on population size, number of households, and road types for 1991. Using as matching information village, *tehsil,* and block names, we were able to match 234 of the 253 villages in the 1999 survey to the 1991 Census information.[12] The 1999 REDS provides histories of the electrification of villages, which were used to determine which of the villages were electrified in 1991. Finally, based on the village geo-codes, we also matched information on annual rainfall to each of the villages in each of the four relevant years using information on the nearest weather station from the set of 30 weather stations reporting data to the National Climate Data Center over the 29-year period.

Table I provides the means and standard deviations for all variables for each of the four years, along with the data source for the variables, and the number of villages in each round for which there are survey or Census data. As can be seen, the data indicate that India experienced a growth in forests, economic development, and population growth over the 29-year period spanned by the data: HYV crop productivity more than tripled, real agricultural wages grew by 150 percent, the proportion of villages that were electrified rose from less than a third in 1971 to almost 93 percent in 1999, the proportion of villages with a paved access road grew from 29 percent to over 73 percent, and the average population of the villages increased by almost 91.7 percent while the proportion of land with forest more than doubled.

V. Estimates of the Effects of Productivity and Population Growth on Factor Prices and Income

To assess the reasonableness of our framework, we first estimate log-linear approximations to reduced-form equations relating the variation in agricultural productivity, population size (number of households and household size), and rural infrastruc-

12. Surprisingly, a nontrivial number of the villages in the Census data do not report population or household size. The fraction of nonreporting villages for the years 1971, 1982, 1991 are .055, .279, and .051, respectively. Population estimates for the 1999 village survey are missing for 13.1 percent of the villages. Similarly, 12.4 percent of the villages in 1991 and 15.7 percent in 1999 had no information on number of households so that it was not possible to compute average household size. In the econometric analyses reported below, we include observations with missing values for population and household size by setting the missing values to zero and adding to the specification dummy variables indicating that these variables were not available.

TABLE I
VILLAGE CHARACTERISTICS (MEAN AND SD), BY SURVEY AND CENSUS YEAR

Variable	1971	1982	1991	1999
Proportion of land forested (NDP)	.105[a]	.210[b]	.239[c]	.239[d]
	(.176)	(.264)	(.198)	(.294)
Mean biomass of forested land (NDT)	.0271[a]	.0579[b]	.0462[c]	.0842[d]
	(.0487)	(.0790)	(.0235)	(.1195)
Mean net cultivated area (acres)	1344[f]	1564[g]	NA	1541[h]
	(1575)	(1579)		(1641)
Village population size	2033[e]	2642[e]	3311[e]	3877[h]
	(3121)	(3466)	(4948)	(5510)
Household size	5.88	6.12	6.05	6.51
	(1.24)	(1.72)	(1.51)	(2.53)
HYV yield (1971 rupees/acre)	321.7[f]	561.2[g]	NA	1001.9[h]
	(384.3)	(353.3)		(500.4)
Annual rainfall	1153.4[i]	1012.1[i]	944.0[i]	1004.3[i]
	(547.1)	(285.1)	(462.8)	(647.8)
Male agricultural wage (1982 rupees/day)	6.68[f]	9.99[g]	NA	16.7[h]
	(2.69)	(5.92)		(5.08)
Land price (1982 rupees)	8950.0[f]	8965.4[g]	NA	27218[h]
	(7910.3)	(9792.5)		(26395)
Household income (1982 rupees)	2845.6[f]	3071.3[g]	NA	NA
	(1451.5)	(1806.8)		
Paved (*pucca*) access road	NA	.290[g]	.706[e]	.731[h]
		(.455)	(.457)	(.444)
Factory in village	.135[f]	.622[g]	NA	.949[h]
	(.343)	(.486)		(.221)
Village in IADP[f]		.215		
Proportion of land planted in rice in 1971[f]		.297		
Proportion of land planted in wheat in 1971[f]		.116		
Number of villages	253	242	234	253

Data source: a. Landsat 1, b. Landsat 3, c. Landsat 4, d. Landsat 7, e. India Census, f. ARIS survey, g. REDS survey, h. REDS 1999 survey, i. National Climate Data Center, *Monthly global surface data.*

ture (electricity availability and access road quality) to the equilibrium values of the village wage, agricultural land price, and average household income. The reduced-form estimating equations are given by

(1)

$$z_t = b_{zt} + b_{z\theta}\theta_t + b_{zl}l_t + b_{zN}N_t + b_{z\eta}\eta_t + b_{ze}e_t + b_{zv}v + b_{zt}t_t + \varepsilon_{zt},$$

where $z = r$, the log of the average price of land in the village; w, the log of the village male agricultural wage rate; and y, average log of household income in the village. θ_t is an index of agricultural productivity, measured by the four-crop productivity index; η_t represents industrial infrastructure and is measured by dummy variables indicating whether the village was electrified and had a paved access road; e_t represents actual weather conditions at time t and is measured by the annual amount of rainfall in the nearest weather station;[13] l_t is the average log of household size in the village, and N_t is the log of the population in the village, t_t is a set of dummy variables capturing year effects.[14] Finally, v captures village-specific attributes of weather and soil as well as proximity to urban areas and markets, and ε_{zt} is a time-varying, village-specific shock.

Estimation of (1) by ordinary least squares (OLS) that exploits the variation across villages may be misleading because the unmeasured environmental variable v capturing time-invariant agroclimatic conditions and proximity to urban areas influences prices and incomes, and is likely to be correlated with agricultural productivity, the presence of industry, and the density and size of forests, including errors in the NDVI-based measures of forests due to differing topographic conditions. We exploit the fact that we have data from multiple time periods, eliminating all such fixed effects by adding to (1) village dummy variables. We also include dummy variables for the survey/census years to capture aggregate trends in the variables, including changes in the prices of the traded agricultural and wood-based goods.

Net of village and year fixed effects, the time-varying errors ε_{zt} in (1) representing, for example, period- and village-specific productivity shocks other than rainfall in the two time periods may jointly affect wages and incomes as well as crop productivity (e.g., forest fires that naturally decrease forest area, increase the

13. The relevant years for the reduced-form wage and land price equations are the NCAER ARIS and the two REDS survey years (1971, 1982, and 1999). The income equations are estimated using data from 1971 and 1982, because the 1999 village survey does not provide household income measures.

14. Note that prices of traded (across villages) inputs and outputs are impounded in the constant term b_{zt} and the year effects b_{zt}. Differential changes across villages in prices due to changes in transportation technology, for example, might induce bias due to the omission of such prices, but only to the extent that they are correlated with other included variables.

supply, and thus lower the price of arable land and average crop productivity if the new land is less productive). In addition, our estimate of village crop productivity likely measures with considerable error true agricultural productivity. We thus use instruments to predict the village-specific changes in crop productivity. We exploit three characteristics of the green revolution in India to assemble our instrument set. First, climate conditions across India make some areas of India substantially more suitable for growing rice, while other areas are suitable for growing wheat but not rice [ICAR 1978, 1985]. In 1971, 46 percent of the sample villages did not grow wheat, and 32 percent did not grow any rice. In those areas not growing wheat, over 45 percent of land was devoted to growing rice while in the villages not growing rice, on average 18 percent of crop land was planted with wheat.

A second characteristic of the green revolution is that advances in productivity varied by crop. In particular, technological advances in yields for wheat preceded those for rice but slowed more than did those for rice in the later period, so that the areas differing by crop suitability experienced differential advances in crop productivity [Evenson and David 1993]. To capture these crop-specific yield growth differentials, we used as instrumental variables predicting the growth in the HYV-crop index over the 1971–1999 period the proportion of land in the village devoted to rice and wheat in 1971, respectively, multiplied by year dummies. Finally, we used a variable representing whether or not the village was located in an Intensive Agricultural District Program (IADP) district. The IADP was initiated in the late 1960s in one district in each Indian state to promote the adoption of the new seed varieties of the green revolution through information dissemination and credit subsidy. This variable is thus unlikely to be correlated with the initial crop productivity shock in 1971 but should be a good predictor of agricultural productivity growth at least in the first decade of the sample.

Table II reports OLS and village fixed effects (FE) estimates of the predicting equation for the log of the crop productivity index. F-statistics indicate that the complete set of variables and the set of instruments explain a statistically significant proportion of the variability in HYV yields across the villages over the three sample periods. The estimates appear to capture the main attributes of the green revolution, mainly the early productivity growth for wheat yields and the more rapid advancement for rice yields later in the period. The OLS estimates indicate that in 1971 wheat yields were almost 50 percent higher than rice yields

TABLE II
PREDICTING EQUATIONS FOR LOG OF HYV YIELD: OLS AND VILLAGE FIXED-EFFECTS (FE) ESTIMATES[a]

Variable	OLS	FE
Year = 1982	.834	1.02
	(3.88)[b]	(7.74)
Year = 1999	1.26	1.55
	(5.83)	(10.1)
Proportion village area under wheat in 1971	1.49	—
	(3.77)	
Wheat * year = 1982	−.929	−1.12
	(1.88)	(2.58)
Wheat * year = 1999	−.756	−.894
	(1.51)	(2.13)
Proportion village area under rice in 1971	.566	—
	(1.45)	
Rice * year = 1982	−.158	−.404
	(0.41)	(1.93)
Rice * year = 1999	−.269	.518
	(0.76)	(2.80)
Village in IADP	.0690	—
	(0.31)	
IADP * year = 1982	−.108	−.0204
	(0.42)	(0.14)
IADP * year = 1999	−.187	−.163
	(0.77)	(1.24)
Village electrified	.391	.244
	(4.08)	(2.55)
Good (*pucca*) access road in village	.0278	−.103
	(0.36)	(1.13)
Log household size	−.151	−.390
	(1.13)	(3.36)
Log population	.0642	.0845
	(1.60)	(1.35)
Rainfall ($\times 10^{-3}$)	−.0889	.0084
	(0.93)	(0.08)
Panchayat/common land in village	−.0778	—
	(1.03)	
Constant	4.87	—
	(16.1)	
F-statistic, all variables (d.f., d.f.)	18.0	4.26
	(20,252)	(268,434)
F-statistic, instruments (d.f., d.f.)	3.04	2.63
	(9252)	(6434)
Number of observations	703	703

a. All specifications include dummy variables indicating missing values for population and household size.

b. Absolute value of t-ratio in parentheses is corrected for nonindependence of errors within villages.

but according to the FE estimates, which eliminate the influences of permanent differences in soil and climate conditions across villages, both rice and wheat yields did not advance as strongly over the 1971–1982 period compared with the other two crops in the HYV yield index, corn and sorghum, with wheat yields evidently not advancing at all over that period. In the 1982–1999 period, wheat yield growth, though positive, was less than half that of corn and sorghum, while rice yields increased substantially more than the other three HYV crops composing the yield index. The FE point estimates suggest that rice yields in 1999 were four times those in 1971, while wheat yields were less than double what they were at the beginning of the sample period. The FE estimates also indicate that village electrification on average raised yields (on irrigated lands) by 24 percent.

The cross-sectional (OLS), fixed effects (FE) and instrumental-variables fixed effects (FE-IV) estimates of the reduced-form land price, wage and income equations (1) are provided in Table III. The estimated effects of increases in crop productivity on the prices of the two forest inputs, land prices and wages, in Table III, whether estimated using the cross-sectional data only and with or without instruments, conform to the relationships that are derived from the theory—increases in crop productivity increase both the price of land and the price of labor, and also increase average incomes. The two estimates of agricultural productivity effects on the land price and wage based on the specification including village fixed effects are substantially smaller than those estimates based on the cross section, consistent with the existence of unmeasured land productivity factors that persist over time. Of the FE estimates of agricultural productivity on the two input prices, those obtained using the instruments are larger in magnitude, consistent with the existence of measurement error, and are estimated with reasonable precision. The FE-IV estimate of crop productivity is similar to that estimated without the instrument, but the standard error of the coefficient is substantially higher.[15]

The FE-IV point estimates of agricultural productivity effects suggest that exogenously increasing crop yields by 75 percent, roughly the increase in the first decade of the green revolution in India for the four HYV crops, doubles land prices, increases rural

15. The less precise estimate using instruments for household income may reflect the fact that the data on incomes come only from the 1971–1982 period. The power of our instruments, which rely on the contrast in changes in HYV productivity over time in rice and wheat areas, are considerably weaker for this period.

TABLE III

REDUCED-FORM EFFECTS OF AGRICULTURAL PRODUCTIVITY, POPULATION, AND PRESENCE OF RURAL INFRASTRUCTURE ON LOG LAND PRICES, LOG WAGES, AND LOG HOUSEHOLD INCOME: CROSS-SECTION OLS, VILLAGE FIXED EFFECTS AND FE-IV ESTIMATES[a]

Variable	Log land price			Log agricultural wage			Log HH income		
Estimation procedure	OLS	FE	FE-IV	OLS	FE	FE-IV	OLS	FE	FE-IV
Log HYV productivity (rupees)[b]	.443	.265	1.65	.0690	.0239	.164	.102	.0852	.0776
	(7.85)[c]	(5.13)	(3.15)	(2.17)[c]	(1.31)	(1.34)	(5.14)[c]	(3.34)	(0.25)
Log household size	.336	.626	1.29	.0647	−.122	−.0556	.827	.617	.517
	(1.16)	(4.65)	(3.90)	(0.85)	(2.20)	(0.67)	(10.0)	(7.53)	(2.46)
Log population	.231	−.164	−.162	.132	−.0693	−.0716	.0274	.0844	.0872
	(2.61)	(2.38)	(1.43)	(6.04)	(2.44)	(2.41)	(0.95)	(2.33)	(2.19)
Village electrified	.218	−.0176	−.133	.187	.0497	.0176	.0001	.170	.172
	(1.91)	(0.16)	(0.72)	(3.71)	(1.08)	(0.32)	(0.01)	(2.60)	(2.41)
Paved (*pucca*) access road in village	.152	−.00786	.0772	.187	.102	.0959	.269	.0834	.120
	(1.00)	(0.07)	(0.43)	(2.07)	(2.32)	(2.10)	(3.58)	(1.59)	(1.32)
Rainfall (mm $\times 10^{-3}$)	.0711	−.170	−.0364	.0749	.0909	.0998	−.176	.0419	.0229
	(0.60)	(1.56)	(0.20)	(0.22)	(2.06)	(2.15)	(5.27)	(0.68)	(0.30)
Number of obs.	697	697	697	703	703	703	484	484	484

a. All specifications include year-effects dummy variables and dummy variables indicating missing values for population and household size.
b. Endogenous variable in columns 4, 7, 10, and 13. Instruments are rice-, wheat-growing regions and IADP interacted with year indicator variables.
c. Absolute value of t-ratio in parentheses is corrected for nonindependence of errors within villages.

agricultural wage rates by 12 percent, and raises agricultural incomes by 6 percent. The estimates also suggest that wages are 10 percent higher in villages with a *pucca* road. This in part reflects the fact that road improvement programs in rural India over this period employed local labor and were designed to supplement the incomes of landless laborers. In Foster, Rosenzweig, and Behrman [2001] we also find that improvements in village roads and electrification increase the probability that a factory is built in a village, which also presumably increases the local demand for labor. Consistent with this, the last column of Table III indicates that village electrification and road improvement also significantly increase average household incomes.

The reduced-form estimates of the effects of population growth are also in conformity with the general-equilibrium framework when the fixed attributes of villages are taken into account. For given total population, an increase in household size reflects the effect of an increase in the number of household members and a decrease in the total number of households per unit area. This effect is positive for the land price and negative for wages, as expected, when fixed effects are included in the specification. The FE-IV point estimates suggest that a doubling of the population would, given household density, double land prices (1.29–.162) and depress wages by 13 percent (−.0556–.0716). Increases in the number of households (increasing total population for given household size), however, decrease land prices (and wages), suggesting that there are scale economies in production. The FE-IV estimate in the household income equation suggests that a doubling in household size, for a given number of households, increases household income by 52 percent. The estimate thus implies that doubling household size, holding agricultural technological progress fixed, reduces per capita incomes by 48 percent.

VI. Forest Area and Forest-Input Costs

The estimates in Table III indicate that two input costs of forests—wage rates and the value of land—are determined locally by local population density, agricultural productivity, and infrastructure in a way consistent with economic theory and factor mobility in India. We now turn to the issue of whether advances in agricultural productivity and the rise in wage rates, given income change, can account for the rise in forests in India over the past 30 years making use of changes in these variables across Indian villages.

The aggregate land-use and forest cover equilibrium equations we estimate are given by

$$(2)\quad A_t = d_t + d_\theta \theta_t + d_w w_t + d_l l_t + d_N N_t + d_y y_t + d_t t_t + d_e e_t + d_v v + \zeta_t,$$

where A_t = the two measures of forest coverage and density NDP and NDT, respectively, and the proportion of land cultivated at time-period t, the d_i are coefficients, and ζ_t is a village-specific time-varying error.[16] As for the reduced-form equations (1), we include in (2) dummy variables for year and for village to eliminate the influence of trends in aggregate agricultural output and traded wood-product prices and time-invariant soil and climate conditions that jointly affect agricultural productivity, equilibrium wages, land use, and forest growth. The time-varying shocks are also, however, likely to be correlated with the endogenous changes in equilibrium prices and incomes. For example, a contemporaneous positive soil, pest, or weather shock may be manifested in greater forest growth, higher wages and greater crop productivity. Moreover, any shock leading to an increase in land cultivated may directly affect agricultural wages if the time intensity of agricultural productivity differs from that in forest-product production.

To eliminate these feedback effects and others on forests and wages and incomes, we use as instruments the exogenous growth factor variables affecting technology θ_t and the infrastructural variables η_t—initial-period crop composition interacted with time, electrification, and road building along with the IADP program variable—that we have seen in Tables II and III affect crop productivity, the price of land, wages, and incomes. A feature of the model is that these variables only affect forest exploitation, conditional on agricultural technology, to the extent that they alter the opportunity costs of forest inputs and affect incomes, and thus they are appropriate instruments.

Table IV reports the estimates of equation (2). The results indicate that neglect of cross-sectional heterogeneity in land pro-

16. For the forest area equations the relevant years are those for which we constructed the satellite-based forest measures. As noted, these do not exactly correspond to the first two survey years, 1971 and 1982. To control for the variation in the time span between the satellite observations across villages, a variable was included in the forest equations that measured the difference in years between the years of the survey and the year of the forest observation.

TABLE IV
EFFECTS OF AGRICULTURAL PRODUCTIVITY, WAGE RATES, INCOME, AND POPULATION ON FORESTED AREA (NDP), FOREST BIOMASS (NDT), AND (LOG) PROPORTION LAND AREA CULTIVATED: CROSS-SECTION OLS, VILLAGE FIXED EFFECTS, AND FE-IV ESTIMATES[a]

Variable	NDP			NDT			Log proportion land cultivated		
Estimation procedure	OLS	FE	FE-IV	OLS	FE	FE-IV	OLS	FE	FE-IV
Log HYV productivity (rupees)[b]	.0262	−.0490	−.264	.00780	−.0170	−.110	.145	.107	.566
	(0.87)[c]	(2.32)	(2.72)	(0.66)[c]	(2.36)	(3.09)	(1.04)	(2.02)	(1.68)
Log of wage rate[b]	.0308	−.0722	−.268	.0154	−.0242	−.0823	−.558	−.320	−1.17
	(0.71)	(1.49)	(1.11)	(1.02)	(1.46)	(0.92)	(4.67)	(3.03)	(1.51)
Log household income[b]	.0852	.0493	.0392	.0185	−.00451	−.0416	.149	.0600	.391
	(1.54)	(1.01)	(0.22)	(1.09)	(0.27)	(0.64)	(0.98)	(0.56)	(0.95)
Log household size	−.0671	−.106	−.263	−.0310	−.0303	−.0894	.123	−.00512	.0802
	(1.61)	(1.98)	(2.86)	(1.82)	(1.66)	(2.64)	(0.81)	(0.04)	(0.32)
Log population	.0778	.137	.119	.0221	.0359	.0312	−.194	.0112	.00484
	(5.50)	(5.10)	(3.28)	(5.57)	(3.91)	(2.33)	(2.97)	(0.17)	(0.04)
Rainfall (mm $\times 10^{-3}$)	.0534	.0238	.0331	.0250	.0362	.0202	—	—	—
Number of obs.	568	568	568	568	568	568	672	672	672

a. All specifications include year-effects dummy variables and dummy variables indicating missing values for population and household size.
b. Endogenous variable in columns 4, 7, and 10. Instruments are rice-, wheat-growing regions and IADP interacted with year indicator variables.
c. Absolute value of t-ratio in parentheses is corrected for nonindependence of errors within villages.

ductivity and time-varying shocks to overall soil productivity results in the expected upward biases in the OLS and FE estimated agricultural productivity and wage rate effects on forest area. Similarly, the direct feedback effects of cultivated area on wages and crop productivity evidently result in underestimates of the negative effects of wage rates on land devoted to crops and the positive effect of crop productivity on total land under cultivation. However, both the FE and FE-IV estimates indicate that the advances in agricultural productivity associated with the green revolution did not lead to either less cultivated acreage or greater forest growth. The FE-IV estimates suggest that increases in crop productivity, where they occur, are associated with a significant reduction in the proportion of area forested, a reduction in forest density, and an increase in the proportion of total area cultivated for given price of agricultural goods. The point estimates suggest that a rise in crop productivity of 50 percent leads to a 55 percent fall in forested area, a 65 percent decline in forest biomass, and a 32 percent increase in the proportion of total land cultivated.

The estimates also indicate that the increases in agricultural wage rates over the past 30 years in India, observed in Table I, also were not likely to have been a major factor leading to the increase in forests. Although higher agricultural wage rates appear to be strongly negatively associated with net cultivated area, the relationships between wage rates and forested area and density are also negative, although they are imprecisely estimated. Thus, the significant increases in the cost of the two major forest inputs—land and labor—associated with Indian rural economic growth since the late 1960s could not have been factors leading to the growth in forests since that time.

VII. Income, the Demand for Wood Products, and Forests

The estimates suggesting that forest input cost increases decrease forest growth is consistent with the main feature of the model that the demand for local forest products is positively associated with local forest density. The population growth estimates in Table IV are also consistent with this finding. In particular, the number of households in a village is presumably positively associated with the aggregate household demand for local forest products, and the FE-IV point estimates suggest that a doubling of the number of village households (increasing population size for given household size), approximately what has occurred in India since 1970, increases forest area by 50 percent and forest biomass by 37 percent for given household income, wage rates, and the price of traded wood products. On the other hand, increases in household size, given total population, decrease forest area. This might indicate, given the model, that local forest product consumption per household is increasing in per capita household income. But if this were the case, one would expect an increase in household income to lead to a significant increase in forest area, which it does not. One explanation is that larger households face lower costs of extracting wood products from local forests, which would be the case if labor markets are imperfect for certain groups (e.g., women, children) and larger household are overrepresented with respect to these groups. Note, in any case, that over the past 30 years in India while the number of households in rural areas almost doubled, the average household size only increased by 11 percent. The changing size of households could not therefore have been a major factor in determining forest growth.

The surprising result in Table IV is that changes in local income do not appear to have an effect on local forest area for given household size. As noted, because the price of the local forest product (fuelwood) is excluded from the specification, the household income effect is underestimated—if income growth raises the local demand for wood, this increases the local wood-product price, which attenuates demand and thus the estimated local income effect. Moreover, not all forest products are locally produced. The income estimates in Table IV are obtained holding fixed the nationally determined equilibrium price of traded forest products. Thus, in contrast to the case for locally produced forest goods, a positive income elasticity of demand for traded forest products would not necessarily be evident in the relationship between local income and local forest area. Instead, increases in income would raise the demand and thus tend to increase the price of traded forest products on a national basis, as seen in Figure III. Given higher prices for traded forest goods, one would expect to see an overall increase in demand for local forest products and thus forest area, but this increase should not necessarily be concentrated in those areas with more rapid income growth. A third reason for the weak estimated income effect is that increases in income may raise the demand for amenities that compete with forests. For example, 25 percent of the sample villages built schools, health centers, government offices, or community centers, which use public lands, over the period. The income results in Table IV thus appear to reject the hypothesis that

TABLE V
WITHIN-VILLAGE DETERMINANTS OF HOUSEHOLD EXPENDITURES ON FUEL (1982 RUPEES) AND PURCHASE OF PAPER PRODUCTS AND WOOD FURNITURE

Variable	Log expenditure on fuel	Any purchases of books and newspapers	Any purchases of wood furniture
Estimation procedure	Fixed-effects	Fixed-effects logit	Fixed-effects logit
Mean of dependent variable (s.d)	5.37	.192	.113
	(.845)	(.394)	(.317)
Log household per capita income	.359	.754	.196
	(16.8)[a]	(11.6)	(2.27)
Log household size	.483	.594	.401
	(22.7)	(7.19)	(3.89)
Number of households	4897	4521	2851
Number of villages	247	238	143

a. Absolute value of t-ratio is in parentheses. *Source:* 1982 REDS.

income growth has resulted in afforestation because of increased demand for trees as environmental amenities, but are ambiguous with respect to wood-product demand effects on forests.

To explore more deeply the role of changing demand for forest products in the growth of forests, we use the survey information from the 1971 ARIS and 1982 REDS on wood product expenditures. The 1982 REDS permits inferences about wood product consumption at the household level differentiated by whether the products are locally produced. We can thus estimate price-constant income effects on forest products from these data. In particular, we obtain within-village estimates of the relationships between the log of per capita household income and total household size and the log of annual total household expenditures on fuel, which contains a high local wood component,[17] and whether or not a household purchased wood furniture and books and newspapers in the survey year. These within-village estimates control for all intervillage wage and price variation.

The first column in Table V reports the within-village log fuel expenditure estimates. These indicate that fuel demand increases

17. A national rural survey of India in 1978–1979 indicates that the percentage of wood fuel in total rural fuel expenditures is 54.6. In 1992–1993 this rose to 61.6 percent of total fuel expenditures [Natarajan 1995].

significantly with income—the estimated income elasticity is .36. The next two column estimates, obtained using fixed-effects logit, also indicate that books and newspapers are highly income elastic and that wood furniture purchases also rise with income. The point estimates indicate that at the sample mean a 10 percent increase in household income raises the probability that a household purchases books or newspapers by 29.2 percent and the probability of a wood furniture purchase by 2 percent, for given household size.

The estimates in Table V thus indicate that increases in income raise the demand for wood products, holding prices fixed. We now directly assess whether increases in the demand for fuel, which uses local wood, increase or decrease local forest area. We do this by computing mean household fuel expenditure for each village in each of the two survey years, 1971 and 1982, and regressing the change in our measure of village forest area NDP between 1971 and 1982 on the change in average village per-household fuel expenditure and the change in the number of households in the village. To the extent that fuel is a major product of local forests, we should observe a positive relationship between changes in fuel consumption and forest growth.

The fixed-effects regression estimates are

$$(3) \quad \text{NDP} = \underset{(4.09)}{.000262} * \text{fuel consumption} + \underset{(2.62)}{.0000833} * \text{number of households}, \; N = 400,$$

where t-ratios are in parentheses. As can be seen, the relationship between changes in local fuel consumption and changes in local NDP is positive and statistically significant—villages experiencing faster growth in fuel expenditures also are observed to have experienced greater forest growth. Figure VII provides the partial-regression leverage plot of the relationship between average household fuel expenditures and NDP.

Does the positive relationship displayed in Figure VI suggest that increases in local wood demand induce more trees? A potential problem is that changes in fuel expenditures reflect changes in both quantities and price, and the local fuel price is not observed. Thus, an alternative explanation for the positive relationship between changes in expenditures on fuel and forest growth is that in areas which experienced an exogenous increase in forest (e.g., through conservation), there was a fall in the price of fuelwood. Fuel expenditures would increase in such areas if the price

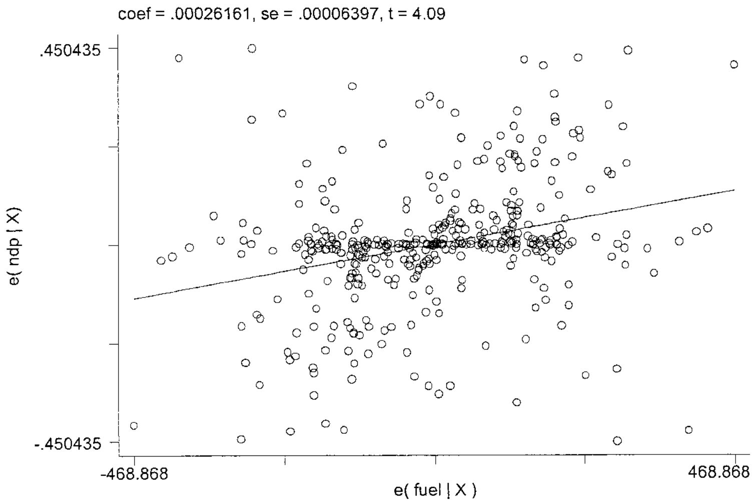

FIGURE VII
Relationship between Change in Fuel Expenditures and Change in NDP, Indian Villages, 1971–1982

elasticity of fuel demand exceeds one. Similarly, if the fuel-price demand elasticity exceeds one, the fuel expenditure-NDP estimate in (3) is consistent with higher demand for fuelwood decreasing forests. If the price elasticity is less than one, however, then supply-induced changes in expenditure would result in a negative relationship between forest area change and changes in fuel expenditure and changes in forest area would be positive only if the forest supply price response is positive.

Without village-level information on the price of fuelwood, it is not possible to directly estimate the price elasticity of fuelwood. However, to the extent that household fuel consumption is a household public good, the relationship between changes in household size and fuel consumption provide information on the fuel price elasticity. Intuitively, increasing household size lowers the effective price of the public good to each household member. We establish in Appendix 1 that in the context of a simple household model a sufficient condition for the price elasticity of demand for fuel to be less than one is that the elasticity of household fuel consumption with respect to household size is less than one, given per capita household income. As seen in Table V, the (price-constant) household size-fuel elasticity is .48, statistically significantly less than one. Thus, the estimates in (3) suggest that increases in fuel demand, where they have occurred, increased local forest area.

VIII. Conclusion

In this paper we have sought to identify the underlying paths by which economic growth affects forests, focusing on the roles of forest-product demand, demand for forests as environmental goods, agricultural technical change, and rural labor costs. We have shown that a key to identification is the geographic scope of the market for forest products. If forest goods are traded broadly, there can only be a weak link between the local demand for forest goods and local forests. Inattention to the tradability of forest products can thus obscure inferences about the role of forest-product demand in affecting forest cover. We show empirically using newly assembled cross-national data on economic growth and forest change in developing countries that in open economies there is indeed no systematic relationship between economic growth and changes in forest cover, reflecting the relatively weak results in the existing literature. On the other hand, for closed economies that supply much of their own demand for forest products, we find a clear significant positive relationship between changes in income and changes in forest area. This combination of results thus implies that the supply of forests responds to increased demand for forest products, but that absent the profitability of supplying local tree products, income growth does not necessarily increase the demand for trees where it occurs, as implied if trees were desired as environmental goods.

To more precisely assess alternative explanations for how economic growth affects forests, we have focused on one country, India, in which because of government policies there is limited international trade in forest products and in which there is limited spatial mobility of a major wood product (fuelwood) due to its relatively low value to volume. Thus, Indian forests reflect domestic forces of product demand and resource costs at both national and local levels. Time-series data at the national and village levels both suggest that rising demand for wood products has led to a rise in forests in India in the past 30 years. Aggregate domestic wood-product consumption, the relative price of fuelwood and forests have risen in India during this time period. Moreover, we show, based on merged detailed household survey data and satellite imagery covering the period 1970–1999, that fuel demand in India is increasing in income and that local increases in fuel demand are associated with increased local tree area. Our analysis of these data also rules out two other explanations that have appeared in the literature for forest growth. In particular, we find no evidence that increased agricultural productivity, such as that associated with the Indian green revolution, increases tree area by decreasing the need for expansion of agricultural lands or that growth in rural employment increases forests by moving labor out of forest-resource extraction. Indeed, as might be expected given the relative tradability of agricultural products an increase in agricultural productivity has an adverse effect on forest area at the local level.

Our results indicating that increasing demand for forest products associated with income growth leads to a rise in forests suggest that conservation-based measures that either reduce the demand for forest products (e.g., recycling of paper or the inhibition of suburban homebuilding) or place local restrictions on forest exploitation do not save trees. With respect to the latter, the Indian national government after some states put in place constraints on forest use (green felling) in the late 1980s, lowered tariffs on timber imports to relieve somewhat the subsequent rise in the price of wood products. This merely shifted the source of wood supply to and presumably increased forest growth in areas of the world outside of India. Our results imply that future reductions in barriers to trade in wood will thus likely lead to a worldwide increase in forests, although there will also be a reduction in the association between growth in domestic forest-product demand and domestic forest growth.

Our findings should not be interpreted as meaning that issues of forest management emphasized in the literature are not important. The translation of increased demand for forest products into expanded forests is not automatic, but depends importantly, as expressed by Arrow et al. [1995], on the "context of growth" [p. 521]. In part, this context is itself affected by growth. In India, in particular, the increase in the demand for marketable tree products is in part responsible for the implementation of the Joint Forest Management Program in the 1980s, which provides villagers with a share of the sales proceeds from timber extracted from public forests. Clearly, without appropriate incentives in place, shifts in demand and supply would not be aligned. However, it is possible that without the shift in demand for forest products, effective policy reforms expanding forests may not have been feasible. Finally, future demand-led forest growth clearly will affect the composition of forests and their distribution worldwide. To the extent that tree species diversity, "natural" forests, or specific locations of forests are valued, and not just the aggregate world quantity of trees, restrictions on forest exploitation in particular contexts may be warranted.[18]

18. In the Indian state of Uttar Pradesh between 1960 and 1990 more than half of the natural forests were cleared to plant eucalyptus, a faster-growing tree

APPENDIX 1

Consider a household with n individuals, each with preferences $u(c_{fi},c_{xi})$ over own effective consumption of fuel c_{fi} and own consumption of other goods c_{xi}. Effective consumption of fuel for an individual depends on the extent of economies of scale and thus, in effect, on the technology by which quantities of fuel purchased c_f^*, given household size, are translated into effective individual consumption. To capture differences in the extent to which fuel consumption is public, we characterize this idea parametrically by assuming that $c_f = c_f^*/n^\alpha$ for $\alpha \in [0,1]$. The case in which fuel is a pure private good is captured by $\alpha = 1$ while the opposite case in which fuel is a pure public good within the household is represented by $\alpha = 0$. If we restrict attention to symmetric allocations, then the household objective function is to maximize the utility of the representative householder (say individual $i = 1$)

$$u(c_{f1},c_{x1})$$

subject to the household budget constraint,

$$ny = p_f c_{fi}^* - \sum_{i=1}^{n} c_{xi} = p_f c_{fi} n^\alpha - n c_{x1},$$

where y denotes household per capital income, p_f is the price of fuel, and the price of c_{x1} is normalized to one. Dividing the budget constraint through by n yields

$$y = p_f c_{fi} n^{\alpha-1} - c_{x1}.$$

Given that n only appears multiplicatively with the price of forest goods, it may be shown that at the constrained optimum,

$$\frac{d\ln c_{f1}}{d\ln p_f} = -\frac{1}{1-\alpha}\left(\frac{d\ln c_{f1}}{d\ln n} - \alpha\right).$$

It follows from this equation that if the household size elasticity of demand is less than one, then the price elasticity of demand must be either positive or less than one in absolute value as long as fuel has at least some public-good character ($\alpha < 1$).[19]

species [Uttar Pradesh Forest Corporation 1990]. In the United States between 1950 and 1988 Southern pine forest in plantations has increased from 2.5 percent of total pine forest to more than 40 percent, all at the expense of "natural" pine forest [USDA 1988].

19. For $\alpha = 1$ the household size elasticity of demand firewood is uninformative about the price elasticity of demand. However, this pure private goods case can be ruled out if the household size elasticity is not equal to one.

APPENDIX 2: CROSS-COUNTRY REGRESSIONS: FOREST GROWTH RATES AND INCOME GROWTH RATES, BY TRADE OPENNESS, 1980–1995

Variable/classification	Open economies	Closed economies	All
Income growth rate	−.0653	.261	.261
	(0.68)[a]	(5.10)	(5.15)
Open = 1	—	—	−.0380
			(1.06)
Income growth rate × open = 1	—	—	−.326
			(2.98)
Constant	−.111	−.0730	−.0730
	(3.62)	(3.89)	(3.93)
N	35	23	58

a. Absolute value of robust t-ratio is in parentheses.

APPENDIX 3: COUNTRY DATA

Open-economy countries (exports + imports)/GDP > .5			Closed-economy countries (exports + imports)/GDP < .5		
Country	Forest growth rate	Income growth rate	Country	Forest growth rate	Income growth rate
Algeria	−0.184	−0.174	Bangladesh	−0.220	0.329
Belize	−0.043	0.008	Bolivia	−0.140	−0.218
Burkina Faso	−0.105	0.145	Brazil	−0.086	−0.105
Cameroon	−0.096	−0.286	Burundi	0.198	0.133
Cen. Af. Republic	−0.062	−0.330	Chad	−0.111	−0.255
Congo Republic	−0.033	0.069	Chile	−0.024	0.208
Costa Rica	−0.433	−0.052	China	0.053	0.424
Ecuador	−0.255	−0.208	Colombia	−0.086	0.124
Egypt	0.194	0.070	Dom. Republic	0.100	−0.025
El Salvador	−0.396	−0.170	Ghana	−0.196	−0.042
Fiji	−0.005	0.119	Guatemala	−0.273	−0.141
Gabon	−0.083	−0.466	India	0.110	0.375
Guinea	−0.172	−0.579	Iran	−0.267	−0.001
Guinea-Bissau	0.057	0.318	Madagascar	−0.136	−0.487
Honduras	−0.329	−0.127	Mexico	−0.001	0.004
Indonesia	−0.126	0.478	Morocco	−0.050	0.127
Kenya	−0.050	−0.016	Nigeria	−0.206	−0.510
Malawi	−0.197	−0.129	Pakistan	−0.453	0.222
Malaysia	−0.332	0.375	Paraguay	−0.382	−0.241
Mauritania	0.004	0.019	Peru	−0.046	−0.354
Mauritius	0.087	0.451	Rwanda	0.160	−0.009
Mozambique	−0.104	−0.255	Uganda	−0.139	0.281
Namibia	−0.049	−0.114	Uruguay	0.014	0.034
Panama	−0.296	−0.048			
Papua N. Guinea	−0.006	−0.185			
Philippines	−0.503	−0.093			
Sierra Leone	−0.431	−0.447			
Singapore	0.000	0.632			
South Africa	−0.021	−0.163			
Sri Lanka	−0.154	0.302			
Thailand	−0.444	0.575			
Togo	−0.236	−0.289			
Tunisia	0.063	0.165			
Venezuela	−0.163	−0.089			
Zimbabwe	−0.095	−0.035			

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