POPULATION, INCOME AND FOREST GROWTH:

MANAGEMENT OF VILLAGE COMMON LAND IN INDIA*

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Abstract

A newly-assembled data set that combines national household survey data, census data and satellite images of land use in rural India over a 29-year period is used to obtain estimates of economic growth and population effects on forests, to identify the mechanisms by which these factors affect land use, and to address whether forest areas are efficiently managed where community land management is present. The evidence suggests that increases in the returns to alternative uses of land induced by agricultural technical change and population growth, combined with the difficulty of monitoring forest-resource extraction, are the major contributing factors to deforestation.

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I. Introduction

The growing concern about the phenomena of global warming and declining bio diversity has led to an increase in attention paid to the disappearance of the world's forests, particularly in the developing world. Forests cover about 40 percent of land in tropical nations, and deforestation has been especially acute in Asia. Between 10 and 20 million hectares of tropical forest are cleared each year, with annual rates of deforestation between 1980 and 1990 averaging 1.2 percent in Asia, compared with 0.9 percent in the developing world (Ehui and Hertel [1989]; World Bank [1992b]). The Asian Development Bank (ADB) claims that "there are four major environmental problems ... arising from population pressures, lack of development, and the development process itself" and three of these four problems in Asia - "land degradation and depletion of natural resources; ...pollution of soil, water and air; and consequences of global warming due to excessive discharge of green house gases to the atmosphere" - are intimately associated with deforestation [Jalal 1993, p. 2].

While a variety of global economic forces affect the trends in deforestation in developing countries, recent research has emphasized the importance of local-level processes such as agricultural encroachment and product extraction through firewood collection and animal grazing that are themselves importantly influenced by the fact that forest resources in most developing countries are not privately owned (e.g., DasGupta [1995], Loughran and Pritchett [1997], Filmer and Pritchett [1996], Agarwal and Yadama [1997], Jodha [1985], Ligon and Narain [forthcoming], López [1997]).[1] The nonprivate ownership of forests lands, as well as of grazing and waste lands, has raised questions of whether there historically has been and/or currently is a "tragedy of the commons" that characterizes forest operations. Several researchers, most notably Jodha, have investigated whether, in the absence of regulatory institutions, rapid population growth actually leads to degenerative patterns of use and the gradual depletion of common property resources (CPRs) (Chopra and Gulati [1993]; Jodha [1985, 1990]; Runge

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[1]In India, for example, Bowonder [1982] reports that 96 percent of the total forest areas is owned by the government.

[1981]; Repetto and Homes [1984]; Wade [1988]; White and Runge [1994]). Although as popularly conceived depletion of such resources is a straightforward consequence of rapid population growth, these studies suggest that traditionally many CPRs have been well-managed by local institutions so that historically the effects of rapid population growth have been, in Jodha's [1985, p. 247] words, "mediated by institutional factors and often overshadowed by pressures arising from changing market conditions."

Considerably less attention has been given to the related question of how income growth in general, and technical change in agriculture in particular, has impacted forest resources. While it is widely recognized that improvements in agricultural productivity permit population growth without adverse Malthusian income consequences, the effects on forest resources of both population growth and agricultural technical change remain an open question. Moreover, in the substantial economic literature concerned with the question of the efficiency with which common areas such as forest areas are managed in developing countries, there is surprisingly little discussion of the process by which forest area is chosen. 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. These omissions would seem difficult to justify in terms of current patterns of forestation and deforestation in both developed and developing countries. In particular, growth in forests in the developed world in recent years can be attributed in part to investment decisions on the part of private owners in certain regions (such as the Northwest US) and to decreases in the returns to agriculture in others (such as New England) that reflect the changing costs of labor, an important input in forest extraction, and changes in the demand for forest products.[2] An investigation of the determinants of deforestation thus needs to pay attention to the markets for land, labor and forest products as well as land management.

One important barrier to improved understanding of the technological, behavioral and

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[2]Sedjo (1995) provides a useful discussion of the differing trajectories of forest cover in developed and developing countries. He notes, for example, that the state of New Hampshire experienced an increase in forest cover from 50 to 86 percent of total land area in the period 1850-1990.

organizational forces affecting global deforestation has been the absence of adequate data. Many empirical studies of land and forest use are based on case studies over short time periods that do not permit identification of the longer-term consequences of population change or technical progress and cannot easily be generalized.[3] In this paper, we utilize a 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 address limitations to knowledge about how agricultural technical change and population growth affect land management in general and the management of forest exploitation in particular. A key feature of the data is that while in many villages all land is privately owned, a substantial number of the villages have common lands governed by the local village council (*panchayat*). We use the data to obtain estimates of rural economic growth and population effects on deforestation, to identify the mechanisms by which these factors affect land use, and to address the question of whether forest areas are efficiently managed in areas in which community management of lands is present.

India is a particularly interesting and useful setting in which to study the management of forest resources. Over 20 percent of all land in India is designated as forest land, 96 percent of which is publicly managed common land. Moreover, India is a country that has experienced rapid population growth and since the late 1960's has been a major beneficiary of the "green revolution," which has substantially augmented crop productivity growth. Large-scale studies of the effects of agricultural productivity growth or population change on forests in India have been limited, however, by the fact that governmental data sources provide information only on designated forest lands, including newly-designated land for forests on which tree planting may have only been recently initiated rather than on actual tree coverage or forest biomass.[4] Information on actual land use, based on satellite images, is thus

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[3]In a recent article, however, Cropper and Griffiths [1994] have assembled a data base consisting of a time-series of non-OECD countries over the period 1961-91 that serves to describe associations among forest land, per-capita GDP, and population density within major continents of the world.

[4]Cropper and Griffiths (1994) were unable to estimate any significant relationships for Asia or South Asia using official government statistics on forests.

necessary to evaluate the effects on actual forest biomass of population trends and the agricultural productivity increases.

Another reason that India is an important area of study is that there have been substantial efforts to reforest starting in the early 1950's by subsidizing the provision of seedlings to be allocated and distributed by village governments. Indeed, the efforts to increase forest growth stemmed from the notion that increasing population would increase the demand for forest products (FAO, 1999). Figure I plots the (i) proportion of land in India designated by the government as forest land for each Census year from 1951 through 1991 and for 1999 and (ii) our satellite-based estimates of the proportion of land of land with trees surrounding the sample villages in our nationally-representative survey data for the same years starting in 1971 when satellite data first became available.[5] Contrary to popular belief, the government statistics indicate that the amount of land both estimated to be forested and set aside for forests has increased in India since 1951, rising from 12.3% in 1951 to over 23% in the 1990's. Moreover, our data, based on satellite imagery for our national sample of Indian villages, indicate that the increase in set-asides for forest land has been accompanied, with a lag, by increases in actual forests. These estimates indicate that the proportion of land covered by forests increased from just over 10% in 1971 to over 24% in 1999.

During the same 29-year period that forests surrounding our sample villages have experienced growth on average, the average population size of the villages almost doubled and yields of the hybrid-seeds associated with the green revolution have almost tripled. Moreover, as documented below, over the same period the villages have electrified, access roads have substantially improved and factories have been set up in almost all villages. This does not necessarily imply that rural economic development and population growth have not adversely affected forests. These aggregate trends mask important differences in the experiences of Indian villages. For example, 41% of our sample villages experienced a

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

decline in forests between 1971 and 1999.[6] To identify the roles of population change and rural development and to assess the efficiency of local land management thus requires the comparison of the changes in forests across villages over time with their changes in population size, agricultural productivity and rural infrastructure.

Section II of the paper briefly describes the theoretical framework that guides the empirical analysis, highlighting the mechanisms by which technical change in agriculture, rural industrialization and population growth affect forest area and the demand for forest products and contrasting perfect-markets and unmonitorable labor regimes to consider the effects of forest-management institutions on these relationships. Section III describes the data sources and the construction of the variables. Section IV presents the reduced-form estimates and Section V the structural estimates that identify the mechanisms by which economic growth and population change affect forests and the role of land management. Our results indicate that the effect of income growth on forests is importantly conditioned by the specific mechanisms causing incomes to increase. Our structural estimates indicate that the principal mechanism through which both agricultural technical change and population growth cause deforestation is through their effects on pushing up the value of land for growing crops. Rural industrialization has had little impact on forest survival because industrialization did not appear to raise land rents appreciably, in contrast to the effects of the improvements in agricultural productivity, and because changes in income per se appear to have only weak direct effects on forest exploitation. These results suggest that the "green" revolution in India, while forestalling the negative income consequences of a Malthusian equilibrium, was less green than first thought. Our estimates also are also consistent with the hypothesis that the difficulty of monitoring the extraction of forest is a contributing factor, along with agricultural technical change, to inhibiting the growth of forests.

II. Empirical Framework

[6] In addition, it has been argued that reforestation has altered the nature of forest ecosystems such that bio-diversity has been reduced. For example, some local government forest programs involve the distribution of seeds for specific tree species, such as eucalyptus and populus (FAO, 1999).

To highlight the roles of both the demand for forest products and the changing opportunity costs of land and labor in determining forest resources that arise from agricultural technical progress, rural industrialization and population growth and to evaluate the role of constraints on land management in affecting these relationships, we need an empirical framework encompassing three sectors - agriculture, forestry, and industry - with two factors of production - land and labor. We assume that rural India can be characterized as an economy composed of sub-economies (villages) which are locally governed and across which there is little labor mobility. However, manufactured goods and agricultural products are traded across villages and labor is freely mobile across sectors within villages. To capture the effects of local demand for forest products we also allow for constraints on trading such products (firewood) across villages, consistent with the observation that goods such as firewood or the forage consumed by livestock in the forest, the principal uses of forest products in the Indian context that we study, are bulky and thus are not easily transported.[7] Thus, given that land is also immobile, wage rates, land prices and forest-good prices are locally determined.

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, naturally varying local environment variables (rainfall, temperature, soil quality, etc.), and variation in variables affecting labor productivity in the manufacturing sector (the availability of infrastructure, capital, and knowledge relevant to the generation of non-agricultural non-forest employment). How these exogenous factors and population growth affect the land allocated to forests will depend importantly not only on the technology of production and the preferences of households but on the institutional structure governing resource allocation. We contrast two cases that incorporate different constraints on forest management and discuss how these cases may be distinguished empirically.

[7]Bowonder (1982) estimates that 90 percent of the wood extracted in India is used for fuel.

A. Input and Output Markets and the Efficient Allocation of Land

We consider first a benchmark case of complete and perfect input and output markets to examine how shifts in population size and technical change influence forest use when inputs are allocated efficiently. This "complete-markets" framework thus corresponds to a setting in which all labor can be monitored and either all land, inclusive of forests, is privately held by each household or, equivalently, any forest-land commons are first-best efficiently chosen and managed by a village council or other institution. We assume that 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 forest and non-forest 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, as determined by variation in the number and size of households. In this simple framework[8] agricultural technical change, population growth and rural industrialization have quantitatively and perhaps qualitatively different effects on forest survival, even if they have similar effects on the demand for forest products, because they differentially affect the opportunity costs of the two main forest inputs, land and labor.

The effects of improvements in (factor-neutral) agricultural technology on land rents and wages in this framework is straightforward - both increase as agricultural productivity rises. The effects of population growth are more complex. Because the household is the decision-making unit, the effects of increases in household size and density (the number of households per unit area) on land rents and wages may differ depending on the existence of scale economies in consumption and production. For given land

[8]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,

area per household (total number of households), the framework predicts that increases in the size of households and thus the total population will increase land rents and lower wages. Controlling for total population, however, increases in the total number of households population will lower (raise) land prices if there are production scale economies (dis-economies). In the case of the determination of household income, different effects of household size and density are especially likely to be observed because increases in household size directly increase household income, although less than proportionally, by augmenting household labor supply. Finally, manufacturing productivity raises wages and may raise or lower land rents depending on how such change affects the demand for forest products.

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 changes in conditions that promote the expansion of the manufacturing sector affect the forest allocation. It is thus an empirical question as to whether and how agricultural technical change and population growth contribute to deforestation.

The principal reason for the ambiguity with respect to even the consequences for the land allocated to forests of advances in farm technology is that the effects of changes in the opportunity cost of labor used to extract forest products and of changes in income that affect the demand for forest on the forest allocation cannot be predicted. This framework can be used to derive equilibrium conditions that relate the two endogenously-determined cost variables - wages and land rents - and endogenously-determined incomes along with the population variables to the optimal forest allocation. These indicate that while increases in the opportunity cost of land, induced by both technical progress in agriculture and by population growth, unambiguously reduce the amount of land allocated to forests, the sign of the wage rate effect on forest area is ambiguous, depending on the price elasticity of demand for forest products and properties of the production technology. And, of course, the sign and magnitude of income effects induced by technical change and population growth depend on the exact nature of household preferences for forest products.

B. Common-Land Management and Unmonitorable Labor

The benchmark model sketched above in which forest products are treated like a conventional crop provides a sensible way of capturing the idea that forest area will be importantly determined by the returns to alternative uses of land and by pressures on wage rates. While this approach does not provide an explanation for key institutional features of forests such as that they are frequently held in common land, it should be emphasized that the approach does not necessarily assume that forest land is privately held. The market solution could emerge if forests were commonly owned as long as both the area and usage of these forests were first-best efficiently chosen and managed.

There is an important restriction that arises from the complete-markets framework, however. In particular, in the aggregate the signs of the partial effects of income and household size on forest area, conditional on the market wage rate and land price, are the same as those that would be observed in household forest product demand equations.[9] This strong prediction implies that estimation of the effects of household size and income from the market equilibrium equations that condition on wage rates and land prices, given information on the effects of household size and income on household forest-product demand, can provide a test for (local) market completeness, inclusive of the efficient management of forest resources.[10]

In order to assess whether the restrictions from the first-best allocation model concerning the effects of the income and family size variables on forest area net of wage rates and land prices in equilibrium provide a test of first-best allocations requires an alternative model. A reasonable candidate

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[9]This results depends importantly on the absence of dynamic effects of current forest use on future output over a long time period. The test can be generalized, however, to take into account different assumptions about saving and/or borrowing opportunities by replacing income with household expenditures as long as any uncertainty is resolved prior to the making of decisions.

[10]Note that the signs of the income and family size effects on the demand for forest products are not known a priori, and must be estimated. Because firewood, for example, may be considered an inferior fuel, increases in income may result in lower demand for firewood. Similarly, increases in household size may increase or decrease demand depending on the extent to which firewood serves as a public good for household members as well as the price elasticity of demand for that commodity.

is a model in which forest area is selected to maximize some welfare criterion subject to constraints that preclude the implementation of first-best outcomes. One constraint that is highlighted in the literature, given the apparent important of common-management of forest resources, is the high cost of monitoring the extraction of forest resources. The idea is that given the land intensity of forest goods production and the fact that visibility may be obscured in forested areas, even privately owned forest resources would be subject to a "commons tragedy."[11] An obvious but significant implication of the assumption that forest extraction cannot be directly monitored is that households would not wish to hold any land in forests as they would be unable to extract rents from such property. Given the high costs of transporting forest resources it is thus in the interest of the village as a whole to set aside some amount of land as commonly-held forests. Although the amount of land that is thus held, to the extent that it is chosen optimally, will be importantly influenced by the marginal productivity of land, it will not, in general, be chosen as in the benchmark case so that the marginal revenue product of forest land is equal to the equilibrium price of land as determined in the agricultural sector given forest labor.[12]

In the framework in which labor is unmonitorable but all inputs are optimally allocated subject to the monitorability constraint, in contrast to the complete markets regime, the system of equations determining equilibrium in the forest-products sector cannot be decentralized, so that forest area cannot be solved as part of a three-equation system conditional on wages, rentals, and household income. This implies that the restrictions on the forest-area equilibrium conditions are unlikely to hold in this alternative regime. However, the analytic derivation of comparative static results is also prohibitively complex. In Foster, Rosenzweig, and Behrman (1998) we show that for at least one parametric specification of this alternative model, the test of the restrictions associated with the complete-markets

[11]Filmer and Pritchett, for example, report that 34 per cent of firewood in rural Pakistan is collected from land held privately by other households without compensation.

[12]It can be shown that at the social-planner's optimal allocation of forest land, the marginal revenue product of forest land exceeds the marginal revenue product of agricultural land so that, 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 to the competitive case.

regime have power against the alternative of unmonitorable forest labor. Moreover, this model indicates that under conditions in which the demand for forest products, conditional on the forest-good price, is increasing in household income and not affected by household size, increases in both household size and household income can have a negative effect on aggregate forest area net of wages and land prices. Thus, in this particular parametric specification, the consequences of increases in both household size and household income for deforestation, net of wages and land prices, are more adverse when forest area is second-best efficiently managed than in the case in which land is efficiently managed.

III. The Village Panel Data Set

As noted, India represents an interesting and potentially useful setting in which to examine the determinants of forest growth and the role of market failures in determining the management of forest resources. The spatially-differentiated growth in agricultural productivity resulting from the exogenous importation of new seed technologies applied to differentially-suitable agroclimates combined with the relatively high rates of population growth experienced by India in the over the past 30-40 years would appear to have the potential to provide insights into the roles of agricultural technical change and population growth in affecting the levels of and changes in forest area.

Given the existing evidence that villages in India play a prominent role in the management of forest resources,[13] we have constructed a panel data set at the village level for approximately 250 villages covering the period 1971-1999 that combines multiple sources of data, that conforms to our multi-sectoral framework and that incorporates heterogeneity in the organization of land management. In particular, we have merged survey-based information on crop productivity, household incomes, household consumption, household size, numbers of households, land prices, wage rates, rural electrification, roads, and industry presence with governmental statistics on weather and satellite-based information on locale-specific changes in the density of forests. The constructed data set comes from six

[13]For example, using village-level samples from specific sub-regions of India both Jodha (1985) (Western Rajasthan) and Agarwal and Yadama (1997) (Kumaon Himalaya), find evidence of a relationship between forest conditions and village-level resources and institutions.

sources: (i) the 1970-71 National Council of Applied Economic Research (NCAER) Additional Rural Incomes Survey (ARIS), (ii) the 1981-82 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.

A. Measuring Forests

As noted, official Indian data sources for the period spanning the three NCAER surveys provide information on land officially classified as forest. This includes land newly set aside for growing trees but which may not yet exhibit any vegetative growth as well as designated forest areas that have been encroached upon by local growers. The absence of ground-level censuses of trees for the relevant period covered by the survey 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 infra-red 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 infra-red light and absorb red light.[14] 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.[15]

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[14]Roughly speaking, the high infra-red reflectance accounts for the relative coolness of vegetation and the low red reflectance accounts for the green color.

[15]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 mask the presence of leaves at lower levels thus yielding a non-linear relationship between the NDVI and leaf area. Moreover it is sometimes difficult to distinguish forest area from agricultural crops. We address that issue through our selection of the timing of images, as discussed below. It is, however, not clear that any single measure clearly dominates the NDVI in terms of being

To match the satellite and survey data we first geo-coded the survey data. To do this we obtained geographic position codes for the ARIS survey villages based on maps from the district-level volumes of the 1971 and 1981 Indian censuses. To ensure that survey village names corresponded to those in the census, we used the survey information on village, *tehsil*, and district names. Seven villages had to be dropped from the original 250 because a village of the name specified in the ARIS sample was not found (4 of 7) or because more than one village of the same name was found in the corresponding tehsil and district (3 of 7). The *tehsil* maps, which plot the locations of each village, were then geo-registered using the district-level maps, which contain latitude and longitude information.

Measurement of forest cover for each of the sample villages that could be linked to the corresponding time periods involved accessing three distinct sources as discussed in detail below: Multispectral Scanner (MSS) images from Landsats I-III 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 VII 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).

The MSS images have a spatial resolution of approximately 80 meters in four bands of the spectrum. Each “path” and “row” pair uniquely determine a geographical area of approximately 185 kms square for the MSS images. A number of criteria were used to select specific scenes. First, it was desirable to have scenes for each location that corresponded as closely as possible to the crop-years covered by the ARIS (1970-71) and REDS (1981-1982) surveys. The most important constraints in matching by crop-year are that the first Landsat satellite, Landsat 1, was not launched until late in 1972

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able to provide a robust measure of forest area across a wide variety of areas and climatic conditions given the nature of available remote sensing data from the period in question. Moreover, errors associated with the use of NDVI to measure forest cover that are fixed over time in particular areas will not importantly influence our results when we examine differential changes in the NDVI across regions.

and the availability of the relevant scenes for India is limited after 1980. Second, in order to control for seasonal variation in vegetative cover, scenes were selected for a given area that were at similar points within the crop-cycle and corresponded to periods within the year during which there is minimal presence of standing crops, which can be difficult to distinguish from forest area using satellite imagery. Preliminary analysis suggested that the months of January and February were best. Third, because areas covered by clouds cannot be used to assess vegetative cover, images were selected with little or no cloud cover. The choice of the winter months was also useful in this regard because the cloud-laden monsoon period was excluded.

We were reasonably successful in meeting all of these criteria. Ninety-six 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. 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. In addition, 81 percent of the selected scenes came from January and February, with all scenes coming from the November-April period. Finally, 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.

For each of the selected 146 scenes corresponding to a specific path-row-day combination we obtained positive transparency images for both the near infra-red and red bands of the spectra. These images were then scanned at a resolution of 300 pixels per inch. Images were then registered to latitude and longitude using data on the locations of the four corners of each image. The intensity of the images was then adjusted using the grey-scale bands printed on the side of each image. Scans of these two images were combined to construct a measure of NDVI for each of 6.5×10^6 pixels in each scene. Based on these, we obtained a distribution of the values of the NDVI pixels within a 10km radius of each village for each of the surveys. On average there were 53,904 pixels within the desired radius for each village.

Selection and analysis of the Landsat VII images from early 1999 followed a roughly similar procedure, with the exception that images were available digitally making it unnecessary to manually geo-register and intensity-correct the images. Coverage of the relevant villages required 85 distinct path-row combinations for this satellite. Images were selected to have low cloud cover and correspond to the time-period of the year for the early images. The images are at a resolution of 30 meters but were resampled to a resolution comparable to that of the 1971-1982 images before the NDVI measures were calculated. The selected Landsat VII 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, an alternative source was used to construct NDVI measures to correspond to the 1991 Indian census. In particular, 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[16] we resampled these images to a higher resolution based on the content of the 1999 images. In particular, selected 1999 images were first sampled to a resolution of 80m and then averaged to a resolution of 1km. We then constructed a linear regression equation relating NDVI in the 80m images to that in the 1km images for 1999 and determined the variance of the resulting residual. This regression equation combined with random draws from the corresponding error distribution were used to construct NDVI images with a nominal resolution of 80m based on the original 1km AVHRR images.

B. Village-level Economic and Demographic Variables

The national NCAER surveys and the 1991 Indian Census village-level data provide information

[16]This arises from the non-linearity of the forest-cover measure. Consider, for example, a 10km radius image consisting of 50,000 pixels, 40 percent of which have an NDVI of .3 and 60 percent of which have an NDVI of .4. At this resolution our measured forest cover (NDVI>.2) is 40 percent. Now suppose the image is degraded by a factor of 100 so that the village now contains 500 pixels. In the extreme case that the forest and non-forest pixels are independently distributed across the village then, using the same .2 cutoff one would obtain a forest cover measure of only 3.6 percent.

on variables describing the economic environment of the villages matched to the satellite data on forests over the 1971-99 period. The 1970-71 round of the ARIS data provides information on household structure (age-sex composition); income by source, agricultural inputs, outputs and costs, by item, and wage rates and labor supply for 4,659 households in 259 villages that were selected based on a stratified random survey design. The data set contains sample weights reflecting the stratified sample design so that population statistics, necessary for aggregation and merging, can be obtained from the survey data. Also provided is information on village population size, village-level land prices, for irrigated and unirrigated land, and on village infrastructure, including whether the village was electrified and the presence of rural industry and whether or not the village was located in a district participating in the Intensive Agricultural District Program (IADP), a national program instituted in the late 1960's that provided agricultural resources and subsidies of agricultural input (seeds, fertilizer)in areas believed to be those that would be subject to the most significant productivity improvements as a consequence of the green revolution..

The 1982 REDS data provide similar information for the 1981-82 crop year on a subset of the original 1970-71 households as well as data on a new, random sample of households based on the same survey design as in the ARIS and on a complete census of households in the original 259 ARIS villages. However, because of political constraints, all households in the state of Assam were dropped from the sampling frame. The panel and the new households together number 4,947 and, based on the sample weights, are representative of the entire national rural Indian population (except for Assam) in 1981-82. The REDS data also provide sampling weights for all households, as described in more detail in Vashishtha [1989], thus permitting construction of a representative data set at the village level for 1981-82 that can be matched with that from 1970-71. In 1999, NCAER under our direction carried out a survey of the same villages as in the 1970-71 ARIS, excepting those in Jammu and Kashmir states, collecting information consistent with that collected at the village-level in 1982.

To construct a measure of agricultural technology, information from the three 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 constant 1971 prices for each of the villages for the three survey years. The 1970-71 ARIS and the 1981-1982 and 1999 REDS data sets thus provide a consistent set of rural agricultural wage rates, land prices, HYV crop productivity, and rural industry measures and information on the size and numbers of households for up to 253 villages spread all over India for the years 1971, 1982 and 1999. We also obtained information from the 1991Indian Census on a subset of the 1999 survey villages. 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.[17] The 1999 REDS provides histories of the electrification of villages, which were used to determine which of the villages were electrified in 1991. 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. Figure 2 maps the location of the survey villages as well as the weather stations.

Table 1 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 is survey or Census data. As can be seen, the data indicate that India experienced economic development over the 29-year period spanned by the data: HYV crop productivity more than tripled, real agricultural wages grew by 150%, the proportion of villages that were electrified rose from less than a third in 1971

[17]The sources for village population sizes for the ARIS and the 1981-82 REDS surveys were the 1971 and 1981 Censuses of India. Surprisingly, a non-trivial number of the villages in the Census data do not report population or household size. The fraction of non-reporting villages for the years 1971, 82, 91 are .055, .279, and .051, respectively. Population estimates for the 1999 village survey are missing for 13.1% of the villages. Similarly, 12.4% of the villages in 1991 and 15.7% 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.

to almost 93% in 1999, and the proportion of villages with a factory increased from 14% to 95%. At the same time the average population of the villages increased by almost 91.7% and the proportion of land with forest more than doubled.

An important feature of the 1999 survey data is the identification of those villages with common or local-authority (*panchayat*) governed lands. Approximately 56% percent of the villages had village commons, so that it is possible to examine the relationship between forest growth and property rights and, in particular, carry out the tests, described above, of efficiency in the management of forest resources. In particular, we can assess whether the estimates of the equilibrium equations more closely conform to the restrictions of the first-best model in villages in which there is no common land compared with villages with joint management of forest resources, presumably established as a response to the high cost of labor monitoring.[18]

Table II provides information on forest area and density, population, crop productivity, wage rates and prices from 1971 through 1999 for the sample villages stratified by whether or not they had locally-managed common lands. The figures indicate that the proportion of land area devoted to forests in the initial period was 39% higher in common-land villages compared with those villages without government-controlled land. Villages with common lands also had agricultural land that was almost 8% more productive than villages without common lands. The fact that common-land villages in 1971 had both a greater proportion of land under forest and greater crop productivity than villages without common lands might suggest that common-land governance succeeds in protecting forests despite high returns to alternative land use. However, it is also possible that conditions favoring crop productivity also favor tree growth, or that forest land is of lower quality than crop land such that where more land is devoted proportionally to agriculture, average crop productivity is lower. Given land and climate heterogeneity, it is not possible to distinguish between these hypotheses from cross-sectional

[18]Bardhan [1993] discusses the notion that incentives to undertake group management of common resources may be importantly related to local ecological conditions. Narain [1999] presents evidence that the costs of monitoring forest resources is closely related to the degree of forest degradation and considers the implications of this relationship for group management of resources.

associations.

Table II also indicates that forest cover increased slightly more in the common-land villages over the last 29 years - the proportion of land covered by forest grew by 135% in common-land villages and by 114% in the other villages. However, crop productivity growth in the villages with common land was 41.9 percentage points slower than that in the common-land villages. This suggests, in contrast to the cross-sectional relationships in 1971, that the inability to monitor and enforce forest exploitation in the face of rural economic growth may have attenuated forest growth. However, common-land villages experienced faster population growth compared with the other villages over the same period. A more systematic examination of the roles of population and economic growth in affecting the change in forests is thus needed that takes into account land and climate heterogeneity and the interrelationships among population, technical change, and the demand for forest products in assessing the efficiency of common-land forest management and identifying the consequences for forests that emanate from improvements in agricultural productivity.

IV. Estimates of the Effects of Productivity Growth by Sector and Population Growth on Factor Prices, Income and Forests

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

$$(1) \qquad z_t = b_{zt} + b_{z\theta}\theta_t + b_{zl}l_t + b_{zN}N_t + b_{z\eta}\eta_t + b_{ze}e_t + b_{z\nu}\nu + b_{zt}t_t + \epsilon_{zt}$$

where $z = r$, the log of the average price of land in the village; w, the log of the village male agricultural wage rate; y, average log of household income in the village; presence of a factory, and A_f, the share of village land area under forest and forest density, measured both by NDP and NDT, respectively. θ_t is an index of agricultural productivity, measured by the four-crop productivity index; η, 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;[19] 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.[20] Finally, ν 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.

As the relationships in Table II suggest, estimation of (1) by ordinary least squares (OLS) using variation across villages at one point in time may be misleading because the unmeasured environmental variable ν, 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. We exploit the fact that we have data from multiple time periods to eliminate 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.

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

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[19]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. 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.

[20]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.

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; ICAR 1985). In 1971, 46% of the sample villages did not grow wheat and 32% did not grow any rice. In those areas not growing wheat, over 45% of land was devoted to growing rice while in the villages not growing rice, on average 18% 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 1971-99 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 1960's 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 III 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% higher than rice yields 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 1971-82 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 1982-99 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%.

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 IV. The estimated effects of increases in crop productivity on the prices of the two forest inputs, land prices and wages in Table IV, whether estimated using the cross-sectional data only and with or without instruments, conform to the relationships that are derived from the standard complete-markets framework - 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 estimated based on the cross-section, consistent with the existence of unmeasured land productivity factors that persist over time. Of the two FE estimates of agricultural productivity on the two input prices and on incomes, those obtained using the instruments are larger in magnitude, consistent with the existence of measurement error, and are estimated with precision except for the productivity effect on agricultural wages.

The FE-IV point estimates of agricultural productivity effects suggest that exogenously increasing crop yields by 75%, roughly the increase in the first decade of the green revolution in India for the four HYV crops, doubles land prices, increases rural agricultural wage rates by 4 percent and raises agricultural incomes by 26%.[21] The relatively small estimated effect of yield growth on wages may reflect the fact that labor is mobile, so that local changes in crop productivity on wages may understate the national effect. That labor mobility may be a factor affecting wages is suggested by the finding that increasing the quality of the village's access road increases the average wage in the village - agricultural wages are almost 12% higher in villages with a *pucca* road. However, improvements in village accessability also increase the probability that a factory is built in the village, which presumably increases the local demand for labor. The estimates in the last column suggest that villages with paved access roads are 15% more likely to have a factory. Improved village access also evidently increases the local price of land - land prices are over 22% higher in villages with *pucca* access roads.

The reduced-form estimates of the effects of population growth, for given household density, are also in conformity to the market framework when the fixed attributes of villages are taken into account. The effect of changing population size, given area per household, is the sum of the log household and log population coefficients. This sum 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, in the absence of production scale economies, push up land prices by 48% (.764-.283) and depresses wages by 21% (-.118-.0898). 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 80 percent. The estimate thus implies that doubling household size, for given agricultural technological progress, reduces per-capita incomes by 20 percent.

The different qualitative and quantitative estimated effects of agricultural productivity increases,

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[21]Our reduced-form estimates of agricultural technology effects on wages are comparable to those obtained by Evenson (1993) for North India based on district-level data over a comparable period - his results indicate that an increase in productivity raises wages by 19 percent. Evenson's North Indian elasticity estimates also indicate, however, that agricultural productivity growth lowers land rents.

rural infrastructure and population growth on input prices and income indicated in Table IV, in general conformity to the market framework, suggest that these growth factors will have different effects on forests, to the extent that opportunity costs of land and labor use and incomes affect land allocations. Table V reports the reduced-form OLS, FE and FE-IV estimates for the two forest-area measures. The differences among the OLS, FE and FE-IV estimates of crop productivity effects are again consistent with the presence of heterogeneity in soil productivity and measurement error in our productivity measure. The cross-sectional OLS estimates suggest that areas with high crop productivity also tend to have more area devoted to forest and more forest biomass. In contrast, the two sets of FE estimates, which control for soil productivity and other fixed factors of the villages, indicate that increases in agricultural productivity growth have negative effects on forest change, with the FE-IV productivity estimates larger in absolute value than the two corresponding FE estimates.[22] Indeed, the FE-IV point estimates suggest that a 50% increase in crop productivity, for given number and size of households, would reduce the proportion of forested area (NDP) by about 64 percent and forest density by about 76 percent. Thus while technological change in agriculture evidently forestalls the Malthusian income trap by increasing wages and income (Table IV), it reinforces any destructive effects of population growth on forests.

The population and household size effects on forests, like the estimates for crop productivity, suggest the importance of the opportunity costs of land for forest growth. While the OLS estimates indicate that population size and forest density are positively correlated, the FE-IV estimates, which take into account measurement errors in crop productivity and differences across areas in inherent land productivity that may attract population and facilitate vegetation, suggest that like crop productivity improvements increases in the size of the population lead to deforestation. The point estimates indicate that a doubling in population, leaving land parcels at the same size, would decrease the proportion of land

[22]The negative FE and FE-IV estimates of the relationship between crop productivity and our measures of forest density suggest that the growth in the values of these measures over time do not simply reflect the fact that we have not been successful in distinguishing tree foliage growth from crop growth.

forested by 14% ((-.122+.088)/.239) and forest biomass by 28% ((-.0419+.0187)/.0842).The estimates also suggest, however, that increases in household density for given household size, which evidently lower the average value of crop land (Table IV) and may also increase the demand for forest products, leads to forest growth. The point estimates indicate that increasing the number of households by 50%, while leaving household size constant, for example, would increase the proportion of land forested by 18% and increase forest biomass by 11%.

Finally, the FE-IV estimates provide a mixed picture for the effects of rural infrastructure development and industrialization on forests. The Table IV estimates indicate that both electrification and road improvement accelerate rural industrialization, but in Table V, although electrification appears to augment forest growth, road improvement appears to accelerate deforestation. The difference may suggest that villagers directly substitute electricity for fuelwood.[23]

V. Estimates of the Equilibrium Equations: Opportunity Costs and The Efficiency of Common Land Management

The reduced-form estimates suggest that both agricultural technical change and population growth reduce forested land and forest density, with two potential mechanisms being the pressure they put on the value of land for crop use, as reflected in the change in the price of arable land, and changes in income. We now (i) assess which of these mechanisms is the most important in affecting the survival of forests and (ii) address the question of whether inefficient common land management at the local level also contributes to deforestation. We do this by estimating forest change (equilibrium) equations that condition on land prices, wages and incomes and by making use of our information on the presence of village-governed common lands.

A. Opportunity Costs of Forest Inputs, Incomes and Forest Survival

The aggregate forest-equilibrium estimating equation is given by

(2) $$A_{ft} = d_t + d_r r_t + d_w w_t + d_l l_t + d_N N_t + d_y y_t + d_t t_t + d_{yC} C \times y_t + d_e e_t + d_{lC} C \times l_t + d_\nu \nu + \zeta_t$$

[23]In villages that were electrified in 1999, only 46.6% of the households used electricity.

where the d_i are coefficients, and ζ_t is a village-specific time-varying error. As for the reduced-form equations (1), we include in (2) dummy variables for year and for village to eliminate aggregate trends and time-invariant soil and climate conditions that jointly affect both the equilibrium prices and forest area, as well as whether or not villages manage common property resources. The time-varying shocks are also, however, likely to be correlated with the endogenous changes in equilibrium prices and incomes. The most direct example is that, given the fixity of land supply, a mandated increase in forest area in a given year must reduce the amount of crop land and thus would raise the equilibrium price of land. This would lead to a spurious positive relationship between land prices and forests.

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

Table VI reports the equilibrium-equation estimates. These are estimated using the data from 1971 and 1982 only, as neither the 1991 census data nor the 1999 village survey provides information on household incomes. The results indicate that neglect of heterogeneity in land productivity and the possibility that shifts in the amount of land devoted to forest area directly affect land prices results in expected upward biases in the OLS and FE estimated land price effects, respectively, on forest area. The estimated effect of the wage rate on forest area and density also becomes successively more negative when fixed-effects and fixed-effects with instruments are used. Again, the OLS estimates indicate that areas with highly productive land, as reflected in higher land prices, are more forested. However, controlling for soil conditions and other fixed factors that vary across villages, the estimates indicate that agricultural technical change and population growth affect forest survival by affecting the opportunity cost of forest land in terms of the value of arable land and by changing wage rates and incomes, although the former effect is estimated more precisely.

The FE-IV estimates of the effects of an increase in the log price of arable land on forest area and density, net of wage and income growth, are negative and statistically significant, indicating that an important mechanism by which both agricultural productivity increases and population growth deplete forests is by increasing the attractiveness (profitability) of using land for crops. The FE-IV point estimates indicate that a doubling of the price of land would reduce the proportion of land devoted to forest by 54% and forest biomass by 58%. The coefficients on log income and log wage are measured less precisely, but the coefficients are not economically trivial indicating that both income and wage growth lead to increased forest extraction.[24] The estimates also suggest that net of variation in income and prices, increasing the size of the population, keeping land per household constant, does not add to deforestation, while increasing the number of households, and thus increasing the demand presumably for forest products, appears to increase the proportion of land allocated to forests.

B. The Contribution of Common-Land Management to Deforestation

The estimates in Table VI suggest that net of equilibrium wage rate and land price effects, increasing household size and incomes have negative effects on forest area and density. As discussed in section III, when markets are complete and land management is first-best efficient the signs of the household size and income effects in the forest product demand equation should be replicated in the equilibrium forest equations. Testing for this conformity over all Indian villages as a means of assessing land management efficiency has the important weakness that rejection could take place as a result of violation of any one of a number of assumptions, such as the assumption that agricultural labor markets are fully efficient, not just inefficiency in the management of forest labor. However, using the equilibrium equation specification we can identify the presence of problems in the management of forest labor with two additional assumptions, given our information identifying villages with common lands. First, markets other than the forest-labor market must be no less complete in villages with common lands

[24]The results are unchanged whether income or expenditure is used as the measure of household resource availability.

than they are in villages without common lands. Second, at the household level, for given prices and infrastructure, the demand equation for fuel must not differ across common-land and private-ownership villages (i.e., household behavior is the same in the two village types). Given these two assumptions, the finding that the estimated equilibrium-equation effects on forestation of changes in household size and household income deviate more strongly from the estimated effects of changes in household size and income in the household fuel demand equation in common-land villages compared with private-land villages would suggest that forest resources were not first-best efficiently managed in villages with common land.

The first assumption concerning efficiency differences in markets other than that for forest products across common-land and private-land villages, although reasonable, cannot be readily tested. We can test the second assumption concerning differences in household fuel demand behavior, conditional on prices, however. The 1970-71 ARIS data provide information on fuel expenditure (including the imputed cost of self-collected firewood) for all households, of which wood is a major component.[25] Table VII presents estimates from these household data of the relationship between household fuel expenditure, household size, and household income for all villages and separately for common-land and private-ownership villages. All specifications include dummy variables for village location to pick up differences across villages in village-level prices and environmental conditions.

In the sample including all villages household size has a positive and statistically significant, but small, effect on fuel expenditure - adding one more individual to the household increases fuel expenditure by from .85 to 1.9 rupees (average annual fuel expenditure is 43 rupees). The household size effect is also positive within both common-land villages and villages without common land. Household income also has a positive effect on fuel expenditure for each village type. Test statistics based on the pooled equation including all households reported in the last column of the table indicate non-rejection of

[25]Filmer and Pritchett, using data from Pakistan find that 54 percent of all fuel used by households is firewood. Their data indicate that most rural households (75 percent) collect at least some of their own firewood.

the hypothesis that the household size and income or expenditure coefficients are the same across village types.[26] If markets are complete in both sets of villages we should therefore expect to observe positive household size and income effects in the forest equilibrium equations for each village type; alternatively, if there are comparable degrees of market inefficiency in common-land and private-land villages, then we should observe the same deviation in both types of villages from the predicted effect of family size and income observed in the household fuel expenditure equations.[27]

The aggregate forest-equilibrium estimating equation augmented to include the common-land interaction variables is given by

(3) $$A_{ft} = d_t + d_r r_t + d_w w_t + d_l l_t + d_N N_t + d_y y_t + d_{yC} C \times y_t + d_e e_t + d_{lC} C \times l_t + d_\nu \nu + \zeta_t$$

where as before the d_i are coefficients and C is a dummy variable taking on the value of one if the village manages common land. Given the results in Table VII, the finding that $d_l<0$ and $d_y<0$ would be inconsistent with the hypothesis of perfect markets, inclusive of efficiently-managed land resources. The test of the null hypothesis that common-land villages do not differentially face problems in the monitoring of forest labor is thus that $d_{lC} \geq d_{yC} = 0$.

The weak positive FE and FE-IV coefficient estimates for household size in Table VI are not statistically inconsistent with the estimates of the effect of household size variation on the household demand for fuel, reported in Table VII, which is positive and statistically significant. Thus we do not have a strong result on overall market failure. However, in Table VIII, where the household size variable is interacted with the dummy variable indicating whether a village is managing common lands, the results from the estimation procedures that control for village fixed-effects indicate that market failure is evidently confined to such villages. In particular, net of any effects of increasing household size on land prices, wage rates, or household incomes, in villages where common lands are locally managed, growth in household size has an additional statistically significant negative effect on forest area and forest

[26]The test statistic ($F_{2,3961}$) is 0.73.

[27]Because it is possible that the wood component of fuel is inferior, the finding of a different sign for income in the forest equilibrium equations may not signify rejection of efficient land management.

density, opposite in sign to that in the household fuel demand equation. Not only do these results suggest that common-land villages cannot efficiently monitor forest labor, but they also suggest that these limitations importantly exacerbate the negative consequences of population growth on forest resources.

The income interactions are also consistent with differential market efficiency in the two types of villages. For all estimation procedures and for both measures of forest the difference in income effects across common-land villages and those without common land are statistically significant, in contrast with the results of Table VI, which indicate the absence of differences in income effects on fuel expenditures across the two village types. Thus given no differential in the efficiency of markets with the exception of that for forest labor, these results coupled with those for household size suggest that villages holding common land may do so because they cannot efficiently monitor forest labor and thus cannot rely on private ownership of forest lands to produce efficient outcomes.

VI. Conclusion

The issue of environmental degradation in rural areas of developing countries has received substantial attention in recent years and has been cited as a possible motivation for a wide variety of programs and policies. One important concern in particular is the efficiency with which land is managed, particularly forest land that is communally owned. Despite the importance of forest management in terms of global externalities, however, little is known about the magnitudes and, in some cases, the signs of the consequences of agricultural technical change, population growth, and rural industrial growth for forest cover and deforestation. Even less is known about the mechanisms underlying these relationships and, in particular, the relative efficiency of alternative mechanisms of forest-resource management.

In this paper, we have assembled a village-level data set based on longitudinal household survey and census data combined with satellite images that cover a wide area of rural India over a 29-year period to partially address limitations to knowledge about how the specific mechanisms of economic and population growth affect land management in general and forest exploitation in particular. Our empirical investigation is based on a general-equilibrium approach that incorporates the two major inputs to forest exploitation - land and labor - and considers the allocation of these resources across three sectors - agriculture, industry and forestry. We use this framework both to characterize how changes in the opportunity costs of land use and of labor induced by technical change in agriculture and population growth affect forest survival and to examine the role of institutional constraints associated with common property resources.

Our reduced-form econometric results confirm that higher population growth does indeed lead to reductions in forest area and density, but that if this growth is accompanied by land fragmentation, which reduces land productivity, some of these adverse population effects are ameliorated. The results also indicate that the effect of income growth on forests depends most importantly on how growth affects the opportunity cost of land use. The specific mechanisms by which growth is achieved thus matter for forest survival. In the case of India we find that both agricultural technical change and infrastructural development in the form of electrification and road improvements attracting rural industry increased equilibrium wages and incomes, but because only agricultural technical change evidently also raises equilibrium rents for arable land, the former results in decreased forest area while the latter has little effect on forest survival. These results suggest that the green revolution, at least in India, while forestalling the negative income consequences of a Malthusian equilibrium, contributed significantly to deforestation, and thus was less green than some have thought. Our estimates based on equilibrium relationships between forest area and density and wages, land prices and incomes is also consistent with the hypothesis that villages facing high costs of monitoring forest labor choose to commonly manage forest resources rather than relying on the private market to set aside forest area. The presence of this type of inefficiency also appears to exacerbate the negative impact of population growth on forest survival, and is thus a contributing factor, along with agricultural technical change, to deforestation.

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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)
Village population size	2033[e]	2642[e]	3311[e]	3877[h]
	(3121)	(3466)	(4948)	(5510)
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)		
Village electrified	.316[f]	.593[g]	.855[h]	.925[h]
	(.466)	(.492)	(.353)	(.264)
Good (*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)
Common land in village[h]		.559		
Village in IADP[f]		.215		
Rice-growing village[f]		.297		
Wheat-growing village[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]REDS1999 survey, [i]National Climate Data Center, *Monthly global surface data*.

Table II
Characteristics of Villages (Mean and SD), by Presence of *Panchayat*/Common Land and Survey and Census Year

	Panchayat/Common- Land Villages				Villages without Common Land			
Variable	1971	1982	1991	1999	1971	1982	1991	1999
Proportion of land forested (NDP)	.120 (.180)	.244 (.278)	.248 (.208)	.283 (.307)	.0864 (.169)	.168 (.240)	.223 (.178)	.185 (.270)
Mean biomass of forested land (NDT)	.0311 (.0507)	.0678 (.0842)	.0487 (.0162)	.102 (.128)	.0220 (.0458)	.0454 (.0702)	.0423 (.0182)	.0621 (.105)
Village population size	2276 (3252)	2883 (3737)	3728 (5568)	4521 (6185)	1746 (2947)	2348 (3102)	2793 (4014)	3141 (4538)
HYV yield (1971 rupees / acre)	332.5 (276.0)	596.7 (384.4)	NA	974.8 (457.7)	308.9 (294.6)	517.3 (353.3)	NA	1035 (548.6)
Male agricultural wage (1982 rupees / day)	7.05 (2.91)	10.9 (6.89)	NA	17.4 (5.11)	6.25 (2.35)	8.75 (3.98)	NA	16.0 (4.96)
Land price (1982 rupees)	9396 (8213)	9884 (11452)	NA	30052 (27528)	8410 (7530)	7828 (7273)	NA	23726 (24602)
Village electrified	.403 (.492)	.604 (.491)	.863 (.345)	.935 (.247)	.211 (.409)	.544 (.500)	.825 (.382)	.912 (.284)
Good (*pucca*) access road	NA	.365 (.483)	.738 (.442)	.748 (.436)	NA	.192 (.396)	.663 (.475)	.711 (.456)
Number of villages	111	112	132	109	88	92	102	89

Table III
Predicting Equations for Log of HYV Yield: OLS and Village Fixed-Effects (FE) Estimates[a]

Variable	OLS	FE
Year=1982	.834 (3.88)[c]	1.02 (7.74)
Year=1999	1.26 (5.83)	1.55 (10.1)
Proportion village area under wheat in 1971	1.49 (3.77)	-
Wheat*year=1982	-.929 (1.88)	-1.12 (2.58)
Wheat*year=1999	-.756 (1.51)	-.894 (2.13)
Proportion village area under rice in 1971	.566 (1.45)	-
Rice*year=1982	-.158 (0.41)	-.404 (1.93)
Rice*year=1999	-.269 (0.76)	.518 (2.80)
Village in IADP	.0690 (0.31)	-
IADP*year=1982	-.108 (0.42)	-.0204 (0.14)
IADP*year=1999	-.187 (0.77)	-.163 (1.24)
Village electrified	.391 (4.08)	.244 (2.55)
Good (*pucca*) access road in village	.0278 (0.36)	-.103 (1.13)
Log household size	-.151 (1.13)	-.390 (3.36)
Log population	.0642 (1.60)	.0845 (1.35)
Rainfall (x10^{-3})	-.0889 (0.93)	.0084 (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 (20,252)	4.26 (268,434)
F-statistic, instruments (d.f.,d.f.)	3.04 (9,252)	2.63 (6,434)
Number of observations	703	703

[a]All specifications include village-effects dummy variables and dummy variables indicating missing values for population and household size. [c]Absolute value of t-ratio in parentheses corrected for non-independence of errors within villages.

Table IV
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			Factory in Village		
Estimation procedure	OLS	FE	FE-IV	OLS	FE	FE-IV	OLS	FE	FE-IV	OLS	FE	FE-IV
Log HYV productivity (rupees)[b]	.423 (7.27)[c]	.265 (5.25)	1.52 (3.81)	.0515 (1.94)[c]	.0232 (0.98)	.0576 (0.47)	.0329 (1.43)[c]	.0352 (0.88)	.341 (1.54)	-.0428 (1.76)[c]	-.0489 (2.01)	-.0274 (0.20)
Log household size	.438 (1.70)	.379 (2.97)	.764 (3.30)	.0460 (0.63)	-.131 (2.27)	-.118 (1.62)	.214 (4.66)	.0690 (0.83)	.752 (5.37)	.0347 (0.49)	.0102 (0.17)	.0180 (0.23)
Log population	.182 (2.42)	-.210 (3.03)	-.283 (2.57)	.114 (6.06)	-.0872 (2.85)	-.0898 (2.83)	-.0211 (1.14)	.0160 (0.36)	.0687 (1.58)	.0826 (5.27)	.193 (6.04)	.192 (5.80)
Village electrified	.174 (1.41)	.0023 (0.02)	-.201 (1.13)	.155 (3.12)	.0317 (0.66)	.0223 (0.39)	-.0045 (0.07)	-.0411 (0.55)	.170 (2.15)	.0567 (1.23)	.166 (3.33)	.162 (2.82)
Good (*pucca*) access road in village	.255 (2.08)	.0056 (0.06)	.228 (1.32)	.229 (3.28)	.113 (2.53)	.116 (2.53)	.196 (3.57)	.246 (4.19)	.0124 (0.14)	.112 (2.53)	.0937 (2.00)	.0956 (1.98)
Rainfall (mm x 10^{-3})	.0711 (0.60)	-.265 (2.60)	-.195 (1.22)	.0225 (0.68)	.0697 (1.52)	.0702 (1.53)	-.0387 (1.99)	.170 (2.97)	.0828 (1.15)	.0013 (0.05)	.0717 (1.48)	.0725 (1.48)
Panchayat/common land in village	-.0768 (0.53)	-	-	.0628 (1.44)	-	-	-.0236 (0.76)	-	-	-.0522 (1.55)	-	-
Number of obs.	697	697	697	703	703	703	484	484	484	726	726	726

[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 corrected for non-independence of errors within villages.

Table V
Reduced-Form Effects of Agricultural Productivity, Population, and Presence of Rural Infrastructure on Forested Area (NDP) and Forest Biomass (NDT):
Cross-section OLS, Village Fixed Effects and FE-IV Estimates[a]

Variable	NDP			NDT		
Estimation procedure	OLS	FE	FE-IV	OLS	FE	FE-IV
Log HYV productivity (rupees)[b]	.0534 (3.87)[c]	-.00362 (0.22)	-.306 (3.25)	.0176 (3.59)[c]	-.00209 (0.36)	-.101 (3.12)
Log household size	-.0199 (0.65)	-.0531 (1.32)	-.122 (2.21)	-.0188 (1.74)	-.0192 (1.35)	-.0419 (2.20)
Log population	.0348 (3.96)	.0887 (4.02)	.0881 (3.13)	.0103 (3.29)	.0189 (2.41)	.0187 (1.93)
Village electrified	-.0196 (0.80)	-.0109 (0.31)	.0884 (1.63)	-.00410 (0.47)	-.00665 (0.53)	.0260 (1.39)
Good (*pucca*) access road in village	.0535 (2.41)	-.0357 (1.22)	-.0657 (1.71)	.0174 (2.21)	-.0167 (1.61)	-.0266 (2.01)
Rainfall (mm x 10^{-3})	-.00009 (0.01)	.0420 (1.26)	.0315 (0.74)	-.0102 (1.75)	-.0296 (1.24)	.0181 (0.91)
Panchayat/common land in village	-.0011 (0.06)	-	-	.0012 (0.19)	-	-
Number of obs.	791	791	791	791	791	791

[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 and 7. Instruments are: rice-, wheat-growing regions and IADP interacted with year indicator variables. [c]Absolute value of t-ratio in parentheses corrected for non-independence of errors within villages.

Table VI
Equilibrium Equations: Effects of Land Prices, Wage Rates, Income and Population on Forested Area (NDP) and Forest Biomass (NDT)[a]

Variable	NDP			NDT		
Estimation procedure	OLS	FE	FE-IV	OLS	FE	FE-IV
Log of land price[b]	.0480 (2.17)[c]	-.0283 (1.51)	-.130 (2.65)	.0480 (2.17)[c]	-.00928 (1.41)	-.0486 (2.77)
Log of wage rate[b]	.00851 (0.58)	-.0471 (0.98)	-.356 (1.35)	.00639 (0.16)	-.0135 (0.80)	-.124 (1.32)
Log household income[b]	-.00256 (0.16)	-.0961 (1.93)	-.186 (1.08)	.0213 (0.43)	-.0532 (3.05)	-.107 (1.73)
Log of household size	-.0409 (1.87)	-.00226 (0.04)	.0103 (0.13)	-.0785 (1.58)	.00641 (0.36)	.0162 (0.57)
Log of population	.0131 (2.17)	.106 (3.93)	.0816 (2.26)	.0511 (2.84)	.0273 (2.88)	.0192 (1.48)
Rainfall (mm x 10^{-4})	-.212 (1.72)	.341 (0.59)	.195 (0.29)	.242 (0.70)	-.240 (1.18)	-.288 (1.21)
Panchayat/common land in village	.00422 (0.32)	-	-	.00477 (0.13)	-	-
Number of obs.	540	540	540	540	540	540

[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 and 7. Instruments are: rice-, wheat-growing regions and IADP interacted with year indicator variables, presence of village *pucca* access road, and village electrified dummy. [c]Absolute value of t-ratio in parentheses corrected for non-independence of errors within villages.

Table VII
Village Fixed-Effects Estimates: Determinants of Household Fuel Expenditure (1971 Rupees)

Variable	All Villages	Villages with Commons	Villages without Commons	All Villages
Household size	1.92 (4.53)[a]	1.88 (2.75)	1.99 (4.10)	1.99 (4.11)
Household income	.00653 (10.6)	.00677 (8.02)	.00617 (7.36)	.00617 (7.38)
Common-land village*household size	-	-	-	-.110 (0.13)
Common-land village*income	-	-	-	.00060 (0.51)
Number of households	4,461	2,454	2,007	4,461
Number of villages	259	137	114	259

[a]Absolute value of t-ratio is in parentheses

Table VIII
Test of Equality of the Effects of Household Income, Household and Population Size on Forested Area (NDP) and Forest Biomass (NDT) Between Common-Land and Non Common-Land Villages[a]

Variable	NDP			NDT		
Estimation procedure	OLS	FE	FE-IV	OLS	FE	FE-IV
Log of land price[b]	.0503 (2.33)[c]	-.0241 (1.28)	-.0815 (2.11)	.0216 (2.76)	-.00846 (1.28)	-.0295 (2.15)
Log of wage rate[b]	.00883 (0.22)	-.0629 (1.32)	-.108 (0.59)	.00960 (0.66)	-.0183 (1.10)	-.0510 (0.79)
Log household income[b]	.0317 (0.63)	-.0988 (1.95)	-.204 (1.62)	.00166 (0.10)	-.0557 (3.14)	-.0987 (2.21)
Village common land*log of household income[b]	-.0164 (1.87)	-.0152 (2.31)	-.0153 (1.96)	-.00630 (1.85)	-.00610 (2.64)	-00630 (2.29)
Log of household size	.0274 (0.24)	.213 (2.17)	.246 (2.33)	.00509 (0.13)	.0859 (2.50)	.0996 (2.67)
Village common land*log of household size	-.149 (1.19)	-.308 (2.73)	-.305 (2.53)	-.0653 (1.45)	-.112 (2.82)	-.115 (2.69)
Log of population size	.0523 (2.40)	.106 (2.87)	.117 (2.87)	.0124 (1.73)	.0306 (2.37)	.0345 (2.38)
Village common land*log of population size	.00056 (0.03)	.0126 (0.25)	-.0162 (0.30)	.00217 (0.31)	-.00256 (0.15)	-0333 (0.69)
Rainfall (mm x 10^{-4})	-.322 (0.96)	.460 (0.80)	.354 (0.58)	-.240 (2.04)	.196 (0.98)	.222 (1.03)
Panchayat/common-land in village	.359 (1.34)	-	-	.137 (1.46)	-	-
Constant	-.752 (2.70)	-	-	-.250 (2.61)	-	-
Number of obs.	540	540	540	540	540	540

[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 and 7. Instruments are: rice-, wheat-growing regions and IADP interacted with year indicator variables and whether or not the village has common land, presence of village *pucca* access road, and village electrified dummy interacted with whether or not the village has common land. [c]Absolute value of t-ratio in parentheses corrected for non-independence of errors within villages.

Figure I
Proportion of Total Land Area Classified as Forest (Govt. Statistics) and Proportion of Land Forested (Satellite Data for Survey Villages), India 1951-1999

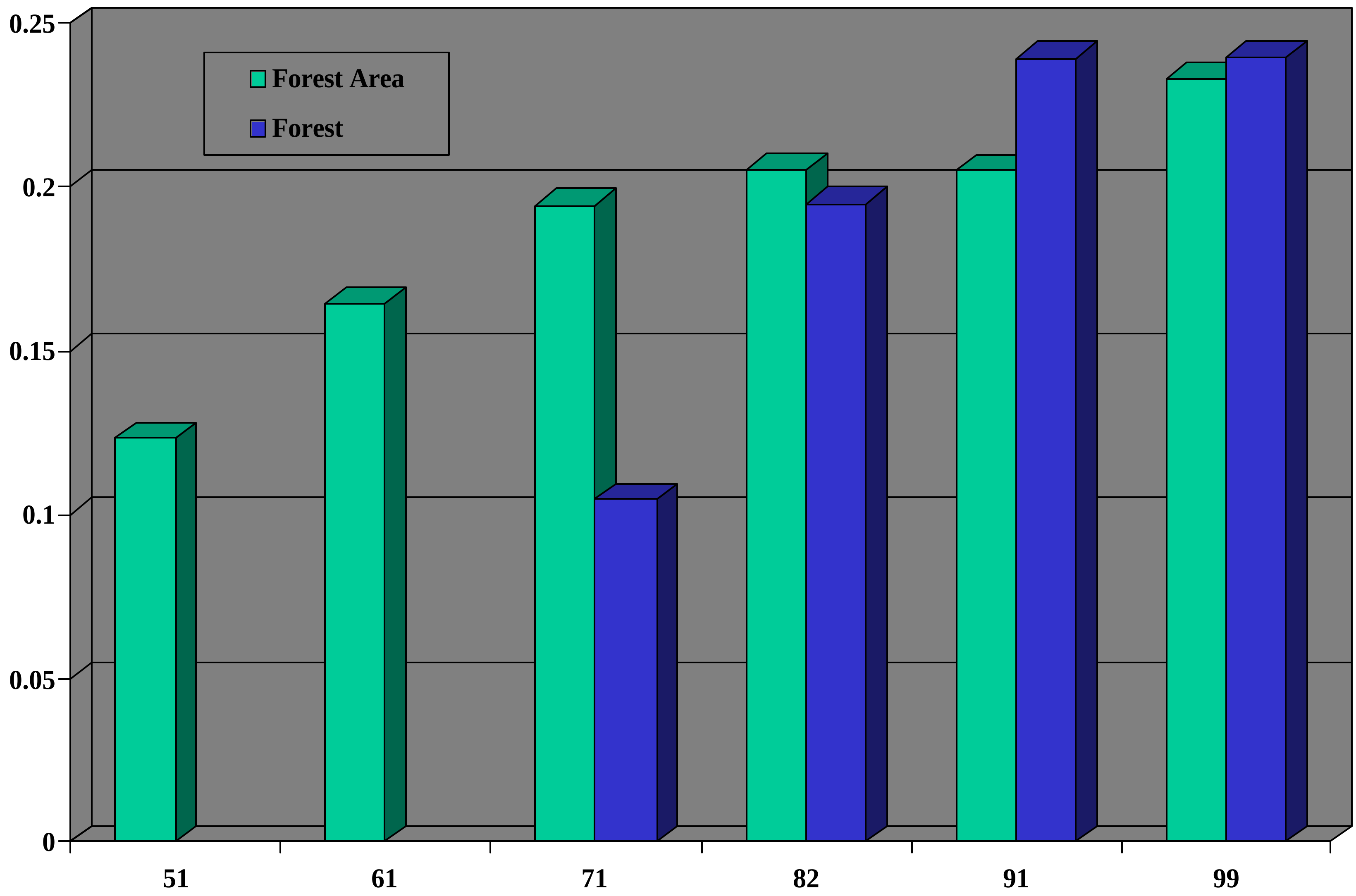

Figure II
Location of NCAER Survey Villages and NCDC Weather Stations