DEVELOPMENT AND THE ENVIRONMENT: EMPIRICAL EVIDENCE FROM INDIA

by

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ABSTRACT

The studies in this dissertation present empirical analyses of the relationship between environmental change and two important aspects of the development process - population growth and poverty. The studies have been conducted using cross-section district level data from South, West and Central India during the decade of 1990's. The use of satellite image based vegetation indices to represent environmental quality enabled accurate and reliable assessment of change in vegetation 'quality' that traditional measures like area under forests lack. The first chapter analyzes the relationship between population growth and vegetation change. It is the first study to account for the endogeneity in the relationship between population growth and environmental change in a literature that has predominantly focused on unidirectional impact of population growth on deforestation. This is also the first study to distinguish between rural and urban population growth as well as natural population growth and migration in a unified framework. The second chapter analyzes the impact of rural poverty on vegetation change while the third chapter looks at the other direction of the relationship i.e. the effect of vegetation change on rural poverty change. These two are the pioneering studies to account for the endogeneity in the relationship between rural poverty and environmental change. These studies not only shed light on the environmentally sustainable development challenges facing the developing world, they also provide ground for further investigation into the role of institutional setups in shaping these relationships.

INTRODUCTION

Environmental change is becoming an increasing concern across the globe. Environmental change has serious implications not only for the natural balance of the ecological system but also for stability of the economic and social systems as the environment has played a crucial role in the human development process (Maxwell and Reuveny, 2000). Hence it is very important to understand the impact of the development process on the environment as well as the extent to which the development process is affected by environmental change in order to plan for an environmentally sustainable development path. Yet there is surprisingly little systematic empirical analysis of these issues. This dissertation is an attempt to improve our understanding of the bi-directional relationship between a specific aspect of environmental quality, vegetation and two important socio-economic aspects of the development process, namely, population growth and rural poverty.

There exists an extensive literature spanning many realms of social science that acknowledges the importance of the relationship between population growth and the environment for sustainability of human development. For example, there has been a long-standing debate between two schools of thought – the "Malthusians" and the "Boserupians". The Malthusians (Ehrlich, et al., 1993; Meadows, 1972) conjecture that unchecked population growth will ultimately lead to a complete collapse of the natural environment that will halt population growth or even wipe out the human population. In contrast the Boserupians (Boserup, 1965; Kahn, Brown and Martel, 1976; Simon, 1996) argue that population growth and the resulting natural resource scarcity will spur technological and environmental innovation that conserves natural resources and increases the material services that the resources deliver, which can continue to sustain the population. Whichever school of thought one ascribes to, there appear to be a general agreement that population growth and the natural environment both affect one another (Dasgupta, 2000). However the empirical literature is relatively small and so far the primarily focus has been on the effect of population growth on environmental degradation with only a few recent studies analyzing the other direction of the relationship, the effect of environment on population growth. However, none of these studies have accounted for the potential endogeneity in the population-environment relationship implied by the 'Malthusian' or 'Boserupian' hypotheses. Chapter 1 of this dissertation presents an empirical study of the bi-directional relationship between population growth and vegetation change over the period 1991-1994. Unlike the prior studies in the empirical literature that predominantly focus on unidirectional causal effect of population growth on deforestation, this study is the first to treat population growth and environmental change as jointly determined. This is also the first study to distinguish between rural and urban populations, and the two components of population growth, natural population growth and migration in a unified framework.

Poverty, in itself has been a long-standing development concern for the less developed countries. In the face of recent increase in environmental concern across the world, the relationship between poverty and environmental change has drawn the attention of international development agencies and policy makers (Angelsen, 1997). The concern about the impact of rural poverty on environmental change arises since it is well established that the rural poor in developing countries are heavily dependent on local natural resources for their sustenance (Cavendish, 2000; Jodha, 2000; Escobal and Aldana, 2003; Narain, Gupta & Veld, 2005) and due to weak property rights and limited access to credit, insurance and capital markets, rural poverty can lead to resource degradation (Dasgupta and Mäler, 1994; Swinton, Escobar and Readon, 2003). Rural poverty not only affect environmental change, it also gets affected by it. Since the environment is not just an amenity, rather a necessary input for the rural households in the developing world, hence environmental degradation implies a shrinking input base for the poor households. Thus environmental degradation spurred by rural poverty can in turn increase the severity of poverty (Mink, 1993; Jodha, 2000), which can result in a persistent negative cyclical relationship between rural poverty and environmental degradation. This 'vicious cyclical' relationship is commonly referred to as the poverty-environment nexus (Nelson and Chomitz, 2004; Dasgupta et al. 2005, Duraiappah, 1998). In spite of the assertion of existence of such nexus, the newly emerging empirical literature in this field has rarely used the usual causal inference techniques to estimate the relationship between poverty and environment and none have accounted for the potential endogeneity in the relationship. Chapter 2 presents an empirical analysis of the effect of rural poverty on vegetation change over the period 1994-2001. This is the first study in this newly developing literature to systematically examine the impact of intensity of rural poverty on environmental quality. This is also the first study to account for the endogeneity of poverty and also to account for the effect of initial income distribution on environmental change. Chapter 3 presents an empirical analysis of the impact of environmental change in rural poverty over the period 1994-2001. This is also the first study to provide estimates of the impact of environmental change on rural poverty. In doing so, it accounts for the potential endogeneity of environmental change.

These analyses are based on district-level data from eight states of South, Central and West India. India is an interesting case for the purpose of these studies as it is a fast growing developing country, where population growth, rural poverty and environmental change are important policy concerns. India is the second most populated country in the world, with a population over a billion that is growing at the rate of 1.5 percent per annum (World Development Indicators, 2003). Approximately 72 percent of this huge population resides in rural areas (Census of India, 2001) and rural poverty continues to be a pervasive problem. According to official estimates, the percentage of the rural population living below the official poverty line was approximately 27 percent in 1999-2000. In light of India's prominent national economic growth, with approximately 9 percent GDP growth during 2006-2007, the analysis of the relationship between environment and development potential policy implications not only for the sustainable development of India but for global sustainability as well. India is likely to play an increasing role in the world economy and in demographic changes that will shape global environmental conditions.

When the word 'environment' is used, there are various interpretations, as the environment is a very broad term that is defined as the conditions and circumstances that surround and affect the development of organisms (Maler, 1997). However the aspect of the environment that has become a cause of major concern in many realms of social and natural sciences is the depletion of 'natural resources' caused by the human development process. The existing studies on the relationship between environmental quality and the development process is predominantly represented by the Environmental Kuznets Curve (EKC) literature that is based on the conjecture that environmental quality deteriorates with rising per capita income during the initial phases of economic growth but improves after a certain critical level of per capita income is achieved. With the demand for environmental quality rising in the later phases of economic development, there arises a U-shaped relationship between environmental quality and per capita income. In addition to its focus on a very specific aspect of development, per capita GDP, which may not be an all encompassing measure of development, the empirical EKC literature also has been quite narrow in its measure of environmental health, focusing almost exclusively on air or water 'pollution'. Another strand of literature considers the effect of population growth on a different measure of environmental health, namely, deforestation.

In this dissertation, environmental quality is measured using a satellite image based vegetation index called NDVI (see Appendix B for details). This vegetation index represents overall biomass per unit of land area. A high-quality vegetation index was constructed to proxy for forest vegetation. The use of the satellite images has several advantages over the traditional measure of forest health, area under forests. These indices provide more accurate, reliable and frequent measures of vegetation at very disaggregated levels. The monthly NDVI data was available for two decades from 1981 to 2001. More importantly, these vegetation indices enable comparison of vegetation quality across time and space. In contrast, the traditional (area under forest) measure not only fails to distinguish the vegetation quality across time and space: they also suffer from measurement errors associated with survey methods; moreover, adequately disaggregated time series measures are rarely available especially for developing countries such as India. As a result, satellite image based vegetation measures are gaining wider applications in empirical analysis. In this dissertation, they enable the analysis to be conducted at district level, rather than only a more aggregated state level analysis with more conventional environmental measure.

Due to limited availability of desired socio-economic indicators, the analysis is restricted to the eight states whose profiles are presented in Appendix A. The socio-economic indicators are obtained for the year 1991, which represent the initial socio-economic conditions for the rural and urban sectors within and across districts. The corresponding disaggregated annual birth and death data were available for the period 1991-1994, which defines the study period for the first chapter. Consumption expenditure is used to proxy for permanent income. The availability of the consumption expenditure data shaped the time frame of analysis for chapter 2 and 3.

The study region exhibits tremendous heterogeneity in both socio-economic and climatic conditions, as is indicated by the summary statistics of the data used in the three chapters (see Table 2 of each of these chapters). The cross-sectional heterogeneity helps to capture the effects of different levels of socio-economic progress on environmental quality.

The analysis in chapter 1 shows that environmental decline spurs increased natural population growth and increased net in-migration in rural areas. The population increase in turn, prompts further environmental decline. The analysis thereby provides evidence in support of a neo-Malthusian 'vicious cycle' hypothesis. In contrast, in urban areas environmental improvement spurs increased natural population growth and increased net in-migration. Another key result is that lower initial environmental quality spurs environmental improvement, which provides evidence in support of the neo-Boserupian hypothesis that resource scarcity induces technological and institutional innovations for resource conservation. Thus the analysis reveals two simultaneous and countervailing (neo-Malthusian and neo-Boserupian) forces at work.

The evidence from the analysis of chapter 2 is consonant with the dominant view in the literature that rural poverty spurs environmental degradation. In addition the analysis reveals that rural income distribution plays a significant role in vegetation change. The result that higher initial per capita consumption expenditure has a negative effect on environmental change is supported by the EKC hypothesis; as a low income country, India is expected to be in the initial phase of the EKC where per capita income is negatively associated with environmental quality. However evidence that higher initial income inequality (Gini coefficient) and poverty affect environmental change reveals a limitation of the EKC literature that only focuses on the effects of per capita income. Controlling for average rural per capita consumption expenditure and poverty, higher Gini coefficient indicates higher concentration of resources at the upper tail of the income distribution; hence the positive effect of the Gini coefficient on environmental change is likely to be attributed to the ability of the richest rural population to invest in resource conserving technologies or institutional changes.

The evidence from chapter 3 indicates that environmental improvement comes at the cost of increasing rural poverty, suggesting a tradeoff between the social objectives of rural poverty reduction lessening environmental degradation. In investigating the potential cause of this trade off, preliminary evidence suggests that the explanation, which argues that improvement in vegetation associated with change in property rights either in form of privatization of the open access vegetative resources or stricter enforcement of public property laws that limits the access of the rural poor to these resources is most plausible. Further research is warranted to formally test this hypothesis using micro-data on property rights and their implementation in rural India.

In sum, these studies highlight the need for accounting for the endogeneity in the relationship between environmental change and development for estimating the direction and magnitudes of the effects. They also provide ground for further research, especially into the inquiry of the role of institutional setups in shaping the environment-development relationship, which can provide important policy inputs for environmentally sustainable development.

CHAPTER 1. AN EMPIRICAL EXPLORATION OF THE RELATIONSHIP BETWEEN POPULATION AND THE ENVIRONMENT IN INDIA

1.1. Introduction

The links between population growth and the environment are debated in many realms of social science. There has been a long-standing debate between two schools of thought – the “Malthusians” and the “Boserupians”. The Malthusians (Ehrlich, et al., 1993; Meadows, 1972) conjecture that unchecked population growth will ultimately lead to a complete collapse of the natural environment that will halt population growth or even wipe out the human population. In contrast the Boserupians (Boserup, 1965; Kahn, Brown and Martel, 1976; Simon, 1996) argue that population growth and the resulting natural resource scarcity will spur technological and environmental innovation that conserves natural resources and increases the material services that the resources deliver, which can continue to sustain the population. Whichever school of thought one ascribes to, there appear to be general agreement that population growth and the natural environment both affect one another (Dasgupta, 2000).

Population growth can increase overexploitation of open access environmental resources (Brander and Taylor, 1998) or it may increase the demand for environmental resources, such as timber or non-timber forest products, natural beauty as an amenity or for recreational purpose, thus raising the prices of environmental goods and potentially providing the incentive to maintain the stock of natural resource supplies for reaping the flow of the resource rent (Foster and Rosenzweig, 2003). In the other direction, environmental deterioration may increase the demand for children to fetch water and fuelwood or manage livestock (Nerlove, 1991; Dasgupta, 1995) or, by worsening individual and public health (and thus raising child and adult mortality), to provide economic support to the household (Sah, 1991; Wolpin, 1997). Fusing these forces is a "vicious cycle" theory (modern Malthusianism) that conjectures a reinforcing downward spiral wherein population growth depletes the environment, spurring yet more population growth, and so on.[1] Intermediating forces may operate to break or lessen this cycle, including migration and/or government and community action to stem environmental decline.

The empirical literature on population and the environment focuses on one-way effects. Some studies show how population growth affects the environment. Others focus on how the environment influences population growth. This chapter uses cross-section district-level data from South, West and Central India to study bi-directional links between population growth and environmental change, accounting for their joint endogeneity. The distinctions between rural and urban populations that can have different effects on the environment and respond differently to environmental changes have been accounted for in the analysis. The in modeling population growth, distinguish between natural growth (births minus deaths) and migration. Satellite image based

[1]Modern theoretical formalizations of the Malthusian hypothesis, its implications for the environment and the economy in dynamic systems, and the potential roles for technological change, human capital investments and population management policies to break "boom and bust" cycles are studied in Brander and Taylor (1998), Erickson and Gowdy (2000), and Reuveny and Decker (2000). Key motivation for these works is provided by the contrasting historical experiences of Easter Island, where civilization ultimately collapsed in a downward spiral of population growth and resource depletion, and Tikopia Island, where resource conserving socioeconomic practices led to a thriving and stable population. The Malthusian hypothesis is also a key ingredient to other recent work on economic growth (e.g., Galor and

"greenness" indices have been to measure environmental health, which implicitly capture both forest and overall biomass resources in India's rural environment.

There is a large literature on how population and other variables affect environmental health, as generally measured by forest stocks. A common finding is that population growth and/or elevated population density increase rates of deforestation. Cross-national studies include Cropper and Griffiths (1994), Deacon (1994), Ehrhardt-Martinez, et al. (2002), Allen and Barnes (1985), and Lugo, et al. (1981). Within-nation cross-section studies focus on Brazil (Reis and Margulis, 1990; Pfaff, 1999), the Phillipines (Kummer and Sham, 1994), Uganda (Place and Otsuka, 2000), Cambodia and Lao PDR (Dasgupta, et al., 2005), Ecuador (Southgate, et al., 1991) and China (Rozelle, et al., 1997). Three papers study panel data from Thailand (Panayotou and Sungsuwan, 1994; Cropper, Griffiths and Mani, 1999) and India (Foster and Rosenzweig, 2003). See Panayotou (2000) for further references. This literature identifies deleterious effects of population pressure on deforestation, with one exception of Foster and Rosenzweig (2003) who find a positive link between population and forest stocks. Few studies distinguish the effects of rural and urban population pressure or of natural growth and migration. Cropper and Griffiths (1994) consider effects of rural population density, and Ehrhardt-Martinez, et al. (2002) consider rural-urban migration. Cropper, Griffiths and Mani (1999) distinguish effects of agricultural population density (vs. non-agricultural population). None of these studies treat population growth as endogenous. Southgate, et al. (1991) consider effects of roads on the agricultural population, but do not treat rates of

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Moav, 2002; Galor and Weil, 2000); however, this literature does not focus on natural resource depletion deforestation and agricultural population as jointly endogenous. A number of these studies are less concerned with population effects per se (which they incorporate for purposes of proper control) than with other forces driving environmental change, including land tenure, political systems, spatial forces, and economic growth. In addition, many of these studies use population density measures that are arguably predetermined at the time of measured environmental deterioration. However, the main focus of this study is on the effect of population 'growth' on the environment, in part because population growth is the potential object of policy. For the reasons described above, population growth and environmental change are very likely to be jointly determined.

A smaller literature considers environmental effects on population growth, documenting both the empirical importance of the environment as a determinant of birth rates in developing countries, and the distinct effects of environmental health on birth rates and migration as components of regional population growth. There are very few recent studies that focus on environment - fertility linkages. Aggarwal, et al. (2001) and Filmer and Pritchett (2002) study cross-sectional survey data from South Africa and Pakistan, respectively, generally finding a positive relationship between fuelwood scarcity and fertility. Merrick (1981) studies cross-section data from Brazilian provinces, finding evidence of an indirect and positive effect of land scarcity on fertility. However, Loughran and Pritchett (1997) find a negative relationship between the time taken to collect fuelwood and water (interpreted as a measure of resource scarcity) and fertility in

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per se.

Nepal. Two other papers focus principally on how the environment affects migration. Amacher, Cruz, Grebner and Hyde (1998) study urban-rural migration in the Phillipines, finding that migration tends to be spurred by the presence of more open-access environmental resources (as measured by the share of forest land that is public and lesser road density in arable lands). Chopra and Gulati (1997) study cross-section data from districts in Central and Western India, finding that distress outmigration (as measured by the change in the district-level sex ratio) is spurred by environmental deterioration. Much (though not all) of this empirical evidence suggests that resource scarcity has a positive effect on rural birth rates, but a negative effect on in-migration.

In view of this evidence, a failure to account for the joint determination of population and the environment may lead to false inferences from studies on the other direction of causation, namely, population effects on deforestation or environmental deterioration. Finding a positive link in such cases may be due to correlation, perhaps because environmental deterioration spurs population growth, even though population growth may not cause environmental deterioration per se. The policy implications of such inferences are potentially important. For example, if environmental deterioration is the object of policy concern, such inferences, if false, imply a misplaced focus on reducing population growth as a mechanism to improve the environment.

1.2. Criticisms and Limitations

A study of bi-directional links between population and the environment comes at a cost. Economists generally prefer to study micro-level determinants of birth rate and migration behavior. However, effects of this behavior on the environment are at an aggregated level. For this reason, birth rates have been modeled at the level of a district in India -- rather than at the level of a household -- thus implicitly aggregating across the district population. While this approach is quite common in the literature (e.g., see Merrick, 1981; Bhattacharya, 1998; Barro, 1991; Chopra and Gulati, 1997), it abstracts from household-level heterogeneity for which can only be imperfectly controlled by using district-level data.

Since the availability of the cross-section data is for a relatively short (four year) time frame, there are several potential criticisms of this analysis. First, the short time frame seemingly precludes the longer-run innovation and adaptation implicit in the "Boserupian" theory of environmental management. However, the analysis implicitly captures the patterns of adaptation and innovation across more and less stressed environments. Second, one might argue that the short (four year) time frame of this study casts doubt on the relevance of measured environmental change for population decisions that are presumably based on longer-term forecasts of environmental, economic and other conditions. However, families make birth decisions based upon the information available to them at the time of their decisions. Since a complete set of environmental indicators have been included to capture available environmental information, including the initial state of the environment, recent past (five year) changes in measured environmental health, and contemporaneous (four year) changes, hence the data contains a good picture of environmental conditions that are relevant to family planning choices.

Third, perhaps population change is measured over an interval that is too short to appreciably affect the local natural environment. This, of course, is an empirical question, and the analysis does identify an impact over the sample interval. This outcome is not entirely unexpected as four years of population growth in a rapidly growing country like India can have significant effects on overall population levels and, hence, on natural environments occupied by these populations. In the sample region, for example, rural populations grew on average by approximately 5.2 percent over the sample interval, while urban populations grew by approximately 7.8 percent. Moreover, these averages tend to understate magnitudes of change, with some areas experiencing negative growth while others have double-digit positive growth.

Finally, the population data limits us to a cross-section analysis, preventing us from using fixed effects to control for unobserved heterogeneity. For this reason, the focus is on changes in environmental indicators and population aggregates, which controls for unobserved heterogeneity that drives levels. Moreover, the analysis pertains to contiguous regions in a single country with some commonalities in culture, history and institutions, and controls have been constructed for a wide variety of relevant district attributes. Like the vast prior literature of cross-section work on population and the environment, this study does the best to avoid unobserved heterogeneity that might be correlated with key variables of interest.

1.3. An Illustrative Conceptual Model

A simple conceptual model is developed here to illustrate many of the economic forces that shape the population-environment relationship. The model provides an integrated theoretical framework based on which the hypotheses are formulated in the next section.The model necessarily abstracts from much (including private ownership, endogenous property rights, dynamics, etc.), but captures several key attributes of the environment-population nexus in developing countries such as India. In particular, it is assumed that (i) a model of rural household decision-making in which household production is central, (ii) urban household decision-making in which children are consumption goods, and (iii) a model of open access rural environmental (e.g., forest) resources that are inputs in rural household production, the source of marketed surplus to the urban sector, and have amenity value to urban households. Child-bearing and migration are modeled in a two-period framework wherein first period decisions (on children and migration) affect second period labor allocations in resource extraction. The model builds generally on the household production literature (e.g., Renkow, 1990; Renkow, et al., 2004; Singh, Squire and Strauss, 1986; Innes, 1993). The proofs of the propositions and lemmas are provided in Appendix C.

Rural Households. In period 2, a representative rural household obtains utility from environmental (forest) products X_c, other (numeraire) goods Z, and leisure L,

(A1) $U^R(X_c, L) + Z$,

where U^R is increasing concave with $U^R_{21} \geq 0$ (subscripts denoting partial derivatives with respect to the ith argument). The number of children (c_R) and labor that migrates to the urban sector (m) are chosen in period 1. Migrant labor earns an exogenous net wage in the urban sector in period 2, w. Children c_R are available for production of forest products X in period 2, but also involve costs (measured in units of the numeraire) in periods 1 and 2, $\beta_1 c_R$ and $\beta_2 c_R$, respectively ($\beta_1+\beta_2<1$). Children also consume environmental/forest goods in the amount $v_R c_R$ in period 2. Forest goods are produced according to the function,

(A2) $X=X(E,L=l+c_R-m)$,

where l=total adult labor allocated to production and migration, E=initial state of the environment/forest in period 2, and X is increasing concave with $\partial^2X/\partial L\partial E=X_{12}\geq 0$ (labor and environment are complements) and $X_L>v_R$ (children are net contributors to household production).. Out of production, the household markets X_m of forest products to the urban sector at (endogenous) price P. Consumption of X_c is:

(A3) $X_c = X() – X_m - v_R c_R$.

Period 2 leisure satisfies the identity, $\mathcal{L}=\underline{L}-l$, where $\underline{L}$ is total available adult labor. Hence, in period 2, rural households solve the problem:

(A4) $U^{R*}(E,c_R,m,P) = \max_{l,Xm} U^R(X(E,l-m+c_R)-X_m- v_R c_R, \underline{L}-l) + PX_m + wm - \beta_2 c_R$,

which yields $l^*(E,c_R,m,P)$ and $X_m^*(E,c_R,m,P)$. Normalizing β_1 to account for intertemporal discounting, c_R and m are chosen to

(A5) $\max_{cR,m} U^{R0} = U^{R*}() - \beta_1 c_R$.

Environmental Change. Period 2 environmental change depends on both the initial state of the environment E (the autonomous component) and the extraction X (the endogenous component):

(A6) $\Delta E = f(E,X)$, where $\partial f/\partial X < 0$.

The autonomous effect can have any sign. For example, autonomous growth in either a decimated landscape or a dense mature forest can be negligible, but in a weakened landscape (with new trees, for example), can be large.

Urban Households. In period 2, a representative urban household obtains utility from the environmental amenity (E), children (c_U), forest products (X_U), and other (numeraire) goods (Z) according to

(A7) $U^U(E,c_U,X_U) + Z$,

where, U^U is increasing concave with $U^U_{23} \geq 0$ and $U^R_{12} \geq 0$. Children c_U are chosen in period 1 and bear numeraire costs $\gamma_1 c_U$ and $\gamma_2 c_U$ in periods 1 and 2, as well as consuming $v_U c_U$ in forest products in period 2. With exogenous urban household income of Y, the period 2 household choice problem is

(A8) $U^{U*}(E,c_U,P) = \max_{Xd} U^U(E,c_U,X_d - v_U c_U) + Y - \gamma_2 c_U - PX_d$,

which yields $X^*_d(E,c_U,P)$. Children are chosen to

(A9) $\max_{cU} U^{U*}(E,c_U,P) - \gamma_1 c_U$.

Market Equilibrium. The market price for forest goods equates supply and demand:

(A10) $P(E,c_R,c_U,m)$: $X^*_m(E,c_R,m,P) = X^*_d(E,c_U,P)$.

Demographic Effects on Environmental Change. Differentiating (A6) with respect to c_R and m:

(A11a) $d\Delta E/dc_R = (\partial f/\partial X)(\partial X/\partial L)[(dl^*/dc_R)+1]$

$\overset{s}{=} - [(dl^*/dc_R)+1] = - [1+(\partial l^*/\partial c_R)+(\partial l^*/\partial P)(dP/dc_R)]$, (A11b) $d\Delta E/dm=(\partial f/\partial X)(\partial X/\partial L)[(dl^*/dm)-1]$

$\overset{s}{=}[1-(dl^*/dm)]=1-(\partial l^*/\partial m)-(\partial l^*/\partial P)(dP/dm)]$,

where the sign equalities are due to $\partial f/\partial X<0$ and $\partial X/\partial L>0$.

Proposition 1. (a) $d\Delta E/dc_R <0$. Higher rural birth rates promote environmental decline. (b) $d\Delta E/dm <0$. Greater rural out-migration yields environmental improvement.

Next, differentiating (A6) with respect to c_U:

(A14) $d\Delta E/dc_U = (\partial f/\partial X)(\partial X/\partial L)(\partial l^*/\partial P)(\partial P/\partial c_U)$.

Proposition 2. $d\Delta E/dc_U < 0$. Higher urban birth rates promote environmental decline.

Intuitively, more rural births translate into more extractive labor that increases exploitation of the open access resource. More urban births raises demand for the products of the environmental resource, thus elevating the price of the products, which in turn increases incentives for exploitation of the forest resource in order to sell the resulting products. Propositions 1-2 provide a formal statement of Hypotheses 1-2 in the next section.

Effects of Environmental Change on Demographic Decisions. We are interested in the effects of first period environmental change on three choices: c_U, c_R, and m. Because $E=E_0+\Delta E_0$, these comparative static effects can be deduced from the derivatives,

(A15a) $dc_U^* = (\partial c_U^*/\partial E) + (\partial c_U^*/\partial P)(dP/dE)$,

(A15b) $dc_R^* = (\partial c_R^*/\partial E) + (\partial c_R^*/\partial P)(dP/dE)$,

(A15c) $dm^* = (\partial m^*/\partial E) + (\partial m^*/\partial P)(dP/dE)$.

Note that even this simple model becomes rather exceptionally complex at this juncture. To develop potential (illustrative) outcomes with maximum simplicity, it is thus assumed here that $U^U_{31} = U^R_{12} = X_{LL} = 0$. Lets begin by examining the partial derivative effects in (A15).

Lemma 1. Assume $U^U_{31} = U^R_{12} = X_{LL} = 0$. Then (1) $\partial c^*_R/\partial E>0$ and $\partial c^*_R/\partial P>0$; (2) $\partial m^*/\partial E<0$ and $\partial m^*/\partial P<0$; (3) $\partial c^*_U/\partial E\geq 0$ and $\partial c^*_U/\partial P<0$; and (4) $\partial P/\partial E<0$, $\partial P/\partial c_R<0$, $\partial P/\partial m>0$, and $\partial P/\partial c_U>0$.

Intuitively, a better environment increases the marginal product of rural child labor in resource extraction, yielding greater demand for children by rural households. Similarly, a higher resource price raises the marginal benefit of child labor in resource extraction. Likewise, a better environment and higher resource price raise the cost of migration in foregone resource extraction activity. Complementarity between children and the rural environmental amenity in urban household consumption imply a non-negative relationship between the environment and urban child demand. On the other hand, a higher price for environmental/forest goods raises the costs of supporting urban children, thus reducing net incentives for child-bearing in the urban sector. A better rural environment, greater supply of rural child labor, or reduced out-migration of rural labor, all raise net marketed surplus of the environmental good, thus depressing its market price. Conversely, a greater number of urban children increases the urban demand for the resource-related good, thus raising its market price.

To characterize the effect of environmental change on market resource price, dP/dE, note that households take the price as parametric in all decisions. However, the equilibrium price accounts for impacts of all decisions. Hence, the total derivative is:

(A24) $dP/dE = \partial P/\partial E + (\partial P/\partial c_R)(dc^*_R/dE) + (\partial P/\partial m)(dm^*/dE) + (\partial P/\partial c_U)(dc^*_U/dE)$.

Substituting (A15) into (A24) and solving gives

(A25) $dP/dE=(1/A)\{\partial P/\partial E+(\partial P/\partial c_R)(\partial c^*_R/\partial E)+(\partial P/\partial m)(\partial m^*/\partial E)+(\partial P/\partial c_U)(\partial c^*_U/\partial E)\}$,

where, $A = 1 - \{(\partial P/\partial c_R)(\partial c^*_R/\partial P) + (\partial P/\partial m)(\partial m^*/\partial P) + (\partial P/\partial c_U)(\partial c^*_U/\partial P)\} > 0$,

with the inequality due to Lemma 1. Note that the first three (bracketed) right-hand terms in (A25) are negative and the last term is positive. These first three terms correspond to the following effects: A better environment directly lowers the resource price by spurring greater marketed supply and indirectly lowers it by prompting elevated levels of both rural child labor and rural adult labor (due to reduced incentives for migration) that in turn depress the market price by raising marketed surplus of the environmental good. Opposing these effects is the impact of a better environment in stimulating the demand for urban children (as complements in consumption) which in turn elevates the market price by raising urban demand for the environmental good. Provided the last effect is sufficiently small relative to the former three (as expected), we have:

Lemma 2. Provided $(\partial c^*_U/\partial E$ is sufficiently small (because U^U_{21} is sufficiently small), $dP/dE<0$.

Returning to the original derivatives of interest, equation (A15), one can see that there is an unambiguous positive sign for the effect of environmental change on urban child-bearing c_U, provided dP/dE<0. For the rural household decisions, however, direct and indirect (price) effects on rural child demand and migration are opposing. In practice, of course, either effect may dominate. However, if price effects dominate (as they will if the marginal labor productivity impact of environmental change, X_{LE}, is sufficiently small), then we have:

Proposition 3. Assume that dP/dE<0. Then: (a) $dc^*_U/dE>0$. Urban child demand rises with environmental improvement. (b) Provided $|dP/dE| > U^R_1 \; X_{LE} \; /(X_L - v_R)$, $dc^*_R/dE<0$ and dm*/dE>0. Rural child demand and rural in-migration both fall with environmental improvement.

Proposition 3 provides a formal counterpart to Hypotheses 3-5 in the next section.

Effects of Environmental "Scarcity" on Environmental Change. Recall, from (A7), that there are two components of environmental change, the "autonomous" effect and the endogenous component due to the resource extraction activities of rural households. We will focus here on the endogenous component only, namely, whether a higher level of initial environmental quality (E) leads to an increase in exploitation (higher X), and conversely, whether a poorer initial environment leads to less exploitation. Formally,

$$(26) \qquad dX/dE = \partial X/\partial E + (\partial X/\partial l)(dl^*/dE) \quad , \quad dl^*/dE = \partial l^*/\partial E + (\partial l^*/\partial P)(\partial P/\partial E).$$

(Note that here we control for demographic decisions and, hence, only need be concerned with direct effects of E on the second period equilibrium P, ∂P/∂E.) Evaluating (26), we have:

Proposition 4. dX/dE>0. Lower initial environmental quality leads to less endogenous environmental degradation.

1.4. Hypotheses

The study has used two measures of environmental status, one an index of overall vegetation (or "greenness") and the other a measure of the proportion of land that has a high level of "greenness." The former index incorporates both forest biomass and impacts of soil productivity on cropland vegetation, while the latter is constructed as a measure of forest cover. Both indices are measures of *rural* environmental health that are correlated with fuel wood availability, water and soil resources, and “amenities” such as scenery and wildlife.

To understand potential forces driving the relationship between these local rural environmental /vegetation measures and district-level population decisions, a conceptual model has been developed in Appendix C with several features:[2] (1) Rural households use child and adult labor to exploit an open access environmental resource (e.g., forest) in order to produce goods that are both consumed in the household and sold to the urban sector. The households make decisions on child-bearing and migration, as well as labor allocation and marketing, in view of anticipated environmental and market conditions. In doing so, they trade off benefits of children in household /resource-good production against costs of birthing and child maintenance; and they trade off benefits of migrant family labor in remittances against costs in lost adult labor in household production and

[2] Building on the household production literature (e.g., Renkow, 1990; Singh, Squire and Strauss, 1986), the model is illustrative of a number of salient forces that affect the choices and outcomes that are examined here, but it is not comprehensive. In stating the hypotheses, other forces are point out that may

leisure. More intensive rural household production comes at the cost of greater deterioration in the environmental resource. In India, for example, abundant anecdotal and statistical evidence documents the use of natural resources by rural populations for household production (e.g., grazing and production of non-timber forest goods) and consumption (e.g., fuel and water), activities that often deplete the commons (Rao, 1994). (2) In urban households, children and the state of the environment are consumption goods, with benefits of children in consumption traded off against costs of children, including requisite purchases of the marketed product from the rural sector. (3) An equilibrium in the local market for the rural product affects incentives for child-bearing, migration, and rural production. Thus, it is assumed that local economic conditions have price effects in local markets for environmental goods. For India, this premise is plausible for forest products that are costly to transport long distances and for which international trade is essentially non-existent (Foster and Rosenzweig (FR), 2003). To a lesser extent, this premise is plausible for food products that are also costly to transport inter-regionally.

In this setting, rural population growth (in the form of more children and less out-migration) increases the supply of rural labor available for resource exploitation (household production), thereby leading to more exploitation in equilibrium. This gives us a well-known implication of open access resource models (see Appendix Proposition 1 and Brander and Taylor, 1998, Proposition 2):

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be relevant to outcomes observed in the sample, but do not pretend to attempt a comprehensive theoretical discourse on all aspects of the population environment relationship.

Hypothesis 1. Higher levels of rural population growth lead to increased deterioration of open access land and forest resources.

This hypothesis is tested by estimating effects of rural population growth rates on the measures of environmental change.

Greater urban population growth raises the demand for the products from rural resource exploitation and thereby leads to a higher equilibrium price for these products, spurring more (resource-degrading) rural production (see Appendix Proposition 2):

Hypothesis 2. Higher levels of urban population growth lead to increased deterioration of open access land and forest resources.

There is a potential opposing effect missed in this model. A larger urban population implies greater resource scarcity in per-capita terms, potentially yielding greater political will for local protection of the environment and/or strengthening of local property rights (Libecap and Smith, 2002; Demsetz, 1967). However, if these political impacts are small by comparison with the market impacts that are modeled here (as one might expect if political effects arise at a State or Central level), then Hypothesis 2 will continue to hold.

If forest resources are protected by property law, effects of population growth can be very different, with increased populations potentially spurring an increased equilibrium supply of these resources (Foster and Rosenzweig (FR), 2003). Use of land for forest products may compete with use of land for food crops, with the former generating more than the latter in "greenness," the measure of environmental strength. To the extent that food markets are more integrated (with lower transport costs) than markets for forest products, local population changes will have a greater impact on local forest product markets than on local food markets, implying the FR outcome. Thus for testing Hypotheses 1-2, one can distinguish between dominance of open access resource effects and potential impacts on private forest resources (FR).

Turning to the other direction of causation, the model implies competing effects of environmental improvement on the rural demand for children and migration. On one hand, a better environment can raise the marginal product of child and adult labor in household (resource based) production, thus increasing the demand for children and reducing incentives for out-migration. However, a better environment also enables more rural production, which in turn depresses the equilibrium price for the product sold by rural households. The lower output price in turn depresses the demand for child and adult labor in household production. The latter price effects will dominate if environmental improvement has a small effect on marginal labor productivity, as implied by the prevailing view that children are substitutes for natural resource health in household production (e.g., Nerlove, 2001). In this case, the following hypothesis arises (see Appendix Proposition 3):

Hypothesis 3. Environmental improvement reduces the rural demand for children.

There are other mechanisms for Hypothesis 3 as well. An improved environment, by improving child health and productivity, can reduce the demand for children as social insurance (Dasgupta, 1995; Wolpin, 1997); by improving adult health and productivity, it can also raise the time costs of children and reduce the need for children as social insurance.

Hypothesis 4. Environmental improvement reduces rural in-migration and raises urban out-migration.

Potentially confounding Hypothesis 4 are incentives for inter-district migration that are missed in the simple conceptual model. With such opportunities, resource scarcity can spur distress out-migration (Chopra and Gulati, 1997), and environmental improvement may attract new migrants (Amacher, et al., 1998).

For urban households, environmental improvement also has two effects on the demand for children. If environmental health and children are complements in consumption, an improved environment will directly raise child demand. In addition, by lowering the equilibrium price of resource-based goods (including food and fuel), environmental improvement will lower the costs of child maintenance. Both effects favor more children (see Appendix Proposition 3).

Hypothesis 5. Environmental improvement raises the urban demand for children.

Finally, consider the effects of initial resource scarcity (the "state of the environment") on environmental change. In this simple model, a worsened environment depresses the productivity of exploitive activities and thereby spurs less of them. Additional forces may also be at work. As open access environmental resources become increasingly scarce – and hence increasingly valuable and costly to exploit – governmental incentives to protect the resources grows, whether in terms of improved property law (Libecap and Smith, 2002; Demsetz, 1967) or increased enforcement of environmental protection laws. For privately owned environmental resources, scarcity spurs higher prices for environmental products and, hence, heightened incentives for the private supply of these resources. These lead to the Boserup (1965) / Simon (1996) conjecture (see Appendix Proposition 4):

Hypothesis 6. Poorer environmental health will promote environmental improvement.

1.5. Data

The study uses district level data from eight states of the southern (Andhra Pradesh, Tamil Nadu, Karnataka, Kerala), western (Maharashtra, Gujarat, Rajasthan) and central (Madhya Pradesh) regions of India. The time frame of this study is 1991-94. It is based on availability of disaggregated birth and death data for rural and urban areas of the districts of the study region. Adjusting for district redefinitions and missing data, and excluding one all-rural and three all-urban districts, gives us a sample size of 190 districts. Table 1.1 presents the variable notations and descriptions, and Table 1.2 provides sample statistics. In the data, urban (vs. rural) areas are defined, per the census of India, as (i) all places within a defined municipality, and (ii) all other places that have a minimum population of 5000, at least 75 percent of the male working population engaged in non-agricultural pursuits, and a population density of at least 400 persons per square kilometer.

In the sample, district-level rural natural growth rates (births minus deaths) average 2.8 percent of 1991 populations over the four-year period 1991-1994. Corresponding urban natural growth rates are much higher, averaging 10.2 percent of 1991 populations. However, there is a great deal of cross-district heterogeneity in these growth statistics. For example, rural population growth rates vary from minus 10 percent to over 27 percent. Population densities (1991) are also highly variable, averaging 223 people per square kilometer in rural areas and almost 3200 people per square kilometer in urban areas. The sample districts are predominantly rural, with an average rural population percentage of almost 75 percent. Incomes are substantially lower in rural areas than in urban areas, with average 1994 monthly consumption expenditures of approximately 355 rupees (US$8) per capita in rural areas and 482 rupees in urban areas. Urban areas also exhibit signs of greater development, with higher literacy rates and lower infant death rates than their rural counterparts. Average household sizes are about 5.4 people in both urban and rural areas. However, female workforce participation is much higher in rural areas (averaging 28.9 percent) than in urban areas (at 9.6 percent). Climatically, districts in the sample are quite heterogeneous, with normal annual rainfall varying from less than one-third of a meter to 3.5 meters.

Described below are the measures of important variables used in this study. Details on the sources and construction of the data are provided in Appendix B.

The environmental quality is measured using satellite image based vegetation index called Normalized Difference Vegetation Index (NDVI) that represents the overall vegetation quality of the district. NDVI takes into account both agricultural as well as forest vegetation. The higher the value of the index, higher is the average ‘greenness’ of the district. It is a pure biological measure of environmental quality. Since the hypotheses of this study closely relates to the forest vegetation, a measure of high quality vegetation was constructed that closely proxies for the forests (see Table 1.3 for correlation between the measure of high quality vegetation and area under forests). This measure of high quality vegetation is labeled as ‘z-NDVI’. The change in these two measures of vegetation indices over the period 1991-1994 have been used to represent the change in environmental quality.

The changes in rural and urban population of a district are represented by the natural growth rate (birth minus death rate) and the net in migration rate (in-migration minus out migration rate) of the respective sector. These population growth rates are cumulative growth rates over the period 1991-1994.

Socio-economic variables that influence population growth and/or vegetation change are measured at the initial time period 1991. Disaggregated socio-economic indicators are available only for the decadal census years. Hence the initial heterogeneity in socio-economic conditions has been used to explain the heterogeneity in the population-environment relationship across the districts.

Lack of direct measure of district level income, led us to use district level rural and urban average per-capita consumption expenditure data, which are available from the National Sample Survey Organization. Per capita consumption expenditures are generally thought to be good indicators of permanent incomes. Because consumption expenditures are measured in 1994, there is the potential for joint endogeneity, albeit limited by the short duration of the study period. The test statistic for testing the exogeneity of these expenditures are reported at the end of in Tables 1.5 – 1.10. Since the test results provide evidence in favor of the exogeneity hypothesis, hence the treatment of consumption expenditures as exogenous in the estimations is valid for this study. The (Hausman) exogeneity test statistics are constructed using state dummies as instruments for consumption; because these instruments perform well in explaining consumption expenditures (judging from first-stage regressions, following Bound, et al., 1995), the Hausman statistics are reasonably interpreted as tests of exogeneity (as opposed to instrument quality).

1.6. The Empirical Models

To analyze the relationship between change in environmental quality and population growth, a system of five simultaneous linear equations has been estimated, one each for rural natural growth rates (births minus deaths, G_R), urban natural growth rates (G_U), net rural migration (M_R), net urban migration (M_U), and the change in the environmental / "greenness" index (ΔE):

(1) $$G_R = \alpha_1 + \beta_1 \Delta E + \gamma_1 X_P + \varepsilon_1$$

(2) $$G_U = \alpha_2 + \beta_2 \Delta E + \gamma_2 X_P + \varepsilon_2$$

(3) $$M_R = \alpha_3 + \beta_3 \Delta E + \gamma_3 X_P + \varepsilon_3$$

(4) $$M_U = \alpha_4 + \beta_4 \Delta E + \gamma_4 X_P + \varepsilon_4$$

(5) $$\Delta E = \alpha_5 + \delta_1 G_R + \delta_2 M_R + \delta_3 G_U + \delta_4 M_U + \gamma_5 X_E + \varepsilon_5$$

where all endogenous variables are measured over 1991-1994 and the exogenous X variables are in initial (1991) levels.

The first four (population) equations contain no mutual interactions, but rather only the jointly endogenous environmental change on the right-hand-side. Hence, taking these four equations as a unit, a "quasi"-reduced-form model was estimated. There are a number of reasons for this approach. First, the focus of the study is to analyze the effect of environmental change on various population growth rates rather than the links between the different components of population growth. Second, as a practical matter, finding instruments that distinctly identify migration and natural growth is not possible in the sample. Third, natural growth and migration are not aggregated into a net population growth variable because these two components of population growth have very different structures (both in theory and in the estimations). However, as discussed in Section 1.7 below, both components of population growth (G_R and M_R, and G_U and M_U, respectively) are expected to have common effects on environmental change in equation (5).

With regard to the exogenous variables, X, included in each equation, Table 1.4 describes the model. Motivations for the variable selections are as follows.

Natural Growth and Migration Regressions. In the population regressions, three environmental measures are included as regressors: the jointly endogenous contemporaneous environmental change, the initial state of the environment (in 1991) and the environmental change over the preceding five-year period (1986-1990). The two pre-determined variables are included because birth decisions are likely to depend upon both the state of the environment and the anticipated trajectory of environmental change.

Beyond impacts of the environment, birth rates are influenced by socio-economic factors that include income, literacy, health services, social norms and religious beliefs (Freedman, 1987; Dasgupta, 1995; Schultz, 1997; Rosenzwieg and Stark, 1997; Bhattacharya, 1998; Dreze and Murthy, 2001; Martine, Dasgupta and Chen, 1998). To control for these effects, per-capita consumption expenditure, female, male and total literacy[3], female workforce participation, average household size, sex (female to male) ratio, tribal population proportion and the religious makeup of the population have been included as explanatory variables. Because Hindus and Muslims represent over 95 percent of the Indian population, the Muslim population share is used as an indicator of a district's religious composition. Three measures of health status have been included: infant death rates, overall population death rates and life expectancy at birth, all measured at the start of the study period (1991). Potential congestion effects are captured by including population density as a regressor. All of these explanatory variables are specific to the rural / urban sector of a district. In addition, Dasgupta (2000) observes that the extent of urbanization may affect the outward orientation of a district's population, which may affect birth rates (as well as attitudes toward the environment). Therefore a district's urban population share is also included. Because there may be rural-urban spillovers and the population models are in “quasi”-reduced-form (equations (1)-(4)), all exogenous urban regressors are included in the rural population equations, and vice versa. Finally, the extent of agricultural cultivation may affect economic opportunities, the supply of common lands in rural areas, and hence, rural natural growth rates. Therefore the district's 1991 percentage net sown area (NSA) is also included.

[3] Male, female, and total literacy measures have been included in the regression equations for a number of reasons. First, it is expected that total literacy is likely to drive political demands for environmental protection, while rural female literacy may be an important determinant of rural female resource extraction activity. Second, male and female literacies are likely to be important determinants of birth decisions. Female literacy is widely cited as important because (among other reasons) it may affect the costs of bearing and raising children; male literacy can potentially affect attitudes toward family planning, access to health care, and other determinants of natural growth outcomes. Third, literacy measures are poor candidates for identifying instruments. Hence, it was imperative to properly control for literacy, at the potential cost of imprecisely measuring its effects, by including all three literacy measures as regressors and thereby avoiding the use of any literacy measures for identification.

The Environment Regressions. Determinants of environmental change fall into three classes: environmental and climatic factors, population pressure, and socio-economic variables. To control for natural processes, both rainfall data and data on prior environmental change from 1986-1990 have been used, as prior environmental degradation can spur subsequent environmental improvement efforts and extraordinary environmental improvement may have a limiting effect on subsequent environmental change. In addition, NSA and the initial state of the environment in 1991 (initial NDVI and z-NDVI), are included, the latter of which can be interpreted as an inverse indicator of biomass and forest stock "scarcity."

Population variables include predetermined population densities (1991) and the jointly endogenous population growth measures. Other socio-economic regressors include literacy measures, the urban population share (a measure of "openness"), per-capita consumption expenditures (proxy for income), and tribal population share. Rural and urban incomes affect the demand for environmental resources, while rural incomes may also affect rural households' net benefits from the exploitation of open access resources and their reliance on more environmentally depleting livestock and agricultural production practices. Tribal populations are widely regarded as resource-conserving. Additional socio-economic variables may affect social and cultural norms, and/or the availability of female labor that is traditionally used for resource gathering activities. For example, lower rural sex ratios and higher rural female workforce participation rates are indicators of the availability of female labor.

1.7. Identification Strategy

Identifying Environmental Change in the Population Equations. Environmental change is identified in the natural growth and migration rate regressions using district level rainfall. In judging the merits of this instrument, several issues arise. First, is the instrument highly correlated with environmental change? Following standard practice (Bound, et al., 1995), the instrument's strength is assessed from its performance in a first stage regression of environmental change on all exogenous variables in the model. The instrument performs very well in these regressions (see F statistics in Section 7).

Second, does the rainfall variable identify transitory environmental changes, rather than longer-run environmental changes that are more likely to drive births or migration decisions? This is an empirical question as much as a conceptual one, and the estimations will indicate whether or not identified environmental change has affected natural growth and migration decisions in the sample. Note that subdivision-level rainfalls are highly correlated over time in the study region; for example, the correlation coefficient between rainfall over 1986-1990 and 1991-1994 is over .99. Hence, contemporaneous rainfall is likely to capture systemic weather differences across districts in the sample and thus identify more than transitory environmental change.

Third, is the instrument exogenous to natural growth and migration decisions? In principle, rainfall may affect agricultural productivity, which in turn affects natural growth and migration; could these effects imply that the instrument is correlated with the error in the natural growth or migration rate equations?[4] The answer is expected to be "no" because all likely channels through which such effects may manifest themselves, including incomes (particularly in the rural sector), the initial state of the environment, and the extent of agricultural cultivation (the net sown area variable) have been controlled for. However, to make absolutely sure that the potential productivity effects are properly controlled for, additional rainfall variables were constructed that should capture any potential residual impact of rainfall shocks on agricultural productivity. Specifically, agronomic research indicates that agricultural productivity is affected by deviations of rainfall outside of normal bands (see Azzam and Sekkat, 2003).[5] Therefore two pairs of district level rainfall deviations were constructed. The first pair is obtained by summing positive and negative deviations of annual rainfalls, over the period 1991 to 1994, from average annual rainfall (calculated over the twenty year period, 1981 to 2000). The second pair of deviations measures potential effects of the timing of the start of the monsoon; specifically, these were constructed by summing the positive and negative deviations of June rainfall from historic district averages. Formally, with μ_j representing 20-year average rainfall for subdivision j, district i (of subdivision j) has the raw rainfall deviation for year t, $R_{it} = (NDVI_i/NDVI_j)(Rain_j - \mu_j)$. The first pair of district-level rainfall deviations sums (respectively) the positive and negative R_{it} deviations over t

[4] A second potential criticism of the rainfall instrument, due to common folklore, is that rain breeds rural births. There are two responses to this argument. First, to the extent that there is any truth to this folklore, there are likely to be economic underpinnings that are tested in this study. Second, this argument really does not represent a critique of the qualitative results; to the extent that rainfall directly promotes rural births, the estimated effects of environmental change (as instrumented by rainfall) on rural natural growth will be biased upwards; nevertheless the estimations depict significant and robust negative effects of environmental change, as measured, on rural natural growth rates.

= 1991,…,1994. The second (start of monsoon) pair of district rainfall deviations is the same as the first, only using June rainfalls. Present below are the results using the first (raw) set of rainfall deviations as controls; qualitatively similar results were obtained when using the second (start of monsoon) deviations.

Identifying Natural Growth and Migration in the Environment Equation. There are four jointly endogenous variables in the environment equation, two natural growth rates (rural and urban) and two net migration rates (rural and urban). Four "core" instruments were used to jointly identify these four variables, namely, the health indicators, the raw 1991 death rates (rural and urban) and the 1991 infant death rates (rural and urban). In addition, other supplemental instruments were considered that are discussed later.

The core instruments are clearly important for natural growth. Higher infant death rates can deter birthing by increasing the costs of having children (ceteris paribus). Conversely, from the population literature (e.g., see Dreze and Murthy, 2001), it is known that higher raw death rates, by raising the risks that children will not live to help support parents in later life, can increase net birth rates. These instruments are also potentially important for migration behavior. Poorer health status is likely to deter in-migration (and promote out-migration). In addition, however, migration is a likely substitute for natural growth in supplying labor; if a higher infant death rate tends to reduce birth rates (by raising the costs of children), then in-migration may rise to provide substitute labor. In the case of raw death rates, these two forces operate in tandem.

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[5] Several agricultural experts were consulted in this regard and all of them confirm this general conclusion

Hence, negative effects of raw (sector-specific) death rates on net (sector-specific) migration are expected. However, for infant death rates, if the second effect dominates, positive effects are expected on migration. The empirical results are consistent with these relationships. Following standard practice (Bound, et al., 1995), the strengths of the instruments have been tested by evaluating their joint significance in first-stage regressions. For all instrument combinations that have been considered, strong evidence of joint significance was found (see Section 1.7).

But are the instruments exogenous to measured environmental change? One can imagine two potential channels for health status to affect the environment, other than via the population impacts that the study seeks to identify and income effects which is controlled for. First, because improved health enhances life expectancy and longer-lived peoples potentially have greater incentives for conservation, improved health may conceivably promote environmental improvement directly. Beyond statistical tests that do not support such conjectured effects, the model controls for them directly by including measures of district-level (rural and urban) life expectancies as regressors in the environmental change equations. Second, there is the potential for joint endogeneity between death rates and environmental change; environmental degradation may worsen the climate for disease (including the spread of malaria and gastro-intestinal parasites). However, this link is not possible between environmental change (the endogenous variable) and past death rates (the instruments). Moreover, the model controls for prior period environmental change, thus vitiating any potential link due to serial correlation.

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of agronomic research.

In order to improve the predictions of the population variables, two additional instruments have been considered: rural and urban household sizes. It is expected (and found in the data) that household size is an important determinant of natural population growth. Larger households may enjoy economies of child care/management, lowering costs of children and thus favoring higher levels of birth rates or larger households may enjoy economies of household production and social security, lowering the demand for children. Either effect may dominate in practice.

In principle, larger rural households may enjoy economies of natural resource extraction, potentially leading directly to greater environmental degradation. Although the empirical results belie any such effect, this logic leads us to consider identifying instrument sets that exclude rural household size (RHS) (i.e., that include RHS as a regressor in the environmental change equation). Notably, no such logic applies to urban household size.[6]

In view of these arguments, three different identifying instrument sets were considered for the population variables: (1) the "core" instruments alone, (2) the "core", plus urban household size, and (3) the "core", plus both rural and urban household size. With the first (core) set of instruments, the environment equation is exactly identified. For the latter two instrument combinations, the empirical results support the implicit hypothesis maintained in the use of the posited "supplemental" instruments, in two regards. First, whenever either supplemental instrument is included in an environment

[6] For the urban sector, potential direct links to rural environmental health are due to resulting demands for the products of the rural environment (e.g., food and fuel) and potential political demands for environmental preservation. Such links are expected to be captured by income, literacy, and population variables, and thus expect no direct links between urban household size and environmental change.

equation, its estimated impact is statistically insignificant even at rather high levels of significance. Second, in the presence of any supplemental instruments, standard tests of the over-identifying restrictions (the null of no correlation with the environment error) can be conducted. In both cases, the restrictions are not rejected at any reasonable level of significance (e.g., at thirty percent).

1.8. Results

Tables 1.5 to 1.13 present results from the estimations. The first stage estimations are presented in tables 1.11 to 1.13. The results of rural and urban natural growth equations are presented in tables 1.5 and 1.6; those of rural and urban net migration are in tables 1.7 and 1.8; and environmental changes are presented in tables 1.9 and 1.10. In most cases, three estimations are presented, ordinary least squares (OLS), two-step GMM (GMM), and three-stage least squares (3SLS), for two specifications, one using NDVI (vegetative biomass) measures to proxy for environmental health and change, and the other using z-NDVI (forest cover) measures. For the population change estimations, reported 3SLS results are based on the model with only the “core” instruments used to identify population changes in the environment change equation. Test for heteroskedasticity was conducted for all equations. Since the data does not provide sufficient degrees of freedom to construct White’s general-form statistic, Pagan-Hall statistics was constructed to test for a log error variance that is linear in all exogenous variables; these statistics are reported at the bottom of each results table (table 1.5 to 1.10). Note that the two-stage GMM estimation gives us robust standard errors, accounting for the normal bias associated with two-stage procedures (Murphy and Topel, 1985); the three-stage estimation corresponds to FIML, again yielding consistent standard errors. Both two and three stage estimators, by accounting for joint endogeneity, are consistent. The three stage (3SLS) estimator potentially adds efficiency by accounting for cross-equation correlation and implementing feasible GLS.[7]

As indicated by F statistics at the bottom of each table (tables 1.5 to 1.10), the identifying instruments are strong in the desired sense that they are significant explanators of the endogenous variable that is being identified (following Bound, et al., 1995).[8] In addition, Pagan-Hall test statistics for the null of homoskedasticity, and Hausman test statistics for the null that consumption expenditures are exogenous, are insignificant in all cases. For the environmental change equations, there are two additional test statistics. For the expanded instrument sets, the Hansen test of the over-identifying restrictions supports the maintained hypothesis of instrument exogeneity. In addition, for efficiency and since overall population growth is expected to affect environmental change, the coefficients for the two components of population growth

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[7] For the environment equations, two-stage and three-stage coefficient estimates are essentially identical, even though corresponding two and three stage estimated population change equations are quite different from one another. For expositional economy, only one set of multi-step estimates are present in Table 1.7. As observed by Bhattacharya (2004) and a number of econometricians whose opinion was taken in this regard, such an outcome (verified with alternative statistical packages and alternative approaches to constructing the estimators) can derive from small covariances between the environment equation error and the population errors, and relatively large covariances between the various population errors, both of which are observe in the sample.

[8] Instrument strength is gauged from first stage (rather than second or third stage) estimations because (in 2SLS or 3SLS) the jointly endogenous regressors are identified from the first stage. For example, if the rainfall instrument performs well in explaining environmental change in the first stage, but is not a statistically significant regressor in the third stage (as is true in the vegetation regressions), the latter property does not negate the claim of the rainfall instrument's strength (Bound, et al., 1995). The reason is that the measured strength of an instrument in first stage identification is determined by the sum of two effects: (1) the direct (partial) effect of the instrument (rainfall) on the endogenous variable (environmental change), as measured in second and third stage estimations, and (2) the equilibrium effect of the instrument on the endogenous variable (environmental change) due to changes in other endogenous variables

were restricted to be the same. The tests of the constraints provide evidence in favor of the maintained constraints, as the F statistics are strongly insignificant in all the cases.

From the estimations, a number of qualitative conclusions are evident.

Rural natural growth rates rise with environmental deterioration. In all specifications that account for joint endogeneity (GMM and 3SLS), environmental change has a statistically significant negative impact on rural natural growth rates (Table 1.5). For example, a contemporaneous increase in the NDVI index by one percent of its initial sample range is associated with a reduction in rural natural growth rates of approximately nine percent.[9] Similarly, a contemporaneous increase in the z-index by one percent of its sample range is associated with approximately a 16 percent reduction in rural natural growth. These results broadly support the Hypothesis 3. In the OLS estimations, estimated effects of environmental change on rural natural growth are negative, but smaller and insignificant. Although the predicted bias from structural endogeneity is downward (contrary to the findings), there is an additional source of bias here that is likely to explain the smaller and insignificant effects in the OLS estimation: measurement error for environmental change. Note that the instrumental variables estimators account for both structural endogeneity and measurement error, yielding consistent parameter estimates.

Urban natural growth rates rise with environmental improvement. In both GMM and 3SLS specifications, environmental change has a statistically and quantitatively

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(population changes). Even if the first effect is "small" (i.e., statistically insignificant), the second effect can be large, and thus identify the endogenous variable.

[9]One percent of the 1990-1991 NDVI sample range is .62. Multiplied by the coefficient of environmental change (in Table 1.5) and divided by average rural natural growth gives the indicated percentage change.

significant positive effect on urban natural growth rates (Table 1.6), broadly supporting the Hypothesis 5. For example, a one percent (of initial sample range) contemporaneous rise in the NDVI is associated with approximately a 4 percent increase in urban natural growth rates, while a corresponding rise in the z-score spurs approximately an 8 percent increase.

Increased rural population growth tends to deplete forest resources. As indicated in table 1.9 and 1.10, coefficients on rural population growth (natural growth plus migration) are negative and statistically significant in the models of z-NDVI change, but not statistically significant in the models of NDVI change. Assessing the quantitative significance of these coefficients is not straightforward.[10] However, a one-standard-deviation increase in rural natural growth is associated with a reduction in the z-NDVI-score of 72 to 143 percent of the standard deviation for the z-score change. The data thus provides some support for Hypothesis 1 as it relates to forest resources.

Urban population growth is also estimated to have a negative effect on changes in NDVI and z-NDVI. However, these estimated effects are statistically significant (at the five or ten percent level) only in the z-NDVI model for which the most complete set of identifying instruments were used (Model 3). Hence, the data provides only rather weak evidence for Hypothesis 2. Moreover, the effect of urban population growth on environmental change is significantly less negative than the corresponding effect of rural population growth. For example, in the z-NDVI Model 3, the difference between the two

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[10]The quantification here has been patterned on Bohn and Deacon (2000) who, for example, report effects of a one-standard-deviation change in an ownership index on rates of deforestation.

estimated coefficients is -.092 and the Chi-square test statistic (p-value) for common coefficients is 5.26 (.022).

Net rural in-migration falls with environmental improvement as measured by changes in the forest-based z-NDVI index. Environmental improvement can free up rural labor for migration to urban areas or other districts with employment opportunities. These estimated effects are both statistically and quantitatively significant. For example, an improvement in a district's z-score equal to one percent of the sample range for the initial z-NDVI is estimated to increase rural out-migration by approximately .44 percent of the rural population, which is approximately 1.7 percent of the sample range for rural migration. This provides support for the Hypothesis 4.

Net urban in-migration rises with environmental improvement as measured by z-NDVI changes. Environmental improvement attracts freed rural labor to the urban sector (the flip side of rural migration) and also cross-district migrants to the improved environmental amenities. Again, these effects are significant in both senses. For example, a one-percent-of-sample-range improvement in z-score is estimated to increase urban in-migration by almost one (.94) percent of the urban population, which is approximately 1.7 percent of the sample range for urban migration.

Lower initial forest resources tends to spur subsequent increases in forest resource stocks, with significant negative coefficients on the initial z-NDVI in the z-score change estimations. Approximately 25 percent of prior degradation of the z-NDVI is offset by subsequent environmental improvement during the four-year study period.

Taken together, the results provide some evidence of the "vicious cycle" between rural population growth and environmental degradation, particularly as it relates to the forest resource that is represented using the z-score index. Indeed, the results suggest that the "vicious cycle" may operate not only by spurring increased natural growth in rural populations, which in turn increases environmentally-depleting resource extraction activities. In addition, environmental depletion may be reinforced by drawing in labor that might otherwise migrate to urban employment opportunities. Moreover, the magnitude of estimated environmental (z-change) effects on rural migration is roughly the same as those on rural natural growth, implying roughly equal roles for the two components of population growth in the "vicious cycle."

However, the evidence indicates the existence of two forces that counter the "vicious cycle." First, as forest resources become more scarce (with lower z), heightened incentives for forest preservation lead to improvements in forest health. And second, deforestation is estimated to spur reductions in both components of urban population growth, which in turn are (weakly) found to prompt environmental improvement.

To gain a loose sense of the relative magnitudes of these reinforcing and countering forces, consider how a downward shock to forest resources (i.e., a negative exogenous z-score change) is reinforced or countered by attendant changes in rural populations, urban populations, and "scarcity." In this exercise, one abstracts from much by ignoring all effects of lagged z changes; ignoring long-run effects of changes in the initial z on population changes; and focusing on the 3SLS estimation for the model with the most complete set of population instruments (Model (4), Table 1.10). For this estimation, consider three effects: (1) the reinforcing rural population effect, $V_R=(\beta_1+\beta_3)\delta_1$, where the β and δ coefficients are per equations (1)-(5); (2) the countering urban population effect, $V_U=(\beta_2+\beta_4)\delta_3$; and (3) the countering lower initial environmental quality effect, $V_S=\gamma_{5z}$ = coefficient on initial z-NDVI in equation (5). Each of these V effects enters the long-run z-change multiplier for the initial z shock.[11] For Model 3, the estimated values for these effects are: V_R=1.209, V_U=-.574, and V_S=-.257. Hence, loosely speaking, the urban population effect counters almost fifty percent (47.5%) of the "vicious cycle" effect of the rural population, and the lower initial environmental quality effect counters 21.3 percent more.[12]

1.9. Conclusion

This chapter analyzed the bi-directional links between population growth and environmental change using cross-sectional district-level data from South, Central and West India. The results provide some support for the conceptual ingredients to the so-called "vicious cycle" theory. Under this doctrine, population growth spurs environmental degradation; because child labor is in greater demand in environmentally degraded circumstances, the environmental depletion in turn fuels further population growth, and so on. The evidence suggests that environmental degradation – whether

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[11] Under the indicated premises, the z-change multiplier equals $(1-V_R-V_U-V_S)^{-1}$.

[12] Although they are not the focus of this study, a number of socio-economic variables also have some statistically significant effects in the estimations. For example, as expected, higher raw death rates tend to spur increased natural growth and reduced in-migration. Higher rural consumption expenditures lower rural natural growth rates. Higher rural (urban) household sizes are associated with higher (lower) rural (urban) natural growth and lower (higher) rates of rural (urban) in-migration. Higher rural sex ratios and lower rural life expectancies are associated with lower rural natural growth. Higher urban rates of female workforce participation and infant mortality spur lower urban natural growth. More urban districts tend to yield lower rates of urban natural growth and rural in-migration; higher rates of urban in-migration; and more forest depletion.

measured in terms of biomass or forest resources – indeed spurs both increased rural natural growth and, perhaps more surprisingly, increased rural in-migration. The results also imply that increased rural population growth in turn spurs depletion in forest resources. However, the results on the impact of rural natural growth on biomass resources are mixed.

Despite some confirmation of the "vicious cycle", the analysis suggests the operation of forces that counter the cycle. Whether due to market forces or community / government action, it was found that lower initial environmental quality tends to spur environmental improvement. In addition, for the Indian context, the results suggest that the depletion of forest resources can spur reductions in urban populations, both via reduced natural growth rates and via reduced rates of in-migration; lowered urban population growth may, in turn, operate to offset the original forest depletion.

Pieces of these conclusions are contained in prior work. For example, a number of scholars identify negative effects of rural population growth on the environment (Panayotou, 2000) and positive effects of environmental degradation on rural birth rates (Aggarwal, et al., 2001; Filmer and Pritchett, 2002). Unlike prior studies, this study attempted to account for the joint determination of population and environmental outcomes and, in doing so, find evidence of joint endogeneity. In addition, by virtue of an empirical model that accounts for distinct urban and rural populations, distinct effects of natural growth rates and migration, and the joint endogeneity of population changes and biomass / forest resources in a complete system of relationships, the forces countering the "vicious cycle" could be identified that are missed elsewhere. To some extent, identification of these offsetting forces confirms the "Boserupian" conjecture that lower initial environmental quality breeds creativity, innovation and policy that conserves natural resources.

1.10. Tables

Table 1.1. Variables Definitions

DEMOGRAPHIC VARIABLES (classified by rural (R) and urban (U) areas)	
G	Natural population growth (births minus deaths)(1991 to 1994) per thousand 1991 rural population
M	Net(in)migration (in-migration minus out-migration)(1991 to 1994) per thousand 1991 rural population
ENVIRONMENTAL VARIABLES	
ΔNDVI	Change in average NDVI from 1990-91 to 1994-95
Δz-NDVI	Change in z-NDVI from 1990-91 to 1993-95
NDVI[a]	Average NDVI for 1990 and 1991
z-NDVI[a]	Average z-NDVI of NDVI for 1990 and 1991
LagΔNDVI	Change in average NDVI from 1986 to 1990
LagΔz-NDVI	Change in z-NDVI of NDVI from 1986 to 1990
Rainfall	District level computed average rainfall in centimeters (1991 to 1994)
Rain Dev(+)	Sum of positive deviations in rainfall from the normal (1991 to 1994)
Rain Dev(-)	Sum of negative deviations in rainfall from the normal (1991 to 1994)
SOCIO-ECONOMIC VARIABLES (classified by rural (R) and urban (U) areas)	
Popn Dens	Population per square kilometer (1991)
Cons Exp	Per capita average monthly consumption expenditure in Rupees (1994)
Inf Death	Infant deaths per thousand live births (1991)
Death Rate	Deaths (1991) per thousand 1991 population
Life Exp	Life expectancy at birth (1991)
AHS	Average Household Size (1991)
Fem Lit	% literates in female population (1991)
Male Lit	% literates in male population (1991)
Total Lit	% literates in total population (1991)
Sex Ratio	Females per thousand males (1991)
Fem Work	% of females in working age group participating in workforce (1991)
Muslims	% Muslim population (1991)
Tribals	% Tribal population (1991)

Table 1.1 (contd...)

OTHER VARIABLES	
Urban Popn	% urban population in the district (1991)
NSA	Proportion of district land area cultivated (1991)

[a] NDVI is the Normalized Difference Vegetation Index, a satellite image based measure of terrestrial vegetation. z-NDVI is an index measuring the extent to which a district has 'high NDVI' land, namely, with NDVI values in the highest 20 percent of NDVI values for the sample.

Table 1.2. Sample Statistics

Variable	Obs	Mean	Std.Dev	Min	Max
DEMOGRAPHIC CHANGE VARIABLES					
G_R	190	27.49	24.27	-5.12	109.62
G_U	190	102.81	54.28	7.62	309.25
M_R	190	16.96	34.62	-95.84	161.85
M_U	190	-29.72	66.38	-300.04	247.67
ENVIRONMENTAL VARIABLES					
ΔNDVI	190	5.51	3.89	-10.75	28.62
Δz-NDVI	190	0.48	0.35	-0.22	2.95
NDVI	190	168.73	11.47	133.33	195.41
z-NDVI	190	-0.74	1.17	-7.98	1.25
LagΔNDVI	190	4.48	3.45	-1.83	14.09
LagΔz-NDVI	190	0.85	2.04	-2.78	13.89
Rainfall	190	111.25	82.49	19.42	343.20
Rain Dev(+)	190	421.25	293.38	0	1114.67
Rain Dev(-)	190	-225.39	138.26	-630.22	-43.74
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)					
Popn Dens(R)	190	223.46	191.52	7	1236
Popn Dens(U)	190	2968.18	2566.28	267.34	27490.64
Cons Exp(R)	190	355.61	90.89	204.27	864.63
Cons Exp(U)	190	477.95	114.11	292.86	1258.90
Inf Death(R)	190	23.16	17.37	0.91	88.60
Inf Death(U)	190	17.67	12.55	0.11	86.21
Death Rate(R)	190	4.50	2.29	0.48	11.24
Death Rate(U)	190	5.79	2.24	0.21	15.45
Life Exp(R)	190	60.68	7.19	39.5	74.9
Life Exp(U)	190	67.32	7.03	47	87.1
AHS(R)	190	5.42	0.69	3.74	7.07
AHS(U)	190	5.36	0.58	4.12	7.47
Female Lit(R)	190	32.62	20.75	4.2	93.96
Female Lit(U)	190	61.74	12.47	32.54	94.16
Male Lit(R)	190	59.99	15.43	20.53	97.39
Male Lit(U)	190	82.39	6.54	66.86	97.66
Total Lit(R)	190	46.67	17.54	13.74	95.67
Total Lit(U)	190	72.51	9.04	51.05	95.91
Sex Ratio(R)	190	960.07	56.72	786	1230
Sex Ratio(U)	190	931.42	75.06	764	1685
Fem Work(R)	190	28.83	13.96	2.18	59.5
Fem Work(U)	190	9.65	3.95	1.98	26.61
Muslims(R)	190	5.93	7.07	0.10	67.07
Muslims(U)	190	17.09	9.20	0.68	70.36
Tribals(R)	190	13.38	18.06	0.04	91.14
Tribals(U)	190	3.40	4.30	0.01	28.02

Table 1.2 (contd...)

OTHER VARIABLES					
Urban Popn	190	24.68	13.87	3.41	86.16
NSA	190	0.51	0.16	0.05	0.83

Table 1.3. Correlation Between Environmental Measures

	NSA	z-NDVI	NDVI	ΔNDVI
Forest Area(proportion)	-0.524	0.505	0.587	
NSA	1	-0.002	-0.153	
z-NDVI		1	0.925	
Δz-NDVI				0.274

Table 1.4. Model Structure

Explanatory variables	X_P	X_N
ENVIRONMENTAL VARIABLES		
NDVI/z-NDVI	√	√
LagΔNDVI/LagΔz-NDVI	√	√
Rainfall**		√
Rain Dev(+)	√	√
Rain Dev(-)	√	√
SOCIO ECONOMIC VARIABLES (RURAL AND URBAN)		
Popn Dens	√	√
Cons Exp	√	√
Inf Death***	√	
Death Rate***	√	
Life Exp	√	√
AHS	√	√
Fem Lit	√	√
Male Lit	√	√
Total Lit	√	√
Sex Ratio	√	√
Fem Work	√	√
Muslims	√	√
Tribals	√	√
OTHER VARIABLES		
Urban Popn	√	√
NSA	√	√

Note: ** represents identifying instrument for environmental change
*** represents identifying instruments for population growth

Table 1.5. Rural Natural Population Growth Rate Regressions

Dependent Variable - Rural Natural population growth Rate (G_R)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
ENVIRONMENTAL VARIABLES						
ΔNDVI	-0.3346	-4.0684**	-4.1027***			
	(0.291)	(0.024)	(0.007)			
NDVI	-0.1164	-0.0926	-0.1437			
	(0.451)	(0.721)	(0.449)			
Lag ΔNDVI	0.5566	0.0892	0.1244			
	(0.201)	(0.882)	(0.827)			
Δz-NDVI				-6.5520	-48.6937***	-47.8496***
				(0.249)	(0.006)	(0.004)
z-NDVI				1.6432	-9.2816	-9.1620*
				(0.542)	(0.107)	(0.063)
LagΔz-NDVI				3.0305**	2.5179*	2.5815**
				(0.012)	(0.100)	(0.043)
Rain Dev(+)	-0.0134	-0.0170	-0.0152	-0.0158*	-0.0152*	-0.0147*
	(0.109)	(0.188)	(0.135)	(0.054)	(0.066)	(0.088)
Rain Dev(-)	-0.0048	-0.0173	-0.0149	-0.0053	-0.0091	-0.0084
	(0.660)	(0.228)	(0.296)	(0.613)	(0.442)	(0.449)
RURAL SOCIO-ECONOMIC VARIABLES						
Cons Exp	-0.0261	-0.0334	-0.0350	-0.0295*	-0.0370**	-0.0372**
	(0.145)	(0.130)	(0.114)	(0.097)	(0.023)	(0.048)
Popn Dens	-0.0326***	-0.0178	-0.0172	-0.0296***	-0.0206*	-0.0207**
	(0.001)	(0.268)	(0.185)	(0.002)	(0.080)	(0.045)
Death Rate	6.9605***	8.2147***	7.7148***	7.1922***	8.8300***	8.7218***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fem Lit	16.5683***	22.2384**	16.6983***	14.5405**	18.2621***	16.3449***
	(0.004)	(0.022)	(0.010)	(0.014)	(0.009)	(0.009)

Table 1.5 (contd...)

Dependent Variable - Rural Natural population growth Rate (G_R)						
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	GMM	3SLS	OLS	GMM	3SLS
Male Lit	16.7677***	22.2459**	16.3271**	14.9684**	19.1890**	17.1394***
	(0.007)	(0.030)	(0.016)	(0.016)	(0.010)	(0.010)
Total Lit	-32.4935***	-43.8283**	-32.2874**	-28.7518**	-36.7691**	-32.7849**
	(0.007)	(0.028)	(0.015)	(0.018)	(0.011)	(0.011)
Sex Ratio	-0.2482***	-0.3711**	-0.2920***	-0.2295**	-0.3407***	-0.3122***
	(0.005)	(0.018)	(0.007)	(0.011)	(0.006)	(0.002)
Fem work	-0.2585*	-0.3517	-0.2797	-0.2490	-0.0581	-0.0461
	(0.094)	(0.158)	(0.140)	(0.105)	(0.724)	(0.793)
Tribals	0.1160	-0.1537	-0.1598	0.1053	0.0800	0.0785
	(0.469)	(0.492)	(0.478)	(0.505)	(0.658)	(0.638)
Inf death	0.0459	-0.0001	0.0652	-0.0122	-0.0753	-0.0644
	(0.685)	(1.000)	(0.577)	(0.914)	(0.565)	(0.596)
AHS	24.7632***	23.3613***	23.1337***	23.0360***	19.1966***	19.2335***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Muslims	0.5859**	0.3404	0.3903	0.4712*	0.5181*	0.5188*
	(0.028)	(0.269)	(0.250)	(0.074)	(0.072)	(0.061)
Life Exp	3.7997***	2.3195	2.2267*	4.0391***	3.7929***	3.7695***
	(0.000)	(0.117)	(0.090)	(0.000)	(0.000)	(0.000)
URBAN SOCIO-ECONOMIC VARIABLES						
Cons exp	0.0077	0.0169	0.0180	0.0099	0.0164	0.0164
	(0.536)	(0.304)	(0.258)	(0.419)	(0.207)	(0.211)
Popn Dens	-0.0001	0.0010	0.0010	-0.0001	-0.0003	-0.0003
	(0.846)	(0.284)	(0.208)	(0.796)	(0.584)	(0.622)
Death Rate	2.2154***	3.4244***	3.2521***	1.8522***	2.2477**	2.1811***
	(0.002)	(0.000)	(0.001)	(0.008)	(0.014)	(0.003)
Fem Lit	17.6369**	9.6021	17.2528**	17.9488**	-1.1232	1.6224
	(0.024)	(0.454)	(0.041)	(0.031)	(0.936)	(0.884)
Male Lit	19.9464**	11.0683	19.6785**	20.4575**	-0.5125	2.5775
	(0.024)	(0.444)	(0.039)	(0.029)	(0.973)	(0.836)

Table 1.5 (contd...)

Dependent Variable - Rural Natural population growth Rate (G_R)						
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	GMM	3SLS	OLS	GMM	3SLS
Total Lit	-38.0878**	-21.0605	-37.3026**	-38.7366**	1.2386	-4.5851
	(0.021)	(0.438)	(0.038)	(0.028)	(0.966)	(0.845)
Sex Ratio	-0.2112***	-0.1603	-0.2371***	-0.2078**	-0.0112	-0.0391
	(0.010)	(0.204)	(0.006)	(0.017)	(0.936)	(0.735)
Fem work	-0.7777*	-0.5878	-0.7903	-0.5984	-0.4036	-0.4576
	(0.079)	(0.366)	(0.145)	(0.174)	(0.396)	(0.328)
Tribals	0.0038	0.1778	0.1828	0.1033	0.0133	0.0158
	(0.995)	(0.760)	(0.794)	(0.851)	(0.979)	(0.978)
Inf Death	0.0652	-0.1171	-0.0559	0.0652	-0.1189	-0.1078
	(0.529)	(0.385)	(0.675)	(0.530)	(0.478)	(0.402)
AHS	-10.3961**	-11.6711*	-12.5995*	-10.5439**	-13.9690**	-14.3217***
	(0.047)	(0.063)	(0.052)	(0.042)	(0.022)	(0.010)
Muslims	-0.3549	0.0629	0.0484	-0.1854	0.0201	0.0243
	(0.121)	(0.862)	(0.882)	(0.419)	(0.944)	(0.923)
Life Exp	-3.2633***	-2.0740*	-1.9766*	-3.5001***	-3.2588***	-3.2368***
	(0.000)	(0.099)	(0.086)	(0.000)	(0.000)	(0.000)
NSA	-5.0080	1.9263	0.0136	0.5753	10.9499	10.5945
	(0.610)	(0.902)	(0.999)	(0.951)	(0.376)	(0.318)
Urban Popn	-0.0082	-0.1419	-0.1644	-0.0427	-0.1505	-0.1546
	(0.937)	(0.324)	(0.234)	(0.676)	(0.252)	(0.178)
Constant	381.5449***	483.0817***	487.5200***	336.3883***	295.5485***	293.8752***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
R-squared	0.707			0.716		

Table 1.5 (contd...)

Dependent Variable - Rural Natural population growth Rate (G_R)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
F test for instrument for vegetation change	7.14 (0.0083)				15.08 (0.0002)	
Pagan-Hall test for Heteroskedaticity	10.919 (0.9999)				18.542 (0.9799)	
Exogeneity (Hausman) test for Cons Exp	3.57 (0.9999)				3.43 (0.9999)	

#observations = 190; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 1.6. Urban Natural Population Growth Rate Regressions

Dependent Variable - Urban Natural population growth Rate (G_U)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
ENVIRONMENTAL VARIABLES						
ΔNDVI	-0.4777	6.5260*	6.5937**			
	(0.474)	(0.079)	(0.032)			
NDVI	-0.5117	-0.5562	-0.4555			
	(0.117)	(0.237)	(0.231)			
Lag ΔNDVI	0.6259	1.5027	1.4331			
	(0.495)	(0.250)	(0.210)			
Δz-NDVI				-5.0755	87.6773**	88.2861**
				(0.678)	(0.042)	(0.014)
Z-NDVI				-4.1895	19.8556*	20.1769*
				(0.471)	(0.088)	(0.058)
LagΔz-NDVI				0.8196	1.9479	1.9243
				(0.751)	(0.492)	(0.487)
Rain Dev(+)	0.0512***	0.0578**	0.0544***	0.0489***	0.0476**	0.0467**
	(0.004)	(0.034)	(0.008)	(0.006)	(0.021)	(0.012)
Rain Dev(-)	-0.0674***	-0.0439	-0.0486*	-0.0679***	-0.0596**	-0.0606**
	(0.004)	(0.102)	(0.090)	(0.003)	(0.024)	(0.012)
URBAN SOCIO-ECONOMIC VARIABLES						
Cons Exp	0.0124	-0.0049	-0.0070	0.0106	-0.0036	-0.0038
	(0.637)	(0.912)	(0.826)	(0.688)	(0.923)	(0.895)
Popn Dens	0.0017	-0.0005	-0.0004	0.0015	0.0018	0.0019
	(0.135)	(0.820)	(0.799)	(0.157)	(0.212)	(0.109)
Death Rate	10.9561***	8.6882***	9.0286***	10.9053***	10.0348***	10.1386***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fem Lit	30.8280*	45.8997*	30.7908*	31.5777*	73.5546**	69.4960***
	(0.060)	(0.063)	(0.071)	(0.077)	(0.014)	(0.004)

Table 1.6 (contd...)

Dependent Variable - Urban Natural population growth Rate (G_U)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
Total Lit	-62.5421*	-94.4818*	-62.4061*	-64.2924*	-152.2768**	-143.649***
	(0.072)	(0.068)	(0.084)	(0.088)	(0.014)	(0.005)
Male Lit	32.6691*	49.3227*	32.3189*	33.8033*	79.9577**	75.3786***
	(0.078)	(0.072)	(0.093)	(0.093)	(0.014)	(0.005)
Sex Ratio	-0.2510	-0.3466	-0.1950	-0.2541	-0.6867**	-0.6457***
	(0.143)	(0.152)	(0.261)	(0.172)	(0.024)	(0.010)
Fem Work	-2.4180**	-2.7742**	-2.3743**	-2.3857**	-2.8144***	-2.7378***
	(0.010)	(0.028)	(0.029)	(0.012)	(0.005)	(0.007)
Tribals	-1.4087	-1.7351	-1.7449	-1.3671	-1.1689	-1.1481
	(0.233)	(0.180)	(0.212)	(0.249)	(0.252)	(0.360)
Inf Death	-1.1095***	-0.7677***	-0.8885***	-1.0964***	-0.6911**	-0.6977**
	(0.000)	(0.003)	(0.001)	(0.000)	(0.026)	(0.012)
AHS	-31.7706***	-29.3790**	-27.5455**	-31.6707***	-24.1320**	-23.3700*
	(0.004)	(0.011)	(0.034)	(0.005)	(0.042)	(0.052)
Muslims	1.1901**	0.4065	0.4350	1.2629**	0.8108	0.8180
	(0.014)	(0.600)	(0.507)	(0.011)	(0.174)	(0.135)
Life Exp	0.1264	-2.1045	-2.2967	-0.2580	-0.7892	-0.8024
	(0.945)	(0.411)	(0.319)	(0.884)	(0.683)	(0.670)
RURAL SOCIO-ECONOMIC VARIABLES						
Cons Exp	-0.0149	-0.0012	0.0019	-0.0180	-0.0017	-0.0014
	(0.693)	(0.982)	(0.966)	(0.637)	(0.969)	(0.973)
Popn Dens	-0.0274	-0.0551	-0.0562**	-0.0288	-0.0488	-0.0496**
	(0.166)	(0.191)	(0.031)	(0.151)	(0.126)	(0.027)
Death Rate	-5.1322***	-7.4848***	-6.4975***	-5.3261***	-8.9308***	-8.7977***
	(0.008)	(0.001)	(0.005)	(0.008)	(0.000)	(0.000)
Fem Lit	-17.4077	-28.0435*	-17.1028	-17.9527	-26.1437*	-24.5899*
	(0.152)	(0.087)	(0.189)	(0.154)	(0.061)	(0.070)
Male Lit	-16.1664	-26.4423	-14.7537	-16.4134	-25.7028*	-24.0017*
	(0.209)	(0.122)	(0.279)	(0.217)	(0.082)	(0.095)

Table 1.6 (contd...)

Dependent Variable - Urban Natural population growth Rate (G_U)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
Total Lit	34.9339	56.1957*	33.4043	35.7024	53.3482*	50.0577*
	(0.163)	(0.094)	(0.211)	(0.169)	(0.064)	(0.073)
Sex Ratio	0.1041	0.3346	0.1784	0.1109	0.3556	0.3337
	(0.576)	(0.200)	(0.410)	(0.565)	(0.129)	(0.132)
Fem Work	0.0165	0.1913	0.0490	0.0168	-0.4032	-0.4227
	(0.959)	(0.667)	(0.897)	(0.959)	(0.242)	(0.266)
Tribals	0.1652	0.6712	0.6833	0.2126	0.2684	0.2720
	(0.625)	(0.125)	(0.130)	(0.532)	(0.406)	(0.451)
Inf Death	0.1189	0.2051	0.0763	0.1001	0.2391	0.2112
	(0.618)	(0.535)	(0.746)	(0.682)	(0.384)	(0.420)
AHS	9.3851	12.0148	12.4642	8.7187	17.1689*	16.7851*
	(0.290)	(0.223)	(0.227)	(0.326)	(0.052)	(0.089)
Muslims	0.3693	0.8299	0.7313	0.2545	0.1511	0.1209
	(0.508)	(0.292)	(0.282)	(0.652)	(0.844)	(0.840)
Life Exp	0.0287	2.8053	2.9886	0.4600	1.0018	1.0140
	(0.989)	(0.322)	(0.256)	(0.817)	(0.631)	(0.631)
NSA	-31.1446	-44.1519	-40.3746	-22.0907	-44.9250	-43.9706*
	(0.134)	(0.203)	(0.103)	(0.276)	(0.130)	(0.056)
Urban Popn	-1.4231***	-1.1724***	-1.1279***	-1.4055***	-1.1684***	-1.1547***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	273.4619	83.0023	74.2375	167.0910	256.9783	239.7425
	(0.123)	(0.733)	(0.719)	(0.327)	(0.196)	(0.189)
R-squared	0.739			0.737		

Table 1.6 (contd...)

Dependent Variable - Urban Natural population growth Rate (G_U)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
F test for instrument for vegetation change		7.14 (0.0083)			15.08 (0.0002)	
Pagan-Hall test for Heteroskedaticity		13.248 (0.9991)			29.603 (0.6370)	
Exogeneity (Hausman) test for Cons Exp		3.23 (0.9999)			2.76 (0.9999)	

#observations = 190; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 1.7. Rural Migration Rate Regressions

Dependent Variable – Rural Migration Rate (M_R)

	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
ENVIRONMENTAL VARIABLES						
ΔNDVI	-0.5373	-2.9166	-2.9661			
	(0.294)	(0.114)	(0.122)			
NDVI	0.3795	0.3946	0.3210			
	(0.130)	(0.210)	(0.175)			
LagΔNDVI	-0.8973	-1.1951*	-1.1443			
	(0.203)	(0.085)	(0.109)			
Δz-NDVI				-19.5119**	-48.0646**	-47.2738**
				(0.037)	(0.042)	(0.048)
z-NDVI				-7.5593*	-14.9613*	-15.4341**
				(0.088)	(0.072)	(0.028)
LagΔNDVI				-2.7943	-3.1416	-2.9199
				(0.156)	(0.104)	(0.109)
Rain Dev(+)	-0.0089	-0.0111	-0.0086	-0.0007	-0.0003	0.0033
	(0.512)	(0.398)	(0.495)	(0.959)	(0.981)	(0.784)
Rain Dev(-)	0.0314*	0.0234	0.0269	0.0304*	0.0278	0.0324**
	(0.075)	(0.292)	(0.133)	(0.077)	(0.187)	(0.043)
RURAL SOCIO-ECONOMIC VARIABLES						
Cons Exp	0.0323	0.0277	0.0254	0.0301	0.0251	0.0236
	(0.264)	(0.353)	(0.357)	(0.300)	(0.407)	(0.381)
Popn Dens	0.0254*	0.0348*	0.0357**	0.0272*	0.0334*	0.0352**
	(0.095)	(0.074)	(0.028)	(0.075)	(0.062)	(0.018)
Death Rate	-8.1065***	-7.3073***	-8.0292***	-7.6486***	-6.5389***	-7.1857***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fem Lit	-13.3141	-9.7008	-17.7012**	-14.0441	-11.5226	-20.2824***
	(0.153)	(0.340)	(0.020)	(0.142)	(0.210)	(0.006)

Table 1.7 (contd...

Dependent Variable – Rural Migration Rate (M_R)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
Male Lit	-14.0678	-10.5768	-19.1241**	-14.9838	-12.1242	-21.6021***
	(0.154)	(0.322)	(0.017)	(0.139)	(0.218)	(0.006)
Total Lit	25.7588	18.5356	35.2018**	27.5478	22.1158	40.4951***
	(0.180)	(0.374)	(0.024)	(0.162)	(0.245)	(0.008)
Sex Ratio	0.2412*	0.1629	0.2772**	0.2317	0.1564	0.2841**
	(0.092)	(0.358)	(0.032)	(0.115)	(0.342)	(0.027)
Fem Work	-0.2648	-0.3242	-0.2201	-0.0734	0.0559	0.1353
	(0.287)	(0.192)	(0.349)	(0.769)	(0.825)	(0.584)
Tribals	-0.9098***	-1.0816***	-1.0905***	-0.8286***	-0.8458***	-0.8589***
	(0.001)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)
Inf Death	-0.1255	-0.1548	-0.0606	-0.0934	-0.1362	-0.0309
	(0.492)	(0.383)	(0.651)	(0.615)	(0.455)	(0.833)
AHS	-22.9429***	-23.8362***	-24.1649***	-23.8530***	-26.4543***	-25.2246***
	(0.001)	(0.006)	(0.000)	(0.001)	(0.004)	(0.000)
Muslims	-1.0409**	-1.1974***	-1.1253***	-0.8479**	-0.8161*	-0.7305*
	(0.016)	(0.009)	(0.008)	(0.049)	(0.066)	(0.065)
Life Exp	-4.8114***	-5.7547***	-5.8887***	-5.1442***	-5.3110***	-5.3959***
	(0.003)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
URBAN SOCIO-ECONOMIC VARIABLES						
Cons Exp	-0.0336*	-0.0277	-0.0262	-0.0315	-0.0271	-0.0265
	(0.097)	(0.201)	(0.189)	(0.118)	(0.219)	(0.162)
Popn Dens	-0.0002	0.0005	0.0005	-0.0005	-0.0006	-0.0007
	(0.827)	(0.576)	(0.621)	(0.517)	(0.296)	(0.394)
Death Rate	-4.6535***	-3.8830**	-4.1320***	-4.5522***	-4.2842***	-4.7476***
	(0.000)	(0.019)	(0.000)	(0.000)	(0.002)	(0.000)
Fem Lit	-22.5348*	-27.6551*	-16.6067*	-29.5513**	-42.4734**	-24.5722*
	(0.073)	(0.069)	(0.090)	(0.030)	(0.013)	(0.090)
Male Lit	-26.5902*	-32.2478*	-19.8138*	-34.6942**	-48.9022**	-28.7364*
	(0.061)	(0.060)	(0.074)	(0.024)	(0.011)	(0.075)

Table 1.7 (contd...)

Dependent Variable – Rural Migration Rate (M_R)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
Total Lit	51.0747*	61.9254*	38.4702*	65.8754**	92.9603**	54.9502*
	(0.055)	(0.054)	(0.064)	(0.022)	(0.010)	(0.072)
Sex Ratio	0.2859**	0.3184**	0.2076**	0.3613**	0.4945***	0.3133**
	(0.030)	(0.038)	(0.038)	(0.011)	(0.005)	(0.039)
Fem Work	1.1996*	1.3207*	1.0283	1.1083	1.2403*	0.9004
	(0.093)	(0.050)	(0.127)	(0.124)	(0.069)	(0.174)
Tribals	2.4774***	2.5883**	2.5955***	2.1695**	2.1084**	2.0575**
	(0.007)	(0.012)	(0.003)	(0.017)	(0.022)	(0.014)
Inf Death	0.1234	0.0073	0.0956	0.0679	-0.0568	-0.0108
	(0.460)	(0.974)	(0.551)	(0.689)	(0.785)	(0.950)
AHS	23.9688***	23.1563*	21.8155***	21.5443**	19.2236	16.3201**
	(0.005)	(0.066)	(0.007)	(0.011)	(0.110)	(0.040)
Muslims	0.6231*	0.8893*	0.8685**	0.4935	0.6326*	0.6193*
	(0.093)	(0.050)	(0.034)	(0.189)	(0.098)	(0.086)
Life Exp	3.9260***	4.6839***	4.8245***	4.2873***	4.4508***	4.5354***
	(0.006)	(0.002)	(0.001)	(0.002)	(0.002)	(0.000)
NSA	4.7620	9.1809	6.4188	1.0370	8.0662	4.4136
	(0.764)	(0.691)	(0.678)	(0.946)	(0.663)	(0.771)
Urban Popn	-0.4701***	-0.5553***	-0.5878***	-0.5112***	-0.5843***	-0.6311***
	(0.005)	(0.001)	(0.001)	(0.003)	(0.001)	(0.000)
Constant	-480.5396***	-415.8353**	-409.4258***	-447.8630***	-475.5339***	-430.273***
	(0.001)	(0.019)	(0.001)	(0.001)	(0.002)	(0.000)
R-squared	0.623			0.627		

Table 1.7 (contd...)

Dependent Variable – Rural Migration Rate (M_R)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
F test for instrument for vegetation change		7.14 (0.0083)			15.08 (0.0002)	
Pagan-Hall test for Heteroskedaticity		29.617 (0.6363)			26.235 (0.7922)	
Exogeneity (Hausman) test for Cons Exp		2.69 (0.9999)			2.65 (0.9999)	

#observations = 190; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 1.8. Urban Migration Rate Regressions

Dependent Variable – Urban Migration Rate (M_U)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
ENVIRONMENTAL VARIABLES						
ΔNDVI	0.3270	6.4239	6.4916			
	(0.770)	(0.231)	(0.131)			
NDVI	-0.3984	-0.4372	-0.3366			
	(0.465)	(0.434)	(0.529)			
LagΔNDVI	-2.0731	-1.3098	-1.3793			
	(0.178)	(0.376)	(0.389)			
Δz-NDVI				5.7012	100.8614*	103.4453*
				(0.780)	(0.093)	(0.059)
Z-NDVI				4.1529	28.8221*	28.6424*
				(0.669)	(0.067)	(0.078)
LagΔz-NDVI				3.0898	4.2473	4.5934
				(0.476)	(0.377)	(0.275)
Rain Dev(+)	0.0006	0.0063	0.0029	0.0042	0.0028	0.0074
	(0.985)	(0.840)	(0.920)	(0.888)	(0.923)	(0.794)
Rain Dev(-)	-0.0362	-0.0157	-0.0204	-0.0230	-0.0144	-0.0087
	(0.345)	(0.729)	(0.612)	(0.543)	(0.721)	(0.813)
RURAL SOCIO-ECONOMIC VARIABLES						
Cons Exp	-0.0736	-0.0617	-0.0586	-0.0786	-0.0619	-0.0638
	(0.244)	(0.431)	(0.347)	(0.220)	(0.427)	(0.305)
Popn Dens	0.0856**	0.0616*	0.0604*	0.0910***	0.0705*	0.0719**
	(0.010)	(0.088)	(0.098)	(0.007)	(0.053)	(0.035)
Death Rate	4.6549	2.6069	3.5929	5.3815	1.6833	0.8431
	(0.148)	(0.566)	(0.282)	(0.107)	(0.727)	(0.822)
Fem Lit	34.9309*	25.6721	36.5982*	29.7630	21.3593	8.9912
	(0.086)	(0.338)	(0.062)	(0.158)	(0.334)	(0.649)

Table 1.8 (contd...)

Dependent Variable – Urban Migration Rate (M_U)

	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
Male Lit	37.3559*	28.4104	40.0834*	32.0793	22.5488	9.2209
	(0.084)	(0.315)	(0.052)	(0.151)	(0.344)	(0.660)
Total Lit	-72.7559*	-54.2469	-77.0077*	-62.3545	-44.2507	-18.3846
	(0.083)	(0.326)	(0.056)	(0.151)	(0.337)	(0.652)
Sex Ratio	-0.4776	-0.2769	-0.4329	-0.3955	-0.1444	0.0372
	(0.126)	(0.493)	(0.175)	(0.221)	(0.675)	(0.909)
Fem Work	1.2380**	1.3902**	1.2481**	1.1655**	0.7346	0.8350
	(0.024)	(0.029)	(0.020)	(0.036)	(0.273)	(0.148)
Tribals	0.7005	1.1410**	1.1531*	0.5293	0.5866	0.5712
	(0.216)	(0.043)	(0.068)	(0.354)	(0.255)	(0.299)
Inf Death	0.0376	0.1127	-0.0160	-0.0322	0.1104	0.2326
	(0.925)	(0.811)	(0.965)	(0.937)	(0.817)	(0.548)
AHS	-19.6882	-17.3990	-16.9502	-16.7472	-8.0776	-6.8492
	(0.185)	(0.238)	(0.244)	(0.261)	(0.594)	(0.649)
Muslims	0.3418	0.7428	0.6443	0.3077	0.2016	0.2828
	(0.714)	(0.345)	(0.500)	(0.745)	(0.812)	(0.757)
Life Exp	-0.4217	1.9954	2.1784	-1.7727	-1.2168	-1.3473
	(0.902)	(0.621)	(0.558)	(0.595)	(0.717)	(0.674)
URBAN SOCIO-ECONOMIC VARIABLES						
Cons Exp	0.0533	0.0383	0.0361	0.0632	0.0486	0.0493
	(0.226)	(0.363)	(0.417)	(0.155)	(0.298)	(0.256)
Popn Dens	-0.0020	-0.0038	-0.0037*	-0.0019	-0.0016	-0.0016
	(0.288)	(0.164)	(0.091)	(0.300)	(0.324)	(0.361)
Death Rate	-1.4865	-3.4609	-3.1209	-2.0941	-2.9872	-3.5652
	(0.541)	(0.552)	(0.250)	(0.399)	(0.532)	(0.140)
Fem Lit	-26.9992	-13.8790	-28.9676	-18.3088	24.7577	47.4697
	(0.323)	(0.648)	(0.268)	(0.538)	(0.533)	(0.187)

Table 1.8 (contd...)

Dependent Variable – Urban Migration Rate (M_U)	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
Male Lit	-30.3189	-15.8216	-32.8025	-21.3865	25.9660	51.5446
	(0.327)	(0.646)	(0.267)	(0.524)	(0.555)	(0.199)
Total Lit	54.2944	26.4900	58.5226	36.4759	-53.7924	-102.0034
	(0.348)	(0.681)	(0.291)	(0.562)	(0.518)	(0.178)
Sex Ratio	0.1580	0.0749	0.2262	0.0754	-0.3684	-0.5983
	(0.581)	(0.801)	(0.395)	(0.808)	(0.365)	(0.110)
Fem Work	2.0100	1.6998	2.0992	2.1418	1.7020	1.2667
	(0.197)	(0.292)	(0.171)	(0.177)	(0.269)	(0.410)
Tribals	-1.8111	-2.0953	-2.1051	-2.0034	-1.8001	-1.8421
	(0.359)	(0.302)	(0.282)	(0.313)	(0.375)	(0.336)
Inf Death	0.9330**	1.2305***	1.1099***	0.9218**	1.3376***	1.4049***
	(0.011)	(0.004)	(0.005)	(0.015)	(0.003)	(0.001)
AHS	42.6183**	44.7003**	46.5313**	41.1944**	48.9287***	45.4477**
	(0.022)	(0.014)	(0.011)	(0.028)	(0.009)	(0.013)
Muslims	-1.9997**	-2.6818***	-2.6534***	-1.9348**	-2.3986***	-2.4018***
	(0.014)	(0.007)	(0.004)	(0.020)	(0.009)	(0.004)
Life Exp	0.5067	-1.4353	-1.6273	1.7352	1.1903	1.3172
	(0.868)	(0.685)	(0.618)	(0.558)	(0.687)	(0.645)
NSA	-5.7880	-17.1111	-13.3390	-15.7262	-39.1532	-43.3397
	(0.867)	(0.665)	(0.702)	(0.643)	(0.332)	(0.216)
Urban Popn	1.3510***	1.5693***	1.6137***	1.3125***	1.5558***	1.5030***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	361.9111	196.1103	187.3572	301.1589	393.3802	431.9662
	(0.222)	(0.497)	(0.534)	(0.292)	(0.177)	(0.113)
R-squared	0.511			0.506		

Table 1.8 (contd...)

Dependent Variable - Urban Migration Rate (M_U)

	(1) OLS	(2) GMM	(3) 3SLS	(4) OLS	(5) GMM	(6) 3SLS
F test for instrument for vegetation change		7.14 (0.0083)			15.08 (0.0002)	
Pagan-Hall test for Heteroskedaticity		16.393 (0.9930)			22.402 (0.9183)	
Exogeneity (Hausman) test for Cons Exp		0.84 (0.9999)			0.90 (0.9999)	

#observations = 190; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 1.9. Vegetation Change Regressions

Dependent Variable -	ΔNDVI			Δz-NDVI		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	GMM	3SLS	OLS	GMM	3SLS
ENDOGENOUS DEMOGRAPHIC VARIABLES						
Popn Grth(R)	-0.0297*	-0.2045	-0.2045	-0.0026***	-0.0207*	-0.0207*
	(0.071)	(0.181)	(0.138)	(0.004)	(0.099)	(0.067)
Popn Grth(U)	-0.0061	-0.0254	-0.0254	-0.0007**	-0.0056	-0.0056
	(0.315)	(0.538)	(0.496)	(0.031)	(0.143)	(0.104)
ENVIRONMENTAL VARIABLES						
NDVI	0.0316	0.0291	0.0291			
	(0.426)	(0.597)	(0.558)			
LagΔNDVI	-0.1120	-0.2121	-0.2121			
	(0.291)	(0.201)	(0.157)			
z-NDVI				-0.2438***	-0.2529***	-0.2529***
				(0.000)	(0.000)	(0.000)
LagΔz-NDVI				-0.0052	0.0158	0.0158
				(0.738)	(0.690)	(0.659)
Rainfall	0.0159***	-0.0021	-0.0021	0.0013***	0.0000	0.0000
	(0.006)	(0.884)	(0.872)	(0.000)	(0.989)	(0.988)
Rain Dev(+)	-0.0032	-0.0041	-0.0041	-0.0001	-0.0001	-0.0001
	(0.124)	(0.145)	(0.106)	(0.271)	(0.781)	(0.758)
Rain Dev(-)	0.0006	-0.0000	-0.0000	0.0001	-0.0000	-0.0000
	(0.816)	(0.998)	(0.998)	(0.357)	(0.957)	(0.952)
RURAL SOCIO-ECONOMIC VARIABLES						
Cons Exp	-0.0034	-0.0020	-0.0020	-0.0004*	-0.0006	-0.0006
	(0.410)	(0.729)	(0.702)	(0.068)	(0.247)	(0.200)

Table 1.9 (contd...)

Dependent Variable -	ΔNDVI			Δz-NDVI		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	GMM	3SLS	OLS	GMM	3SLS
Popn Dens	0.0024	0.0037	0.0037	0.0001	0.0004	0.0004
	(0.305)	(0.303)	(0.254)	(0.311)	(0.217)	(0.172)
Fem Lit	1.4253	2.1777	2.1777	0.0656	0.1107	0.1107
	(0.305)	(0.296)	(0.247)	(0.388)	(0.494)	(0.450)
Male Lit	1.3473	2.1356	2.1356	0.0740	0.1288	0.1288
	(0.362)	(0.340)	(0.291)	(0.358)	(0.457)	(0.411)
Total Lit	-2.8162	-4.4779	-4.4779	-0.1402	-0.2490	-0.2490
	(0.326)	(0.304)	(0.255)	(0.370)	(0.459)	(0.412)
Sex Ratio	-0.0326	-0.0339	-0.0339	-0.0025**	-0.0025	-0.0025
	(0.127)	(0.260)	(0.212)	(0.036)	(0.308)	(0.259)
Fem Work	-0.0222	-0.0892	-0.0892	0.0061***	0.0028	0.0028
	(0.543)	(0.172)	(0.130)	(0.002)	(0.574)	(0.534)
Muslims	-0.0416	-0.1275	-0.1275	0.0039	-0.0034	-0.0034
	(0.524)	(0.228)	(0.182)	(0.267)	(0.705)	(0.676)
Tribals	-0.0876**	-0.1958**	-0.1958**	-0.0009	-0.0103	-0.0103
	(0.027)	(0.047)	(0.027)	(0.668)	(0.190)	(0.147)
AHS	-0.2417	-0.1535	-0.1535	-0.1062**	-0.0958	-0.0958
	(0.810)	(0.908)	(0.898)	(0.047)	(0.388)	(0.339)
Life Exp	-0.4388**	-0.4851*	-0.4851*	-0.0087	-0.0267	-0.0267
	(0.037)	(0.094)	(0.063)	(0.419)	(0.298)	(0.249)
URBAN SOCIO-ECONOMIC VARIABLES						
Cons Exp	0.0026	-0.0014	-0.0014	0.0002	0.0000	0.0000
	(0.402)	(0.767)	(0.743)	(0.246)	(0.900)	(0.890)
Popn Dens	0.0002*	0.0002	0.0002	-0.0000*	-0.0000	-0.0000
	(0.083)	(0.302)	(0.253)	(0.083)	(0.205)	(0.160)
Fem Lit	-1.1774	-2.8141	-2.8141	-0.3628***	-0.3897*	-0.3897**
	(0.514)	(0.285)	(0.237)	(0.000)	(0.067)	(0.042)
Male Lit	-1.3712	-3.4284	-3.4284	-0.4022***	-0.4723*	-0.4723**
	(0.506)	(0.269)	(0.221)	(0.000)	(0.054)	(0.032)

Table 1.9 (contd...)

Dependent Variable -	ΔNDVI			Δz-NDVI		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	GMM	3SLS	OLS	GMM	3SLS
Total Lit	2.6326	6.4898	6.4898	0.7668***	0.8739*	0.8739**
	(0.494)	(0.260)	(0.213)	(0.000)	(0.056)	(0.034)
Life Exp	0.3615*	0.3662	0.3662	0.0086	0.0221	0.0221
	(0.055)	(0.150)	(0.111)	(0.370)	(0.319)	(0.270)
Sex Ratio	0.0047	0.0260	0.0260	0.0038***	0.0045*	0.0045**
	(0.808)	(0.375)	(0.326)	(0.000)	(0.052)	(0.031)
Muslims	0.0721	0.1257	0.1257*	0.0004	0.0038	0.0038
	(0.186)	(0.116)	(0.081)	(0.888)	(0.563)	(0.523)
Fem Work	0.0614	0.1012	0.1012	0.0045	0.0096	0.0096
	(0.567)	(0.490)	(0.445)	(0.436)	(0.443)	(0.396)
Tribals	0.1541	0.4610	0.4610*	0.0047	0.0268	0.0268
	(0.276)	(0.119)	(0.083)	(0.534)	(0.228)	(0.182)
AHS	1.0305	2.6052	2.6052	0.0532	0.2399	0.2399
	(0.418)	(0.267)	(0.219)	(0.435)	(0.212)	(0.167)
NSA	1.8932	0.1551	0.1551	0.2330*	-0.0861	-0.0861
	(0.434)	(0.968)	(0.965)	(0.064)	(0.801)	(0.781)
Urban Popn	-0.0544**	-0.1299	-0.1299*	-0.0038***	-0.0130*	-0.0130**
	(0.034)	(0.100)	(0.068)	(0.005)	(0.060)	(0.036)
Constant	25.0121	14.3578	14.3578	-0.8702	-0.5211	-0.5211
	(0.216)	(0.633)	(0.598)	(0.397)	(0.826)	(0.808)
R-square	0.304			0.757		

Table 1.9 (contd...)

Dependent Variable -	ΔNDVI		|	Δz-NDVI		
	(1)	(2)	(3) |	(4)	(5)	(6)
	OLS	GMM	3SLS |	OLS	GMM	3SLS
F test for instrument for G_R		30.61 (0.0000)			29.54 (0.0000)	
F test for instrument for G_U		30.05 (0.0000)			27.02 (0.0000)	
F test for instrument for M_R		20.02 (0.0000)			18.54 (0.0000)	
F test for instrument for M_U		3.52 (0.0088)			3.60 (0.0078)	
Pagan-Hall test for Heteroskedaticity		0.369 (0.9999)			0.148 (0.9999)	
Exogeneity (Hausman) test for Cons Exp		0.10 (0.9999)			1.69 (0.9999)	
Test for validity of constraints(F test)		0.03 (0.9734)			0.02 (0.9768)	

#observations = 190; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 1.10. z-NDVI Regressions

Dependent Variable :	Δz-NDVI			
	(1)	(2)	(3)	(4)
	GMM	3SLS	GMM	3SLS
ENDOGENOUS DEMOGRAPHIC VARIABLES				
Popn Grth(R)	-0.0104*	-0.0104**	-0.0122**	-0.0122**
	(0.070)	(0.044)	(0.022)	(0.011)
Popn Grth(U)	-0.0025	-0.0025	-0.0030*	-0.0030**
	(0.154)	(0.115)	(0.074)	(0.049)
ENVIRONMENTAL VARIABLES				
z-NDVI	-0.2579***	-0.2579***	-0.2575***	-0.2575***
	(0.000)	(0.000)	(0.000)	(0.000)
LagΔz-NDVI	0.0002	0.0002	0.0019	0.0019
	(0.992)	(0.991)	(0.937)	(0.931)
Rainfall	0.0006	0.0006	0.0005	0.0005
	(0.400)	(0.353)	(0.494)	(0.452)
Rain Dev(+)	-0.0001	-0.0001	-0.0001	-0.0001
	(0.661)	(0.628)	(0.721)	(0.695)
Rain Dev(-)	0.0001	0.0001	0.0000	0.0000
	(0.728)	(0.702)	(0.841)	(0.825)
RURAL SOCIO-ECONOMIC VARIABLES				
Cons Exp	-0.0004	-0.0004*	-0.0005	-0.0005
	(0.136)	(0.099)	(0.157)	(0.119)
Popn Dens	0.0003	0.0003	0.0003	0.0003
	(0.178)	(0.137)	(0.146)	(0.109)
Fem Lit	0.0488	0.0488	0.0671	0.0671
	(0.602)	(0.565)	(0.482)	(0.439)
Male Lit	0.0573	0.0573	0.0770	0.0770
	(0.564)	(0.524)	(0.446)	(0.402)
Total Lit	-0.1099	-0.1099	-0.1487	-0.1487
	(0.568)	(0.529)	(0.447)	(0.403)
Sex Ratio	-0.0019	-0.0019	-0.0021	-0.0021
	(0.203)	(0.159)	(0.186)	(0.146)
Fem Work	0.0045	0.0045*	0.0041	0.0041
	(0.123)	(0.088)	(0.179)	(0.139)
AHS	-0.0340	-0.0340		
	(0.572)	(0.533)		
Muslims	-0.0002	-0.0002	-0.0010	-0.0010
	(0.971)	(0.968)	(0.853)	(0.838)
Tribals	-0.0051	-0.0051	-0.0061	-0.0061*
	(0.205)	(0.161)	(0.125)	(0.091)
Life Exp	-0.0191	-0.0191	-0.0197	-0.0197
	(0.207)	(0.163)	(0.231)	(0.187)

Table 1.10 (contd...)

Dependent Variable :	Δz-NDVI			
	(1)	(2)	(3)	(4)
	GMM	3SLS	GMM	3SLS
URBAN SOCIO-ECONOMIC VARIABLES				
Cons Exp	0.0000	0.0000	-0.0000	-0.0000
	(0.901)	(0.890)	(0.991)	(0.990)
Popn Dens	-0.0000	-0.0000*	-0.0000	-0.0000
	(0.134)	(0.097)	(0.166)	(0.127)
Fem Lit	-0.3341***	-0.3341***	-0.3340**	-0.3340***
	(0.009)	(0.003)	(0.015)	(0.007)
Male Lit	-0.3833***	-0.3833***	-0.3869**	-0.3869***
	(0.007)	(0.003)	(0.013)	(0.006)
Total Lit	0.7233***	0.7233***	0.7277**	0.7277***
	(0.007)	(0.003)	(0.013)	(0.006)
Life Exp	0.0162	0.0162	0.0164	0.0164
	(0.217)	(0.173)	(0.252)	(0.207)
Sex Ratio	0.0037***	0.0037***	0.0038**	0.0038***
	(0.006)	(0.002)	(0.011)	(0.005)
Fem Work	0.0049	0.0049	0.0058	0.0058
	(0.503)	(0.460)	(0.448)	(0.404)
Muslims	0.0047	0.0047	0.0050	0.0050
	(0.238)	(0.193)	(0.253)	(0.208)
Tribals	0.0124	0.0124	0.0143	0.0143
	(0.282)	(0.235)	(0.233)	(0.189)
NSA	0.1233	0.1233	0.0755	0.0755
	(0.496)	(0.453)	(0.665)	(0.634)
Urban Popn	-0.0078**	-0.0078***	-0.0087***	-0.0087***
	(0.020)	(0.009)	(0.006)	(0.002)
Constant	-0.6144	-0.6144	-0.4603	-0.4603
	(0.669)	(0.638)	(0.764)	(0.742)
F test for instrument for G_R	23.80		25.13	
	(0.0000)		(0.0000)	
F test for instrument for G_U	25.40		21.17	
	(0.0000)		(0.0000)	
F test for instrument for M_R	14.84		14.31	
	(0.0000)		(0.0000)	
F test for instrument for M_U	4.30		3.92	
	(0.0011)		(0.0011)	
Hansen J statistic (OIR test)	0.026		2.346	
	(0.8722)		(0.3095)	

#observations = 190; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 1.11. First Stage Regression Results for Vegetation Change (Equations 1-4: G_R, G_U, M_R, M_U)

	ΔNDVI		Δz-NDVI	
	coeff	p-value	coeff	p-value
ENVIRONMENTAL VARIABLES				
NDVI	0.045	0.320		
LagΔNDVI	-0.095	0.323		
z-NDVI			-0.221	0.000
LagΔz-NDVI			-0.001	0.922
Rain Dev(+)	-0.003	0.148	0.000	0.058
Rain Dev(-)	-0.001	0.753	0.000	0.450
Rainfall	0.018	0.008	0.001	0.000
RURAL SOCIO-ECONOMIC VARIABLES				
Cons Exp	-0.002	0.600	0.000	0.324
Popn Dens	0.002	0.514	0.000	0.467
Death Rate	0.321	0.067	0.039	0.000
Fem Lit	1.939	0.267	0.119	0.089
Male Lit	1.848	0.304	0.128	0.083
Total Lit	-3.851	0.278	-0.250	0.083
Sex Ratio	-0.041	0.138	-0.003	0.002
Fem Work	-0.038	0.424	0.004	0.024
Tribals	-0.068	0.033	0.000	0.831
Inf Death	-0.022	0.379	-0.002	0.085
AHS	-0.006	0.995	-0.071	0.087
Muslims	-0.041	0.442	0.003	0.439
Life Exp	-0.306	0.197	0.002	0.839
URBAN SOCIO-ECONOMIC VARIABLES				
Cons Exp	0.003	0.410	0.000	0.233
Popn Dens	0.000	0.126	0.000	0.195
Death Rate	0.310	0.065	0.007	0.468
Fem Lit	-2.090	0.310	-0.457	0.000
Male Lit	-2.216	0.341	-0.495	0.000
Total Lit	4.352	0.319	0.952	0.000
Sex Ratio	0.012	0.594	0.005	0.000
Fem Work	0.078	0.530	0.007	0.207
Tribals	0.090	0.346	0.002	0.753
Inf Death	-0.038	0.015	-0.004	0.018
AHS	0.428	0.672	-0.020	0.781
Muslims	0.083	0.103	0.003	0.345
Life Exp	0.236	0.267	-0.002	0.853
OTHER VARIABLES				
Urban Popn	-0.027	0.321	-0.002	0.130
NSA	2.828	0.270	0.307	0.057
Constant	23.503	0.263	-0.788	0.425

Table 1.12. First Stage Regression Results for Population Growth (Equation 5 - for ΔNDVI)

	G_R coeff	G_R p-value	G_U coeff	G_U p-value	M_R coeff	M_R p-value	M_U coeff	M_U p-value
ENVIRONMENTAL VARIABLES								
NDVI	-0.276	0.103	-0.262	0.398	0.263	0.41	-0.147	0.752
LAGΔNDVI	0.476	0.286	0.883	0.33	-0.918	0.114	-1.92	0.155
RAIN DEV(+)	-0.003	0.738	0.035	0.061	-0.001	0.937	-0.016	0.617
RAIN DEV(-)	-0.015	0.22	-0.048	0.027	0.025	0.25	-0.02	0.638
RAINFALL	-0.072	0	0.116	0.011	-0.052	0.073	0.114	0.169
RURAL SOCIO-ECONOMIC VARIABLES								
CONSEXP	-0.024	0.101	-0.016	0.686	0.034	0.226	-0.077	0.303
POPN DENS	-0.027	0.005	-0.041	0.127	0.028	0.074	0.076	0.018
DEATH RATE	6.908	0	-5.39	0	-8.244	0	4.669	0.255
FEM LIT	14.349	0.008	-15.388	0.138	-15.357	0.104	38.13	0.079
MALE LIT	14.729	0.012	-14.385	0.186	-15.965	0.114	40.279	0.086
TOTAL LIT	-28.161	0.012	31.064	0.145	29.768	0.127	-78.986	0.081
SEX RATIO	-0.204	0.029	0.067	0.674	0.282	0.085	-0.54	0.096
FEM WORK	-0.196	0.157	-0.058	0.837	-0.213	0.326	1.145	0.042
TRIBALS	0.123	0.313	0.228	0.482	-0.883	0.001	0.704	0.113
INF DEATH	0.089	0.397	0.062	0.819	-0.091	0.575	-0.028	0.945
AHS	23.384	0	11.979	0.103	-23.82	0.003	-17.435	0.22
MUSLIMS	0.509	0.038	0.56	0.347	-1.077	0.005	0.477	0.528
LIFE EXP	3.566	0	0.805	0.671	-4.861	0.001	0.027	0.993

Table 1.12 (contd...)

	G_R coeff	G_R p-value	G_U coeff	G_U p-value	M_R coeff	M_R p-value	M_U coeff	M_U p-value
URBAN SOCIO-ECONOMIC VARIABLES								
CONSEXP	0.006	0.585	0.012	0.664	-0.035	0.063	0.055	0.235
POPN DENS	0	0.979	0.001	0.362	0	0.76	-0.002	0.183
DEATH RATE	2.163	0.003	10.712	0	-4.787	0.001	-1.469	0.748
FEM LIT	18.105	0.021	32.261	0.028	-21.56	0.127	-27.304	0.265
MALE LIT	20.083	0.024	34.863	0.034	-25.785	0.107	-30.055	0.283
TOTAL LIT	-38.768	0.02	-66.078	0.032	49.231	0.1	54.45	0.295
SEX RATIO	-0.208	0.009	-0.271	0.07	0.285	0.047	0.149	0.553
FEM WORK	-0.907	0.032	-2.262	0.011	1.092	0.087	2.204	0.108
TRIBALS	-0.189	0.683	-1.146	0.287	2.325	0.013	-1.516	0.429
INF DEATH	0.036	0.705	-1.013	0	0.117	0.57	0.989	0.003
AHS	-13.413	0.01	-26.585	0.004	21.907	0.079	47.451	0.007
MUSLIMS	-0.275	0.215	0.949	0.04	0.647	0.082	-2.148	0.009
LIFE EXP	-3.035	0	-0.564	0.749	3.995	0.002	0.081	0.977
OTHER VARIABLES								
URBAN POPN	-0.034	0.745	-1.345	0	-0.478	0.001	1.399	0
NSA	-9.578	0.326	-25.699	0.271	0.934	0.965	1.053	0.976
CONSTANT	387.462	0	236.382	0.197	-484.384	0.004	347.091	0.259

Table 1.13. First Stage Regression Results for Population Growth (Equation 5 - for Δz-NDVI)

	G_R coeff	G_R p-value	G_U coeff	G_U p-value	M_R coeff	M_R p-value	M_U coeff	M_U p-value
ENVIRONMENTAL VARIABLES								
z-NDVI	1.467	0.570	0.503	0.912	-4.352	0.434	6.559	0.407
LagΔz-NDVI	2.589	0.049	1.820	0.456	-3.072	0.118	4.100	0.358
Rain Dev(+)	-0.006	0.462	0.031	0.088	0.009	0.498	-0.016	0.620
Rain Dev(-)	-0.014	0.179	-0.050	0.020	0.023	0.295	-0.004	0.930
Rainfall	-0.066	0.000	0.119	0.008	-0.065	0.035	0.137	0.098
RURAL SOCIO-ECONOMIC VARIABLES								
ConsExp	-0.028	0.048	-0.019	0.642	0.034	0.241	-0.081	0.277
Popn Dens	-0.025	0.005	-0.040	0.119	0.029	0.065	0.080	0.019
Death Rate	6.935	0.000	-5.519	0.000	-8.409	0.000	5.608	0.168
Fem Lit	12.469	0.019	-15.712	0.142	-17.241	0.057	33.359	0.106
Male Lit	12.977	0.023	-14.518	0.196	-18.256	0.061	35.416	0.110
Total Lit	-24.605	0.026	31.446	0.152	34.122	0.069	-69.446	0.105
Sex Ratio	-0.181	0.047	0.069	0.671	0.314	0.048	-0.475	0.129
Fem Work	-0.231	0.101	-0.093	0.735	-0.114	0.598	1.092	0.051
Tribals	0.101	0.438	0.231	0.500	-0.825	0.001	0.543	0.239
Inf Death	0.041	0.713	0.030	0.911	-0.022	0.902	-0.130	0.754
AHS	0.369	0.119	0.420	0.506	-0.964	0.011	0.511	0.528
Muslims	22.669	0.000	10.917	0.122	-23.027	0.005	-15.270	0.278
Life Exp	3.691	0.000	1.185	0.530	-5.411	0.000	-1.006	0.762

Table 1.13 (contd...)

	G_R		G_U		M_R		M_U	
	coeff	p-value	coeff	p-value	coeff	p-value	coeff	p-value
URBAN SOCIO-ECONOMIC VARIABLES								
ConsExp	0.008	0.496	0.012	0.694	-0.036	0.073	0.066	0.175
Popn Dens	0.000	0.858	0.001	0.337	0.000	0.621	-0.002	0.175
Death Rate	1.913	0.008	10.638	0.000	-4.615	0.001	-2.293	0.595
Fem Lit	21.122	0.006	33.501	0.027	-20.516	0.177	-21.319	0.399
Male Lit	23.593	0.007	36.554	0.031	-25.108	0.139	-23.964	0.406
Total Lit	-45.125	0.006	-68.796	0.031	47.196	0.140	42.242	0.432
Sex Ratio	-0.236	0.003	-0.283	0.066	0.273	0.074	0.096	0.713
Fem Work	-0.766	0.083	-2.162	0.013	0.882	0.187	2.453	0.083
Tribals	-0.083	0.847	-0.995	0.348	2.013	0.027	-1.600	0.405
Inf Death	0.052	0.609	-0.998	0.000	0.112	0.609	0.984	0.002
AHS	-13.004	0.012	-25.870	0.005	20.177	0.094	46.929	0.008
Muslims	-0.130	0.532	1.081	0.023	0.484	0.181	-2.088	0.011
Life Exp	-3.177	0.000	-0.937	0.593	4.532	0.000	1.020	0.729
OTHER VARIABLES								
Urban Popn	-0.051	0.634	-1.348	0.000	-0.486	0.001	1.350	0.000
NSA	-3.981	0.662	-18.041	0.411	-6.672	0.727	-8.226	0.805
Constant	333.906	0.000	187.913	0.262	-437.672	0.002	313.929	0.2

CHAPTER 2. DOES POVERTY AGGRAVATE ENVIRONMENTAL DEGRADATION IN RURAL INDIA?

2.1. Introduction

The literature on the relationship between economic development and environmental change that emerged in the decade of 1990's has predominantly focused on the Environmental Kuznets Curve (EKC) hypothesis. EKC argues that in the initial phase of the development process, economic growth is associated with rising environmental degradation. After a certain level of economic growth is achieved, the demand of environmental conservation (environmental amenities) forces technological adoption and institutional changes that brings about environmental improvement. This hypothesis is depicted by an inverted U shaped relationship between environmental degradation and economic growth (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 2000). The empirical EKC literature has exclusively used per capita GDP to represent economic development. As a result, it abstracts away from the fact that income distribution has an important role to play in the economic development process (Kuznets, 1955) and hence in influencing the environmental change as well.

There is a relatively small literature that has focused on one aspect of income distribution, poverty, and its relationship with environmental change. Poverty is a pervasive development issue, hence it is important to understand the relationship between poverty and the ever increasing global concern, environmental change. The foundation of this literature is based on the well-established phenomenon that the rural poor in developing countries rely heavily on local natural resources for their sustenance (Cavendish, 2000; Jodha, 2000; Shiva & Verma, 2002; Escobal and Aldana, 2003; Narain, Gupta & Veld, 2005). Due to weak property rights, which includes open access or inefficient common property right regimes as well as poorly enforced regulations for public or government resources, the rural poor often overexploit natural resources like the forests, pastures, water (Jodha, 2000). Animals like sheep or goats that act as capital resource for the rural poor degrade the vegetation and soil faster than the livestock of the richer rural population like buffaloes (Rao, 1994). Cultivable land degrades quickly due to lack of investment for maintaining the soil quality that erodes the soil fertility (Reardon and Vosti, 1995). It indicates that due to limited access to credit, insurance and capital markets, the rural poor often fail to invest in resource conserving technologies (Dasgupta and Mäler, 1994). This has led to the formation of a predominant view in the literature that rural poverty is detrimental for environment (Duraiappah, 1998).

Due to the heavy reliance of the rural poor on natural resources, it is expected that change in the availability of natural resources will affect rural poverty. Since these natural resources constitute the rural natural environment and the components of this natural environment are not just amenities, rather necessary inputs for the rural households in the developing world, hence environmental degradation imply shrinking input base for the poor households. Thus environmental degradation spurred by rural poverty can in turn increase the severity of poverty (Mink, 1993; Jodha, 2000). This can result in a persistent negative cyclical relationship between rural poverty and environmental degradation, which is commonly referred to as the poverty-environment nexus (Nelson and Chomitz, 2004; Dasgupta et al. 2005, Duraiappah, 1998). Hence it implies that rural poverty and environmental change are jointly endogenous.

In spite of the assertion of existence of such a nexus, the existing empirical studies have rarely[13] estimated the impact of direct measures of poverty on environmental change and none have accounted for the endogeneity in the poverty-environment relationship implied by the poverty-environment nexus hypothesis. Studies (like Bahamondes, 2003, on Chile; Swinton and Quiroz, 2003, and Escobal and Aldana, 2003, on Peru) have analyzed the impact of household characteristics (like access to capital, alternative employment opportunities and education which the poor usually lack) on sustainable resource management practices, thereby providing indirect evidence about the impact of poverty on environment. Other studies (like Dasgupta et al., 2005, on Cambodia, Lao-PDR and Vietnam; and Nelson and Chomitz, 2004, on Guatemala and Honduras) have focused on spatial correlations to establish the relationship between poverty and environment.

This study attempts to advance the understanding of the poverty-environment relationship by estimating the impact of rural poverty[14] on a specific aspect of environment[15], vegetation. This is the first study that estimates the effect of change in intensity of rural poverty on vegetation change. It is also the first one to account for the endogeneity of rural poverty change. In addition, this study accounts for the effect of the

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[13] Dasgupta et al. (2005) is the only study that directly estimates the effect of poverty (number of poor per unit of forest cover area) on environmental change (deforestation) using district level data from Cambodia. They did not find any significant effect of poverty on deforestation.
[14] Several alternative measures of poverty have been used in the literature. Two alternative measures have been used in this study – poverty gap index and squared poverty gap in this analysis. See the data section for details.

entire spectrum of initial income distribution on environmental change. The analysis is conducted using cross-section data from South, West and Central India. Satellite image based "vegetation" indices are used to measure environmental health, which implicitly capture both forest and overall biomass resources in India's rural environment[16].

2.2. Data

India is an interesting case for the purpose of this study as it is the second most populated country in the world, with a population over a billion that is growing at the rate of 1.5 percent per annum (World Development Indicators, 2003), and approximately 72 percent of the population resides in rural areas (Census of India, 2001). Despite the presence of several government poverty alleviation programs with specific focus on rural areas like Integrated Rural Development Programme (IRDP), Training of Rural Youth for Self-Employment (TRYSEM), National Rural Employment Programme (NREP), Rural Landless Employment Guarantee Programme, Jawahar Rojgar Yojana (JRY), rural poverty continues to be one of the predominant problems. According to official estimates, the national head count index of poverty[17] was approximately 23 percent and rural head count index was 27 percent in 1999-2000. In the light of the fact that rural population, especially rural poor, rely heavily on natural resources, as is depicted by studies like Rao (1994); Jodha (2000); Narain,Gupta and Veld (2006), it is important for environmental policy makers to account for impact of rural poverty on environmental change. Policy

[15] Environment is a very broad term that is defined as the conditions and circumstances that surround and affect the development of organisms (Maler, 1997).

[16]Only rural poverty has been included in this analysis as rural poor are heavily dependent on the measure of environment - vegetation. The urban poor have stronger links with other aspects of environment like air and water (Satterthwaite 2003). The terms environment and vegetation have been used interchangeably in this study.

[17] Head count index represents the percentage of people below poverty line in total population.

initiative like Joint Forest Management (JFM), which is aimed to reduce rural poverty while improving environmental quality by providing formal common property rights of forest resources to the local villages close to the forests, reflects the recognition of the need to address the issues of rural poverty and environmental conservation in a unified framework. Hence the systematic estimation of the impact of poverty change on environmental change in rural India while accounting for the endogeneity in the relationship can provide important policy inputs for sustainable development.

The study uses district level data from 172 districts of the study region. As mentioned in chapter 1, the study region exhibits enormous variation in climatic as well as socio-economic conditions. This study analyzes the impact of rural poverty change on vegetation change over the period 1994-2001. The vegetation measures that represent environmental quality are described in chapter 1 as well as Appendix B. The consumption expenditure data from National Sample Survey of India has been used to construct district level rural and urban per-capita consumption expenditure, income inequality and poverty measures. The consumption expenditure data from NSS 51st and 56th rounds (corresponding to 1994-95 and 2000-01 respectively) has been used for this purpose that depicts the time frame over which the changes in the variables of interest of this study have been measured.

The analysis has used two alternative measures of poverty, Poverty gap index and Squared Poverty Gap Index, which represent the severity of poverty. Gini coefficient has been used to represent income inequality in the initial rural income distribution. Details on the sources and construction of the income distribution measures are provided below.

Income Distribution. Due to unavailability of direct district-level measures of income in India, district level rural and urban consumption expenditure data have been used to proxy for income. National Sample Survey of India has been conducting random household sample surveys for a long time. But publication of district wise household survey data on consumption expenditure started from 51st round (1994-95) onwards. Hence the initial period of this study is 1994-95. The consumption expenditure data from NSS 51st and 56th rounds (corresponding to 1994-95 and 2000-01 respectively) have been used to construct district level rural and urban per-capita consumption expenditure, income inequality and poverty measures.

Poverty. In the context of environmental degradation, poverty can be defined in two ways – welfare poverty and investment poverty (Reardon and Vosti, 1995). Welfare poverty is the traditional definition of poverty accounting for people below a 'poverty line'. Poverty line is a benchmark level of income, usually defined by government, that is expected to enable a person to procure the basic basket of commodities needed for sustaining human life. The official poverty lines are presented in Table 2.3. The table highlights significant difference in the cost of living not only across districts as well as across rural and urban areas, which is indicative of the difference in economic progress across space. Investment poverty goes one step further. It accounts for people who do not have adequate assets to invest in sustaining the environment as this definition considers sustainability of environment as one of the basic requirements for human sustenance. Since only consumption expenditure data is available, investment poverty cannot be captured in this study. There are several measures of the traditional welfare poverty:

Head count index, Poverty gap index, Squared Poverty Gap Index. These measures are called Foster-Greer-Thorbecke (FGT) class of poverty measures:

$$Y_a = \sum_{(y_i < p)} [(p - y_i) / p]^a / n$$

where,Y is the measure of poverty, y_i is the consumption of the i^{th} household, p is the poverty line, n is the population size, α is a non-negative parameter. If α = 0, Y gives the Head Count Index (the percentage of people who fall below the poverty line in a population is known as the headcount index). If α = 1, Y gives the Poverty Gap Index. Poverty gap index is the mean distance below the poverty line as a proportion of the poverty line where the mean is taken over the whole population, counting the non-poor as having zero poverty gap. That is the mean shortfall from the poverty line (counting the non-poor as having zero shortfall), expressed as a percentage of the poverty line (United Nations Statistics Department). If α = 2, Y gives the Sqaured Poverty Gap (SPG) index.

The basic needs of people can vary across location and time. To set up a standard benchmark for measuring poverty, the governments define poverty lines. People with income below the poverty line are counted as poor. In India the poverty lines are defined to capture rural-urban and inter-state differentials in cost of living. Hence the most disaggregated poverty lines that are defined by the government are available are at state level classified by rural and urban areas. The official poverty lines are presented in Table 2.3. Though the cost of living can vary across districts within a state, due to lack of data availability, the state level rural poverty lines have been used for constructing the district level rural poverty measures. The poverty lines used for constructing the poverty measures of this study are twice the actual government specified poverty lines. The official poverty lines are too low as they are constructed to depict the minimum expenditure required for bare survival. Poverty lines are usually kept as low as possible to project better performance of the government in controlling poverty. Hence people just above the official poverty line live in absolute poverty as well. In the construction of the poverty indices, using the official poverty line will put zero weight to the people barely above the poverty line, which is not desirable. The poverty line was modified for constructing the poverty indices to reduce this undesirable effect of official poverty line. This modification is very subjective, as one could have used any other scaling factor instead of 2. Another poverty line scaled up by 1.5 times the official poverty line was also tried. The results were qualitatively similar. Since the objective of this is to analyze the impact of vegetation change on change in the severity of poverty, the poverty gap index and the squared poverty gap are used in the analysis as these provide better measure of the severity of poverty than the head count index (Ravallion and Dutt, 1996 and 1999; Jha, 2001).

Income Inequality. The most commonly used measure of inequality is *Gini* coefficient. It is derived from the Lorenz curve. Lorenz curve, l=l(y), plots the relationship between cumulative proportion of income receivers, y, and the corresponding cumulative proportion of income. Gini coefficient is defined as: $G = 1 - 2 \int_0^1 l(y)\, dy$, where G lies in the range (0,1). Higher values of G indicate higher inequality. G=1 implies perfect inequality i.e. all income is received by one person and G=0 indicates perfect equality. This study uses a commonly used formula for estimating the Gini coefficients called the Pyatt et al. (1980) formula: $G = 2\ \mathrm{Cov}(y, r_y) / (n\ y_m)$ where, Cov (y, r_y) is the covariance between income, y, and the ranks of income (in ascending order) recipients, r_y; ym denotes the mean income and n is the population size (Abounoori and McCloughan 2003).

Due to limited data availability, the socio-economic variables from the year 1991 represent the heterogeneity in initial socio-economic conditions across the districts. The only exception is the population growth rate that represents the population growth over the period 1991-1994[18]. Table 2.1 describes the variables used in this study. Table 2.2 provides summary statistics for these variables.

2.3. Hypotheses

Despite the dominant view in the literature that poverty causes environmental degradation, there are some contradicting empirical evidences. Some studies have shown that traditional communities have managed the resources efficiently despite their poverty (Tiffen, Mortimore & Gichuki, 1994) while others have shown that it is not the poor but the non-poor population that deplete the rural environment (Swinton and Quiroz, 2003; Ravnborg, 2003). Hence the effect of poverty on environment is an empirically testable issue. This study tests the dominant view in the literature:

Hypothesis 1. Increase in the intensity of rural poverty aggravates environmental degradation.

This study also contributes to the literature by analyzing the effect of entire spectrum of the initial rural income distribution on environmental change. Since India is

[18] Population growth can affect and get affected by environmental change, as is depicted by the analysis in chapter 1. However in this case, the population growth rate (1991-94) is lagged with respect to this study's

still a developing country, based on the Environmental Kuznets Curve (EKC) literature that predicts a U shaped relationship between environmental quality and per capita income, one would expect the country and especially the rural areas to be in the early phase of the curve which would imply a negative effect of higher rural per capita income on environmental quality. This leads us to the next hypothesis:

Hypothesis 2: Higher initial rural per capita consumption expenditure leads to environmental improvement.

The impact of rural poverty on environment has been analyzed in the literature mostly by descriptive and empirical studies. Ikefuji and Horii (2005) is the only study that provides a formal (dynamic mathematical) model to depict the poverty – environment trap. They show that the income distribution plays a crucial role in shaping the poverty-environment relationship. The most interesting result of this study is that increase in the wealth of the richest segment of the rural population can improve the environment. The result is based on the argument that increase in the ability of the rural elite to invest in resource conserving technological and institutional changes can help in resource conservation and through trickle down effect can reduce poverty as well. This provides the next hypothesis of this study.

Hypothesis 3. Higher rural income inequality leads to environmental improvement.

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time frame (1994-2001). Hence, one can treat it as exogenous with respect to measure of environmental change used here.

2.4. Empirical Estimation Strategy

In order to empirically test the hypotheses stated above, the following linear regression is employed:

$$\Delta E_{1994\text{-}95 \text{ to } 2000\text{-}01} = \alpha + \beta \ \Delta P_{1994\text{-}95 \text{ to } 2000\text{-}01} + \gamma X + \varepsilon$$

where, ΔE: change in environmental quality, ΔP: change in poverty index, X: exogenous explanatory variables (see table 2.4).

Two alternative measures of environmental quality have been used here – overall vegetation represented by NDVI and high quality vegetation (approximating the measure for forests) represented by z-NDVI. The analysis also uses two alternative measures of poverty – poverty gap index (PGI) and squared poverty gap (SPG). The use of poverty measures that account for the intensity of poverty rather than the simple head count index is important for the purpose of this analysis. It is not just the number of poor people in the rural areas that drive the resource exploitation; the intensity of the rural poverty plays an equally crucial role as reduction in intensity of poverty, holding constant the number of 'poor' people below the poverty line can ease the need for exploiting the vegetative resources and vice versa. Hence using just the head count index of poverty, one would miss out the costs or benefits of intervening factors that increase or reduce the severity of rural poverty even if the number of poor people do not change significantly.

The primary objective of this study is to estimate the impact of rural poverty on vegetation change while accounting for the fact that poverty and environment evolve together. In order to capture the dynamics of the relationship using cross sectional variations, the variables of main interest, vegetation and poverty have been used in form of changes rather than levels. The heterogeneity across districts, reflected in the summary statistics in Table 2.2, help in estimating the effect of poverty change on environmental change using cross-sectional data. Both the level of poverty and the change in poverty have been included to assess the impact of poverty on vegetation change. Two alternative measures of vegetation and poverty have been used to test the robustness of the estimations. Due to limited data availability, the socio-economic variables are at 1991 levels that depict the initial socio-economic conditions of the districts[19].

Beyond the impact of change in poverty, environmental change is expected to be influenced by climatic factors, demographic factors, income distribution, land use pattern and other socio-economic factors represented by 'X' in the model above. Initial vegetation (1994-95) and average rainfall (1994-2000) represent the climatic factors. Rural population growth rate (1991-94) and rural population density (1991) represent the rural demographic factors. Rural per capita consumption expenditure (1994-95), initial rural poverty (1994-95) and rural Gini-coefficient (1994-95) represent the rural income distribution. Proportion of area under agriculture represented by proportion of net sown area indicates initial land use pattern. Rural literacy rate (1991), rural sex ratio (1991) and rural female work force participation rate (1991) are the social indicators that can affect environmental change. Literacy rate is an indicator of general education and awareness about the importance of environment. Higher sex ratio (female to male) and lower female work force participation rate represent greater availability of female labor for resource extraction. The extent of urbanization of a district can affect the

[19] Banerjee and Somanathan (2005) and Chopra and Gulati (1997) use similar empirical model in their study i.e.

environmental change. These are captured by proportion of urban population (1991), urban population growth rate (1991-94), urban population density (1991) and urban per capita consumption expenditure (1994-95). The level of initial poverty represents the history prior to 1994. Hence initial poverty level is treated as an exogenous variable. However the change in poverty (1994-95 to 2000-01) is contemporaneous with respect to environmental change and hence it is treated as an endogenous variable that is identified by the socio-economic variables described below.

Identification Strategy: The analysis seeks to identify poverty change using the district level rural infant death rate (1991) as the identifying instrument. Infant death rate is widely used as a health indicator (inversely related with health outcome) in the demography literature. As a health indicator, it is expected to explain average productivity and poverty variations across rural areas of the districts as poor health conditions are expected to negatively affect productivity and thus associated with higher poverty. Hence infant death rate is expected to be positively associated with change in rural poverty. One may argue that poverty is an important cause of infant mortality. Since the model controls for the initial level of poverty, the rural infant death rate represents other factors over and above the initial rural poverty that can explain the heterogeneity in health conditions across districts, which affects the subsequent poverty change.

Following standard practice (Bound, et al., 1995), the instrument's strength is assessed from its performance in a first stage regression of poverty change on all exogenous variables in the model. As reported in Table 2.5, the instrument performs well

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dependent variable is in form of change and explanatory variables are at levels and changes.

in these regressions as it has the expected sign (positive coefficients) and is statistically significant. The first stage F statistic for the instrument lies between 9.45 and 11.61 for the model specifications with alternative measures of vegetation and rural poverty[20].

The second requirement for the instrument is to be exogenous with respect to the dependent variable, vegetation change. At a first glance, one might conjecture environmental degradation can potentially increase infant death rates. However, the instrument, infant death rate, corresponds to the year 1991 and the dependent variable, vegetation change is measured over the period 1994 to 2001. Hence due to the lagged time frame of the measure of instrument, vegetation change (1994-2001) could not have any possible affect on infant death rate in 1991. In principle, rural infant death rate can affect rural population growth, which in turn can affect vegetation change. However, the likely channel through which such effects may manifest themselves i.e. population growth rate (1991-94) in the rural sector is controlled for. One may also argue that infant death rate, which is used as a health indicator, might affect environmental change as healthier people who live longer are likely to generate higher demand better environmental conservation. To counter this argument the model controls for the life expectancy at birth (1991) that accounts for the channel through which such effect can occur. Hence controlling for all the potential channels that can indirectly link infant death rate with environmental change, one can argue that infant death rate (1991) is exogenous with respect to vegetation change (1994-2001).

[20] The inverse of the F statistic represents the weak instruments bias. In this case the weak instrument bias bias is approximately 10 percent or less, which is a well-accepted benchmark level of bias.

To account for the endogeneity of poverty, the empirical model has been estimated by two-step generalized method of moments (GMM) estimation procedure[21] that yields consistent estimates of the coefficients as well as the standard errors of the coefficients.

2.5. Results

Table 2.6 and 2.7 present the NDVI change and z-NDVI (high quality vegetation index) change regression results respectively. These tables present both the OLS and the GMM estimates.

The main finding of the analysis is that rural poverty negatively affects environmental quality. Rural poverty change (1994-95 to 2000-01) as well as the initial level of poverty (1994-95) has statistically significant negative effect on the environmental quality change (1994-95 to 2000-01) in all the model specifications. The result is robust for the different measures of poverty as well as environmental quality. The elasticity of environmental change (ΔNDVI and Δz-NDVI change) with respect to poverty change (ΔPGI and ΔSPG) measured at measured at initial sample ranges of vegetation and rural poverty, as depicted in table 2.8 ranges between -0.16 and -0.29. Hence very strong evidence is found in support of hypothesis 1 that rural poverty aggravates vegetation degradation.

It is also worth noting that the GMM estimates for poverty change coefficients are much larger in magnitude than the OLS estimates, though both have the same negative signs. Under the poverty-nexus hypothesis, the OLS estimates are expected to be more

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[21] The 'ivereg2' procedure in STATA was used for this purpose.

negative relative to GMM estimates, which are contradicted by the results. This contradiction can arise due to two reasons. First is an econometric reason, as instrumental variables not only accounts for endogeneity, they also account for measurement errors. In this case the measurement error correction effect of the instrumental variable for rural poverty can lead to the observed effect. The second reason can be the assumption of poverty-environment nexus hypothesis. It was found that increase in rural poverty has negative effect on vegetation change; thereby it validates one side of the nexus hypothesis. However, the other direction of the hypothesis might not hold in reality i.e. environmental improvement might have no effect or the opposite (positive) effect on rural poverty change and hence the nexus might not exist. Chapter 3 provides evidence, which indicates that environmental improvement can come at the cost of increasing rural poverty. Hence it demonstrates that treatment of poverty as an exogenous variable explaining environmental change provides upward biased estimates in this case. Thus it implies that accounting for endogeneity is crucial in estimating the effect of rural poverty on environment.

The estimation also depicts that the initial income distribution has significant impact of environmental change. Rural per capita consumption expenditure negatively affects environmental quality, which provides evidence in support of Hypothesis 2 based on the predictions of the Environmental Kuznets Curve (EKC) literature. This result is also robust to model specifications. It indicates that districts with higher initial rural per capita consumption expenditure (proxy for per capita income) experienced more environmental degradation. It can be reflecting the fact that India is still a developing country and hence higher income is associated with higher demand for resource extraction.

The results also imply that higher rural income inequality improves high quality vegetation as is indicated by the positive effect of rural Gini coefficient. It provides evidence in support of Hypothesis 3 based on the Ikefuji & Horii (2005) model prediction, which suggests that controlling for initial average income and poverty, higher initial income inequality implies that the richest segment of rural population has more investment capacity that can be invested for environmental improvement (through adoption of environmentally sustainable technologies or through political influence for demand for environmental conservation).

It is worth noting that rural poverty aggravates vegetation degradation not only by over extraction but also due to lack of investment ability to maintain the natural resources, referred to as investment poverty by Reardon & Vosti (1995). Hence income inequality can be helpful in environmental improvement if it helps is spreading the use of environmentally sustainable technologies.

The above results imply that income distribution plays a crucial role in shaping the trajectory of environmental quality. Hence the empirical studies analyzing the impact of economic growth on environmental quality, predominantly represented by the Environmental Kuznets Curve literature[22], that typically use per capita income to represent economic growth should also take into account effect of the income distribution measures on environmental quality.

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[22] see for example Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), Panayotou, 2000

The results also bring forward an interesting phenomenon, which implies that lower initial environmental quality spurs environmental improvement. Significant negative effect of initial environmental quality (for both types of environmental quality measures) indicates prior lower initial environmental quality generates subsequent environmental improvement. The positive effect of net sown area (higher net sown area is reflection of scarcity of high quality vegetation like forests) on z-NDVI change further strengthens the conclusion that prior environmental degradation is offset, to some extent, by subsequent environmental improvement. This provides support to the Boserupian school of thought (Boserup, 1965; Kahn, Brown and Martel, 1976; Simon, 1996), which argues that resource scarcity generates demand for resource conservation and thereby results in resource conserving institutional or technological innovations. Micro-data on institutional changes (property rights) and adoption of new technologies can shed light on the mechanism through which this effect comes into being.

Although they are not the focus of this study, the estimation shows that socio-economic variables play an important role in influencing environmental change. Greater availability of rural female labor tends to worsen environmental decline. Higher rural sex (female to male) ratios and lower rural rates of female workforce participation, both of which imply a greater availability of female labor for resource gathering activities, have a statistically significant negative effect on environmental change. Higher proportion of urban population has negative effect on environmental quality. It indicates that urbanization has damaging effect of vegetation change. Literacy rate boosts high quality vegetation change. Literacy is a very crude measure of education. Yet it reflects that higher literacy can create awareness that can benefit the vegetation change. This is especially the case for high quality vegetation (z-NDVI change) that represents the forests.

2.6. Conclusions

This analysis, based on district level data from South, West and Central parts of rural India, is the first study to estimate the impact of rural poverty change on vegetation change while accounting for endogeneity of poverty. The results provide strong evidence in support of the hypothesis, in consonance with the dominant view in the literature, that rural poverty change negatively affects vegetation change. The estimates also highlight that lack of accounting of the endogeneity yields upwardly biased estimates contrary to the expectation formulated based on the existing poverty-environment nexus hypothesis. This result questions the validity of the poverty-environment nexus and calls for testing the other direction of the relationship, the effect of environmental change on rural poverty, which is done in the next chapter.

The results also reveal that initial income distribution plays a significant role in shaping subsequent vegetation change. While higher rural per capita consumption expenditure has negative effect on vegetation change; it is the higher initial rural income inequality that provides an interesting positive effect on high quality vegetation change. The ability of the skewed income distribution to help in environmental improvement is pointing towards the argument that environment friendly technological adoptions can be afforded only by rural elite and if the model assumptions of Ikefuji and Horii (2005) hold, the benefits of the technological adoption by the rural rich would trickle down to the rural poor as well. However if the benefits of the environmental improvement do not trickle down, it is likely to further aggravate the rural poverty.

The significant effect of income distribution on environmental quality points towards the limitation of the Environmental Kuznets Curve (EKC) literature that focuses only of the per capita income to analyze the effect of economic growth on environmental quality, thereby missing out the aspect of income growth that can be helpful in environmental improvement.

The estimations also indicate that initial lower environmental quality spurs subsequent environmental improvement and rural socio-economic features play a very important role in shaping the trajectory of vegetation, especially high quality that is the proxy for forests. Thus this study highlights the socio-economic factors affecting vegetation change in rural India that can provide useful inputs for policy formulations for environmentally sustainable development.

2.7. Tables

Table 2.1: Variables Definitions

Variable Name	Description
INCOME DISTRIBUTION VARIABLES	
ΔPGI (94-01)	Change in PGI from 1994-95 to 2000-01
Initial PGI(94)	Poverty gap index for 1994-95 (NSS round 51)
ΔSPG (94-01)	Change in SPG from 1994-95 to 2000-01
Initial SPG(94)	Squared poverty gap for 1994-95 (NSS round 51)
Initial GINI (94)	Gini coefficient for 1994-95 (NSS round 51)
Cons Exp(94)	Per capita average monthly consumption expenditure (1994-95) in Rupees
ENVIRONMENTAL VARIABLES	
ΔNDVI ch(94-01)	Change in average NDVI from 1994-95 to 2000-01
Δz-NDVI ch(94-01)	Change in z-NDVI from 1994-95 to 2000-01
Initial NDVI(94)	NDVI 1994-95
Lag ΔNDVI(91-94)	Change in average NDVI from 1990-91 to 1993-94
Initial z-NDVI(94)	z-NDVI 1995-95
Lag Δz-NDVI(91-94)	Change in average NDVI from 1990-91 to 1993-94
Net Sown Area(91)	Net sown area as a proportion of total district area (1991)
Rainfall(94-00)	Average rainfall in centimeters (1994 to 2000)
Rain Dev(+)(94-00)	Positive deviation in rainfall from the norm during 1994-2000
Rain Dev(-)(94-00)	Negative deviation in rainfall from the norm during 1994-2000
SOCIO-ECONOMIC VARIABLES	
Popn Grth Rt(91-94)	Births minus deaths (1991 to 1994) per thousand 1991 population
Popn Density(91)	Population per square kilometer in 1991
Urban Popn(91)	% of urban population in a district(1991)
Female Workers(91)	Females in workforce as percentage of working age female population (1991)
Sex Ratio(91)	Females per thousand male(1991)
Literacy Rate(91)	Literates per thousand population (1991)
Avg Hh Size(91)	Average household size(1991)
Inf Death Rate(91)	Infant deaths per thousand live births (1991)

Table 2.2. Summary Statistics

	Min	Max	Mean	Sdev
INCOME DISTRIBUTION VARIABLES (R – RURAL, U – URBAN)				
ΔPGI (94-01)	-0.18	0.33	0.06	0.10
Initial PGI (94)	0.04	0.46	0.22	0.08
ΔSPG (94-01)	-0.14	0.23	0.036	0.06
Initial SPG (94)	0.01	0.26	0.09	0.05
Initial GINI (94)	0.13	0.58	0.24	0.06
Cons Exp(R) (94)	204.26	864.63	356.35	92.52
Cons Exp(U) (94)	292.85	909.27	471.97	101.47
ENVIRONMENTAL VARIABLES				
ΔNDVI (94-01)	-18.99	8.5	-10.26	4.63
Δz-NDVI (94-01)	-1.41	0.72	-0.57	0.35
Initial NDVI (94)	139.63	198.8	174.16	11.51
Lag ΔNDVI (91-94)	-1.57	13.28	5.57	2.49
Initial z-NDVI (94)	-5.20	1.68	-0.19	0.97
Lag Δz-NDVI (91-94)	-0.24	2.89	0.47	0.35
Net Sown Area (91)	0.05	0.83	0.51	0.16
Rainfall(94-00)	113.17	84.47	27.89	346.51
Rain Dev (+)(94-00)	1096.5	12967.6	4671.8	2741.1
Rain Dev (-)(94-00)	-13873.9	-1773.1	-4568.2	2326.4
SOCIO-ECONOMIC VARIABLES (R – RURAL, U – URBAN)				
Popn Grth Rt(R) (91-94)	-3.72	91.36	19.5	18.86
Popn Grth Rt(U) (91-94)	5.28	229.58	77.39	41.38
Popn Density(R) (91)	7	1236	223.23	190.67
Popn Density(U) (91)	0	27490	3015	2677
Urban Population(91)	3.41	86.16	24.79	14.32
Literacy Rate(R)(91)	13.74	95.67	46.60	17.92
Female Workers(R)(91)	2.18	58.82	28.16	13.36
Sex Ratio(R) (91)	786	1230	958.42	57.98
Avg Hh Size(R) (91)	3.74	7.07	5.39	0.71
Inf Death Rate(R)(91)	0.91	88.6	23.33	18.01

Table 2.3. Official Poverty Line (in Rupees)

	Rural (1993-94)	Urban (1993-94)	Rural (2000-01)	Urban (2000-01)
Andhra Pradesh	163.02	278.14	262.94	457.40
Gujarat	202.11	297.22	318.94	474.41
Karnataka	186.63	302.89	309.59	511.44
Kerala	243.84	280.54	374.79	477.06
Madhya Pradesh	193.1	317.16	311.34	481.65
Maharashtra	194.94	328.56	318.63	539.71
Rajasthan	215.89	280.85	344.03	465.92
Tamil Nadu	196.53	296.63	307.64	475.60
India	205.84	281.35	327.56	454.11

Table 2.4. Model Structure

Explanatory variables (X)
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)
Per Capita Cons Exp(R & U)(94)
Initial PGI or SPG(R)(94)
Initial Gini(R)(94)
ENVIRONMENTAL VARIABLES
Initial NDVI (94) or Initial z-NDVI (94)
Lag ΔNDVI (91-94) or Lag Δz-NDVI (91-94)
Net Sown Area(91)
Rainfall (94-00)
Rain Dev(+)(94-00)
Rain Dev(-)(94-00)
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)
Popn Grth Rt(R & U)(91-94)
Popn Density(R & U)(91)
Urban Population(%)(91)
Literacy Rate(R)(91)
Female Workers(R)(91)
Sex Ratio(R)(91)
Life Expectancy(R)(91)
Avg Hh Size(R)(91)

Table 2.5. First Stage Results and Test for Instrument Strength

	ΔPGI		ΔSPG		ΔPGI		ΔSPG	
	Coeff	p-value	coeff	p-value	coeff	p-value	coeff	p-value
ENVIRONMENTAL VARIABLES								
Initial NDVI(94)	-0.001	0.534	0.000	0.862				
Lag ΔNDVI(91-94)	0.004	0.277	0.002	0.312				
Initial z-NDVI(94)					0.006	0.490	0.005	0.343
Lag Δz-NDVI(91-94)					0.047	0.088	0.026	0.117
Net Sown Area(91)	-0.115	0.045	-0.076	0.040	-0.107	0.024	-0.074	0.019
Rainfall(94-00)	0.0001	0.317	7.9e-05	0.382	0.0001	0.303	7.2e-05	0.394
Rain Dev (+)(94-00)	6.2e-05	0.049	4.3e-05	0.038	6.4e-05	0.038	4.4e-05	0.029
Rain Dev (-)(94-00)	-2.1e-06	0.949	3.6e-06	0.860	-2.4e-06	0.939	2.9e-06	0.886
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)								
Initial PGI(94)	-0.916	0.000			-0.948	0.000		
Initial SPG(94)			-0.941	0.000			-0.972	0.000
Cons exp (R)(94)	-0.015	0.324	-0.012	0.219	-0.017	0.262	-0.013	0.170
Cons exp (U)(94)	-0.005	0.464	-0.002	0.596	-0.005	0.458	-0.002	0.587
Initial Gini(94)	0.232	0.184	0.172	0.172	0.244	0.154	0.182	0.143

Table 2.5 (contd...)

	ΔPGI		ΔSPG		ΔPGI		ΔSPG	
	Coeff	p-value	coeff	p-value	coeff	p-value	coeff	p-value
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)								
Popn Grth Rt(R)(91-94)	0.001	0.098	0.000	0.092	0.001	0.105	0.000	0.098
Popn Grth Rt(U)(91-94)	0.000	0.117	0.000	0.104	0.000	0.179	0.000	0.152
Popn density (R)(91)	0.009	0.841	0.011	0.704	-0.002	0.961	0.005	0.847
Popn density (U)(91)	-0.001	0.650	-0.001	0.685	-0.001	0.640	-0.001	0.678
Urban popn (91)	-0.001	0.016	-0.001	0.043	-0.001	0.045	-0.001	0.094
Literacy rate (R)(91)	0.000	0.853	0.000	0.803	0.000	0.968	0.000	0.927
Female workers(R)(91)	0.002	0.011	0.001	0.008	0.002	0.016	0.001	0.012
Sex ratio(R)(91)	0.000	0.486	0.000	0.753	0.000	0.707	0.000	0.992
Life Expectancy(R)(91)	-0.004	0.000	-0.003	0.001	-0.004	0.000	-0.003	0.000
Avg Hh size (R)(91)	0.042	0.006	0.025	0.014	0.046	0.002	0.027	0.005
Inf death rt (R)(91)	0.002	0.003	0.001	0.002	0.002	0.001	0.001	0.001
Constant	0.426	0.141	0.158	0.382	0.273	0.141	0.107	0.358
F Statistic for instrumental variable (Infant Death Rate)	9.45	0.0025	9.52	0.0024	11.56	0.0009	11.61	0.0008

Table 2.6. NDVI change regressions

	Dependent Variable: ΔNDVI (94-01)			
	(1)	(2)	(3)	(4)
	OLS	GMM	OLS	GMM
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)				
ΔPGI(94-01)	-8.1732**	-41.4100**		
	(0.013)	(0.014)		
Initial PGI(94)	-20.1959***	-45.8505***		
	(0.001)	(0.001)		
ΔSPG(94-01)			-10.9133**	-61.5849**
			(0.032)	(0.018)
Initial SPG(94)			-29.6654***	-68.8247***
			(0.004)	(0.003)
Initial Gini(94)	5.1387	10.8185	5.4095	11.4849
	(0.464)	(0.217)	(0.464)	(0.220)
Cons exp (R)(94)	-2.3109***	-2.5023***	-2.1652***	-2.4331***
	(0.002)	(0.006)	(0.003)	(0.005)
Cons exp (U)(94)	-0.2141	-0.4403	-0.1941	-0.3769
	(0.496)	(0.247)	(0.540)	(0.315)
ENVIRONMENTAL VARIABLES				
Initial NDVI(94)	-0.2675***	-0.2601***	-0.2620***	-0.2420***
	(0.000)	(0.000)	(0.000)	(0.000)
Lagged ΔNDVI(91-94)	-0.2643**	-0.1074	-0.2582*	-0.1216
	(0.049)	(0.506)	(0.055)	(0.429)
Net Sown Area(91)	0.9062	-2.1681	0.9710	-2.0663
	(0.659)	(0.476)	(0.640)	(0.497)
Rainfall(1994-2000)	0.0344***	0.0438***	0.0331***	0.0421***
	(0.000)	(0.000)	(0.000)	(0.000)
Rain Deviation(+)(94-00)	0.001	0.003*	0.001	0.003
	(0.320)	(0.074)	(0.409)	(0.104)
Rain Deviation(-)(94-00)	0.005***	0.006***	0.005***	0.006***
	(0.000)	(0.000)	(0.001)	(0.000)

Table 2.6.(contd...)

	Dependent Variable: ΔNDVI (94-01)			
	(1)	(2)	(3)	(4)
	OLS	GMM	OLS	GMM
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)				
Popn Grth Rt(R)(91-94)	-0.0243	0.0114	-0.0227	0.0118
	(0.139)	(0.665)	(0.170)	(0.644)
Popn Grth Rt(U)(91-94)	-0.0016	-0.0174	-0.0013	-0.0180
	(0.858)	(0.171)	(0.886)	(0.176)
Popn density (R)(91)	2.8947	2.1045	2.9125	2.3304
	(0.188)	(0.476)	(0.189)	(0.430)
Popn density (U)(91)	-0.0064	-0.0177	0.0081	0.0035
	(0.954)	(0.877)	(0.942)	(0.972)
Urban popn(91)	-0.0345	-0.0804**	-0.0293	-0.0683**
	(0.132)	(0.026)	(0.202)	(0.049)
Literacy rate (R)(91)	0.0619**	0.0486	0.0609**	0.0483
	(0.041)	(0.173)	(0.046)	(0.161)
Female workers(R)(91)	0.0954***	0.1401***	0.0883***	0.1332***
	(0.001)	(0.003)	(0.003)	(0.005)
Sex ratio(R)(91)	-0.0112*	-0.0172**	-0.0109	-0.0146*
	(0.093)	(0.039)	(0.104)	(0.062)
Life Expectancy(R)(91)	0.0598	-0.0765	0.0669	-0.0742
	(0.165)	(0.344)	(0.124)	(0.382)
Avg hh size (R)(91)	-0.5600	0.6734	-0.7302	0.3842
	(0.349)	(0.532)	(0.219)	(0.717)
Constant	53.5233***	67.5749***	50.4589***	58.8140***
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	172	172	172	172
R-squared	0.600		0.593	

p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 2.7. z-NDVI change regressions

	Dependent Variable: Δz-NDVI (94-01)			
	(1)	(2)	(3)	(4)
	OLS	GMM	OLS	GMM
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)				
ΔPGI(94-01)	-0.5128**	-3.1064**		
	(0.047)	(0.012)		
Initial PGI(94)	-1.5060***	-3.5760***		
	(0.002)	(0.001)		
ΔSPG(94-01)			-0.5924	-4.4906**
			(0.138)	(0.014)
Initial SPG(94)			-2.3571***	-5.4415***
			(0.004)	(0.001)
Initial Gini(94)	0.9489*	1.4421**	1.0624*	1.5717**
	(0.088)	(0.041)	(0.070)	(0.033)
Cons exp (R)(94)	-0.2200***	-0.2433***	-0.2199***	-0.2462***
	(0.000)	(0.002)	(0.000)	(0.001)
Cons exp (U)(94)	-0.0390	-0.0551*	-0.0365	-0.0489*
	(0.112)	(0.060)	(0.138)	(0.083)
ENVIRONMENTAL VARIABLES				
Initial z-NDVI(1994)	-0.2530***	-0.2232***	-0.2514***	-0.2176***
	(0.000)	(0.000)	(0.000)	(0.000)
Lag Δz-NDVI(91-94)	-0.2089***	-0.1099	-0.2132***	-0.1341
	(0.006)	(0.414)	(0.005)	(0.297)
Net Sown Area(91)	0.3107*	0.0799	0.3163*	0.0774
	(0.054)	(0.740)	(0.051)	(0.754)
Rainfall(1994-2000)	0.0022***	0.0030***	0.0021***	0.0029***
	(0.000)	(0.000)	(0.000)	(0.000)
Rain Deviation(+)(94-00)	0.00002	0.0001	9.9e-06	0.0001
	(0.815)	(0.181)	(0.923)	(0.220)
Rain Deviation(-)(94-00)	0.0003***	0.0004***	0.0003***	0.0004***
	(0.004)	(0.001)	(0.006)	(0.000)

Table 2.7. (contd...)

	Dependent Variable: Δz-NDVI (1994-2001)			
	(1)	(2)	(3)	(4)
	OLS	GMM	OLS	GMM
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)				
Popn Grth Rt(R)(91-94)	-0.0013	0.0014	-0.0012	0.0014
	(0.296)	(0.437)	(0.336)	(0.414)
Popn Grth Rt(U)(91-94)	-0.0003	-0.0014	-0.0002	-0.0014
	(0.688)	(0.157)	(0.758)	(0.158)
Popn density (R)(91)	-0.0504	-0.1396	-0.0482	-0.1114
	(0.770)	(0.577)	(0.780)	(0.639)
Popn density (U)(91)	-0.0131	-0.0145	-0.0121	-0.0130
	(0.132)	(0.215)	(0.166)	(0.217)
Urban popn(91)	-0.0025	-0.0058**	-0.0021	-0.0049**
	(0.169)	(0.019)	(0.242)	(0.037)
Literacy rate (R)(91)	0.0068***	0.0055**	0.0068***	0.0058**
	(0.005)	(0.043)	(0.005)	(0.027)
Female workers(R)(91)	0.0115***	0.0149***	0.0109***	0.0143***
	(0.000)	(0.000)	(0.000)	(0.000)
Sex ratio(R)(91)	-0.0012**	-0.0016**	-0.0011**	-0.0014**
	(0.031)	(0.011)	(0.034)	(0.019)
Life Expectancy(R)(91)	0.0048	-0.0065	0.0054	-0.0060
	(0.163)	(0.293)	(0.117)	(0.341)
Avg hh size (R)(91)	0.0294	0.1365	0.0176	0.1110
	(0.528)	(0.115)	(0.702)	(0.179)
Constant	0.4834	1.6447**	0.3399	1.2433*
	(0.442)	(0.029)	(0.587)	(0.067)
Observations	172	172	172	172
R-squared	0.556		0.552	

p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 2.8. Elasticities measured at initial sample ranges

Dependent Variable:	ΔNDVI (1994-2001)	Δz-NDVI (1994-2001)
ΔPGI (94-01)	-0.2939	-0.1898
ΔSPG (94-01)	-0.2602	-0.1631

CHAPTER 3. DOES ENVIRONMENTAL CHANGE AFFECT RURAL POVERTY IN INDIA?

3.1. Introduction

Poverty reduction is one of the most challenging problems for a developing country like India. Traditionally, the focus of research pertaining to rural poverty has involved analysis impact of socio-economic factors and policy interventions like public expenditure on rural development, health and education on rural poverty (see for example, Ravallion, 2002; Jha, 2001). These traditional poverty analyses did not take into account the effect of environment on poverty. However, it is well established that rural population and especially rural poor are heavily depend on natural resources for their livelihood. Studies conducted using data from developing countries like India (Rao,1994; Jodha,2000; Narain, Gupta & Veld, 2005), Zimbabwe (Cavendish, 2000), Peru (Escobal and Aldana, 2003; Swinton and Quiroz, 2003), Chile (Bahamondes, 2003), Cambodia, Lao PDR and Vietnam (Dasgupta et al., 2005), Guatemala and Honduras (Nelson and Chomitz, 2004) show that apart from agriculture, the rural poor depend heavily on the natural resources, especially open access and common property resources, like the forests, pastures and water resources. Forests are extremely crucial for maintaining ecological balance and they have multiple uses for the rural economy, hence forest resources have been the focus for most of these studies. Along with fuelwood and fodder for the animals, the forests also provide a wide range of non-timber forest products (Shiva and Verma, 2002) like edible fruits and nuts, leaves, sap, etc. that are used for household consumption or production of marketable goods by the rural households. Due to the heavy reliance of rural households on the local vegetation, vegetation degradation is expected to increase the severity of rural poverty, as vegetation degradation is equivalent to shrinking input base for poor rural household production (Nelson and Chomitz, 2004; Dasgupta et al. 2005, Duraiappah, 1998).

In spite of the recognition of the importance of natural resources for the rural poor, the empirical literature on the relationship between rural poverty and environmental change surprisingly lacks any formal estimation of the impact of environmental change on rural poverty. This is the first study that estimates the impact of environmental change on rural poverty using cross-section district level data from South, West and Central parts of rural India.

3.2. Literature Review

The empirical literature on the relationship between poverty and environment is an emerging area of research that analyzes the environment-development linkages in the developing world. Summarized below are empirical works that are related to this study, which helps in identifying the contributions and the distinct features of our study.

Rao (1994) used correlation matrices to depict the link between rural poverty and decline in forests using state level data of India for the 1970's and 1980's. Jodha (2000) used village level survey data from dry regions of India to compare the situation in 1950's with that of 1980's to establish the importance of common property resources for the rural poor. Cavendish (2000) depicts the link between poverty and environment using household survey data for 1993-94 and 1996-97 from Zimbabwe by analyzing the descriptive statistics of different income sources of rural households. Mortimore (2003) provides anecdotal evidence from different countries in Africa to emphasize the importance of the relationship between poverty and environment. Bahamondes (2003) analyzes the change in vegetative cover and poverty between the period 1991 and 1999 using descriptive statistics of household survey data from Chile. Swinton and Quiroz (2003) used farm survey data of 1999 from Peru to depict that farming and forestry practices are responsible for soil erosion, overgrazing and deforestation and the income levels of the households influence such practices. Escobal and Aldana (2003) used household level survey data to analyze the link between poverty and environmental management techniques in Peru. They assessed the importance of non-timber forest product (brazil nut) for poor households' income. They also evaluated the influence of household characteristics on natural resource management. Nelson and Chomitz (2004) conduct a spatial analysis using poverty and environment maps for Guatemala and Honduras to test the nexus between forest, hydrology and poverty. Dasgupta et al. (2005) used district level data for Cambodia, Lao PDR and Vietnam to conduct a spatial analysis to depict the link between poverty and various aspects of environmental degradation (deforestation, fragile soil, water quality, indoor and outdoor air pollution). Their regressions focus only on the impact of poverty on environment and the results do not depict any significant effect of poverty on environmental change. Narain, Gupta & Veld (2005) use village level survey data and depict that the entire rural population depends on common property resources. The extent of dependence varies by income group.

Hence the empirical literature on the relationship between rural poverty and environment has not yet assessed the extent of impact of environmental change on rural poverty. In addition to this limitation, none of these studies have taken into account the endogeneity in the rural poverty-environment relationship as has been asserted by the 'poverty-environment nexus' hypothesis (Ikefuji and Horii, 2005; Dasgupta et al., 2005; Duraiappah, 1998) that argues for a negative cyclical relationship between rural poverty and environmental change. Rural poverty is argued to have degrading effect on environment due to several reasons. For example, animals like sheep or goats that act as capital resource for the rural poor degrade the vegetation and soil faster than the livestock of the richer rural population like buffaloes (Rao, 1994) and cultivable land degrades quickly due to lack of investment for maintaining the soil quality (Reardon and Vosti, 1995). Thus environmental degradation caused by rural poverty leads to shrinking resource base for rural production that further increases the severity of rural poverty and results in a vicious cycle. Hence this hypothesis implies that environmental change is an endogenous variable that affects poverty. Failure to account for the endogeneity can provide biased results that can have pronounced policy implications for a developing country where rural poverty and environmental change are prime policy concerns.

This is the first study that seeks to estimate the impact of environmental change on rural poverty using cross-section district level data from South, West and Central parts of rural India. Satellite image based "vegetation" indices are used to measure environmental health, which implicitly capture both forest and overall biomass resources in India's rural environment[23].

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[23]Only rural poverty has been included in this analysis as rural poor are heavily dependent on the measure of environment - vegetation. The urban poor have stronger links with other aspects of environment like air and water (Satterthwaite 2003). The terms environment and vegetation have been used interchangeably in this study.

3.3. Data

Using the data described in chapter 2 and Appendix B, this study analyzes the impact of environmental change, measured by vegetation indices, on change in rural poverty over the period 1994-2001. An additional explanatory variable is used in this chapter, rural development expenditure by the government, which is expected to affect rural poverty change. The development expenditure for the year 1993 is available at state level. A district level rural development expenditure variable is constructed by weighing the state level development expenditure by initial rural poverty as follows: $DevExp_{is} = DevExp_s * (P_{is} / P_s)$; where, DevExp denotes rural development expenditure, P denotes poverty index, subscript *i* denotes district and *s* denotes state. The weighing scheme is based on the premise that within a state, poorer districts are expected to receive more rural development expenditure. Although the rural development expenditure consists of expenditure under various schemes like employment guarantee programs, irrigation and road development, education and health facilities etc., all of these are aimed to address inadequate development that is associated with higher poverty. Hence the weighing structure represents heterogeneity across districts within a state in terms of initial poverty that is expected to account for the heterogeneity in allocation of state level rural development expenditure. The list of variables used in this chapter and their summary statistics are presented in table 3.1 and 3.2 respectively.

3.4. Hypothesis

The objective of this study is to estimate the impact of vegetation change on rural poverty. In the light of the arguments put forward in the existing literature that were discussed in the first two sections, it can be hypothesized that due to heavy reliance of rural poor on natural resources environmental degradation will increase severity of poverty and vice versa. Hence our null hypothesis is:

H_0: The vegetation change has negative effect on change in rural poverty index.

It is worth noting that this hypothesis is based on the poverty-environment nexus hypothesis, which heavily relies on the implicit assumption that the rural poor do not have relocation or alternative employment opportunities. However, if there exists migration or alternative employment opportunities that the rural poor can exploit in case of environmental degradation, environmental change may not have any significant impact on change in rural poverty. It is also feasible for environmental degradation to have positive effect on rural poverty in the long run due to two reasons. First, out migration of the rural poor reduces the number of poor in rural areas. This has a dampening effect on the poverty index. Second, if the migrant members of the poor households find better employment, then repatriations can lead to improvement the conditions of the poor households, which can reduces the poverty gap.

Apart for migration opportunities, several other institutional factors can shape the poverty-environment relationship. For instance, environmental improvement can be associated with improvement in property rights of the natural resources in the rural areas that limits the access of the rural poor to these resources. This may occur due to privatization of open access or common property resources or better enforcement of laws on public (government owned) resources. Limiting the access of the rural poor to natural resources will increase severity of rural poverty.

Hence, the maintained hypothesis of this study (and that of the poverty-environment nexus literature) is an empirically verifiable issue.

3.5. Empirical Estimation Strategy

In order to test the hypothesis presented in the previous section, the following linear regression is employed:

$$\Delta P_{1994\text{to } 2001} = \alpha + \beta \ \Delta E_{1994 \text{ to } 2001} + \gamma X + \varepsilon$$

where, ΔP: change in poverty index, ΔE: change in environmental quality, X: exogenous explanatory variables (see Table 3).

Note that the vegetation index and rural poverty index are continuous variables. Hence the magnitudes of the positive and negative changes in vegetation index and rural poverty index have the same monotonic interpretation.

In order to capture the dynamics of the relationship using cross sectional variations, the variables of main interest, rural poverty and vegetation have been used in form of changes rather than levels. The heterogeneity across districts, reflected in the summary statistics in Table 2, help in estimating the effect of poverty change on environmental change using cross-sectional data.

The study uses used two alternative measures of environmental quality – overall vegetation represented by NDVI and high quality vegetation (approximating the measure for forests) represented by z-NDVI. The analysis also uses two alternative measures of poverty – poverty gap index (PGI) and squared poverty gap (SPG) index. Two alternative measures of vegetation and poverty have been used to test the robustness of the estimations. The model includes contemporaneous (1994 to 2001) and past (1991 to

1994) vegetation changes as well as the initial level of vegetation (1994-95) to assess the impact of the trajectory of environmental change on rural poverty. Due to limited data availability, the socio-economic variables are at 1991 levels that depict the initial socio-economic conditions of the districts[24].

Beyond the impact of the trajectory of environmental change, change in poverty is expected to be influenced by demographic factors, income distribution, land use pattern and other socio-economic factors represented by 'X' in the model above. Rural population growth rate (1991-94) and rural population density (1991) represent the rural demographic factors. Rural per capita consumption expenditure (1994-95), initial rural poverty (1994-95) and rural Gini-coefficient (1994-95) represent the rural income distribution. Proportion of area under agriculture represented by proportion of net sown area indicates initial land use pattern. Rural literacy rate (1991), rural sex ratio (1991) and rural female work force participation rate (1991) are the social indicators that can affect environmental change. Literacy rate is an indicator of general education and awareness about the importance of environment. Higher sex ratio (female to male) and lower female work force participation rate represent greater availability of female labor for resource extraction. The extent of urbanization of a district can affect the environmental change. These are captured by proportion of urban population (1991), urban population growth rate (1991-94), urban population density (1991) and urban per capita consumption expenditure (1994-95). Government intervention through rural development expenditure that is expected reduce rural poverty (Gupta and Mitra, 2004)

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[24] Banerjee and Somanathan (2005) and Chopra and Gulati (1997) use similar empirical model in their study i.e.

through employment generation, infrastructure development etc. is represented by the measure of district level rural development expenditure.

Identification Strategy: The endogeneity of contemporaneous vegetation change requires instruments for identification. Since past vegetation change and initial vegetation quality represent the history prior to 1994, they are treated as exogenous with respect to the poverty change (1994-2001). Contemporaneous vegetation change (1994-2001) is the only endogenous explanatory variable in this regression that the study seeks to identify using the district level average rainfall measure during the period 1994-2001. Rainfall is expected to be positively correlated with vegetation/"greenness". The estimations show that in the first stage regression, as reported in Table 3.4, rainfall has significant positive effect on vegetation change as expected. The F statistic for rainfall in the first stage regressions, ranges between 23.5 and 24.94, which indicates that it is a very strong explanatory variable for vegetation change[25].

The next question regarding the instrument will be whether the instrument is exogenous to poverty change. In principle, rainfall may affect agricultural productivity, which in turn affects poverty; could these effects imply that the instrument is correlated with the error in the poverty regressions? The answer is expected to be "no" because the likely channels through which such effects may manifest themselves are controlled for, including incomes in the rural sector, the initial state of the environment, and the extent of agricultural cultivation (net sown area). However, to make absolutely sure that the potential productivity effects are properly controlled for, additional rainfall deviation

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dependent variable is in form of change and explanatory variables are at levels and changes.

(deviation from normal rainfall) variables were constructed that should capture any potential residual impact of rainfall shocks on agricultural productivity. Agronomic research indicates that agricultural productivity is affected by deviations of rainfall outside of normal bands (see Azzam and Sekkat, 2003). Therefore, two pairs of district level rainfall deviations were constructed. The first pair is obtained by summing positive and negative deviations of annual rainfalls, over the period 1994 to 2001, from average annual rainfall (calculated over the twenty year period, 1981 to 2000). The analysis distinguishes between positive and negative rainfall deviations in order to account for distinct effects of excess rain and shortfalls in rain. The second pair of deviations is designed to measure any potential effects of the timing of the start of the monsoon; specifically, is constructed by summing the positive and negative deviations of June rainfall from historic district averages[26]. Hence the cross-sectional variations in rainfall during the study period is expected to adequately identify cross-sectional variations in vegetation as the potential channels through which rainfall can indirectly affect rural poverty have been controlled for. Presented below are the results using the first (raw) set of rainfall deviations as controls; qualitatively similar results are obtained when using the second (start of monsoon) deviations as controls.

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[25] The inverse of the F statistic represents the weak instruments bias. In this case the weak instrument bias bias much less than 10 percent, which is a well-accepted benchmark level of bias.

[26] Formally, with μ_j representing 20-year average rainfall for subdivision j, district i (of subdivision j) has the raw rainfall deviation for year t, $R_{it} = (NDVI_i/NDVI_j)(Rain_j - \mu_j)$. The first pair of district-level rainfall deviation measures sums (respectively) the positive and negative R_{it} deviations over t=1994,…,2001. The second (start of monsoon) pair of district rainfall deviations is the same as the first, only using June rainfalls.

3.6. Results

Table 3.5 and 3.6 present the impact of overall vegetation (NDVI) change and high quality vegetation (z-NDVI) change on rural poverty change. These tables present both the OLS and the two-step GMM estimates. The main finding of the analysis is that environmental improvement increases rural poverty. The elasticity of rural poverty change with respect to vegetation change, measured at initial sample ranges of vegetation and rural poverty, as depicted in table 3.7 range between 1.19 and 1.97 depending upon the measure of vegetation and rural poverty. While a rise in NDVI by one percent of the initial sample range causes an increase in rural poverty by 1.19 percent of its initial sample range for PGI and 1.27 percent of its initial sample range for SPG, a change in z-NDVI by one percent of its initial sample range causes an increase in rural poverty by 1.88 percent of the initial sample range for PGI and 1.97 percent of the initial sample range of for SPG. Note that the elasticities of rural poverty change are higher with respect to z-NDVI. This indicates that rural poverty is more severely affected by changes in high quality vegetation (forests) that are predominantly open access or common property or public resources.

The significant positive effect of environmental change on poverty change across all the models imply that the hypothesis, environmental improvement reduces rural poverty, does not hold in the study region. This result has very sharp policy implication as it depicts a distinct tradeoff between the social objectives of reducing poverty and improving environmental quality.[27]

The robustness of this result was tested by running two additional sets of regressions. In the first set of regressions, the vegetation change was classified as positive or negative based on the overall rainfall deviation in the district during the study period i.e. for a district that received more rainfall than normal during the study period the vegetation change was put in the group that denoted positive vegetation change and vice versa. In the second set of regressions, the vegetation change was classified into three different groups based on average rainfall and geographic similarities. Group 1 represents lowest rainfall region that comprises of districts in Gujarat and Rajasthan, Group 2 represents moderate rainfall region that consists of districts in Madhya Pradesh, Maharashtra and Karnataka and Group 3 represents highest rainfall region that comprises of districts in Andhra Pradesh, Tamil Nadu and Kerala. Note that these classifications are based on the exogenous variable rainfall that is highly correlated with the vegetation change. Results of these regressions are presented in Table 3.8 and 3.9 respectively. The tables highlight the fact that, even with further classification, vegetation change has significant positive effect on poverty change. Thus these results testify the robustness of the estimates of the original model. Hence it can be inferred from these estimates that environmental improvement comes at the cost of increasing the severity of rural poverty.

[27] Although they are not the main focus of this study, there are several interesting results that indicate the important role of socio-economic factors in influencing the poverty-environment relationship. Districts with higher initial rural poverty experienced greater reduction in poverty. This may be attributed to stronger policy interventions to aid poorer districts. Higher agricultural intensity (represented by net sown area), higher rural life expectancy and lower rural population growth rate are associated with higher rural poverty reduction.

3.7. Exploring the Cause

The study explored three potential avenues that can provide an explanation of the result that environmental improvement comes at the cost of increasing the severity of rural poverty.

Argument 1. Environmental improvement can attract poor in-migrants from other rural areas or urban areas as well. This can contribute towards the increase in the measure of poverty due to increase in the number of poor.

Argument 2. If environmental improvement benefits the poor with more abundant resource availability, it can reduce the mortality rate and thereby increase the survival rate of poor population that may contribute towards the increase in the measure of poverty.

The second argument has two underlying contradicting forces at work. On the one hand if environmental improvement reduces the mortality, it implicitly implies that the gap with respect to the poverty line is declining, that is expected to reduce the measure of intensity of poverty. On the other hand, reduction in mortality also implies rise in the number of poor population and that is the likely source of increase in the measure of poverty. Hence, this argument will hold only if the increase in poor population due to decline in mortality rate offsets the reduction in poverty gap resulting from environmental improvement. Thus the environmental change has to bring about a sharp decline in mortality rate of the poor. It is worth noting that a head count index of poverty would fail to capture the effect of environmental change on the poverty gap.

Argument 3. If the environmental improvement is associated with improvement in property rights like privatizing the open access and common property resources or by better enforcement of property rights of public resources that restricts the rural poor from accessing the resources, it can increase the severity of rural poverty.

The available data for this study is inadequate to put these hypotheses to direct econometric tests. For instance, for a formal test of arguments 1 and 2 the ideal data would be data on rural migration and death rates of the poor population for the period 1994-2001. Similarly, for testing argument 3, one would require micro-data on change in property rights regimes and the way the property rights were implemented i.e. whether the poor were restricted or excluded from accessing the forest resources. A rich survey dataset can potentially help in exploring this avenue. Due to lack of availability of the ideal data, indirect methods were tried out to test arguments 1 and 2. In case of argument 3, anecdotal evidence from existing studies was used to analyze the issue.

Argument 1 is contradicted by chapter 1, which analyzes the relationship between vegetation change and different components of population growth in the same study region. Although the time frame of analysis in Chapter 1 is from 1991 to 1994, yet it can provide some informative evidence as the study region is same and the time frame 1991-94 is contiguous to the time frame of this study 1994-2001. Results from chapter 1 show that in the study region net rural in-migration responds negatively (rather than positively) to environmental improvement. Although the migration numbers in that study cannot distinguish between poor and non-poor migrants, it can still be used for drawing inferences for this purpose as the rural poor are more sensitive to environmental change, it is expected that environmental changes are expected to influence the migration decisions of the rural poor more significantly than the non-poor.

As mentioned above, argument 2 implicitly implies a strong negative effect of environmental improvement on rural mortality. This implication was tested by estimating the effect of environmental change on change in rural infant mortality rate and crude death rate over the period 1991-94. The time frame is different due to lack of availability of data on district wise rural mortality rate for the year 2001. In spite of the different time frame, the estimates are informative as the heterogeneities across the districts are most likely to have persisted after 1994 as well. Similar to the poverty change regressions, in these regressions as well the endogeneity of vegetation change is account for by using average rainfall during the period as identifying instrument while controlling for rainfall deviations from the normal. The estimates (Table 3.10) show that the environmental change does not have any significant impact on either measures of rural mortality. Hence, this estimation provides evidence (though indirect), which indicates that argument 2 is also does not hold in the study region.

Turning to argument 3, there are anecdotal evidences from studies like Kumar (2002) and Wade (1986), which portray that the rural poor are discriminated against by the rural elite, who have disproportionate power in resource management in the context of common property resource use like forests, pastures and irrigation. Thus, these studies implicitly imply that the environmental improvement associated with change in property rights regime can provide the benefits to the rural elite, while leaving out the rural poor from reaping the benefits of environmental improvement, thereby providing some indirect evidence in support of argument 3. Hence, by rule of elimination, only argument 3, which argues that improvement in environmental quality associated with restricting the rural poor from accessing the natural resources, appears to be the plausible explanation of the main finding of this study that depicts a trade off between environmental improvement and rural poverty reduction. Further research using micro-data on property rights changes is warranted for formal empirical validation of this argument.

3.8. Conclusions

This empirical analysis is the first study to estimate the impact of vegetation change on rural poverty. The study is also the first one to account for the endogeneity of vegetation change. Using district level data from India, the analysis indicates that vegetation improvement comes at the cost of increasing the severity of rural poverty. This result implies that there exists a trade off between the social objectives of environmental improvement and rural poverty reduction that poses a difficult challenge for policy formulation aimed towards sustainable rural development.

The study explored three plausible reasons behind this result. Using indirect evidence from the four-year period preceding this study, one can rule out the hypothesis that environmental improvement attracts poor migrants that increased the poverty measures or that environmental improvement actually benefits the poor by reducing their mortality that causes the increase in poverty measure because of larger number of poor surviving people. However, in the light of some anecdotal evidences, one can not rule out the hypothesis, which argues that vegetation improvement (especially forests) that is associated with change in property rights that restricts or excludes the rural poor from resource extraction, can increase the severity of rural poverty. More disaggregated data, preferably at village level, on property rights change and poverty is needed to put this hypothesis to direct test. Further research is also warranted to understand the role of institutional factors like property rights, access to credit and capital markets, employment and migration opportunities in rural areas that can be targeted by policy makers to strike a balance between the social objectives of poverty reduction and environmental improvement.

3.9. Tables

Table 3.1: Variables Definitions

Variable Name	Description
ENVIRONMENTAL VARIABLES	
ΔNDVI(94-01)	Change in average NDVI from 1994-95 to 2000-01
Initial NDVI (94)	NDVI 1994-95
Lag ΔNDVI (91-94)	Change in average NDVI from 1990-91 to 1993-94
Δz-NDVI(94-01)	Change in z-NDVI from 1994-95 to 2000-01
Initial z-NDVI(94)	z-NDVI 1995-95
Lag Δz-NDVI (91-94)	Change in average NDVI from 1990-91 to 1993-94
Net Sown Area(91)	Net sown area as a proportion of total district area (1991)
Rain Dev (+)(94-00)	Positive deviation in rainfall from the norm during 1994-2000
Rain Dev (-)(94-00)	Negative deviation in rainfall from the norm during 1994-2000
Rainfall (94-00)	Average rainfall in centimeters (1994 to 2000)
INCOME DISTRIBUTION VARIABLES	
ΔPGI (94-01)	Change in PGI from 1994-95 to 2000-01
ΔSPG (94-01)	Change in SPG from 1994-95 to 2000-01
Initial PGI (94)	Poverty gap index for 1994-95 (NSS round 51)
Initial SPG (94)	Squared poverty gap for 1994-95 (NSS round 51)
Cons Exp(94)	Per capita average monthly consumption expenditure (1994-95) in Rupees
Initial GINI (94)	Gini coefficient for 1994-95 (NSS round 51)
SOCIO-ECONOMIC VARIABLES	
Popn Grth Rt (91-94)	Births minus deaths (1991 to 1994) per thousand 1991 population
Popn Density (91)	Population per square kilometer in 1991
Urban Popn (91)	% of urban population in a district(1991)
Female Workers (91)	Females in workforce as percentage of working age female population (1991)
Sex Ratio (91)	Females per thousand male(1991)
Inf Death Rate(91)	Infant deaths per thousand live births (1991)
Literacy Rate (91)	Literates per thousand population (1991)
Avg Hh Size(91)	Average household size(1991)
Dev Exp w PGI	Per capita Rural Development Expenditure in 1993 weighted by Initial PGI(94)
Dev Exp w SPG	Per capita Rural Development Expenditure in 1993 weighted by Initial SPG(94)

Table 3.2. Summary Statistics

	Min	Max	Mean	Sdev
ENVIRONMENTAL VARIABLES				
ΔNDVI (94-01)	-18.99	8.5	-10.26	4.63
Δz-NDVI (94-01)	-1.41	0.72	-0.57	0.35
Initial NDVI (94)	139.63	198.8	174.16	11.51
Lag ΔNDVI (91-94)	-1.57	13.28	5.57	2.49
Initial z-NDVI (94)	-5.20	1.68	-0.19	0.97
Lag Δz-NDVI (91-94)	-0.24	2.89	0.47	0.35
Net Sown Area (91)	0.05	0.83	0.51	0.16
Rainfall(94-00)	113.17	84.47	27.89	346.51
Rain Dev (+)(94-00)	1096.5	12967.6	4671.8	2741.1
Rain Dev (-)(94-00)	-13873.9	-1773.1	-4568.2	2326.4
INCOME DISTRIBUTION VARIABLES (R – RURAL, U – URBAN)				
ΔPGI (94-01)	-0.18	0.33	0.06	0.10
Initial PGI (94)	0.04	0.46	0.22	0.08
ΔSPG (94-01)	-0.14	0.23	0.036	0.06
Initial SPG (94)	0.01	0.26	0.09	0.05
Initial GINI (94)	0.13	0.58	0.24	0.06
Cons Exp(R) (94)	204.26	864.63	356.35	92.52
Cons Exp(U) (94)	292.85	909.27	471.97	101.47
SOCIO-ECONOMIC VARIABLES (R – RURAL, U – URBAN)				
Popn Grth Rt(R) (91-94)	-3.72	91.36	19.5	18.86
Popn Grth Rt(U) (91-94)	5.28	229.58	77.39	41.38
Popn Density(R) (91)	7	1236	223.23	190.67
Popn Density(U) (91)	0	27490	3015	2677
Urban Population(91)	3.41	86.16	24.79	14.32
Literacy Rate(R)(91)	13.74	95.67	46.60	17.92
Female Workers(R)(91)	2.18	58.82	28.16	13.36
Sex Ratio(R) (91)	786	1230	958.42	57.98
Avg Hh Size(R) (91)	3.74	7.07	5.39	0.71
Inf Death Rate(R)(91)	0.91	88.6	23.33	18.01

Table 3.3. Model Structure

Explanatory variables (X)
ENVIRONMENTAL VARIABLES
Initial NDVI (94) or Initial z-NDVI (94)
Lag ΔNDVI (91-94) or Lag Δz-NDVI (91-94)
Net Sown Area(91)
Rain Dev(+)(94-00)
Rain Dev(-)(94-00)
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)
Per Capita Cons Exp(R & U)(94)
Initial PGI or SPG(R)(94)
Initial Gini(R)(94)
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)
Popn Grth Rt(R & U)(91-94)
Popn Density(R & U)(91)
Urban Population(%)(91)
Literacy Rate(R)(91)
Female Workers(R)(91)
Sex Ratio(R)(91)
Inf Death Rate(R)(91)
Life Expectancy(R)(91)
Avg Hh Size(R)(91)
Dev Exp w PGI or SPG

Table 3.4. First Stage Results and Test for Instrument Strength

	ΔNDVI		ΔNDVI		Δz-NDVI		Δz-NDVI	
	Coeff	p-value	coeff	p-value	coeff	p-value	coeff	p-value
ENVIRONMENTAL VARIABLES								
NDVI(94)	-0.227	0.000	-0.228	0.000				
LagΔNDVI(91-94)	-0.212	0.139	-0.210	0.138				
z-NDVI(94)					-0.230	0.000	-0.233	0.000
Lag?z-NDVI(91-94)					-0.233	0.021	-0.238	0.020
Net Sown Area(91)	1.666	0.393	2.072	0.293	0.355	0.036	0.382	0.023
Rain Dev(+)(94-00)	0.0002	0.817	-2.5e-05	0.981	-3.8e-05	0.679	-4.5e-05	0.620
Rain Dev(-)(94-00)	0.006	0.000	0.006	0.000	0.0004	0.000	0.0004	0.000
Rainfall(94-00)	0.033	0.000	0.034	0.000	0.002	0.000	0.002	0.000
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)								
Initial PGI(94)	-15.026	0.007			-1.029	0.042		
Initial SPG(94)			-22.601	0.018			-1.609	0.041
Cons exp (R)(94)	-1.298	0.068	-1.123	0.104	-0.159	0.009	-0.163	0.007
Cons exp (U)(94)	-0.090	0.770	-0.123	0.691	-0.031	0.175	-0.033	0.150
Initial Gini(94)	-1.033	0.863	-2.879	0.648	0.564	0.237	0.588	0.245

Table 3.4 (contd...)

	ΔNDVI Coeff	p-value	ΔNDVI coeff	p-value	Δz-NDVI coeff	p-value	Δz-NDVI coeff	p-value
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)								
Popn Grth Rt(R)(91-94)	-0.033	0.038	-0.028	0.082	-0.001	0.201	-0.001	0.367
Popn Grth Rt(U)(91-94)	-0.003	0.755	-0.003	0.723	0.000	0.528	0.000	0.509
Popn density (R)(91)	1.330	0.633	1.112	0.695	-0.159	0.452	-0.164	0.433
Popn density (U)(91)	0.023	0.781	0.024	0.770	-0.011	0.153	-0.011	0.158
Urban popn (91)	-0.025	0.255	-0.022	0.306	-0.002	0.177	-0.002	0.199
Literacy rate (R)(91)	0.054	0.128	0.054	0.134	0.006	0.018	0.006	0.021
Female workers(R)(91)	0.053	0.079	0.053	0.074	0.009	0.001	0.009	0.001
Sex ratio(R)(91)	-0.010	0.118	-0.011	0.105	-0.001	0.011	-0.001	0.010
Inf death rt (R)(91)	-0.032	0.146	-0.039	0.082	-0.003	0.061	-0.004	0.029
Life Expectancy(R)(91)	0.051	0.220	0.057	0.174	0.004	0.171	0.005	0.116
Avg Hh size (R)(91)	-0.276	0.673	-0.569	0.374	0.037	0.453	0.016	0.731
Dev Exp w PGI	0.911	0.002			0.049	0.036		
Dev Exp w SPG			0.570	0.008			0.025	0.142
Constant	40.246	0.000	41.521	0.000	0.371	0.509	0.480	0.390
F Statistic for instrumental variable (Rainfall)	24.08	0.000	24.94	0.000	23.50	0.000	24.06	0.000

Table 3.5. Impact of NDVI on Poverty

Dependent Variable:	ΔPGI (1994-2001)		ΔSPG (1994-2001)	
	(1)	(2)	(3)	(4)
	OLS	GMM	OLS	GMM
ENVIRONMENTAL VARIABLES				
ΔNDVI(94-01)	-0.0002	0.0085*	0.0003	0.0054*
	(0.896)	(0.066)	(0.767)	(0.054)
Initial NDVI(94)	-0.0008	0.0010	-0.0001	0.0009
	(0.387)	(0.400)	(0.790)	(0.238)
Lagged ΔNDVI(91-94)	0.0053*	0.0040	0.0029	0.0021
	(0.062)	(0.204)	(0.108)	(0.251)
Net Sown Area(91)	-0.1167**	-0.0996**	-0.0797***	-0.0726**
	(0.015)	(0.044)	(0.009)	(0.020)
Rain Dev (+)(94-00)	0.00006**	0.00007**	0.00004**	0.00005***
	(0.046)	(0.017)	(0.012)	(0.004)
Rain Dev (-)(94-00)	-0.00003	-0.00007**	-0.00002	-0.00004**
	(0.347)	(0.027)	(0.388)	(0.033)
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)				
Initial PGI(94)	-0.6801***	-0.5619***		
	(0.000)	(0.000)		
Initial SPG(94)			-0.6180***	-0.5010***
			(0.000)	(0.001)
Cons exp (R)(94)	-0.0203	-0.0224	-0.0200*	-0.0216**
	(0.239)	(0.126)	(0.071)	(0.013)
Cons exp (U)(94)	-0.0108	-0.0089	-0.0061	-0.0048
	(0.158)	(0.175)	(0.208)	(0.218)
Initial Gini(94)	0.2167	0.3123*	0.2217**	0.2897**
	(0.191)	(0.072)	(0.049)	(0.022)

Table 3.5. (contd...)

Dependent Variable:	ΔPGI (1994-2001) (1) OLS	(2) GMM	ΔSPG (1994-2001) (3) OLS	(4) GMM
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)				
Popn Grth Rt(R)(91-94)	0.0009**	0.0015***	0.0007**	0.0010***
	(0.031)	(0.000)	(0.015)	(0.000)
Popn Grth Rt(U)(91-94)	-0.0002	-0.0003*	-0.0002	-0.0002*
	(0.259)	(0.088)	(0.187)	(0.065)
Popn density (R)(91)	0.0428	0.0104	0.0372	0.0199
	(0.419)	(0.843)	(0.270)	(0.522)
Popn density (U)(91)	-0.0005	-0.0011	-0.0000	-0.0003
	(0.842)	(0.673)	(0.997)	(0.848)
Urban popn (91)	-0.0011**	-0.0012**	-0.0006*	-0.0007**
	(0.034)	(0.025)	(0.059)	(0.032)
Literacy rate (R)(91)	-0.0000	-0.0007	-0.0001	-0.0005
	(0.958)	(0.412)	(0.768)	(0.305)
Female workers(R)(91)	0.0020***	0.0017**	0.0013***	0.0011**
	(0.006)	(0.037)	(0.005)	(0.024)
Sex ratio(R)(91)	-0.0002	-0.0001	-0.0001	-0.0000
	(0.346)	(0.593)	(0.565)	(0.804)
Inf death rt(R)(1991)	0.0010*	0.0008	0.0006**	0.0006
	(0.052)	(0.138)	(0.044)	(0.110)
Life Expectancy(R)(1991)	-0.0028***	-0.0033***	-0.0019***	-0.0022***
	(0.006)	(0.004)	(0.004)	(0.005)
Avg hh size (R)(1991)	0.0135	0.0193	0.0074	0.0123
	(0.392)	(0.233)	(0.442)	(0.219)
PGI*Dev Exp	-0.0237***	-0.0368***		
	(0.006)	(0.000)		
SPG*Dev Exp			-0.0137***	-0.0185***
			(0.000)	(0.000)
Constant	0.6495**	0.3922	0.3021*	0.1406
	(0.013)	(0.257)	(0.066)	(0.507)

#obs=172; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3.6. Impact of z-NDVI (high quality vegetation) on Poverty

Dependent Variable:	ΔPGI (1994-2001)		ΔSPG (1994-2001)	
	(1)	(2)	(3)	(4)
	OLS	GMM	OLS	GMM
ENVIRONMENTAL VARIABLES				
Δz-NDVI(94-01)	0.0050	0.1145*	0.0104	0.0715**
	(0.828)	(0.052)	(0.478)	(0.047)
Initial z-NDVI(94)	0.0068	0.0250**	0.0062	0.0166**
	(0.519)	(0.038)	(0.357)	(0.029)
Lag Δz-NDVI(91-94)	0.0511**	0.0610***	0.0287**	0.0344***
	(0.017)	(0.006)	(0.035)	(0.009)
Net Sown Area(91)	-0.1055**	-0.1148***	-0.0771***	-0.0847***
	(0.024)	(0.004)	(0.009)	(0.001)
Rain Dev (+)(94-00)	0.00006**	0.00008**	0.00005***	0.00006***
	(0.036)	(0.013)	(0.008)	(0.003)
Rain Dev (-)(94-00)	-0.00003	-0.00007**	-0.00002	-0.00004*
	(0.367)	(0.043)	(0.381)	(0.051)
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)				
Initial PGI(94)	-0.7258***	-0.6028***		
	(0.000)	(0.000)		
Initial SPG(94)			-0.6571***	-0.5362***
			(0.000)	(0.000)
Cons exp (R)(94)	-0.0233	-0.0163	-0.0211*	-0.0168**
	(0.175)	(0.280)	(0.057)	(0.049)
Cons exp (U)(94)	-0.0099	-0.0063	-0.0054	-0.0032
	(0.189)	(0.334)	(0.257)	(0.411)
Initial Gini(94)	0.2360	0.2477	0.2313**	0.2408**
	(0.150)	(0.118)	(0.038)	(0.032)

Table 3.6. (contd...)

Dependent Variable:	ΔPGI (1994-2001)		ΔSPG (1994-2001)	
	(1)	(2)	(3)	(4)
	OLS	GMM	OLS	GMM
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)				
Popn Grth Rt(R)(91-94)	0.0009**	0.0013***	0.0006**	0.0009***
	(0.032)	(0.001)	(0.015)	(0.001)
Popn Grth Rt(U)(91-94)	-0.0002	-0.0003	-0.0001	-0.0002*
	(0.380)	(0.134)	(0.260)	(0.093)
Popn density (R)(91)	0.0279	0.0307	0.0322	0.0345
	(0.593)	(0.485)	(0.333)	(0.197)
Popn density (U)(91)	-0.0007	0.0004	0.0000	0.0007
	(0.793)	(0.859)	(0.997)	(0.655)
Urban popn (91)	-0.0009*	-0.0010*	-0.0005	-0.0006*
	(0.086)	(0.073)	(0.120)	(0.082)
Literacy rate (R)(91)	-0.0002	-0.0011	-0.0003	-0.0007
	(0.749)	(0.222)	(0.597)	(0.179)
Female workers(R)(91)	0.0019***	0.0011	0.0012**	0.0007
	(0.009)	(0.286)	(0.010)	(0.229)
Sex ratio(R)(91)	-0.0001	0.0000	-0.0000	0.0000
	(0.613)	(0.943)	(0.845)	(0.759)
Inf death rt (R)(91)	0.0012**	0.0010**	0.0008**	0.0007**
	(0.015)	(0.031)	(0.012)	(0.023)
Life Expectancy(R)(91)	-0.0031***	-0.0035***	-0.0020***	-0.0023***
	(0.002)	(0.001)	(0.002)	(0.002)
Avg Hh size (R)(91)	0.0206	0.0166	0.0103	0.0096
	(0.193)	(0.300)	(0.279)	(0.308)
PGI*Dev Exp	-0.0233***	-0.0336***		
	(0.006)	(0.000)		
SPG*Dev Exp			-0.0135***	-0.0170***
			(0.000)	(0.000)
Constant	0.4528**	0.4741**	0.2407*	0.2436**
	(0.027)	(0.015)	(0.061)	(0.042)

#obs=172; p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3.7. Elasticities measured at initial sample ranges

Dependent Variable:	ΔPGI (1994-2001)	ΔSPG (1994-2001)
ΔNDVI(94-01)	1.1975	1.2781
Δz-NDVI(94-01)	1.8756	1.9677

Table 3.8. Robustness Check - Set A

Dependent Variable:	ΔPGI (1994-2001)		ΔSPG (1994-2001)	
	(1)	(2)	(3)	(4)
	GMM	GMM	GMM	GMM
ENVIRONMENTAL VARIABLES				
Pos ΔNDVI(94-01)	0.0089**		0.0051**	
	(0.039)		(0.050)	
Neg ΔNDVI(94-01)	0.0079		0.0058*	
	(0.144)		(0.098)	
Initial NDVI(94)	0.0011		0.0009	
	(0.392)		(0.241)	
Lagged ΔNDVI(91-94)	0.0039		0.0022	
	(0.202)		(0.238)	
Pos Δz-NDVI(94-01)		0.1231**		0.0714**
		(0.031)		(0.044)
Neg Δz-NDVI(94-01)		0.0807		0.0716
		(0.268)		(0.143)
Initial z-NDVI(94)		0.0235*		0.0166**
		(0.055)		(0.035)
Lagged Δz-NDVI(91-94)		0.0600***		0.0344***
		(0.006)		(0.009)
Net Sown Area(91)	-0.1003**	-0.1110***	-0.0719**	-0.0847***
	(0.042)	(0.005)	(0.021)	(0.002)
Rain Dev (+)(94-00)	8.45e-05*	0.0001**	4.87e-05	6.13e-05*
	(0.080)	(0.031)	(0.103)	(0.056)
Rain Dev (-)(94-00)	-6.61e-05	-4.96e-05	-4.64e-05*	-3.93e-05
	(0.119)	(0.244)	(0.080)	(0.147)
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)				
Initial PGI(94)	-0.5614***	-0.5895***		
	(0.000)	(0.000)		
Initial SPG(94)			-0.4997***	-0.5362***
			(0.001)	(0.000)
Cons exp (R)(94)	-0.0229	-0.0173	-0.0214**	-0.0168*
	(0.120)	(0.247)	(0.016)	(0.054)
Cons exp (U)(94)	-0.0091	-0.0075	-0.0046	-0.0032
	(0.167)	(0.260)	(0.241)	(0.417)
Initial Gini(94)	0.3194*	0.2527	0.2848**	0.2407**
	(0.068)	(0.110)	(0.024)	(0.033)

Table 3.8.(contd...)

Dependent Variable:	ΔPGI (1994-2001)		ΔSPG (1994-2001)	
	(1)	(2)	(3)	(4)
	GMM	GMM	GMM	GMM
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)				
Popn Grth Rt(R)(91-94)	0.0015***	0.0013***	0.0009***	0.0009***
	(0.000)	(0.001)	(0.000)	(0.001)
Popn Grth Rt(U)(91-94)	-0.0003*	-0.0003	-0.0002*	-0.0002*
	(0.089)	(0.132)	(0.065)	(0.094)
Popn density (R)(91)	0.0119	0.0317	0.0188	0.0345
	(0.824)	(0.462)	(0.557)	(0.197)
Popn density (U)(91)	-0.0012	0.0002	-0.0003	0.0007
	(0.658)	(0.919)	(0.863)	(0.655)
Urban popn(91)	-0.0011**	-0.0009*	-0.0007**	-0.0006*
	(0.027)	(0.082)	(0.031)	(0.083)
Literacy rate (R)(91)	-0.0008	-0.0013	-0.0005	-0.0007
	(0.351)	(0.153)	(0.393)	(0.189)
Female workers(R)(91)	0.0016*	0.0009	0.0012**	0.0007
	(0.063)	(0.377)	(0.024)	(0.240)
Sex ratio(R)(91)	-0.0001	0.0001	-0.0000	0.0000
	(0.681)	(0.769)	(0.723)	(0.767)
Inf death rate (R)(91)	0.0008	0.0010**	0.0005	0.0007**
	(0.130)	(0.036)	(0.132)	(0.023)
Life Expectancy(R)(91)	-0.0032***	-0.0033***	-0.0022***	-0.0023***
	(0.007)	(0.004)	(0.006)	(0.003)
Avg hh size (R)(1991)	0.0197	0.0164	0.0118	0.0096
	(0.226)	(0.302)	(0.238)	(0.308)
PGI*Dev Exp	-0.0375***	-0.0354***		
	(0.000)	(0.000)		
SPG*Dev Exp			-0.0184***	-0.0170***
			(0.000)	(0.000)
Constant	0.3744	0.4362**	0.1541	0.2437*
	(0.279)	(0.032)	(0.464)	(0.053)

Observations: 172; Robust p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3.9. Robustness Check - Set B

Dependent Variable:	ΔPGI (1994-2001)		ΔSPG (1994-2001)	
	(1)	(2)	(3)	(4)
	GMM	GMM	GMM	GMM
ENVIRONMENTAL VARIABLES				
Grp1 ΔNDVI(94-01)	0.0079*		0.0060**	
	(0.062)		(0.024)	
Grp2 ΔNDVI(94-01)	-0.0013		-0.0002	
	(0.731)		(0.947)	
Grp3 ΔNDVI(94-01)	0.0077		0.0048*	
	(0.101)		(0.095)	
Grp1 Δz-NDVI(94-01)		0.0820		0.0675*
		(0.141)		(0.055)
Grp2 Δz-NDVI(94-01)		-0.0592		-0.0262
		(0.348)		(0.479)
Grp3 Δz-NDVI(94-01)		0.1100*		0.0639*
		(0.076)		(0.083)
Initial NDVI(94)	-0.0006		-0.0003	
	(0.615)		(0.719)	
Lagged ΔNDVI(91-94)	0.0041		0.0022	
	(0.167)		(0.224)	
Initial z-NDVI(94)		0.0131		0.0079
		(0.266)		(0.276)
Lagged ch z-NDVI(1991-1994)		0.0664***		0.0380***
		(0.000)		(0.001)
Net Sown Area(91)	-0.1371***	-0.1206***	-0.0875***	-0.0769***
	(0.002)	(0.003)	(0.002)	(0.004)
Rain Dev (+)(94-00)	0.00001***	0.00001***	8.5e-05***	7.9e-05***
	(0.000)	(0.001)	(0.000)	(0.000)
Rain Dev (-)(94-00)	-1.4e-05	-5.4e-07	-8.1e-06	-1.1e-07
	(0.677)	(0.988)	(0.672)	(0.955)
INCOME DISTRIBUTION VARIABLES (R-RURAL, U-URBAN)				
Initial PGI(94)	-0.6866***	-0.6999***		
	(0.000)	(0.000)		
Initial SPG(94)			-0.6424***	-0.6414***
			(0.000)	(0.000)
Cons exp (R)(94)	0.0099	0.0128	-0.0002	0.0024
	(0.477)	(0.386)	(0.984)	(0.791)
Cons exp (U)(94)	-0.0095	-0.0090	-0.0052	-0.0049
	(0.127)	(0.151)	(0.168)	(0.195)
Initial Gini(94)	0.0468	0.0332	0.0750	0.0576
	(0.787)	(0.846)	(0.546)	(0.625)

Table 3.9.(contd...)

Dependent Variable:	ΔPGI (1994-2001)		ΔSPG (1994-2001)	
	(1)	(2)	(3)	(4)
	GMM	GMM	GMM	GMM
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)				
Popn Grth Rt(R)(91-94)	0.0008**	0.0008*	0.0006**	0.0006**
	(0.042)	(0.055)	(0.014)	(0.018)
Popn Grth Rt(U)(91-94)	-0.0004**	-0.0004**	-0.0002**	-0.0003**
	(0.036)	(0.027)	(0.038)	(0.030)
Popn density (R)(91)	0.0547	0.0645	0.0384	0.0444
	(0.265)	(0.163)	(0.186)	(0.110)
Popn density (U)(91)	0.0005	0.0015	0.0006	0.0014
	(0.864)	(0.566)	(0.679)	(0.336)
Urban popn(91)	-0.0013***	-0.0012**	-0.0007***	-0.0007**
	(0.004)	(0.016)	(0.008)	(0.030)
Literacy rate (R)(91)	-0.0009	-0.0010	-0.0007	-0.0008
	(0.194)	(0.235)	(0.114)	(0.125)
Female workers(R)(91)	0.0001	-0.0001	0.0002	0.0000
	(0.879)	(0.912)	(0.702)	(0.941)
Sex ratio(R)(91)	-0.0001	-0.0001	-0.0000	0.0000
	(0.382)	(0.653)	(0.697)	(0.990)
Inf death rate (R)(91)	0.0004	0.0005	0.0003	0.0003
	(0.394)	(0.207)	(0.344)	(0.217)
Life Expectancy(R)(91)	-0.0023**	-0.0026**	-0.0017**	-0.0019**
	(0.029)	(0.015)	(0.022)	(0.012)
Avg hh size (R)(91)	0.0050	0.0054	0.0014	-0.0004
	(0.738)	(0.725)	(0.883)	(0.968)
PGI*Dev Exp	-0.0054	-0.0033		
	(0.622)	(0.783)		
SPG*Dev Exp			-0.0058	-0.0051
			(0.216)	(0.310)
Constant	0.6563**	0.4597***	0.3523*	0.2601**
	(0.033)	(0.007)	(0.067)	(0.011)

Note 1: Observations: 172; Robust p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%

Note 2: Grp1 indicates districts in Gujarat and Rajasthan, Grp2 indicates districts in Madhya Pradesh, Maharashtra and Karnataka, Grp3 indicates districts in Andhra Pradesh, Tamil Nadu and Kerala.

Table 3.10. Impact of Vegetation Change on Rural Death Rates

Dependent Variable:	ΔRIDR (91-94)		ΔRCDR (91-94)	
	(1)	(2)	(3)	(4)
	GMM	GMM	GMM	GMM
ENVIRONMENTAL VARIABLES				
ΔNDVI(91-94)	-0.5191		0.0036	
	(0.341)		(0.961)	
Δz-NDVI(91-94)		-9.2694		0.0195
		(0.175)		(0.985)
Initial NDVI(91)	0.0578		-0.0214*	
	(0.581)		(0.089)	
Lagged ΔNDVI(86-90)	0.3253		-0.0198	
	(0.270)		(0.543)	
Initial z-NDVI(91)		-2.3981		-0.3747
		(0.360)		(0.333)
Lagged Δz-NDVI(86-90)		-1.1957		-0.1188
		(0.118)		(0.136)
Net Sown Area(91)	0.1130	3.5041	-0.9726	-0.8623
	(0.988)	(0.628)	(0.244)	(0.229)
Rain Dev (+)(91-94)	-0.0069*	-0.0079*	0.0004	0.0006
	(0.088)	(0.091)	(0.377)	(0.205)
Rain Dev (-)(91-94)	0.0142	0.0161*	-0.0006	-0.0005
	(0.135)	(0.091)	(0.422)	(0.495)
SOCIO-ECONOMIC VARIABLES (R-RURAL, U-URBAN)				
Cons exp-R(94)	0.0154	0.0175	0.0016	0.0015
	(0.307)	(0.252)	(0.192)	(0.251)
Cons exp-U(94)	0.0015	-0.0005	0.0005	0.0004
	(0.851)	(0.944)	(0.433)	(0.538)
Urban popn(91)	-0.0073	-0.0130	0.0180**	0.0194**
	(0.882)	(0.797)	(0.021)	(0.020)
Popn density-R(91)	0.0049	0.0023	0.0005	0.0003
	(0.211)	(0.482)	(0.500)	(0.674)
Female lit rate-R(91)	-0.0890	-0.0900	0.0058	0.0069
	(0.443)	(0.456)	(0.450)	(0.399)
Sex ratio-R(91)	0.0423	0.0471	-0.0031	-0.0032
	(0.128)	(0.107)	(0.220)	(0.243)
Female workers-R(91)	-0.1827*	-0.1640	0.0186**	0.0178*
	(0.083)	(0.120)	(0.038)	(0.099)
Avg hh size-R(91)	-0.9056	-1.6178	0.3654**	0.4185**
	(0.713)	(0.542)	(0.044)	(0.030)
Muslims-R(91)	0.0434	0.0918	0.0083	0.0012
	(0.688)	(0.429)	(0.308)	(0.903)
Life expectancy-R(91)	-0.1303	-0.1231	0.0112	0.0122
	(0.347)	(0.370)	(0.365)	(0.358)
Constant	-33.2596	-23.2572	2.3194	-1.8348
	(0.336)	(0.297)	(0.513)	(0.516)

Robust p values in parentheses;
* significant at 10%; ** significant at 5%; *** significant at 1%
RIDR: Rural Infant Death Rate, RCDR: Rural Crude Death Rate

CONCLUSIONS

The studies in this dissertation have presented empirical analysis of the relationship between environmental change, represented by vegetation indices, and development, represented by population growth and poverty, using data from India during the decade of 1990's. These are the first studies in the literature to account for the endogeneity in the relationship between environment and development. These studies highlight that environmental change and the socio-economic aspects of the development process affect each other. Hence empirical analyses that do not account for the endogeneity in the relationship provide biased estimates of the effect of development on environment and vice versa, which can have pronounced policy implications. Academicians can contribute towards policy inputs for environmentally sustainable development plans in two stages. The first step is systematic understanding of the direction and magnitude of the effect of development on environment and vice-versa. The second step is to analyze the role of institutional factors that shape the environment-development relationship. The studies in this dissertation contribute at the first stage by providing consistent estimates of the effect of population growth and rural poverty on environment and vice versa and point towards the direction in which the second stage research should focus on.

Chapter 1 presents an empirical analysis of the bi-directional relationship between population growth and vegetation change over the period 1991-1994. Apart from accounting for the endogeneity in the population-environment relationship, the analysis also accounted for the distinguishing features of rural and urban populations, and the two components of population growth, natural population growth and migration in a unified framework, which enabled it to identify two simultaneous countervailing forces (neo-Malthusian and neo-Boserupian), which are at work in rural India. The evidence that environmental degradation spurs rural population growth and rural population growth in turn fuels environmental degradation provides evidence in support of a neo-Malthusian 'vicious cycle' hypothesis. At the same time, the evidence that low initial environmental quality spurs subsequent environmental improvement supports the neo-Boserupian school of thought, which argues for scarcity induced technological or institutional innovation that helps in resource conservation. The analysis provides ground for further research to analyze the mechanism by which the neo-Boserupian effect comes into play i.e. the role of technological innovation and institutional changes in shaping the population-environment relationship.

Chapter 2 presents an empirical analysis of the effect of rural poverty on vegetation change over the period 1994-2001. This is the first study in this newly developing literature to systematically estimate the impact of intensity of rural poverty on environmental quality. This is also the first study to account for the endogeneity of poverty and also to account for the effect of initial income distribution on environmental change. The analysis provides evidence in support of the dominant view in the literature that rural poverty spurs environmental degradation and highlights that the estimation bias resulting for lack of accounting for the endogeneity of vegetation change contradicts the rural poverty-environment nexus hypothesis that is prominently discussed in the existing literature. Hence it calls for analysis of the other direction of the relationship i.e. the effect of environmental change on rural poverty change that chapter 3 deals with. In addition the analysis reveals that rural income distribution plays a significant role in vegetation change. The result that higher initial per capita consumption expenditure has a negative effect on environmental change is supported by the Environmental Kuznets Curve (EKC) hypothesis, since India is still a developing country. However the result that higher initial income inequality (Gini coefficient) spurs environmental improvement, is completely missed out by the EKC literature that only focuses on the effect of per capita income on environmental quality, thereby are missing out the effect of income distribution on environmental quality. In addition, the results of this chapter again reiterate that lower initial environmental quality spurs environmental improvement. Hence it again calls for further research to analyze the mechanism through which the environmental improvement occurs that was beyond the scope of these studies due to the lack of adequate data availability.

Chapter 3 presents an empirical analysis of the impact of environmental change in rural poverty over the period 1994-2001 and provided evidence that clearly contradicts the poverty-environment nexus hypothesis and highlights a tradeoff between the social objectives of rural poverty reduction and restricting environmental degradation. This is also the first study to provide estimates of the impact of environmental change on rural poverty change and account for the endogeneity of environmental change. The evidence suggests that environmental improvement comes at the cost of increasing rural poverty. The study also explored the cause of the tradeoff. Preliminary evidence suggests that the argument of improvement in vegetation associated with change in property rights in form of either privatization of the open access or common property vegetative resources or stricter enforcement of public property laws that limit the access of the rural poor to these resources, appears to be the most plausible explanation. The argument could not be formally tested due to lack of adequate data on property rights and their implementation in rural India. Hence it provides ground for further research in this direction.

It is worth noting that the ideal data for analyzing the dynamics of the relationship between environment change and development will be a panel data set spanning across a substantially ‘long’ time frame. Due to lack of availability of such ideal data, these studies were based on cross-section data. In spite of the cross-section nature of the data the studies attempted to optimize the data use to capture the dynamics of the environment-development relationship by focusing on vegetation change, population growth rate, change in rural poverty rather than only analyzing the levels of these variables. Due to heterogeneity in socio-economic and climatic variables across districts, the analyses helped in identifying the development-environment relationships.

In sum, the studies in this dissertation shed light on the interrelationship between environmental change and the development process using evidence from a fast growing developing country, India. The analyses presented here provide systematic estimation of the direction and magnitude of the effects of vegetation change on population growth and rural poverty and vice versa. These analyses highlight the challenges for the formulation of environmentally sustainable development policies and beckon the need for further research in which the fields of environment, development and institutional economics are merged for adequate understanding the role of technological and institutional changes in shaping the environment-development relationship.

APPENDIX A. STUDY REGION

Figure A.1. Map of the Study Region

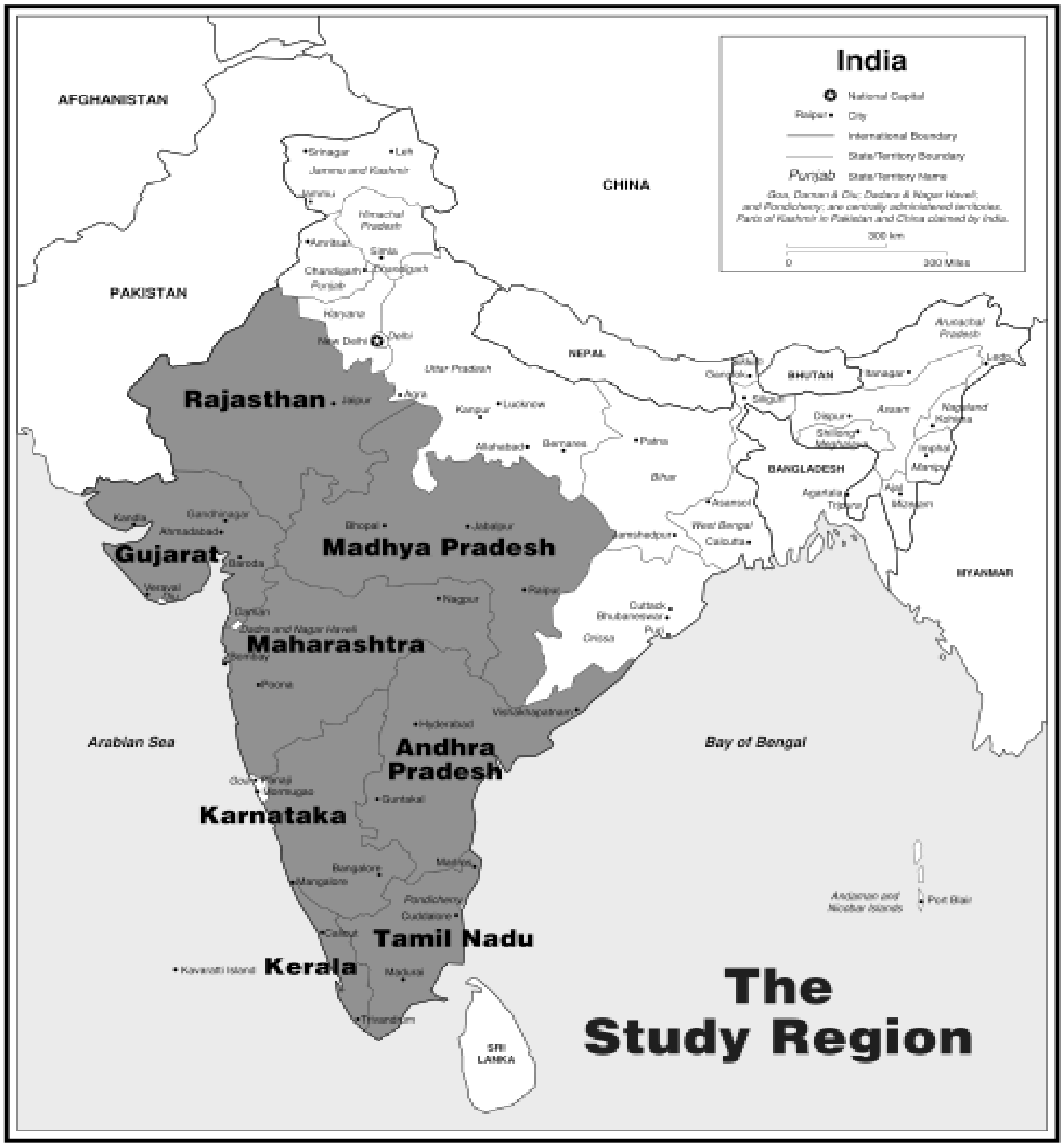

Table A.2. State Profile

Historical and Natural Features

State	State Came into Existence	Area (sq. km)	Normal Rainfall Annual (mm)	Administrative Language	State Capital
Andhra Pradesh	1956	275045	881	Telugu	Hyderabad
Gujarat	1960	196024	838	Gujarati	Gandhinagar
Karnataka	1956	191791	1783	Kannada	Bangalore
Kerala	1956	38863	3071	Malayalam	Thiruvananthapuram
Madhya Pradesh*	1956	443446	1161	Hindi	Bhopal
Maharashtra	1960	307713	1459	Marathi	Mumbai
Rajasthan	1956	342239	494	Hindi	Jaipur
Tamilnadu	1956	130058	982	Tamil	Chennai

Demographic Features

State	Population (1991 Census)	Population Density per sq km (2000)	Birth Rate (1999)	Death Rate (1999)	Sex Ratio (1991)
Andhra Pradesh	66508008	276	22.3	8.8	960
Gujarat	41309582	258	25.3	7.8	921
Karnataka	44977201	273	22	7.9	960
Kerala	29098518	832	18.2	6.4	1036
Madhya Pradesh*	66181170	158	30.6	11.2	931
Maharashtra	78937187	314	22.3	7.6	922
Rajasthan	44005990	157	31.5	8.8	910
Tamilnadu	55858946	478	18.9	8.4	986

Table A.2 (contd...)

Socio-economic Features

State	Per Capita State GDP in Rupees (1999-2000)	Agriculture Dependent Population	Literacy Rate (1991)	Agriculture Dependent Population	Hindus (%)	Muslims (%)
Andhra Pradesh	14878	0.7	0.4409	0.7	89.14	8.9
Gujarat	18685	0.34	0.6997	0.34	89.48	8.73
Karnataka	16343	0.71	0.5604	0.71	85.45	11.64
Kerala	18262	0.42	0.8981	0.42	57.28	23.33
Madhya Pradesh*	10907	0.77	0.442	0.77	92.8	4.96
Maharashtra	22604	0.61	0.7727	0.61	81.12	9.67
Rajasthan	12533	0.39	0.3855	0.39	89.08	8.01
Tamilnadu	18623	0.7	0.7347	0.7	88.67	5.47

Table A.3. List of Districts

Andhra Pradesh (23 districts)

Adilabad, Anantapur, Chittoor, Cuddapah, East Godavari, Guntur, Hyderabad, Karimnagar, Khammam, Krishna, Kurnool, Mahbubnagar, Medak, Nalgonda, Nellore, Nizamabad, Prakasam, Rangareddi, Srikakulam, Visakhapatnam, Vizianagaram, Warangal, West Godavari

Gujarat (19 districts)

Ahmadabad, Amreli, Banas Kantha, Bharuch, Bhavnagar, Gandhinagar, Jamnagar, Junagadh, Kachchh, Kheda, Mahesana, Panch Mahals, Rajkot, Sabar Kantha, Surat, Surendranagar, The Dangs, Vadodara, Valsad

Karnataka (20 districts)

Bangalore, Bangalore Rural, Belgaum, Bellary, Bidar, Bijapur, Chikmagalur, Chitradurga, Dakshina Kannada, Dharwad, Gulbarga, Hassan, Kodagu, Kolar, Mandya, Mysore, Raichur, Shimoga, Tumkur, Uttara Kannada

Kerela (14 districts)

Alappuzha, Ernakulam, Idukki, Kannur, Kasaragod, Kollam, Kottayam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thiruvananthapuram, Thrissur, Wayanad

Madhya Pradesh (45 districts)

Balaghat, Bastar, Betul, Bhind, Bhopal, Bilaspur, Chhatarpur, Chhindwara, Damoh, Datia, Dewas, Dhar, Durg, East Nimar, Guna, Gwalior, Hoshangabad, Indore, Jabalpur, Jhabua, Mandla, Mandsaur, Morena, Narsimhapur, Panna, Raigarh, Raipur, Raisen, Rajgarh, Rajnandgaon, Ratlam, Rewa, Sagar, Satna, Sehore, Seoni, Shahdol, Shajapur, Shivpuri, Sidhi, Surguja, Tikamgarh, Ujjain, Vidisha, West Nimar

Table A.3. (contd...)

Maharashtra (30 districts)

Ahmadnagar, Akola, Amravati, Aurangabad, Bhandara, Bid, Buldana, Chandrapur, Dhule, Gadchiroli, Greater Bombay, Jalgaon, Jalna, Kolhapur, Latur, Nagpur, Nanded, Nashik, Osmanabad, Parbhani, Pune, Raigarh, Ratnagiri, Sangli, Satara, Sindhudurg, Solapur, Thane, Wardha, Yavatmal

Rajasthan (27 districts)

Ajmer, Alwar, Banswara, Barmer, Bharatpur, Bhilwara, Bikaner, Bundi, Chittaurgarh, Churu, Dhaulpur, Dungarpur, Ganganagar, Jaipur, Jaisalmer, Jalor, Jhalawar, Jhunjhunun, Jodhpur, Kota, Nagaur, Pali, Sawai Madhopur, Sikar, Sirohi, Tonk, Udaipur

Tamil Nadu (21 districts)

Chengalpattu-MGR, Chidambaranar, Coimbatore, Dharmapuri, Dindigulanna, Kamarajar, Kaniyakumari, Madras, Madurai, Nilgiri, North Arcot-Ambedkar, Pasumpon M. Thevar, Periyar, Puddukkottai, Ramanathapuram, Salem, South Arcot, Thanjavur, Tiruchirapalli, Tirunelveli Kattabomman, Tiruvannamalai-Sambuvara

Table A.4. District Creation and Renaming between 1991-2001

Gujarat

1. Anand district split from Kheda (1997)
2. Dahod district split from Panch Mahals (1997)
3. Narmada district split from Bharuch (1997)
4. Navsari district split from Valsad (1997)
5. Porbandar district split from Junagadh (1997)
6. Patan district formed from parts of Banas Kantha and Mahesana (2000)

Karnataka

1. Bagalkot district split from Bijapur (1997)
2. Chamrajnagar district split from Mysore (1997)
3. Davanagere district formed from parts of Bellary, Chitradurga, Dharwad, and Shimoga(1997)
4. Gadag district split from Dharwad(1997)
5. Haveri district split from Dharwad(1997)
6. Koppal district split from Raichur(1997)
7. Udupi district split from Dakshina Kannada(1997)

Madhya Pradesh

1. Dantewara and Kanker districts split from Bastar (1998)
2. Dhamtari district split from Raipur (1998)
3. Janjgir-Champa and Korba districts split from Bilaspur (1998)
4. Jashpur district split from Raigarh (1998)
5. Kawardha district formed from parts of Bilaspur and Rajnandgaon (1998)
6. Koriya district split from Surguja (1998)
7. Mahasamund district split from Raipur (1998)
8. Barwani district split from West Nimar (1998)
9. Dindori district split from Mandla (1998)
10. Harda district split from Hoshangabad (1998)
11. Katni district split from Jabalpur (1998)
12. Neemuch district split from Mandsaur (1998)
13. Sheopur district split from Morena (1998)
14. Umaria district split from Shahdol (1998)

In 2000, Chhattisgarh state was formed by taking Bastar, Bilaspur, Dantewara, Dhamtari, Durg, Janjgir-Champa, Jashpur, Kanker, Kawardha, Korba, Koriya, Mahasamund, Raigarh, Raipur, Rajnandgaon, and Surguja districts from Madhya Pradesh.

Table A.4. (contd...)

Maharashtra
1. Greater Mumbai district split into Mumbai City and Mumbai Suburb (1997)
2.Washim district split from Akola (1997)
3. Nandurbar district split from Dhule (1998)
4. Gondiya district split from Bhandara (2000)
5. Hingoli district split from Parbhani (2000)

Rajasthan
1. Baran district split from Kota (1996)
2. Dausa district split from Jaipur (1996)
3. Rajsamand district split from Udaipur (1996)
4. Hanumangarh district split from Ganganagar (1998)
5. Karauli district split from Sawai Madhopur (1999)

Tamil Nadu
1. Chengalpattu district split into Kancheepuram and Thiruvallur (1999)
2. Theni district split from Madurai (1999)
3. Namakkal district split from Salem (1999)
4. South Arcot district split into Cuddalore and Villupuram (1999)
5. Karur and Perambalur districts split from Tiruchirappalli (1999)
6. Nagapattinam and Thiruvarur districts split from Thanjavur (1999)
7. Ariyalur district split from Perambalur (2000)

Names of districts changed:
1. Madras district became Chennai (1996)
2. Kamarajar became Virudhunagar (1996)
3. Pasumpon Muthuramalinga Thevar became Sivaganga (1996)
4. Periyar became Erode (1996)
5. Tiruvannamalai-Sambuvarayar became Tiruvannamalai (1996)
6. Chidambaranar became Tuticorin, later Thoothukudi (1996)
7. North Arcot Ambedkar became Vellore (1996)

APPENDIX B. DATA DESCRIPTION

The Environment. The satellite-based Normalized Difference Vegetation Index (NDVI) provides a measure of vegetation or "greenness" that has been used to represent environmental quality in this dissertation. This measure of vegetation quality has several advantages over the traditional measures like area under forest. First, it allows comparison of vegetation quality over time and space, that measures like area under forest lack completely. Second, the satellite images are accurate and do not suffer from the traditional survey related measurement errors. This index is known to be highly correlated with plant matter; to take on higher values when forest vegetation is present; and to be robust to topographical variation, the sun's angle of illumination, and atmospheric phenomena such as haze.

The NDVI is measured on a 10-day composite basis, at fine resolution (with each pixel eight square kilometers in size), and takes on values between zero and 256. Satellite images are obtained from the National Aeronautics and Space Administration (NASA) and are processed using Geographic Information (GIS) techniques to obtain district-specific index values. Monthly composite images downloaded from NASA are reprojected into Geographic format and stacked to calculate pixel-level averages and standard deviations for one or two-year timeframes. Using the political map of India, district level NDVI averages and standard deviations are extracted from the pixel-level data.

NDVI data is used to construct two measures of the state of the environment. The first is the average district-level NDVI, a measure of overall vegetation. The second represents an index of forest cover, measuring the extent to which a district has "high NDVI" land – land in the top 20 percent of NDVI values. The focus is on the "top 20" percent because, as of 1995, approximately 19.1 percent of the study region was in forest, and in 1990-1991, approximately 21 percent of India was forested. To construct this "high NDVI" measure, a standard practice of GIS geographers was followed (see Yool, 2001). First a critical NDVI level is obtained such that approximately 20 percent of the study region's month-pixel NDVI values are higher than this level. Then a z-score, "z-NDVI" is constructed for each district that is monotonically related to the proportion of time-pixels that are above this critical NDVI index value. Formally, for the two-year (24-month) interval, 1990-1991, the average value (μ_S) and standard deviation (σ_S) were calculated for all monthly pixels in the study area. Then the critical index is constructed as: $N = \mu_S + n_{.20}\, \sigma_S$

where $n_{.20}$ = critical value of a standard normal random variable such that the upper tail has a 20 percent probability $\approx .84$. In the sample, the calculated critical N index is 177. For any given time interval of interest (a year, or the two-year period 1990-1991, for example), then the z-score is constructed as:

$z\text{-NDVI}_i$ = z-score for district i = $(\mu_i - N)/\sigma_i$

where μ_i = district i average of time-pixel NDVI and σ_i = district i standard deviation of time-pixel NDVI.

Population Growth. The population growth rates have been computed based on district level births and deaths (total, rural, and urban) data, published by Registrar General's Office of India for the four years 1991-1994. The Registrar's statistics are based on vital registration data, revised district by district to account for estimated under-reporting. Using this data, as well as district-level rural and urban population levels from the 1991 Census of India, district-level birth rates (rural and urban), death rates (rural and urban), and net migration rates (rural and urban) were derived for the four-year period 1991-1994, as fractions of relevant (rural and urban) 1991 district populations. These calculated migration rates represent net district level out-migration (rural and urban), as point-to-point migration numbers are not available. Primary data on either migration or 1994 rural and urban populations were not available. Hence, estimates of rural and urban net migration were constructed by the following method. Annualized district-level rural and urban population growth rates were computed over the decade from 1991 to 2001 using census population data. With the computed annual growth rates, the 1994 rural and urban population numbers were projected from their 1991 bases. From the projected 1994 population numbers the 1991 populations and natural growth over 1991-1994 were subtracted to obtain estimates of net migration, which were then normalized (as with the natural growth rate measures) to be per thousand 1991 population and revised to accord with 1994 district population totals inferred from the Registrar of India data.

Rainfall. Annual rainfall data are available for meteorological subdivisions of India, each of which is defined according to climatic features and contains several districts. Because there are only 19 subdivisions – and "greener" districts are likely to have higher rainfall – approximations to district-level actual rainfall were obtained by combining subdivision rainfall and district-level NDVI data as follows:

$Rain_{ij} = Rain_j * (NDVI_i / NDVI_j)$

where $Rain_{ij}$ = "rainfall" for district i in subdivision j, $Rain_j$ = annualized 1991-1994 rainfall of subdivision j, $NDVI_i$ = average NDVI of district i for 1990-91, $NDVI_j$ = average NDVI of subdivision j for 1990-91.

Socio-Economic Data: The socio-economic data that are expected to affect poverty and vegetation change have been obtained from various sources. The data sources for the socio-economic variables are Human Development Reports published by National Council for Applied Economic Research (NCAER) of India and data portal site www.indiastat.com. The data on these socio economic variables - population density, proportion of urban population, net sown area, literacy rates, infant mortality rate, female work force participation rate and average household size are for the year 1991. These variables act as indicators of the initial socio-economic conditions of the districts.

APPENDIX C. PROOFS FOR PROPOSITIONS AND LEMMAS

Proposition 1. (a) $d\Delta E/dc_R < 0$. Higher rural birth rates promote environmental decline. (b) $d\Delta E/dm < 0$. Greater rural out-migration yields environmental improvement.

Proof. (a) Suppose not. Then $[(dl^*/dc_R)+1] \leq 0$. Hence, if $dX_m^*/dc_R > 0$, then $dP/dc_R < 0$ (by (A10)),

$$\text{(A12)}\quad dU_1^R/dc_R = U_{11}^R\ \{(\partial X/\partial L)\ [(dl^*/dc_R)+1] - (dX_m^*/dc_R)\} - U_{12}^R\ (dl^*/dc_R) > 0,$$

and, hence, $d\{-U_1^R+P\}/dc_R < 0$ (using $U_{11}^R<0$, $U_{12}^R \geq 0$, and $dl^*/dc_R \leq 0$), contradicting the preservation of the first order condition for X_m in problem (A4). Therefore, we must have $dX_m^*/dc_R \leq 0$ and, therefore, $dP/dc_R \geq 0$; with $\partial l^*/\partial P > 0$ (from differentiation of the first order conditions (FOC) for (A4)), it now suffices to show that $[1+(\partial l^*/\partial c_R)] > 0$, implying the contradiction that $[(dl^*/dc_R)+1] > 0$. Totally differentiating the two FOC for (A4), appealing to second order conditions (SOC), and rewriting, we have

$$\text{(A13)}\qquad 1+(\partial l^*/\partial c_R) \overset{s}{=} U_{11}^R U_{22}^R - (U_{12}^R)^2 > 0,$$

where the inequality follows from concavity of U^R.

(b) Suppose not. Then $[(dl^*/dm)-1] \geq 0$. Hence, if $dX_m^*/dm < 0$, then $dP/dm > 0$ (by (A10)),

$$dU_1^R/dm = U_{11}^R\ \{(\partial X/\partial L)\ [(dl^*/dm)-1] - (dX_m^*/dm)\} - U_{12}^R\ (dl^*/dm) < 0,$$

and, hence, $d\{-U_1^R + P\}/dm > 0$, contradicting the preservation of the FOC for X_m in (A4). Therefore, we must have $dX_m^*/dm \geq 0$ and, therefore, $dP/dm \leq 0$; with $\partial l^*/\partial P > 0$, it now suffices to show that $[(\partial l^*/\partial m) - 1] < 0$, implying the contradiction that $[(dl^*/dm) - 1] < 0$. Totally differentiating the two FOC for (A4), appealing to SOC, and rewriting, we have $(\partial l^*/\partial m) - 1 \overset{s}{=} -\{U_{11}^R U_{22}^R - (U_{12}^R)^2\} < 0$, where the inequality follows from concavity of U^R. QED.

Proposition 2. $d\Delta E/dc_U < 0$. Higher urban birth rates promote environmental decline.

Proof. With $\partial f/\partial X < 0$, $\partial X/\partial L > 0$, and $\partial l^*/\partial P > 0$ (from problem (A4)), it suffices to show that $\partial P/\partial c_U > 0$. Differentiating:

$$\partial P/\partial c_U = (\partial X_d^*/\partial c_U)/[(dX_m^*/dP) - (dX_d^*/dP)] \overset{s}{=} \partial X_d^*/\partial c_U = [U_{32}^U - U_{33}^U v_U]/(-U_{33}^U) > 0,$$

where the inequality follows from $U_{33}^U < 0$ and $U_{32}^U \geq 0$. QED.

Lemma 1. Assume $U_{31}^U = U_{12}^R = X_{LL} = 0$. Then (1) $\partial c_R^*/\partial E > 0$ and $\partial c_R^*/\partial P > 0$; (2) $\partial m^*/\partial E < 0$ and $\partial m^*/\partial P < 0$; (3) $\partial c_U^*/\partial E \geq 0$ and $\partial c_U^*/\partial P < 0$; and (4) $\partial P/\partial E < 0$, $\partial P/\partial c_R < 0$, $\partial P/\partial m > 0$, and $\partial P/\partial c_U > 0$.

Proof. Let us start with rural household decisions, noting first that

$$\text{(A16)} \qquad U_{cm}^{R*} = U_{11}^R\ (X_L - v_R)\ \{X_L[(\partial l^*/\partial m) - 1] - (\partial X_m^*/\partial m)\} = 0,$$

where the equality follows from differentiating the FOC for problem (A4) and substituting in the brackets. Hence, from problem (A5) (and associated SOC), we have

(A17a) $\partial c^*_R/\partial E = (1/H_R)\,[-U^{R*}_{cE}\ U^{R*}_{mm}] \overset{s}{=} U^{R*}_{cE}$,

(A17b) $\partial m^*/\partial E = (1/H_R)\,[-U^{R*}_{mE}\ U^{R*}_{cc}] \overset{s}{=} U^{R*}_{mE}$,

(A17c) $\partial c^*_R/\partial P = (1/H_R)\,[-U^{R*}_{cP}\ U^{R*}_{mm}] \overset{s}{=} U^{R*}_{cP}$,

(A17d) $\partial m^*/\partial P = (1/H_R)\,[-U^{R*}_{mP}\ U^{R*}_{cc}] \overset{s}{=} U^{R*}_{mP}$,

where $H_R>0$ is the determinant of the Hessian for problem (A5).

Differentiating the FOC for (A4), it can be shown (given the assumptions) that

(A18a) $X_E + (\partial l^*/\partial E)X_L - (\partial X^*_m/\partial E) = 0$,

(A18b) $(\partial l^*/\partial P)X_L - (\partial X^*_m/\partial P) = (1/\,U^R_{11}) < 0$.

Using these relationships, we have

(A19) $U^{R*}_{mE} = -U^R_1\ X_{LE} < 0$, $U^{R*}_{cE} = U^R_1\ X_{LE} > 0$, $U^{R*}_{mP} = -X_L < 0$, $U^{R*}_{cP} = (X_L - v_R) > 0$.

Substituting (A19) into (A17) gives results (1)-(2).

Similarly, totally differentiating the FOC for problems (A8) and (A9) (for choices of X_d and c_U) and appealing to SOC gives:

(A20a) $\partial c^*_U/\partial E = (1/H_U)\,[-U^U_{21}\ U^U_{33}] \overset{s}{=} U^U_{21} \geq 0$,

(A20a) $\partial c^*_U/\partial P = (1/H_U)\,[\,U^U_{33}\,v_U - U^U_{23}] \overset{s}{=} U^U_{33}\,v_U - U^U_{23} < 0$,

where $H_U>0$ is the determinant of the joint Hessian for (A8)-(A9). (A20) implies (3).

Finally, from (A11), we have:

(A21) $\partial P/\partial c_R = (1/\Delta)[-(\partial X^*_m/\partial c_R)]$, $\partial P/\partial m = (1/\Delta)[-(\partial X^*_m/\partial m)]$,

$\partial P/\partial c_U = (1/\Delta)(\partial X^*_d/\partial c_U)$, $\partial P/\partial E = (1/\Delta)[(\partial X^*_d/\partial E)-(\partial X^*_m/\partial E)]$

where $\Delta=[(\partial X^*_d/\partial P)-(\partial X^*_m/\partial P)] > 0$. Further, differentiating the FOC for (A4), we have

(A22) $\partial X^*_m/\partial c_R = (X_L-v_R) > 0$, $\partial X^*_m/\partial m = -X_L< 0$, $\partial X^*_m/\partial E = X_E - [U^R_1\ X_{LE}\ X_L/U^R_{22}] > 0$.

Finally, differentiating the FOC for (A8)-(A9):

(A23) $\partial X^*_d/\partial c_U = v_U - (U^U_{23}\ /\ U^U_{33}) > 0$, $\partial X^*_d/\partial E = 0$ (with $U^U_{31}=0$).

Substituting (A22) and (A23) into (A21 implies (4). QED.

Proposition 4. $dX/dE>0$. Lower initial environmental quality leads to less endogenous environmental degradation.

Proof. Suppose not, $dX/dE\leq 0$. Then because X is an increasing function, we must have $dl^*/dE<0$. With $dX/dE\leq 0$ and $dl/dE<0$, following the logic of the proof of Lemma 1, if $\partial X^*_m/\partial E>0$ (and hence, $\partial P/\partial E<0$), then $dU^R_1/dE>0$ and, hence,

$d(-U^R_1+P)/dE<0$, contradicting the preservation of the FOC for X_m in (A4). Therefore, we must have $\partial X^*_m/\partial E\leq 0$ and therefore, $\partial P/\partial E\geq 0$. With $\partial l^*/\partial P>0$ (from the FOC for (A4)) and $\partial P/\partial E\geq 0$, we will have a contradiction ($dl^*/dE>0$) if $\partial l^*/\partial E>0$. Furthermore, differentiating the FOC for (A4) gives: $\partial l^*/\partial E \overset{s}{=} - U^R_{11}\ U^R_1\ X_{LE} > 0$. QED.

REFERENCES

Abounoori, Esmaiel; McCloughan, Patrick "A Simple Way to Calculate the Gini Coefficient for Grouped As Well As Ungrouped Data" *Applied Economics Letters*, 2003, v. 10, pp: 505-09

Aggarwal, R., S. Netanyahu, and C. Romano. "Access to Natural Resources and the Fertility Decision of Women: The Case of South Africa." *Environment and Development Economics,* 2001, v.6, pp: 209-36

Allen, R. and J. Barnes. "The Causes of Deforestation in Developing Countries." *Annals of the Association of American Geographers,* 1985, v.75, pp: 163-184

Amacher, G., W. Cruz, D. Grebner and W. Hyde. "Environmental Motivation for Migration: Population Pressure, Poverty and Deforestation in the Philippines." *Land Economics,* 1998, v.74, pp: 92-101

Anand, Sudhir and Kanbur, S.M.R. "The Kuznets Process and the Inequality-Development Relationship" *Journal of Development Economics,* 1993, v.40, pp: 25-52

Angelsen, Arild "Agricultural Expansion and Deforestation: Modeling the Impact of Population, Market Forces and Property Rights." *Journal of Development Economics,* 1999, v.58, pp: 185-218

Angelsen, Arild "The Poverty-Environment Thesis: Was Brundtland Wrong?" *Forum for Development Studies*, 1997, v.0, pp.135-154

Azzam, A. and Sekkat, K. "Total Factor Productivity in Moroccan Cereal Agriculture: Accounting for Rainfall, Technical Efficiency, Pricing Policy and Demand Effects?" Working Paper, University of Nebraska, 2003

Bahamondes, Miguel "Poverty-Environment Patterns in a Growing Economy: Farming Communities in Arid Central Chile, 1991-99" *World Development*, 2003, v. 31, pp: 1947-1957

Banerjee, Abhijit and Somanathan, Rohini "The Political Economy of Public Goods: Some Evidence from India" *Working paper, Department of Economics,* MIT, 2005

Barro, R. "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics,* 1991, v.106, pp: 407-443

Bhattacharya, D. "Seemingly Unrelated Regressions with Identical Regressors: a Note." *Economic Letters*, 2004, v.85, pp: 247-255

Bhattacharya, P. "Determinants of Fertility in Three North Indian States: Caste, Female Autonomy and Economic Development." *Canadian Journal of Development Studies,* 1998, v.19, pp: 37-53

Bilsborrow, R., ed. *Migration, Urbanization, and Development: New Directions and Issues.* UNFPA, 1998

Bohn, Henning and Deacon, Robert T. "Ownership Risk, Investment, and the Use of Natural Resources" *American Economic Review*, June 2000, v. 90, pp. 526-49

Bohn, Henning; Deacon, Robert T. "Ownership Risk, Investment, and the Use of Natural Resources" American Economic Review, June 2000, v. 90, pp. 526-49

Boserup, E. *The Conditions of Agricultural Growth.* Chicago: Aldine, 1965

Bound, J., D. Jaeger, and R. Baker. "Problems with Instrumental Variables Estimation When the Correlation Between the Instruments and Endogenous Explanatory Variable is Weak." *Journal of the American Statistical Association,* 1995, v.90, pp: 443-50

Brander, J. and Taylor, S. "The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use."*American Economic Review,* 1998, v.88, pp:119-38

Cavendish, William "Empirical Regularities in the Poverty-Environment Relationship of African Rural Households" *World Development*, 2000, v. 28, pp: 1979-2003

Chopra, K., and S. Gulati. "Environmental Degradation and Population Movements: The Role of Property Rights." *Environmental and Resource Economics,* 1997,v.9, pp: 383-408

Copeland, B. and Taylor, S. "Trade, Growth and the Environment." *Journal of Economic Literature,* 2004, v.42, pp: 7-71

Cropper, M. and C. Griffiths. "The Interaction of Population Growth and Environmental Quality." *American Economic Review,* 1994, v.84, pp: 250-254

Cropper, M., C. Griffiths and M. Mani. "Roads, Population Pressures, and Deforestation in Thailand, 1976-1989. *Land Economics,* 1999, v.75, pp: 58-73

Dasgupta, P. "Population and Resources: An Exploration of Reproductive and Environmental Externalities." *Population and Development Review,* 2000,v.26, pp: 643-89

Dasgupta, P. "The Population Problem: Theory and Evidence." *Journal of Economic Literature,* 1995, v.33, pp: 1879-1902

Dasgupta, P. and Mäler, Karl-Goran "Poverty, Institutions, and the Environemntal-Resource Base" *World Bank Environment Paper*, No.9, 1994

Dasgupta, Susmita; Deichmann, Uwe; Meisner, Craig; Wheeler, David "Where is the Poverty-Environment Nexus: Evidence from Cambodia, Lao PDR and Vietnam" *World Development,* 2005, v.33, pp: 617-638

Deacon, R. "Deforestation and the Rule of Law in a Cross-Section of Countries." *Land Economics,* 1994, v.70, pp: 414-30

Dreze, J. and M. Murthy. "Fertility, Education, and Development: Evidence from India." *Population and Development Review,* 2001, v. 27, pp: 33-63

Duraiappah, A. K. "Poverty and Environmental Degradation: A Review and Analysis of the Nexus" *World Development*, 1998, v. 26, pp: 2169-79

Ehrhardt-Martinez, K., E. Crenshaw, and C. Jenkins. "Deforestation and the Environmental Kuznets Curve: A Cross-National Investigation of Intervening Mechanisms." *Social Science Quarterly,* 2002, v. 83, pp: 226-43

Ehrlich, P., A. Ehrlich, and G. Daily. "Food Security, Population, and Environment." *Population and Development Review,* 1993, v.19, pp:1-32

Erickson, J. and J. Gowdy. "Resource Use, Institutions, and Sustainability: A Tale of Two Pacific Island Cultures." *Land Economics,* 2000, v.76, pp: 345-54

Escobal, Javier; Aldana, Ursula "Are Nontimber Forest Products the Antidote to Rainforest Degradation? Brazil Nut Extraction in Madre De Dios, Peru" World Development, November 2003, v. 31, iss. 11, pp: 1873-87

Filmer, D. and L. Pritchett. “Environmental Degradation and the Demand for Children: Searching for the Vicious Circle in Pakistan.” *Environment and Development Economics,* 2002, v.7, pp: 123-146

Foster, A. and M. Rosenzweig. “Economic Growth and the Rise of Forests” *Quarterly Journal of Economics,* 2003, v. 118, pp: 601-37

Foster, James; Greer, Joel and Thorbecke, Erik “A Class of Decomposable Poverty Measures” Econometrica, May 1984, v. 52, pp. 761-66

Freedman, R. “Fertility Determinants.” In *The World Fertility Survey – An Assessment,* J. Cleland, and C. Scott, eds., Oxford University Press, 1987

Galor, O. and D. Weil. “Population, Technology and Growth: From the Malthusian Regime to the Demographic Transition and Beyond.” *American Economic Review*, 2000, v.90, pp: 806-28

Galor, O. and O. Moav. “Natural Selection and the Origin of Economic Growth.” *Quarterly Journal of Economics,* 2002, v.117, pp: 1133-92

Greene, W.H. *Econometric Analysis.* London: Prentice Hall International, 2000

Grossman, Gene and Krueger, Alan “Economic Growth and Environment” *Quarterly Journal of Economics,*1995, v.110, pp:353-377

Gupta, Indrani and Mitra, Arup “Economic Growth, Health, and Poverty: An Exploratory Study for India.” *Development Policy Review*, 2004, v. 22, pp: 193-206

Heath, John; Binswanger, Hans “Natural Resource Degradation Effects of Poverty and Population Growth Are Largely Policy-Induced: The Case of Colombia” *Environment and Development Economics*, 1996, v. 1, pp: 65-84

Heltberg, Rasmus, "Property Rights and Natural Resource Management in Developing Countries" *Journal of Economic Surveys*, 2002, v. 16, pp: 189-214

Ikefuji, Masako and Horii, Ryo "Wealth Heterogeneity and Escape from the Poverty-Environment Trap" Osaka University Economics and OSIPP Working Paper No. 05-09, May 2005

Innes, R. "Two-Season Subsistence Farming, Urban Food Subsidies and Optimal Agricultural Policy." *Oxford Economic Papers,* 1993, v.45, pp: 668-90

Jha, Raghbendra ; Biswal, Bagala; Biswal, Urvashi D. "An Empirical Analysis of the Impact of Public Expenditures on Education and Health on Poverty in Indian States" *Queen's Institute for Economic Research Discussion Paper* 998, March 2001

Jha, Raghbendra "Reducing Poverty and Inequality in India: Has Liberalization Helped?" *Economics Working Paper*, Australian National University, 2002

Jodha, N.S. "Common Property Resources and the Dynamics of Rural Poverty: Field Evidence from Dry Regions of India" in *Economics of Forestry and Rural development – An Empirical Introduction from Asia,* 2000, (eds.) Hyde and Amacher, University of Michigan Press, USA

Juarez, J. "Analysis of Interregional Labor Migration in Spain Using Gross Flows." *Journal of Regional Science,* 2000, v.40, pp: 377-399

Kahn, H., W. Brown and L. Martel. *The Next 200 Years: A Scenario for America and the World.* Morrow: New York, 1976

Khan, A. and L. Shehnaz. "Determinants of Internal Migration." *The Pakistan Development Review,* 2000, v.39, pp: 695-712

Kumar, Sanjay "Does "Participation" in Common Pool Resource Management Help the Poor? A Social Cost-Benefit Analysis of Joint Forest Management in Jharkhand, India" *World Development*, 2002, v. 30, pp: 763-82

Kummer, D. and C. Sham. "The Causes of Tropical Deforestation: A Quantitative Analysis and Case Study from the Philippines." In *The Causes of Tropical Deforestation*, K. Brown and D. Pearce, eds., UCL Press: London, 1994

Kuznets, Simon "Economic Growth and Income Inequality" *American Economic Review,* 1955, v.45, pp: 1-28

Lopez, Ramon "Where Development Can or Cannot Go: The Role of Poverty – Environment Linkages" *Annual World Bank Conference on Development Economics,* 1997

Loughran, D. and L. Pritchett. "Environmental Scarcity, Resource Collection, and the Demand for Children in Nepal." World Bank Working Paper, World Bank, Washington, D.C., 1997

Lugo, A., B. Schmidt, and S. Brown. "Conversion of Tropical Moist Forest: A Critique." *Interciencia,* 1981, v.7, pp: 89-93

Mäler, Karl-Goran "Environment, Poverty and Economic Growth" *Annual World Bank Conference on Development Economics,* 1997

Malthus, T. *An Essay on the Principle of Population*. Pickering: London (1798, republished 1986)

Martine, G., M. DasGupta, and L. Chen, eds. *Reproductive Change in India and Brazil.* Oxford University Press: New Delhi, 1998

Meadows, D. *The Limits to Growth.* Universe Books: New York, 1972

Merrick, T. "Land Availability and Rural Fertility in Northeastern Brazil." *Research in Population Economics,* 1981, v. 3, pp: 93-121

Mink, S.D. "Poverty, Population and the Environment" *World Bank Discussion Paper* no. 189, 1993.

Moran, Emillo; Packer, Alissa; Brondizio, Eduardo and Tucker, Joanna "Restoration of Vegetation Cover in the Eastern Amazon" *Ecological Economics*, 1996, v. 18, pp: 41-54

Mortimore, Michael "Long-Term Change in African Drylands: Can Recent History Point towards Development Pathways?" *Oxford Development Studies*, 2003, v. 31, pp: 503-18

Narain, Urvashi; Gupta, Shreekant; Veld, Klaas Van 't "Poverty and the Environment: Exploring the Relationship between Household Incomes, Private Assets and Natural Assets" Working Paper no. 134, Centre For Development Economics, Delhi (April, 2005)

Nelson, Andrew; Chomitz, Kenneth M. "The Forest-Hydrology-Poverty Nexus in Central America: An Heuristic Analysis" *The World Bank Policy Research Working Paper* Series: 3430, 2004

Nerlove, M. "Population and the Environment: A Parable of Firewood and Other Tales." *American Journal of Agricultural Economics,* 1991, v.73, pp: 1334-1347

Panayotou, T. "Population and Environment." CID Working Paper No. 54, July 2000

Panayotou, T. and S. Sungsuwan. "An Econometric Analysis of the Causes of Tropical Deforestation: The Case of Northeast Thailand." In *The Causes of Tropical Deforestation*, K. Brown and D. Pearce, eds., UCL Press: London, 1994

Pfaff, A. "What Drives Deforestation in the Brazilian Amazon? Evidence from Satellite and Socioeconomic Data." *Journal of Environmental Economics and Management,* 1999, v.37, pp: 26-43

Place, F. and K. Otsuka. "Population Pressure, Land Tenure and Tree Resource Management in Uganda." *Land Economics,* 2000, v.76, pp: 233-51

Rao, C.H.H, Agricultural Growth, *Rural Poverty and Environmental Degradation in India*, Oxford University Press, Delhi, 1994

Ravallion, Martin and Datt, Gaurav "Why Has Economic Growth Been More Pro-poor in Some States of India Than Others?" *Journal of Development Economics*, 2002, v. 68, pp: 381-400

Ravnborg, Helle Munk "Poverty and Environmental Degradation in the Nicaraguan Hillsides" *World Development*, 2003, v. 31, pp: 1933-46.

Reardon, T and Vosti, S. A. "Links between Rural Poverty and Environment in developing countries: Asset Categories and Investment Poverty" *World Development*, 1995, v. 23, pp: 1495-1506

Reis, E. and S. Margulis. "Economic Perspectives on Deforestation in the Brazilian Amazon." Paper presented at the Project Link Conference, Manila, 1990

Reuveny, R. and C. Decker. "Easter Island: Historical Anecdote or Warning for the Future?" *Ecological Economics*, 2000, v.35, pp: 271-87

Rosenzweig, M. and O. Stark, eds. *Handbook of Population and Family Economics.* Volume 1A & 1B, Elsevier: Amsterdam, 1997

Rosenzweig, M. and R. Evenson. "Fertility, Schooling, and the Economic Contribution of Children of Rural India: An Econometric Analysis." *Econometrica,* 1977, v. 45, pp: 1065-79

Sah, R. "The Effects of Child Mortality Changes on Fertility Choice and Parental Welfare." *Journal of Political Economy,* 1991, v. 99, pp: 582-606

Satterthwaite, David "The Links between Poverty and the Environment in Urban Areas of Africa, Asia and Latin America" *The Annals of the American Academy of Political and Social Science*, 2003, v. 590, pp: 73-92

Scherr, Sara J. "A Downward Spiral? Research Evidence on the Relationship between Poverty and Natural Resource Degradation" *Food Policy*, 2000, v. 25, pp: 479-98

Schultz, P. "Demand for Children in Low Income Countries." In *Handbook of Population and Family Economics,* eds., M. Rosenzweig and O. Stark, Volume 1A, Elsevier: Amsterdam, 1997

Seldon, Thomas M. and Song, Daqing "Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions?" *Journal of Environmental Economics and Management*, 1994, v.27, pp:147-16

Shafik, Nemat and Bandyopadhyay, Sushenjit "Economic Growth and Environmental Quality: Time Series and Cross Section Evidence" World Bank Working Paper Series no.904, 1992

Shiva, M.P.; Verma, S.K. *Approaches to Sustainable Forest Management and*

Biodiversity Conservation with Pivotal Role of Non Timber Forest Products. 2002 Valley Offset Printers and Publishers, Dehradun, India

Simon, J. *The Ultimate Resource 2.* Princeton University Press: Princeton,1996

Singh, I., L Squire, and J. Strauss. *Agricultural Household Models: Extensions, Applications and Policy*, 1986, Johns Hopkins University Press: Baltimore

Southgate, D., R. Sierra, and L. Brown. "The Causes of Tropical Deforestation in Ecuador: A Statistical Analysis." *World Development,* 1991, v. 19, pp: 1145-51

Subramaniyan, G. "Determinants of Rural Poverty and Agricultural Performance in Tamil Nadu: 1960-61 to 1970-71" *Economic Affairs*, 1984, v. 29, pp: 23-30

Swinton, Scott M.; Escobar, German; Reardon, Thomas "Poverty and Environment in Latin America: Concepts, Evidence and Policy Implications" *World Development*, 2003, v. 31, pp: 1865-72

Swinton, Scott M.; Quiroz, Roberto "Is Poverty to Blame for Soil, Pasture and Forest Degradation in Peru's Altiplano?" *World Development*, 2003, v. 31, pp: 1903-19

Tiffen, Mary; Mortimore, Michael and Gichuki, Francis. *More People, Less Erosion: Environmental Recovery in Kenya.* 1994, J.Wiley, New York

Wade, Robert "Common Property Resource Management in South Indian Villages" in *Common Property Resource Management*, 1986, National Academy Press, Washington D.C.

Wolpin, K. "Determinants and Consequences of Mortality and Health of Infants and Children" in *Handbook of Population and Family Economics*, Vol. 1A, M. Rosenzweig and O. Stark (ed.s), 1997, Elsevier Science: Amsterdam

Wooldridge, J. *Introductory Econometrics: A Modern Approach*. South-Western: Mason, 2003

Yool, S. “Enhancing Fire Scar Anomalies in AVHRR NDVI Time-Series Data.” *Geocarto International,* 2001, v.16, pp: 5-12