INTERACTION BETWEEN POPULATION GROWTH AND ENVIRONMENTAL QUALITY: EVIDENCE FROM SOUTH, WEST AND CENTRAL INDIA

by

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A Thesis Submitted to the Faculty of the

Department of Agricultural and Resource Economics

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

The University of Arizona

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ACKNOWLEDGEMENTS

I would like to sincerely thank Dr. Robert Innes, whose continuous support, excellent guidance and keen interest in the subject led to the present form of this work. I am fortunate to have Dr. Innes as my mentor. I would like to convey my special thanks to Dr. Dan Osgood, for spending time and showing interest in my work since its inception. I am especially thankful to Dr. Gary Thompson from whom I have learnt a lot, both in and outside the classroom. I would also like to thank Dr. Satheesh Aradhyula for his advice.

I would like to express my gratitude to Kathryn Mauz (Arizona Remote Sensing Center, University of Arizona) for her immense help in image processing. I am also grateful to Dr. Craig Wissler, Mickey Reed and the team of Advanced Resource Technology Lab (Renewable Natural Resources, University of Arizona) for their unconditional help.

The extremely friendly ambience of the AREC department has a major contribution towards this work. I would like to take the opportunity to thank all the faculty members with whom I had the opportunity to interact during my academic experience in this department, especially Dr. Paul Wilson. I also thank Nancy Smith, Nancy Bannister, Jane Wershay and my colleagues for their help and support.

My family deserves a special mention for providing me the moral support all along the way.

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Abstract

Most of the empirical studies have treated the relationship between population growth and environmental quality as a unidirectional causal relation. The focus has been on environmental degradation caused by population growth. The effect of environmental quality on population change has not been given adequate attention. This study examines the interactive relationship between population change and environmental quality for Western, Central and Southern India. A vegetation index called NDVI, has been used to denote the environmental quality. Simultaneous equation models have been used to capture the interactive relation. Evidence from this region for the decade of 1991-2001 suggests that there exists a bi-directional between population change and change in environmental quality. The evidence suggests that in the rural areas where the people are extremely dependent on natural resources, change in environmental quality negatively affects population change and population change also has a negative impact on environmental quality. On the basis of this study it can be concluded that the interactive relation between population change and change in environmental quality is stronger in rural areas of the study region.

1. Introduction

It is a well-recognized fact that human sustenance is dependent on the ultimate resource, the natural environment. The natural environment encompasses all types of natural resources – the flora and the fauna, land, air and water. Overexploitation of the natural resources disturbs the delicate environmental balance thereby degrading the environment. Environmental degradation has serious implications not only for the natural balance of the ecological system but also for the economic and social systems (Maxwell and Reuveny 2000). Hence the effect of population growth on environmental quality has become a major concern, especially in the developing world, where the natural resources are being exploited at alarming rates in order to meet the requirements of the growing population thereby depleting the environmental quality (Regmi and Weber, 2000). According to the theoretical literature, the interaction between population growth and environmental quality is not unidirectional. Environmental quality does have an effect on population growth as well (Malthus 1798; Boserup 1965; Nerlove 1991; Dasgupta 1995, 2000). In the empirical literature, only one paper (Filmer and Pritchett, 2002) has addressed this bi-directional aspect so far.

In this study, the interactive relation between change in environment quality as measured by a vegetation or greenness index[1] and population change has been analyzed for western, central and southern regions of India. India is an interesting case to study in this context. India's population has already surpassed one billion and is still growing at a rate of 1.94 percent per annum (2001 Census of India). Around 70 percent of this huge and growing population resides in rural areas where the livelihood of people is heavily dependent on agriculture (natural resources[2]). Hence the interaction between the population and environmental quality is expected to be pronounced.

This paper is organized as follows. Section 2 reviews the literature. Section 3 outlines the purpose of this paper and section 4 describes the data. Section 5 discusses the model. Section 6 analyzes the regression results and finally section 7 concludes with the implications of this study.

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[1] We have used Normalized Difference Vegetation Index (NDVI) as a measure of environmental quality as vegetation or greenness is highly correlated with environmental quality. Calculation of NDVI is based on several spectral bands of the photosynthetic output in a pixel of a satellite image. It measures the amount of green vegetation in an area. NDVI calculations are based on the principle that green plants strongly absorb radiation in the visible region of the spectrum called Photosynthetically Active Radiation (PAR), while strongly reflecting radiation in the Near Infrared region (NIR). The concept of vegetative "spectral signatures (patterns) is based on this principle. NDVI can take a value between 0 and 256. NDVI for a pixel is calculated from the following formula:
$NDVI = (NIR - PAR) / (NIR + PAR)$.

[2] We have used the term 'natural resources' interchangeably with the term 'environmental quality' as they are very highly correlated.

2. Literature Review

The sustainability of population growth without degrading the carrying capacity[3] of the earth is a highly debated issue. The debate has a long history and is still going on (Arizpe, Stone and Major 1994; Panayotou 2000). The theory of population growth and its relationship with natural resources can be traced back to Malthus about two centuries ago. The famous Malthusian theory about population growth and its implications arose in 1798. According to Malthus, population expands geometrically, but food production can only increase arithmetically. Malthus argued that land scarcity, the limited production capacity of cultivable land, and the law of diminishing returns are the constraints on expansion of food supply. On this basis he predicted that population growth would inevitably reach a maximum limit when limited food supply will restrict further population growth and bulk of the population will be reduced to bare subsistence level or at worst the population might be wiped out.

The development process of the twentieth century seemed to refute the Malthusian hypothesis. Several factors like technological progress, socio-political changes enabled the ever-increasing human population to sustain itself. These trends gave rise to the neoclassical view or the Boserupian view. The Boserupian view is the polar opposite of Malthusian view. Boserup (1965) argued that population pressure induces agricultural intensification using technological and institutional innovations. The innovations can create resource-conserving technologies that can sustain the natural resources along with the population growth. The Boserupian argument seemed to explain the failure of the

Malthusian view. But, Garrett Hardin's (1968) seminal work, "The Tragedy of the Commons" which, argued that users of a common resource (water, land, air etc.) would inevitably destroy the very resource upon which they depend, revived the neo-Malthusian argument. The oil crisis of the seventies and the famines of Africa further strengthened neo-Malthusian views. The neo-Malthusians like Ehrlich (1972,1990,1993) and Meadows (1974) argued that unrestricted population growth and the accompanying production increase would soon exceed the earth's carrying capacity leading to complete breakdown of the environmental and socio-economic systems. The neo-Boserupians like Kahn, Brown and Martel (1976), Simon (1981, 1986) argued that human ingenuity[4] is capable enough to solve the resource scarcity problem. Hence population growth can be easily sustained by continual innovations. Thomas Homer-Dixon (1995) pointed out the socio-economic limitations for the supply of human ingenuity. But the intense debate between the neo-Malthusians and neo-Boserupians still continues as the empirical evidence on this subject is mixed.

There are instances where population growth has resulted in deforestation and soil erosion thereby causing serious environmental problems and social conflicts and in extreme cases the population has also been wiped out. There are other instances where sustainable practices have made it possible to conserve environmental quality along with rising population density. Easter Island and Tikopia Island are interestingly two contrasting historical examples that emphasize the importance of the balance between human population and environment (Brander & Taylor 1998, Erickson & Gowdy 2000).

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[3] The carrying capacity of earth is defined as the maximum number of people that could be sustained at any given time without undermining the planet's capacity to support people in the future.

Both Easter Island and Tikopia Island were settled by Polynesians. While the reckless natural resource depletion by the growing population eventually wiped out the population of Easter Island, Tikopia Islanders sustained themselves by resource conserving socio-economic practices. In the present context, Tiffen (1995) depicted the case of Machakos district in Kenya where increasing population density has contributed to resource conservations. Tiffen's study showed that methods like local community based regulations and/or government regulations can be used successfully to adopt technologies that can allow sustainable use of common resources. Amacher, Cruz and Grebner (1998), Sunderlin and Resosudarmo (1999) describe the negative impact of population pressure on forests for Philippines and Indonesia respectively.

These empirical studies have essentially treated the relationship between population growth and environmental degradation as an issue of unidirectional causality. The effect of population on the environment has been the focus of these studies. Empiricists have not paid due attention to the effect of environment on population growth, but theorists have. Nerlove (1991) looked at the optimal human fertility behavior subject to environmental constraints, along with the impact of population pressure on environment. His work was aimed towards explaining the situation of the developing countries where the human fertility behavior can respond positively to environmental degradation as children become more beneficial to parents in adverse environmental circumstances. This situation arises because of the fact that the survival of the extremely poor people is heavily dependent on natural resource extraction. Nerlove's work was followed by that of

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[4] The generation of ideas that can be applied to solve practical social and technical problems is referred to as 'ingenuity'.

Dasgupta (1995). He looked at the interface of population growth, poverty and environmental degradation by fusing the theoretical models with empirical findings mostly based on studies of sub-Saharan Africa and the Indian subcontinent. He argued that there is no strict causality amongst these three factors but they influence each other. Environmental degradation drives poor people to devote more time in natural resource extraction activities like firewood collection, fetching water, etc. This increases the demand for children as children are entrusted with these gathering activities. In some of the poorest regions of the world these factors affect each other to such an extent that a vicious circle is created. In the literature this is often referred to as the *'vicious cycle'* theory. This theory holds true under very special circumstances where opportunities to break the cycle do not exist. Migration opportunities, government or non-government aid, and/or community efforts can help in breaking this vicious cycle. If this cycle persists without any external intervention, the resource scarcity will eventually halt population growth. Thus, extending the vicious cycle in a long time horizon, the theory will fall in line with the neo-Malthusian view.

The Boserupian theory also implies a bi-directional relationship between population and environmental quality. The neoclassical or Boserupian theory is based on the argument that resource scarcity created by population pressure induces resource conserving technological innovations. Technological innovations bring economic development and economic development, in turn, leads to a decline in the population growth rate, as has been the experience of the developed countries. Hence, the neoclassical theory also implies a bi-directional relationship between population growth and environmental quality through the intermediating factor of technological innovations. Just like the Malthusian hypothesis, the Boserupian hypothesis can be verified only in a long time frame. A short time frame can only be used to test the vicious cycle theory.

To the best of my knowledge,Filmer and Pritchett's (2002) paper on Pakistan is the only empirical study, which treats the relationship between population growth (fertility) and environmental degradation (resource scarcity) as bi-directional. They used data from 1991 Pakistan Integrated Household Survey (PIHS) to test the 'vicious cycle theory' by analyzing the relationship between fertility and firewood scarcity. From the estimates of the effect of presence of children (population) on the consumption of firewood (environment) and the impact of firewood scarcity (environment) on the demand for children (population), they tried to explain the cyclical relation between environment and population. Although, the results did not yield any general conclusion, one province in the study region (the Sindh Province) yielded results consistent with the vicious cycle theory.

3. Objective of Study

The existing empirical literature lacks studies on the bi-directional relationship between population growth and environmental quality. This paper attempts to fill this gap.

This study addresses three main questions. First, does there exist any relation between population change and the change in natural resources in the study region. Second, is the relationship unidirectional or bi-directional? Third, if a bi-directional relation exists, which of the bi-directional theories do the data support — the Malthusian, Boserupian or the vicious cycle theory?

Since the focus of this study is on the interaction between population change and change in environmental quality, simultaneous equation systems have been used to analyze the relation between vegetation change and population change for the districts of eight states belonging to western, central and southern regions of India.

The study is divided into two parts — short run (1991 to 1994) and long run (1991 to 2001) as the long-run relationship can vary significantly from the short-run. In the short-run, empirical evidence can only test the vicious cycle theory. But in the long run the evidence can test all the three theories — the Malthusian, the Boserupian and the vicious cycle theory. Hence the time span of a study is very important.

The relationship between population change and change in vegetation can also vary between rural and urban areas. In rural areas human livelihood is more heavily dependent on natural resources as compared to urban areas where people are mostly employed in industries or services. Thus the interaction between population and natural resources can be expected to be relatively more pronounced in the rural areas. Hence areas have been further classified as rural or urban.

Population growth in a given region can be attributed to two kinds of factors: net birth rate and net migration[5]. Birth rates (fertility) and migration can have different kinds of interactions with the environment. Positive net births and positive net migration to an area, both put more strain on the natural resources. The effect of natural resources on fertility is not unambiguous. Resource scarcity can have a negative impact on the fertility decisions if people view resource scarcity as a constraining factor for their ability to afford more children. But resource scarcity can have a positive impact on fertility if children are viewed as additional help in extracting natural resources for survival as is argued by the proponents of vicious cycle theory. The impact of resource scarcity on migration is unambiguous. While regions with higher natural resources attract migrants, resource scarce regions induce out-migration and even distress migration[6].

So an analysis of the relation between population growth and environmental quality will be further enriched if population growth is decomposed into net births and net migration. Hence population change has been analyzed in terms of fertility and migration in the short-run model (1991 to 1994). The decomposition of population change into fertility and migration is not possible for the 1991 to 2001 (long-run period) due to data limitations. Hence for the period 1991 to 2001, the aggregate population change has been analyzed.

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[5] Net birth rate is defined as births minus deaths per thousand population. Net migration is defined as number of incoming migrants less the number of outgoing migrants.

[6] Distress migration is caused by extreme survival conditions. In the context of this study sever resource degradation causes distress migration.

4. Data

In this study, district level data have been used for eight states of India, for which the required data were available. The eight states are from the southern (Andhra Pradesh, Tamil Nadu, Karnataka, Kerela), western (Maharashra, Gujarat, Rajasthan) and central (Madhya Pradesh) parts of India. The profiles of the states and names of the districts are provided in Appendix Table A.1 and Table A.2 respectively. The shaded portion of the map in Figure A.1 shows the study area.

Several studies (Talbot 1986; Pachauri and Qureshy 1997; Amacher, Cruz and Grebner 1998; Drechsel et al. 2001) have shown that natural resources are mostly affected by the population growth, the level of economic activities, literacy and climatic factors. Fertility is highly influenced by socio-economic factors like income, natural resources or environmental quality, literacy, health facilities, social norms and religious beliefs (Freedman 1987; Dasgupta 1995; Schultz 1997; Rosensweig & Stark 1997; Bhattacharya 1998; Martine, Dasgupta & Chen 1998). Migration is influenced by income, literacy, natural resources and other socio-economic factors (Chopra and Gulati 1997;Bilsborrow 1998; Khan and Shehnaz 2000; Juarez 2000).

Data on natural resources or environment are relatively more difficult to obtain. Land, air, water, minerals, wildlife, forests etc. all comprise the natural resource base. The heterogeneous nature of all these resources makes it very difficult to define a single measure of quality of natural resources or environment. To conduct an empirical study on environmental degradation, one has to focus on a particular aspect. Forests are one of the worst affected natural resources, which are highly correlated with environmental degradation. Hence, data on change in forest cover can be a good measure for environmental degradation. But adequate time series data on India's district-level forest cover were not available. Hence, Normalized Difference Vegetation Index, commonly known as NDVI, has been used as a measure of vegetation or greenness. The higher is the value of the index, the higher is the greenness and vice versa. Hence a positive or negative change in NDVI denotes environmental improvement or degradation respectively. This greenness index is based on satellite images. It captures the greenness not only of the natural forests, but also of commercial plantations and cropped fields to some extent. Thus NDVI is not an exact measure of the forests. But it is quite a good indicator of forests as NDVI and forest area are positively correlated between in the study region whereas NDVI and net sown area are negatively correlated (see Appendix Table B.1). Since the greenness of agricultural lands varies significantly across seasons in a year, the annual average of NDVI is lower in districts with higher proportion of land under agricultural land relative to forests, as the variance in greenness of the forests is less across seasons.

Satellite images obtained from National Aeronautics and Space Administration (NASA) were processed using Geographic Information Systems (GIS) techniques[7] to obtain the district-specific index. GIS techniques allow us to magnify the area according to our requirements, allowing us to obtain the NDVI index at district level from the images of India. For the short-run study the change in annual average NDVI from 1990-91 to 1993-94 was examined. In the long-run model, the change in NDVI is measured by the difference between the 2000-2001 average and the 1990-91 average. Two-year averages are used in order to get better measures, as there were missing observations for the last four months of 1994 and the last two months of 2001. The 1991 annual average of NDVI denotes the base level of environmental quality. The initial level of environmental quality affects fertility and migration decision. Hence NDVI at 1991 levels was used as an explanatory variable for fertility and migration in the short-run and for population density change in the long run. The change in average annual NDVI from 1986 to 1990 was also used, as past changes in environmental quality can affect subsequent population change as well as the subsequent change in environmental quality.

[7]The monthly composite images downloaded from NASA's website were in Interrupted Goodes Homolosine projection. They were reprojected into Universal Transverse Mercater (UTM). From UTM they were reprojected to Geographic projection. The monthly images were stacked to calculate the annual or two-year averages and standard deviations. Using the political map of India, the district level NDVI averages and standard deviations were extracted. ERDAS Imagine and ARC Info softwares were used for this purpose.

Rainfall is an important climatic factor affecting vegetation. Actual annual and normal rainfall data are available for meteorological subdivisions of India. Each meteorological subdivision consists of several districts. The meteorological subdivisions of India have been defined according to climatic features. Hence average deviations[8] from the normal rainfall by subdivision have been used to represent a climatic factor affecting vegetation. Rainfall deviation of the recent past is as important as the contemporaneous deviation. Hence, contemporaneous as well as lagged average annual deviations in rainfall were used. A large deviation in rainfall, either positive (flood) or negative (drought), severely affects the forest covers and other vegetations. The NDVI measure for a given time period can reflect the effect of such a deviation of the recent past. Hence average deviation in rainfall for the period 1988 to 1991 was used to denote the past deviation. For the short-run model the contemporaneous deviation in rainfall is represented by the average deviation during 1991-1994. For the long-run study the average deviation of rainfall during the period 1991-2000, represents the contemporaneous deviation, as the data was available till the year 2000 only.

Indian census provides the demographic data. Indian census is conducted once in every ten years. Data from the 1991 and 2001 census were available. Hence the long-run study covers changes over this decade.

The Registrar General's Office of India publishes annual data on births and deaths. Data on district level (total, rural and urban) births, total deaths and infant deaths were available for four years, 1991 to 1994. Data on annual birth and deaths rates were also

[8] The deviations are calculated as observed annual rainfall minus the normal annual rainfall.

available at district level (without the rural-urban classification) for 1991 to 1994. But migration data were not available. The migration numbers were calculated using the total population, births, deaths, birth rates and death rates. Using the annual birth rates and birth numbers the population for 1994 was calculated. The difference between 1991 and 1994 populations gave the total population change. By subtracting the net births during the period 1991 to 1994 from the population change during that period gave the net migration during that period[9]. Because data on birth and deaths are not yet available for the entire period 1991-2001, the total population change for the decade (1991-2001) could not be disaggregated into net births and net migration.

Adequate district level socio-economic secondary data are extremely difficult to obtain. All the income measures that were available were at a state level. The best measure available as a proxy of income was state-level index of per capita monthly consumption expenditure for rural and urban areas for 1991. Though the state-level indicator masks the district-level heterogeneity within a state, the heterogeneity across the rural and urban areas can be considered. Due to a lack of better measure of health facilities at district level, district-level rural and urban infant mortality rates (infant deaths per thousand live births) and the raw death rates (for the entire population) have been used as indicators of health facilities. District-level rural and urban literacy rates (female literacy and total literacy), percentage of women main workers, average household size,

[9] Since the birth and death rates are computed on the basis of the mid-year population, while the birth and death numbers represent the figures for the calendar years, we calculated the net migration in the following way:
Net Migration = (P94 - P91)-0.5(NB91+NB94)-(NB92+NB93), where P and NB denote population and net births respectively and the numeric notations denote the years.

sex ratio (females per thousand males) and percentage of Muslim population (representing religious composition) are the other socio-economic variables used in this study. Hindus and Muslims constitute majority (over 95 percent) of the total population in India. Hence, the proportion of one of these religions is a good indicator of the religious composition within a district. All these socio-economic variables are for 1991. The population and the socio-economic variables have been further classified into urban and rural for each district. Only the natural factors, NDVI and rainfall, could not be classified by rural and urban area. The data sources for all of the above mentioned data have been provided in Appendix D.

The short-run study includes 197 districts[10] out of the 199 districts belonging to the above-mentioned eight states for (1991-94). In the late nineties significant changes took place in the definition of several districts covered in this study. Adjustments have been made to the data according to the redefinitions so that the 2001 data are comparable to 1991(see Appendix table A.3). Hence there are effectively 196 districts for the long-term study.

An ideal dataset for the analysis of relationship between population growth and environmental degradation would be a micro-level panel dataset with heterogeneous cross sections. But such ideal datasets rarely exist. The district-level data are the most disaggregated level data available. The study area is heterogeneous in terms of demographic, environmental and socio-economic factors (see Appendix Table B.3 for the

[10] Two districts, Nalgonda (Andhra Pradesh) and Tirunelveli-Kattabomman (Tamil Nadu) were omitted because of missing fertility data for the year 1994.

vital statistics of the variables). Due to lack of time series data for district-level socio-economic variables cross-sectional models are used, instead of fixed effect panel model. Initial (1991) levels of the socio-economic variables have been used to explain the changes in the variables of interest – population change and NDVI change. These models analyze the relation between population change and NDVI change for a given level of economic and social development. This captures less of the real world dynamics, as the changes in economic and social indicators are not taken into account. But the cross-sectional approach is not too unrealistic, as economic and social changes take much longer to occur than do environmental and population changes. Chopra and Gulati (1997) have used a similar model structure for analyzing the relationship between environmental degradation and distress migration mediated by property rights for arid and semi-arid regions of western India. The endogenous variables in their simultaneous equation system are migration, change in property rights and environmental degradation. The variables of interest are expressed in terms of change between two points in time in early and late 1980's. Due to lack of time series data, they used several explanatory variables like per capita food grain production, proportion of literate population, and a non-agricultural development index in the levels. Hence inadequate time series data can be handled by the above-mentioned setup.

5. Models

Simultaneous equation models have been used to analyze the short-term (1991 to 1994) and the long-term (1991 to 2001) relationship between population change and NDVI change. The models for the short run and long run differ because of the data limitations. But both have similar structure.

Apart from the socio-economic and climatic factors mentioned in the previous section, two dummy variables have also been used. The dummy variables are called Kerala dummy and Metro dummy. Kerala is a state, which has some special social features that distinguishes it from the other states. For example, Kerala has the highest literacy rate in India. It also has the highest sex ratio (females per thousand males) and is a predominantly matriarchal society. Hence the Kerala dummy has been used to capture effects that are specific to Kerala. This study has some metropolitan districts like Madras, Greater Bombay, Hyderabad, Bangalore, which are economically developed and have extremely high population densities compared to other districts of the study region. The metro dummy has been used to check for any effects specific to these metropolitan districts. Squared per capita consumption expenditure has been used as an explanatory variable for change in NDVI as the environmental Kuznets curve[11] theory suggests that income has a quadratic relation with environmental quality (Cropper and Griffith 1994).

[11] Environmental Kuznets curve theory says that the relationship between environmental degradation and income has an inverted-U shape. As income increases, environemental degradation increases in the beginning. But after a certain critical level of income is reached, people demand environmental quality as a consumption good and environmental degradation starts declining.

Squared per capita consumption expenditure is also used in fertility equations in the short run and population change equations in the long run. Birth rates can increase initially with a rise in income if children are treated as consumption good but can decline subsequently as quality of upbringing of children becomes more important (Schultz 1997). The urban birth rate is included in the rural fertility equation and vice-versa because rural and urban areas are posited as having mutual spillover effects within a district in the short-run model. In the long-run model the urban population change is included in the rural population change equation and vice versa to take into account the spillover effects within a district.

In the short-run models the endogenous variables of interest are rural and urban fertility, migration and change in NDVI. Hence there are four equations in the short-run models. The first two equations capture the effect of socio-economic and environmental variables on rural and urban fertility. The third equation depicts the factors affecting migration and the fourth equation explains the change in NDVI.

Recent literature (Davies, Greenwood and Li 2001; Knapp, White and Clark 2001) indicates that migration can be modeled efficiently using a multinomial logit model. To use a multinomial logit model one needs data on origin and destination of the migrants. Since information on the origin of the migrants was not available, a multinomial logit model could not be used for migration. Instead of a multinomial logit model, a simple linear model has been used to explain the calculated net migration into each district.

The long-run models depict the change in rural and urban population density and change in NDVI. Hence there are three equations in the long-run models. The first two equations depict the factors affecting change in rural and urban population density. The third equation explains the change in NDVI. The same set of socio-economic explanatory variables has been used in the long-run model as in the short-run model as they depict the same initial (1991) socio-economic conditions. Only the contemporaneous average deviation in rainfall has been changed to match the period 1991-2000.

Several model specifications were used for the short run and the long run. The results of the most exhaustive models are presented here. The exhaustive model specifications for the short run and the long run are given in Appendix Table B.4 and B.5 respectively.

All the short-run andlong-run models are simultaneous equation systems because the hypothesis is that the change in environmental quality and population change affect each other simultaneously. Hence, the change in NDVI is used as one of the explanatory variables for fertility and migration in the short-run and for change in population density in the long run. These endogenously determined population change variables subsequently explain the NDVI change. Due to the endogenous nature of the explanatory variables in the system of equations, the three stage least squares method[12] of estimation was used. For exact identification each equation in the short run model should have excluded three exogenous variables. For the long run model exact identification requires exclusion of two exogenous variables for each equation. In both the long run and the short run models, the equations are over identified. The list of excluded exogenous variables for each equation of the exhaustive short run and long run models are provided

[12] The three stage least squares (3SLS) method gives consistent and efficient results for simultaneous equation systems (Greene 2000).

in Appendix Table B.6 and B.7 respectively. In the short run models, the equation explaining rural fertility excludes deviations in rainfall, total literacy and all the urban socio-economic variables. Hence the rural fertility equation excludes 14 exogenous variables. The equation explaining the urban fertility not only excludes deviations in rainfall, total literacy and all the rural socio-economic variables, it also excludes the net sown area. Hence the urban fertility equation excludes 15 exogenous variables. The migration equation excludes sex ratio, percentage of Muslim population and average deviations in rainfall. Thus it excludes 14 exogenous variables. The equation explaining change in NDVI equation excludes selected social variables such as female literacy rate, infant mortality rate, sex ratio, percentage of Muslim population and average household size. Hence it excludes 10 exogenous variables in all. Similarly, in the long run model the equations explaining rural population change, urban population change and change in NDVI exclude 13, 14 and 10 exogenous variables respectively. The estimations were done using the statistical software SAS.

6. Econometric Results

The regression estimates are presented in Appendix tables C.1 to C.4. The column headings denote the variable being explained and the explanatory variables are listed in the rows. Two sets of models are presented for both the short run and the long run. Model 1 represents the most exhaustive specification. Model 1 results show that the squared per capita consumption expenditure (RCE2 and UCE2) terms are not significant in the fertility equations in the short-run and the population change equations in the long run. Hence in Model 2 the squared per capita consumption expenditure was omitted for rural and urban fertility equations in short-run and the rural and urban population change equations in the long run. Results of F-test (see Appendix Table C.5) strengthen the relevance of model 2.

The results of short-run fertility and migration equations provide a glimpse of the disaggregated effect of environmental quality on population change. The long-run population change equations provide only the aggregated picture. On the other hand, significant change in environmental quality can take place only over a long time period; hence the change in environmental quality in long run is more relevant than the short run. The elasticities[13] of environmental quality with respect to population change and vice-versa are presented in Appendix Tables C.6 and C.7 for the short run and the long run respectively.

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[13] The elasiticities have been calculated using the results of model 2 and the sample means of the variables. Hence the estimated elasticities are highly influenced by the mean values. For instance, in the short run, the elasticity of migration with respect to NDVI is very high because of the fact that the average migration rate was extremely low in the sample.

6.1 Implications of the Short-Run Model Estimates

6.1.1 Fertility

Since the focus of this study is on the relation between environmental quality and population, the effect of environmental quality are first examined. Results of both the short run models (Appendix Table C.1 and C.2) show that rural fertility (RBPOP94) is negatively affected by contemporaneous change in NDVI (NC9091T9394) and the base level of NDVI (N91). This result depicts the phenomenon of very high dependence on natural resources in rural areas. Nerlove (1991) and Dasgupta (1995) have argued that children are viewed as additional hands for resource extraction for the poor natural resource dependent people. With a decline in greenness or resources (NDVI), more hands are needed for sustaining a family dependent on resource extraction. Hence declining NDVI is related with higher birth rates. In contrast to the rural fertility, urban fertility (UBPOP94) is positively affected by contemporaneous (NC9091T9394) and lagged (NC86T90) change in NDVI. Since urban dwellers do not depend on the natural resources for their livelihood, this effect is reasonable. In urban areas improvement in environmental quality is viewed as improvement in living conditions. Since environment is a qualitative consumption good in urban areas, higher environmental quality is associated with higher demand for children and vice-versa.

In what follows, the effects of socio-economic factors on fertility are summarized from the results of short-run model 2.

Income: The results of short-run model 2 (Table C.2) show that the per capita consumption expenditure (RCE or UCE) has a negative impact on birth rates in both rural and urban areas. Since per capita consumption expenditure is an indicator of income, this effect is expected. Higher income districts have lower demand for children as with higher income people start aspiring for quality rather than quantity of children.

Urbanization: Rural fertility is positively influenced by urban fertility (UBPOP94). This implies that districts with lower urban birth rates have lower rural birth rates as well. Hence there is strong spillover effect from urban to rural areas. Percentage of urban population (UP) has a negative effect on urban birth rates. It implies that the more urbanized a district is, more prevalent are the modern values and lower is the birth rate.

Female Employment: The proportion of rural female main workers (RFMW) does not have any significant effect on rural birth rates as in rural areas females are mostly engaged in family farms. Employment in family farms implies women can work staying at or near their homes. Thus it does not pose any problem for childcare. Hence birth rates are not affected by the working status of rural females. The proportion of urban female main workers (UFMW) has a negative effect on urban birth rate. The opportunity cost of time for working females in urban areas is much higher as they are employed in industrial or service sector as opposed to family agricultural activities of rural areas. Hence, the higher the proportion on female workers, the lower is the birth rate in urban areas.

Average Household Size: Rural household size (RHS) has a positive impact on the rural birth rates (RBPOP94). Joint family system is more prevalent in rural areas of India. These large joint family setups reduce the cost of raising an additional child. Hence rural birth rates are higher for districts with higher average household size in rural areas. In contrast, urban average household size is negatively related with urban birth rates. The cost of raising an additional child in urban areas is much higher as nuclear families are more common in urban areas. Hence, the larger the family size (UHS), the lower is the demand for an additional child in urban areas.

Literacy: Contrary to the general notion, the results show that female literacy rate (RFL and UFL) is positively associated with birth rates both in rural and urban areas. In a country like India, where the proportion of illiterate females is quite high, literacy helps in creating awareness about better neo-natal care, which increases the probability of live births. Literacy also improves social awareness, thereby reducing cases of infanticides and sex- selective abortions. Since the birth rate is calculated as number of live births per thousand population, literacy can have a positive impact by increasing the probability of live births. Literacy is also associated with higher income and higher income can increase the demand for children if children are treated as consumption goods (Merrick 1981).

Health: Birth rates, both in rural and urban areas, are positively associated with the respective death rates (RDPOP94 and UDPOP94). It implies that districts with lower death rates have lower birth rates as well. A lower death rate is an indicator of better health care facilities and better health care facilities help in reducing fertility rate by increasing the life expectancy of the children. Life expectancy of children is an important factor influencing fertility rates in developing countries as parents mostly treat the children as security or support for their old age. This happens due to lack of adequate social security. Because of the same reason, rural infant mortality rate (RIDR) is positively related with rural birth rate. But urban infant mortality rate (UIDR) is negatively related with urban birth rate. Since the cost of child bearing is much higher in urban areas, high infant mortality rates discourage family expansion plans.

Sex Ratio: In the developing world, discrimination against females is a common phenomenon. Sex selective abortions, high rate of female infanticide, relatively poor nutrition of girl child, poor female education are some common indicators of the discrimination. Hence higher sex ratio is usually interpreted as better status of females. But urban sex ratio (USR) is positively related with urban birth rate. In urban areas females have much better status generally as compared to rural areas. Hence larger numbers of females only imply an increase in the number of child bearers, as marriage is a universal phenomenon in India. So higher sex ratio in urban areas is related with higher birth rates.

Religious composition: Religious composition (RMPOP) does not affect rural birth rates, as in rural areas low literacy rate and low income puts everyone in the same pedestal. However the proportion of Muslim population in urban areas (UMPOP) is positively related with urban birth rate. Due to their religious values, Muslims are generally more pro-natalists. Hence districts with higher proportion of Muslims in urban areas have higher urban birth rates.

Dummies: The Kerala dummy (KD) has a significant negative coefficient in rural fertility equation. It implies that on an average, districts belonging to Kerala have lower rural birth rates as compared to other states. This can be attributed to the social factors specific to the state that help in reducing birth rates like high literacy rates, high sex ratio and a matriarchal society. But the Kerala dummy (KD) has a significant positive coefficient in urban fertility equation. Due to much higher population density of urban Kerala, the urban birth rates are much higher than other states.

The metro dummy (MD) has a significant positive effect on urban birth rate. The metropolitan districts are totally urban or have overwhelmingly high proportion of urban population along with extremely high population densities and high income dispersions. Metropolitan districts usually have the highest employment opportunities in the country, which attracts young people in their childbearing age. Hence it has always been a challenge to control the population growth rates of the metro districts like Greater Bombay (Mumbai) or Madras (Chennai).

6.1.2 Migration

Net migration (MIPOP94) is positively affected by contemporaneous change in NDVI and base level of NDVI, implying greenness is an important factor influencing migration. Migrants tend to move to greener districts. Proportion of net sown area has a negative effect on net migration. In India, the agriculture sector is plagued with disguised employment. Hence people migrate out of regions with more agricultural activity. The rural fertility, death rate, literacy rate and per capita consumption expenditure significantly affects migration. Rural birth rates and death rates have positive and negative coefficients respectively. Rural literacy rate has a negative coefficient. The effects of rural demography and literacy on migration can possibly be explained if migration data is decomposed by rural and urban areas. Due to data limitations migration could not be further classified by urban and rural. Hence the effects of rural variables cannot be analyzed meaningfully.

6.1.3 Environmental Quality

The effects of factors explaining the change environmental quality are summarized below.

Population Change: Rural birth rate (RBPOP94) does not have any significant impact on change in NDVI. But urban birth rate (UBPOP94) and migration (MIPOP94) has a significant positive impact on change in NDVI in the short-run (Appendix Table B8 and B9). In urban areas environmental quality is demanded as consumption good. Hence districts with higher population growth rate (birth rate) put in conscious efforts to improve the environmental quality. Since migration data could not be classified by rural and urban migration, the result cannot be analyzed without making some assumption. Assuming that migration is mostly into urban areas as is the general trend in the developing world, it can be interpreted that migration increases the urban population pressure that results in improvement of the environmental quality, as environmental quality is demanded as consumption good in urban areas. Using the same argument the positive impact of urban population density of the base year on NDVI change can also be explained.

Income: Negative coefficient of per capita rural consumption expenditure (RCE) and positive coefficient of square of the per capita rural consumption expenditure (RCE2) implies that as income goes up environmental quality goes down in the beginning; but after a certain level of income is reached environmental quality goes up as it is demanded as consumption good. Hence rural areas support the Environmental Kuznets Curve theory. The urban per capita consumption expenditure gives the opposite evidence. The positive coefficient of per capita urban consumption expenditure (UCE) and negative coefficient of square of the per capita urban consumption expenditure (UCE2) implies that as income goes up environmental quality goes up in the beginning; but after a certain level of income is reached environmental quality goes down. It can be attributed to the fact that though the urban population demands environmental quality as consumption good, after a critical level of urban income is reached further increase in income is not possible without degrading the environmental quality due to high population pressure.

Past Environmental Quality: Past changes in NDVI (NC86T90) negatively affected the change in NDVI during the early 1990's(1990–91 to 1993-94). It implies that districts with declining environmental quality in the past managed to improve the environmental quality between 1991 and 1994. This may indicate that conscious efforts were put in to conserve the environmental quality.

Agriculture: The base level of net sown area (NSA) has a positive effect on change in NDVI. This can be attributed to the fact that NDVI captures greenness from agricultural lands to some extent. Hence districts with large proportion of lands in agricultural use appeared greener.

Rainfall: Past deviations in rainfall (ADR86T90) positively affected change in NDVI and contemporaneous deviations in rainfall (ADR91T94) negatively affected the change in NDVI during 1990-91 and 1993-94.

Dummies: Kerala dummy (KD) has a significant negative coefficient. This implies that in Kerala NDVI declined more than the other states, which can be attributed to extremely high population density. It indicates that in terms of environmental quality, the population pressure overshadowed the effect of social advancement.

6.2 Implications of Long–Run Model Estimates

6.2.1 Population Change

The long run results are presented in Appendix Table C.3 and C.4. The long-run population change equations cannot be analyzed with clarity as the fertility effects and migration effects cannot be segregated. Hence the effects socio-economic variables on population change are not being discussed here. Only the effect of environmental quality on aggregate population change can be analyzed.

The estimates in Table C.3 and C.4 show that similar to the short-run effect of environmental quality on fertility, the long-run change environmental quality has a negative impact on rural population change and a positive impact on urban population change. The contemporaneous decadal change in NDVI (NC9091T0001), past change in NDVI (NC86T90) and the initial level of NDVI (N91) have significant negative effect on rural population change. The contemporaneous decadal change in NDVI (NC9091T0001) and the initial level of NDVI (N91) has significant positive effect on urban population change.

The negative effect of change in environmental quality on change in rural population density and the negative effect of change in rural population density on change in environmental quality indicate that there is a cyclical relationship between the two.

Increase in population density is associated with deterioration in environmental quality and deterioration in environmental quality is associated with increase in population density. This is similar to the vicious cycle theory except for the fact that the change in population in this model includes fertility as well as migration. Hence the vicious cycle theory cannot be tested using these results as the vicious cycle theory proposes a cyclical relation between fertility and environmental quality only.

6.2.2 Environmental quality

Effects of Population Change: The rural population change (RPDCH91T01) has a significant negative effect on change in environmental quality. The urban population change (UPDCH91T01) has a statistically insignificant negative co-efficient. This implies that in the long run only the rural population change has a significant impact on the change in environmental quality. Since the rural population is heavily dependent on natural resources for their survival, this effect is expected. The insignificant positive effect of urban population change on the change in environmental quality can be attributed to the fact that the population pressure in the urban areas overshadowed the environmental conservation efforts in the long run. The initial rural population density (RPD91) and rural literacy rate (RTL) has a positive impact on the change in NDVI. It implies that initial (1991) rural population pressure and literacy creates awareness to conserve environmental quality in the long run. But the rural population pressure has a stronger negative effect on the environment.

Past Environmental Quality: Initial level of NDVI (N91) and past change in NDVI (NC86T90)) have negative effects on the decadal change in NDVI. This implies that the initial greener districts experienced more degradation and vice versa. It implies that the districts experiencing decline in NDVI in the past put in efforts to preserve the vegetation. Initial level of net sown area (NSA) has a positive effect. The contribution of agricultural areas to greenness can be attributed to this fact.

The insignificant coefficients of many of the socio-economic variables in the long-run models imply that initial levels of socio-economic variables cannot explain the changes over the entire decade. Adequate data about the changes in the socio-economic variables will help in explaining the long-term changes in population and environment.

7. Conclusion

The short-run results show that change in environmental quality (NDVI) has negative and positive impacts on rural and urban birth rates respectively. Change in NDVI positively influences migration. Though the short-run rural and urban birth rates do not have any significant effect on environmental quality, migration has significant positive impact on change in environmental quality. Hence the relationship between migration and change in environmental quality is bi-directional in the short-run. Since migration is a component of population change, it can be concluded that relationship between population change and change in environmental quality is bi-directional in the short run.

The long-run change in environmental quality (NDVI) has negative impact on rural population change and the rural population change has a significant negative impact on change in environmental quality Thus the long-run rural results seem to fall in line with the vicious cycle theory. But the vicious cycle theory is stated in terms of the relationship between fertility and environmental quality and fertility data was not available for the long run period. Hence the theory cannot be confirmed without breaking down the long-run population change into fertility and migration.

The effect of change in environmental quality on change in urban population is positive but urban population change has a statistically insignificant negative impact on change in environmental quality in the long run. The results for the long-run environmental quality were robust across specifications. Hence the long-run claims are stronger. Thus the long run results indicate that the rural areas have stronger linkages with environmental quality.

To sum up, the results strongly indicate that there exists a bi-directional relation between population change and change in environmental quality in both the short-run and the long run. Using the long-run results it can be concluded that the interaction between population growth and environmental quality is stronger in the rural areas. Though there are indications analogous to that of the vicious cycle theory for the rural areas, due to the lack of data on fertility for the long run, it cannot be claimed with certainty that the theory holds for the western, central and southern parts of India. Adequate time series data on the socio-economic and demographic variables will be helpful in analyzing the dynamics of the relationship in a much better way.

Appendix A

Figure A.1 Map of the Study Region

Source: Adapted from MapArt by Cartesia Software, 1994.

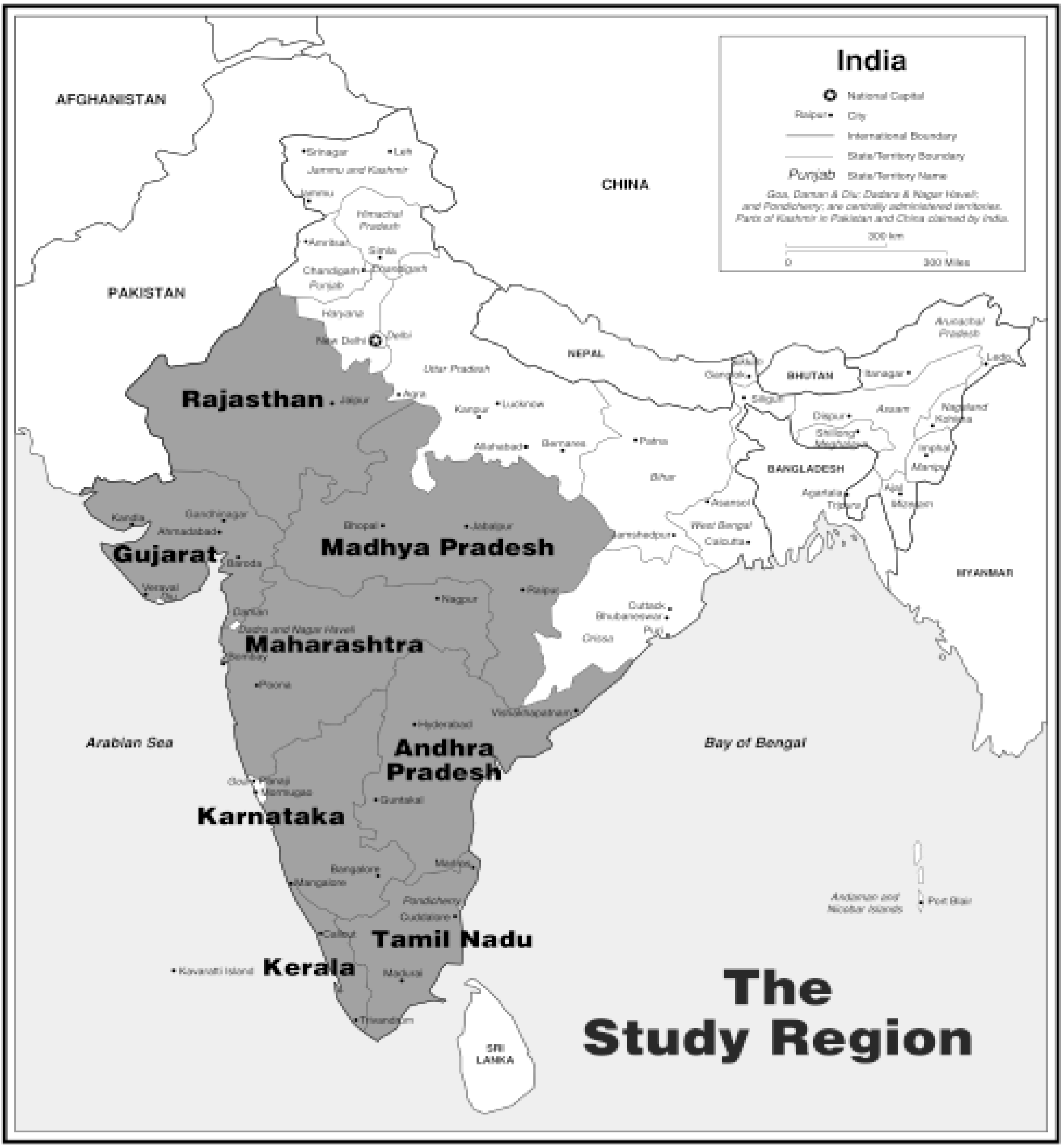

Table A.1 State Profiles

State	*Andhra Pradesh*	*Gujarat*	*Karnataka*	*Kerala*	*Madhya Pradesh**	*Maharashtra*	*Rajasthan*	*Tamilnadu*
State Came into Existence	1956	1960	1956	1956	1956	1960	1956	1956
State Capital	Hyderabad	Gandhinagar	Bangalore	Thiruvanant hapuram	Bhopal	Mumbai	Jaipur	Chennai
Area (in square km)	275045	196024	191791	38863	443446	307713	342239	130058
Rank in terms of Area	5th	7th	8th	18th	1st	3rd	2nd	11th
Population (1991 Census)	66508008	41309582	44977201	29098518	66181170	78937187	44005990	55858946
Rank in terms of Population	5th	10th	8th	12th	6th	3rd	9th	7th
Population Density per square km (2000)	276	258	273	832	158	314	157	478
Average Annual Normal Rainfall(mm)	881	838	1783	3071	1161	1459	494	982
Per Capita State GDP (1999-2000)	Rs.14878	Rs.18685	Rs.16343	Rs.18262	Rs.10907	Rs. 22604	Rs.12533	Rs.18623
Percentage of Population in Agriculture	70%	34%	71%	42%	77%	61%	39%	70%
Birth Rate (1999)	22.3	25.3	22.0	18.2	30.6	22.3	31.5	18.9
Death Rate (1999)	8.8	7.8	7.9	6.4	11.2	7.6	8.8	8.4
Literacy Rate(1991)	44.09%	69.97%	56.04%	89.81%	44.20%	77.27%	38.55%	73.47%
Sex Ratio (1991)	960	921	960	1036	931	922	910	986
Major Religion s	Hindu (89.14%); Muslim (8.9%); Christian (1.83%); Sikh (0.03%)	Hindu (89.48%); Muslim (8.73%); Christian (0.44%); Sikh (0.08%)	Hindu (85.45%); Muslim (11.64%); Christian (1.91%); Sikh (0.02%)	Hindu (57.28%); Muslim (23.33%); Christian (19.32%); Sikh (0.01%)	Hindu (92.80%); Muslim (4.96%); Christian (0.65%); Sikh (0.24%)	Hindu (81.12%); Muslim (9.67%); Christian (1.12%); Sikh (0.21%)	Hindu (89.08%); Muslim (8.01%); Christian (0.11%); Sikh (1.48%)	Hindu (88.67%); Muslim (5.47%); Christian (5.69%); Sikh (0.01%)
Administrative Language	Telugu	Gujarati	Kannada	Malayalam	Hindi	Marathi	Hindi	Tamil

Note: * Before creation of Chattisgarh

Source: Compiled from www.indiastat.com

Table A.2 List of Districts

Andhra Pradesh (23):
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):
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):
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):
Alappuzha, Ernakulam, Idukki, Kannur, Kasaragod, Kollam, Kottayam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thiruvananthapuram, Thrissur, Wayanad.

Madhya Pradesh (45):
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.

Maharashtra (30):
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):
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):
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.

Source: Compiled from www.indiastat.com

Table A.3 District Creation and Renaming between 1991-2001

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

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

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

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

Tamil Nadu
1996: Names of districts changed.
1. Madras district became Chennai;
2. Kamarajar became Virudhunagar;
3. Pasumpon Muthuramalinga Thevar became Sivaganga;
4. Periyar became Erode;
5. Tiruvannamalai-Sambuvarayar became Tiruvannamalai;
6. Chidambaranar became Tuticorin, later Thoothukudi;
7. North Arcot Ambedkar became Vellore.
1999: 1. Chengalpattu district split into Kancheepuram and Thiruvallur;
2. Theni district split from Madurai;
3. Namakkal district split from Salem;
4. South Arcot district split into Cuddalore and Villupuram;
5. Karur and Perambalur districts split from Tiruchirappalli;
6. Nagapattinam and Thiruvarur districts split from Thanjavur.
2000: 7. Ariyalur district split from Perambalur.

Madhya Pradesh

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

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.

Source: http://www.mindspring.com/~gwil/yin.html

To make the 2001 data compatible with the 1991, some of the districts were clubbed together and treated as a single district for the 1991-2001 analysis:

Gujarat: Banaskantha and Mahesana
Karnataka: Bellary and Chitradurga
Madhya Pradesh: Bilaspur and Rajnandgaon.

Appendix B

Table B.1 Matrix of Correlation Coefficients

	NSA	N91	FA
NSA	1		
N91	-0.0921	1	
FA	-0.30289	0.316762	1

where,
NSA: Net Sown Area/Total Area for 1991
N91: Average Annual NDVI for 1991
FA: Forest Area/Total Area for 1991

Table B.2 Abbreviations for Variables Used in Model Specifications

Variable Name	Description
RBPOP94	Rural births (from 1991 to 1994) as a percentage of 1991 rural population
UBPOP94	Urban births (from 1991 to 1994) as a percentage of 1991 urban population
RDPOP94	Rural deaths (from 1991 to 1994) as a percentage of 1991 rural population
UDPOP94	Urban deaths (from 1991 to 1994) as a percentage of 1991 urban population
MIPOP94	Migration (from 1991 to 1994)
RPDCH91T01	Change in rural population density from 1991 to 2001
UPDCH91T01	Change in urban population density from 1991 to 2001
N91	Average NDVI (1991)
NC86T90	Change in NDVI from 1986 to 1990
NC9091T9394	Change in NDVI from 1990-91(2yr avg.) to 1993-94 (2yr avg.)
NC9091T0001	Change in NDVI from 1990-91(2yr avg.) to 2000-01(2yr avg.)
NSA	Net Sown Area/Total Area (1991)
ADR91T94	Average annual deviation in rainfall from 1991 to 1994
ADR86T90	Average annual deviation in rainfall from 1986 to 1990
ADR91T00	Average annual deviation in rainfall from 1991 to 2000
RCE	Per capita monthly rural consumption expenditure (1991) at state level
UCE	Per capita monthly urban consumption expenditure (1991) at state level
RCE2	Square of RCE
UCE2	Square of UCE
RFMW	Percentage of female main workers in rural areas (1991)
UFMW	Percentage of female main workers in urban areas (1991)
RIDR	Rural infant death rate (1991)
UIDR	Urban infant death rate (1991)
RSR	Rural sex ratio (1991)
USR	Urban sex ratio (1991)
RFL	Rural female literacy rate (1991)
UFL	Urban female literacy rate (1991)
RTL	Rural total literacy rate (1991)
UTL	Urban total literacy rate (1991)
RMPOP	Percentage of Muslim population in rural areas (1991)
UMPOP	Percentage of Muslim population in urban areas (1991)
RHS	Average household size in rural areas (1991)
UHS	Average household size in urban areas (1991)
UP	Percentage of urban population (1991)
KD	Kerala dummy
MD	Metro dummy

Table B.3 Vital Statistics of the Variables

	Minimum	Maximum	Mean	Standard Deviation
RBPOP94	0	108.82	35.51	23.4
UBPOP94	6.2	257.14	95.33	45.49
RDPOP94	0	32.74	14.08	7.23
UDPOP94	0.92	46.95	18.24	6.7
MIPOP94	-0.49	7.12	0.03	0.52
RPDCH91T01	-455	1059	29	87.03
UPDCH91T01	-797	19132	990	1724.37
RPD91	0	1236	219.95	195.23
UPD91	0	22077	3093.86	2649.05
NC86T90	-1.82	14.1	4.49	3.48
NC9091T9394	-13.64	21.89	3.18	4.29
NC9091T0001	-13	11	-3	4.12
N91	132.7	192.86	167.02	10.1
NSA	0	0.82	0.5	0.18
RCE	141.98	279.53	182.48	45.41
UCE	160.77	266.22	230.99	31.87
RIDR	0	88.6	22.93	17.47
UIDR	0	86.2	17.9	12.8
RFL	0	93.96	32.04	20.8
UFL	32.54	94.16	61.86	12.38
RSR	0	1230	945.86	130.51
USR	764	1685	930.72	74.26
RFMW	0	59.5	28.6	14.43
UFMW	1.98	26.61	9.69	3.96
RHS	0	7.07	5.34	0.96
UHS	4.12	7.47	5.36	0.57
RMPOP	0	67.07	5.8	7.01
UMPOP	0.68	70.37	17.28	9.57
UP	3.41	100	25.68	16.54
RTL	0	95.67	45.89	18.21
UTL	51.05	95.91	72.58	8.98
ADR86T90	-1279.39	2008.9	-82.3069	766.12
ADR91T94	-971.82	2111.15	-18.32	764.63
ADR91T00	-1160	2060	-41	784.53

Table B.4 Short Run Exhaustive Model Specification

$$RBPOP94 = \beta_0 + \beta_1 \text{ UBPOP94} + \beta_2 \text{ RDPOP94} + \beta_3 \text{ NC9091T9394} + \beta_4 \text{ N91} + \beta_5 \text{ }N\text{C86T90} + \beta_6 \text{ NSA} + \beta_7 \text{RPD91} + \beta_8 \text{ RCE} + \beta_9 \text{ RCE2} + \beta_{10} \text{ RIDR} + \beta_{11} \text{ RFL} + \beta_{12} \text{ RSR} + \beta_{13} \text{ RMFW} + \beta_{14} \text{ RHS} + \beta_{15} \text{ RMPOP} + \beta_{16} \text{ UP} + \beta_{17} \text{ KD} + \beta_{18} \text{ MD} + \varepsilon_1$$

$$UBPOP94 = \gamma_0 + \gamma_1 \text{ RBPOP94} + \gamma_2 \text{ UDPOP94} + \gamma_3 \text{ NC9091T9394} + \gamma_4 \text{ N91} + \gamma_5 \text{ }N\text{C86T90} + \gamma_6 \text{UPD91} + \gamma_7 \text{ UCE} + \gamma_8 \text{ UCE2} + \gamma_9 \text{ UIDR} + \gamma_{10} \text{ UFL} + \gamma_{11} \text{ USR} + \gamma_{12} \text{ UMFW} + \gamma_{13} \text{ UHS} + \gamma_{14} \text{ UMPOP} + \gamma_{15} \text{ UP} + \gamma_{16} \text{ KD} + \gamma_{17} \text{ MD} + \varepsilon_2$$

$$\text{M}IPOP94 = \delta_0 + \delta_1 RBPOP94 + \delta_2 UBPOP94 + \delta_3 RDPOP94 + \delta_4 UDPOP94 + \delta_5 \text{ RCE} + \delta_6 \text{UCE} + \delta_7 \text{UP} + \delta_8 \text{ RHS} + \delta_9 \text{ UHS} + \delta_{10} \text{ RPD91} + \delta_{11} \text{ UPD91} + \delta_{12} NC9091T9394 + \delta_{13} \text{ N91} + \delta_{14} \text{ NC86T90} + \delta_{15} NSA + \delta_{16} RTL + \delta_{17} UTL + \delta_{18} \text{ KD} + \delta_{19} MD + \varepsilon_3$$

$$\text{NC9091t9394} = \alpha_0 + \alpha_2 RBPOP94 + \alpha_3 UBPOP94 + \alpha_4 RDPOP94 + \alpha_5 \text{UDPOP94} + \alpha_6 \text{ MIPOP94} + \alpha_7 \text{R}PD91 + \alpha_8 \text{ U}PD91 + \alpha_9 \text{ N91} + \alpha_{10} \text{ N}C86T90 + \alpha_{11} \text{ N}SA + \alpha_{12} \text{U}P + \alpha_{13} RCE + \alpha_{14} UCE + \alpha_{15} RCE2 + \alpha_{16} UCE2 + \alpha_{17} RTL + \alpha_{18} UTL + \alpha_{19} ADR91T94 + \alpha_{20} ADR86T90 + \alpha_{21} KD + \alpha_{22} MD + \varepsilon_4$$

Table B.5 Long Run Exhaustive Model Specification

$$RPDCH91T01 = \beta_0 + \beta_1 \text{ UPDCH91T01} + \beta_2 \text{ NC9091T0001} + \beta_3 \text{ N91} + \beta_4 \text{ NC86T90} + \beta_5 \, N\text{SA} + \beta_6 \text{ RPD91} + \beta_7 RCE + \beta_8 \text{ RCE2} + \beta_9 \text{ RIDR} + \beta_{10} \text{ RFL} + \beta_{11} \text{ RSR} + \beta_{12} \text{ RMFW} + \beta_{13} \text{ RHS} + \beta_{14} \text{ RMPOP} + \beta_{15} \text{ UP} + \beta_{16} \text{ KD} + \beta_{17} \text{ MD} + \varepsilon_1$$

$$UPDCH91T01 = \gamma_0 + \gamma_1 \text{ RPDCH91T01} + \gamma_2 \text{ NC9091T0001} + \gamma_3 \text{ N91} + \gamma_4 \text{ NC86T90} + \gamma_5 \text{ UPD91} + \gamma_6 UCE + \gamma_7 \text{ UCE2} + \gamma_8 \text{ UIDR} + \gamma_9 \text{ UFL} + \gamma_{10} \text{ USR} + \gamma_{11} \text{ UMFW} + \gamma_{12} \text{ UHS} + \gamma_{13} \text{ UMPOP} + \gamma_{14} \text{ UP} + \gamma_{15} \text{ KD} + \gamma_{16} \text{ MD} + \varepsilon_2$$

$$\text{NC9091t0001} = \alpha_0 + \alpha_2 RPDCH91T01 + \alpha_3 UPDCH91T01 + \alpha_4 \text{N91} + \alpha_5 \text{N}C86T90 + \alpha_6 \text{ N}SA + \alpha_7 \text{R}PD91 + \alpha_8 \text{ U}PD91 + \alpha_9 \text{ U}P + \alpha_{10} RCE + \alpha_{11} UCE + \alpha_{12} RCE2 + \alpha_{13} UCE2 + \alpha_{14} RTL + \alpha_{15} UTL + \alpha_{16} ADR91T94 + \alpha_{17} ADR86T90 + \alpha_{18} KD + \alpha_{19} MD + \varepsilon_3$$

Table B.6 Excluded Exogenous Variables by Equations for the Short Run Exhaustive Model

Rural Fertility	Urban Fertility	Migration	Change in NDVI
ADR91T94	ADR91T94	ADR91T94	RFL
ADR86T90	ADR86T90	ADR86T90	UFL
RTL	RTL	RFL	RIDR
UTL	UTL	UFL	UIDR
UDPOP94	RDPOP94	RCE2	RFMW
UPD91	RPD91	UCE2	UMFW
UCE	RCE	RIDR	RSR
UCE2	RCE2	UIDR	USR
UIDR	RIDR	RFMW	RMPOP
UFL	RFL	UMFW	UMPOP
USR	RSR	RSR	
UFMW	RFMW	USR	
UHS	RHS	RMPOP	
UMPOP	RMPOP	UMPOP	
	NSA		

Table B.7 Excluded Exogenous Variables by Equations for the Long Run Exhaustive Model

Rural Population Change	Urban Population Change	Change in NDVI
ADR91T01	ADR91T94	RFL
ADR86T90	ADR86T90	UFL
RTL	RTL	RIDR
UTL	UTL	UIDR
UPD91	RPD91	RFMW
UCE	RCE	UMFW
UCE2	RCE2	RSR
UIDR	RIDR	USR
UFL	RFL	RMPOP
USR	RSR	UMPOP
UFMW	RFMW	
UHS	RHS	
UMPOP	RMPOP	
	NSA	

Appendix C: Model Estimates

Following estimates were obtained using 'PROC SYSLIN' command with the 3SLS option in SAS (version 8e).
Notation used for presenting the estimates:
*** denotes significant at 1% level of significance.
** denotes significant at 5% level of significance.
* denotes significant at 10% level of significance.
The figures in parentheses denote the standard errors of the estimated coefficients.

Table C.1 Short Run Model 1(Exhaustive) Estimates

	RBPOP94	**UBPOP94**	**MIPOP94**	**NC9091T9394**
Constant	62.37 (72.41)	-108.67 (143.37)	-4.38** (1.76)	-492.77*** (183.7)
RBPOP94		-0.02 (0.15)	0.03*** (0.01)	-0.07 (0.05)
UBPOP94	0.17*** (0.06)		-0.003 (0.003)	0.03* (0.015)
RDPOP94	1.66*** (0.28)		-0.05*** (0.02)	0.05 (0.11)
UDPOP94		3.64*** (0.4)	-0.016 (0.011)	0.02 (0.06)
MIPOP94				3.69*** (1.17)
RPD91	-0.004 (0.01)		0.0001 (0.0004)	0.0001 (0.002)
UPD91		-0.001 (0.001)	-0.00003 (0.00003)	0.0002* (0.00014)
NC86T90	0.18 (0.48)	1.37* (0.72)	0.02 (0.02)	-0.21** (0.09)
NC9091T9394	-4.05*** (0.8)	5.05*** (1.04)	0.15*** (0.03)	
N91	-0.65*** (0.19)	0.12 (0.29)	0.04*** (0.01)	-0.14** (0.06)
NSA	11.59 (8.77)		-1.13*** (0.32)	4.83*** (1.82)
RCE	-0.11 (0.46)		0.01*** (0.002)	-1.81*** (0.6)
UCE		1.15 (1.29)	-0.0008 (0.003)	5.37*** (1.85)
RCE2	0.00002 (0.001)			0.006*** (0.002)

	RBPOP94	UBPOP94	MIPOP94	NC9091T9394
UCE2		-0.003 (0.003)		-0.01*** (0.004)
RIDR	0.15 (0.1)			
UIDR		-0.75*** (0.16)		
RFL	0.63*** (0.16)			
UFL		0.97*** (0.36)		
RSR	-0.01 (0.03)			
USR		0.052* (0.028)		
RFMW	0.1 (0.11)			
UFMW		-1.73*** (0.58)		
RHS	9.98*** (2.38)		-0.11 (0.13)	
UHS		-13.28** (5.26)	-0.07 (0.11)	
RMPOP	0.13 (0.2)			
UMPOP		0.95*** (0.24)		
UP	0.18 (0.12)	-0.72*** (0.18)	-0.003 (0.005)	0.02 (0.03)
KD	-40.18*** (10.54)	32.04** (14.63)	0.98** (0.4)	-13.46*** (3.6)
MD	34.15 (35.83)	50.96* (26.27)	-0.39 (1.03)	-2.99 (3.95)
RTL			-0.02** (0.008)	0.09** (0.05)
UTL			-0.01 (0.01)	-0.03 (0.05)
ADR86T90				-0.01** (0.003)
ADR91T94				0.01** (0.003)

Table C.2 Short Run Model 2 Estimates

	RBPOP94	UBPOP94	MIPOP94	NC9091T9394
Constant	64.66 (53.73)	25.64 (65.08)	-4.44*** (1.72)	-494.03*** (185.18)
RBPOP94		0.02 (0.15)	0.03*** (0.01)	-0.08 (0.05)
UBPOP94	0.17*** (0.05)		-0.003 (0.003)	0.03* (0.015)
RDPOP94	1.66*** (0.27)		-0.05*** (0.016)	0.06 (0.1)
UDPOP94		3.58*** (0.39)	-0.01 (0.01)	0.02 (0.06)
MIPOP94				3.75*** (1.18)
RPD91	-0.003 (0.01)		0.0001 (0.0003)	0.0002 (0.002)
UPD91		-0.001 (0.001)	-0.00003 (0.00003)	0.00027* (0.00014)
NC86T90	-0.16 (0.48)	1.35* (0.71)	0.023 (0.02)	-0.2** (0.1)
NC9091T9394	-4.13*** (0.76)	4.86*** (1.03)	0.15*** (0.03)	
N91	-0.66*** (0.19)	0.17 (0.28)	0.04*** (0.01)	-0.15** (0.06)
NSA	11.99 (8.58)		-1.14*** (0.32)	4.94*** (1.83)
RCE	-0.1*** (0.04)		0.01*** (0.002)	-1.8*** (0.6)
UCE		-0.18** (0.08)	-0.001 (0.003)	5.4*** (1.9)
RCE2				0.006*** (0.002)
UCE2				-0.01*** (0.004)
RIDR	0.16* (0.09)			
UIDR		-0.71*** (0.16)		
RFL	0.62*** (0.15)			
UFL		0.86** (0.35)		

	RBPOP94	UBPOP94	MIPOP94	NC9091T9394
RSR	-0.01 (0.03)			
USR		0.05* (0.03)		
RFMW	0.08 (0.11)			
UFMW		-1.8*** (0.57)		
RHS	9.8*** (2.37)		-0.12 (0.13)	
UHS		-13.35** (5.26)	-0.06 (0.11)	
RMPOP	0.13 (0.19)			
UMPOP		0.9*** (0.23)		
UP	0.19 (0.12)	-0.71*** (0.18)	-0.003 (0.005)	0.018 (0.03)
KD	-40.57*** (9.59)	27.44** (13.86)	0.98** (0.39)	-13.23*** (3.65)
MD	32.26 (35.51)	52.56** (26.04)	-0.43 (1.03)	-3.06 (3.96)
RTL			-0.02** (0.008)	0.09* (0.05)
UTL			-0.01 (0.009)	-0.03 (0.05)
ADR86T90				-0.006** (0.003)
ADR91T94				0.007** (0.003)

Table C.3 Long Run Model 1 (Exhaustive) Estimates

	RPDCH91T01	UPDCH91T01	NC9091T0001
Constant	281.33 (366.37)	-11663 (9275)	236.19 (151.05)
RPDCH91T01		7.38* (4.07)	-0.04*** (0.01)
UPDCH91T01	0.007 (0.01)		0.0001 (0.0004)
RPD91	0.11* (0.06)		0.007*** (0.002)
UPD91		0.09* (0.06)	0.0001 (0.0001)
NC86T90	-4.6** (2.24)	56.83 (44.79)	-0.29*** (0.08)
NC9091t0001	-15.32*** (2.75)	231.84*** (57.8)	
N91	-2.94*** (1.04)	52.93*** (18.84)	-0.15*** (0.03)
NSA	85.6** (40.6)		4.04*** (1.55)
RCE	1.67 (2.12)		0.59 (0.47)
UCE		62.88 (83.66)	-2.18 (1.51)
RCE2	-0.004 (0.005)		-0.002 (0.002)
UCE2		-0.15 (0.2)	0.005 (0.003)
RIDR	-0.05 (0.34)		
UIDR		8.96 (9.96)	
RFL	1.41** (0.68)		
UFL		29.36 (18.16)	
RSR	-0.04 (0.12)		
USR		-3.78* (1.98)	
RFMW	-0.05 (0.56)		

	RPDCH91T01	**UPDCH91T01**	**NC9091T0001**
UFMW		-36.75 (38.97)	
RHS	-2.12 (10.72)		
UHS		-122.59 (314.97)	
RMPOP	-0.18 (0.8)		
UMPOP		5.24 (17.17)	
UP	-0.15 (0.51)	4.93 (10.38)	-0.009 (0.02)
KD	-101.61 (65.04)	-1286 (801.32)	-1.36 (4.00)
MD	14.87 (149.45)	-12.91 (1403.03)	2.15 (3.18)
RTL			0.07** (0.03)
UTL			-0.08** (0.04)
ADR86T90			-0.002 (0.004)
ADR91T00			0.004 (0.004)

Table C.4 Long Run Model 2 Estimates

	RPDCH91T01	UPDCH91T01	NC9091T0001
Constant	525.78** (240.6)	-5514.37 (4254.33)	259.1 (148.5)
RPDCH91T01		7.92** (4.04)	-0.01*** (0.002)
UPDCH91T01	0.007 (0.01)		-0.0001 (0.0001)
RPD91	0.12** (0.06)		0.01*** (0.002)
UPD91		0.09* (0.06)	0.0001 (0.0001)
NC86T90	-4.51** (2.23)	56.77 (44.9)	-0.28*** (0.08)
NC9091t0001	-15.36*** (2.74)	220.2*** (56.27)	
N91	-3.24*** (0.98)	54.76*** (18.79)	-0.16*** (0.03)
NSA	76.48* (39.3)		3.78** (1.53)
RCE	-0.21 (0.17)		0.59 (0.47)
UCE		-0.05 (4.54)	-2.35 (1.49)
RCE2			-0.002 (0.002)
UCE2			0.005 (0.003)
RIDR	-0.12 (0.32)		
UIDR		9.91 (9.75)	
RFL	1.42** (0.68)		
UFL		22.07 (15.87)	
RSR	-0.04 (0.12)		
USR		-3.45* (1.95)	
RFMW	0.02 (0.53)		

	RPDCH91T01	**UPDCH91T01**	**NC9091T0001**
UFMW		-42.57 (38.53)	
RHS	-2.01 (10.66)		
UHS		-136.73 (315.75)	
RMPOP	-0.14 (0.79)		
UMPOP		2.66 (16.75)	
UP	-0.17 (0.51)	5.38 (10.4)	-0.01 (0.02)
KD	-82.2 (61.3)	-1508.02** (756.65)	-0.64 (3.9)
MD	-23.74 (148.2)	19.62 (1408.49)	2.0 (3.17)
RTL			0.07** (0.03)
UTL			-0.08** (0.04)
ADR86T90			-0.002 (0.004)
ADR91T00			0.004 (0.004)

Table C.5 F-test for testing Model 1 Vs Model 2

Ho: $\beta_9 = \gamma_8 = 0$; (For the short-run exhaustive model specified in Table B4)

Ho: $\beta_8 = \gamma_7 = 0$; (For the long-run exhaustive model specified in Table B5)

	DF for Numerator	DF for Denominator	F Value	Pr > F	Reject the Null at 1% or 5% or 10% level of significance
Short Run	2	709	0.31	0.7313	No
Long Run	2	534	0.4	0.6701	No

Table C.6 Short Run Elasticities

	RBPOP94	UBPOP94	MIPOP94	NC9091T9394
RBPOP94				
UBPOP94				0.0064
MIPOP94				0.00067
NC9091T9394	-19.43	8.53	835.1	

Table C.7: Long Run Elasticities

	RPDCH91T01	UPDCH91T01	NC9091T0001
RPDCH91T01			-0.0017
UPDCH91T01			
NC9091T0001	-88.46	37.15	

Appendix D: Data Sources

For Demographic and Socio-Economic Data:

www.indiastat.com

South India Human Development Report - NCAER (National Council of Applied Economic Research), India. Oxford University Press, New Delhi. (2001)

West and Central India Human Development Report - NCAER (National Council of Applied Economic Research), India. Oxford University Press, New Delhi. (2001)

For NDVI images:

http://daac.gsfc.nasa.gov/data/dataset/AVHRR/01_Data_Products/04_FTP_Products/index.html

For India's Political Map:

http://grid.cr.usgs.gov/datasets/datalist.php3#unep

For Definitions of Districts:

http://www.mindspring.com/~gwil/yin.html

Annual Subdivision Rainfall:

http://grads.iges.org/india/partha.subdiv.html

Note: All the above mentioned data sources were accessed between August 2002 and April 2003.

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