Long View of Agricultural Land Use and Population Growth in India: An Assessment of Causal Relationship

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Abstract

The paper investigates the causal relationship between change in agricultural land use and population growth in India using long-term time-series and district level panel datasets (1961-2021). We theorize that there is an inverted 'U-shape' relationship between change in population growth rate and agricultural land. The time-series graphical analyses do reveal an inverted 'U-shape' relationship between population growth rate and cultivated land with a break-point in 1980s. Dynamic panel data regression estimates suggest that the impact of population growth rate on cultivated land was positive and significant—during pre-1980s, there was an expansion of cultivated land in response to the exponential increase of the population, while in the post-1980s, there is a gradual reduction in cultivated land probably due to the rise in agricultural productivity and also decline in population growth rate. The direction of causation is higher from population growth to cultivated land. Findings are re-affirmed using several robustness checks.

Keywords: Population Growth; Agricultural Land; Land-Population Relationship; Time Series Analyses; Dynamic Panel Data Analysis.

1. Introduction

Did population growth change the agricultural land? Or did the change in the share of agricultural land and productivity induce the population to grow? This question has no clear and scientific answers. One difficulty in answering these questions is the lack of robust empirical research that addressed the issue of land use and population growth. Researches hitherto focused on case studies in which result often depends on the individual level interaction of physical and human world. Although there exist useful case studies which illuminate the particular intricacies of population and land use relationship, but they are not comparable across the geographies (Jolly & Torrey, 1993; Hoffmann, 2021).

Our study, in Indian context, will attempt to examine the long-term contested discussions between pessimists and optimists on their concern of population growth and food production which is now shifting towards population and land use with reducing per-capita land in increasing population scenarios of the world. Whether Malthus' views about the food insecurity owing to the assumption of population pressure overtaking the food production, was right or Boserup's opinion of technological transformation to sustain the growing population seem correct, these questions are still debatable. At an outset, this study is an attempt to work for resurgence of population and land, population and development debates through theoretical framework of Boserupian school of thought (Turner & Fischer-Kowalski, 2010).

The core of this study is to theoretically document how the 'man-land' interaction evolved over time in Indian context. Also, we have explained how far change in population growth rate cause the change in agricultural land? Although, there are several studies which investigated the relationship between 'population' and 'agricultural land', but most of them established a correlation at a point of time or merely postulated theoretical arguments. There is hardly any study that assessed the dynamic and causal relationship between population and agricultural land using panel data over a long period of time.

The major contributions of this paper are three-fold: First, the study formulates a theoretical framework to study the long-term relationship between 'population' and 'agricultural land'. Second, it employs a long-

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term cutting-edge dynamic panel data regression approach for testing the hypothesis: whether population growth rate influenced the increase or decrease in agricultural cultivable land. Third, using a spatial econometric regression model it addressed the geographical heterogeneity of population growth rate and agricultural land use. Finally, using robust theorical and empirical approaches it identified two stages of (split) relationship between cultivated land and population growth in India: the impact of population growth rate on cultivated land was positive and significant—during pre-1980s, there was an expansion of cultivated land in response to the exponential increase of the population, while in the post-1980s, there is a gradual reduction in cultivated land probably due to the rise in agricultural productivity and also decline in population growth rate. The direction of causation is higher from population growth to cultivated land in both the periods. The main findings are re-affirmed using several robustness checks.

2. Background and Literature review

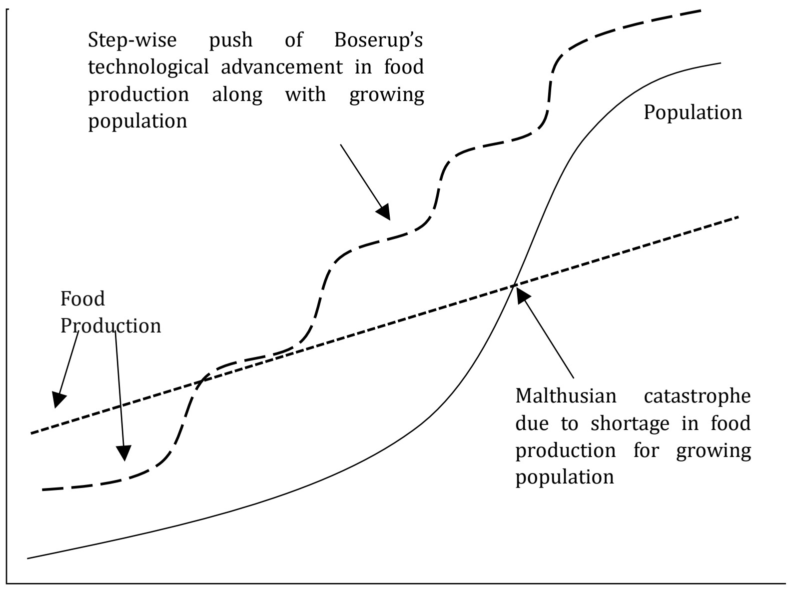
To sustain the growing population, the food production must keep-up with growing demand and there are two ways to do so: either expanding agricultural land or intensify the agricultural land cultivation. However, the concern of biological and agricultural scientists were the ecological limits of food production. They hardly believed any future expansion in agricultural production is possible without the technological advancement. Thus, they have warned about the food insecurity and environmental degradation because of rapid population growth (Ehrlich et al., 1977; Ehrlich & Holdren, 1971; Raven, 1990) and this would result in the Malthusian catastrophe when food supply could no longer support an expanding population (Figure 1). Nevertheless, after two centuries of uninterrupted expansion in population and food production, as well as economic advancement, it is difficult to imagine a disaster caused by overpopulation alone (Johnson, 1997).

Neoclassical economists, on the other hand, promulgated and emphasised technological advancement and the substitution of scarce resources with more abundant ones in order to persist high quality of living with limited resources (Simon, 1981; Stiglitz, 1979). Boserup's investigation on evolution and innovation in agricultural system in African and Asian countries concluded that with evolution and innovation in farm technology (e.g. fertilizers, soil conservation, irrigation system, farming machineries) and innovative use of finite resources (e.g. crop land intensification, terrace farming, fallow shortening), rapid increase in population could possibly be sustained with increased food production (Boserup, 1965, 1970, 1981). According to Boserup, population expansion will spur new innovation in agriculture (Figure 1). However, later she was criticised on the grounds that extreme conditions of poverty and slow economic development would not allow for innovation, as was the situation for many African and Asian countries (P. Dasgupta, 1992). Boserup and Simon were also criticised for their simplistic conclusion: the technological progress would resolve the Malthusian problem and will stay ahead of population growth (Brander, 2007).

In midst of these arguments and counter-arguments in the later 20th century four reports were published by United Nations (1953, 1973) and National Academy of Sciences (1971, 1986), two by each. Both organisations were pessimistic in their views suggesting negative consequences of population growth. On the contrary, report post-1980s were somewhat revisionist in thinking and made a guarded assessment of net impact of population on development (Kelley, 2001). The 1993 report of NAS directly addressed the issue of population and land use in developing countries (Jolly & Torrey, 1993). This report stated that rapid population growth affects the land use in long run and disadvantageous for environmental sustainability and human wellbeing.

Recent arguments between these two perspectives have evolved towards sustainable land use in light of the rising threat of climate change and environmental damage in developing nations due to high population density. Sustainability and living standards are key themes in modern population growth and resource management literature. This debate of sustainability is beyond the scope of this study as it focuses more on earlier debate on the direction of relationships between finite land and growing population pressure. The previous literature in global and Indian context addressing the two important questions that have been discussed below.

Figure 1. Pessimists' vs Optimists: Theoretical differences in arguments of population change and food production



Source: Authors' construction based on the works of Malthus, 1798; Boserup, 1965; Kelley, 2001

2.1. Does population growth change the agricultural land?

In the earlier studies of population and land use, Ester Boserup and Colin Clark have both provided precise, comprehensive, and data-driven conclusions in global trends in land use and population growth. Boserup argued that population growth is independent of food availability, and that the pressure of an increasing population drives land use change through innovations in agricultural technology, land tenure systems, labour intensification, and settlement form (Boserup, 1965). Other economists, however, disagreed with her theory, claiming that in response to population pressure only cropping intensity increases (Grigg, 1979). Colin Clark (1967) recorded considerable research on global land use patterns and population dynamics in his book 'Population Growth and Land Use'. He compared developed and developing countries' land use and population, and demonstrated how much land is required for developing nations to maintain the same food and calorie intake as much as the developed countries. Clark's data are mostly concentrated on developed nations and his major limitation was interpolation of empirical data from the developed to developing world.

The developed countries have passed the stage of population rise, thus aforementioned issue is more pertinent and current in the context of emerging countries. In developing countries, the major factor for changes in agricultural land is associated with the incasing population growth (Lambin et al., 2003). There are limited studies which have systematically analysed the population growth and land use change and agricultural practices in developing nations (Bilsborrow & Geores, 1994; Vosti et al., 1994). Increasing population growth rate would change the land use by increasing cropland and reducing forest cover in developing countries (Bilsborrow & Okoth Ogendo, 1992). Studies in consideration of population density of developing countries especially China and India, stated that along with increasing crop land, adopting intensive farming systems pushed food production manyfold (Hayami & Ruttan, 1987; Pingali & Binswanger, 1987). Bilsborrow & Geores (1994) and Heilig (1994) also concluded a weak but positive relationship between population growth and irrigated land-fertiliser use through temporal changes of country level data. Pender (2001) has given a clear account of this evolutionary relationship between population growth and agricultural land use pattern. Pender points out eight broad stages of the changing process starting with extensification of crop land, followed by shorten of fallow periods, adoption of labour-intensive methods, labour intensive land investments, capital investment, knowledge intensification, mixed land use, change in occupation and migration, and ends with change in fertility decision of household.

2.2. Does limited agricultural land control population growth?

With countering the ideas of change in agricultural productivity and intensification due to population pressure, many scholars probe into the opposite side of the page. Higher population densities do not always result in increased agricultural productivity, particularly in locations where farmers own less land and the area is resource deficient (Lele & Stone, 1989). According to Dasgupta (1992) under extreme poverty and low rates of development, people suffer from a vicious cycle of poverty-population-environmental degradation-poverty, and Boserup's postulations do not function in these settings. The financial cost of bringing new land into cultivation is substantially higher, which would prevent developing countries from expanding their land base. According to Scherr & Yadav (2001), land degradation would pose a severe danger to food production and rural livelihoods in high population density areas of developing countries. They also emphasised the importance of land management and land improvement investments through new policies in order to sustain the population of growing nations by meeting food demand. The diversification in agricultural land use would be possible when basic need of calorific sufficiency through food is attained. Thus, the desire for quality and diversity of food demands control of population growth.

2.3. Population and Agricultural Land Use Studies in India

Several studies have investigated land use changes in India, but their emphasis is mostly on land use change rather than land use-population interactions (Roy & Roy, 2010; Tian et al., 2014). The land cover of India has altered dramatically, particularly the forest cover. From 1880 to 2010, forest cover decreased by 29%, while agricultural area rose by 51% (Tian et al., 2014). Crop land conversion is more faster than crop land extension in India and other emerging nations (Richards & Flint, 1994). Extensification and intensification of crop fields in India have been suggested many literatures (Mishra, 2002; Tian et al., 2014).

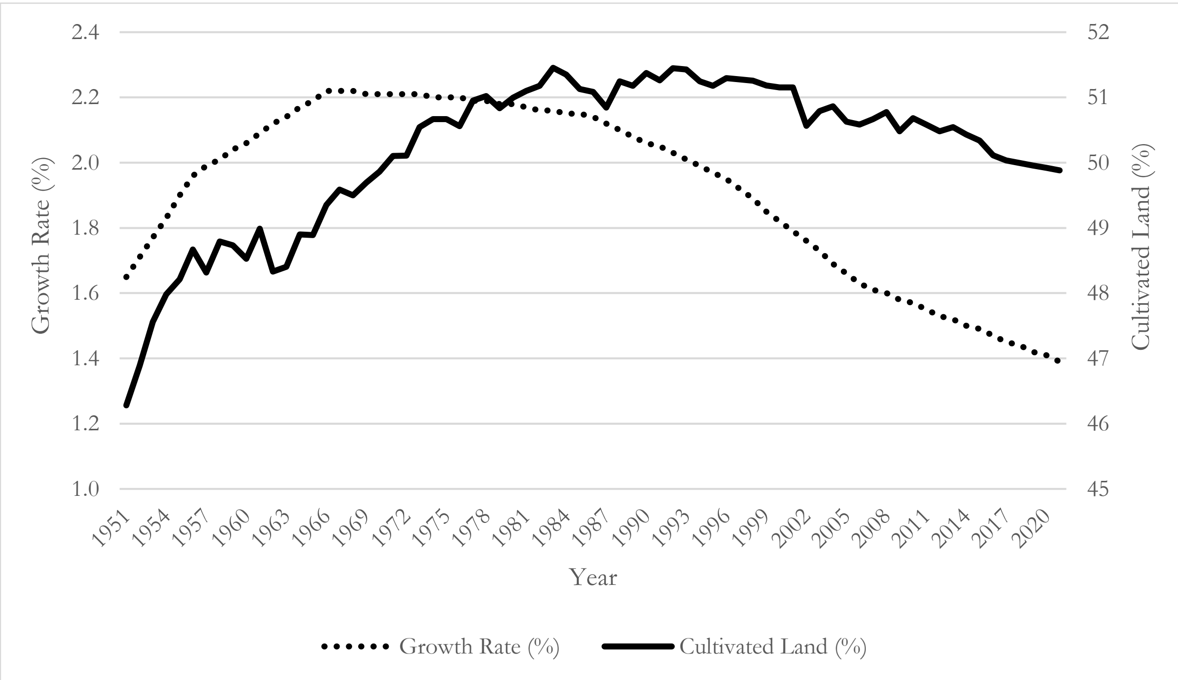
The scant known literatures on population and land use interactions are limited to either local areas or mostly using cross-sectional designs. For instance, a comparative case study undertaken by the United Nations (UN) in 1975 in districts of Punjab and Orissa revealed that positive population growth is connected with agricultural transformation by increasing production (United Nations, 1975). Though they also demonstrated that limited possibility of labour intensification in agriculture in those areas generates labour surplus and forces off-farm employment search. Boyce (1987) used data from 1901 to 1980 for West Bengal and Bangladesh to study agricultural output upon growth of population and concluded that agricultural growth took about 30 years to respond to population growth; while Mukhopadhyay (2001) empirically tested the reverse causality and found that agricultural production does affect the population growth in India in about 5 years. Another study in India using the district level panel data from 1951 to 1991 showed that population density positively induced agricultural intensification (Mishra 2002). However, while his work was focused on agricultural intensification, and no discussion on agricultural land extensification was carried out.

The major conclusion from above studies as follows: positive population growth is associated with expansion of crop land and intensification in agricultural system. Although, above studies have investigated the relationship between 'population' and 'agricultural land', but most of them established a correlation at a point of time or merely postulated theoretical arguments. There is hardly any study that assessed the dynamic and causal relationship between population and agricultural land using panel data over a long period of time. Thus, we empirically studied this question with the presumption that expansion of agricultural land under population pressure is determined by population growth rate and the level of intensification.

3. Description of Agricultural Land and Population Growth in India

Before formulating a theoretical framework of the study, we have described the long-term trends in agricultural land and population in India. Figure 2 illustrates that since 1951, the rate of population growth has been significantly increasing, leading to increase in the percentage of cultivated land[3], in order to support the growing population. The population growth rate was increasing until the late 1960s, but remained high and nearly stable until the 1980s, resulting in rapidly expanding absolute population numbers between 1951 and 1981. Since the 1980s, there has been a continuous drop that is still ongoing. It should be noted that the fall in land percentage followed by the decrease in population growth rate. Though, in later years, the decline in cultivated land was also coupled with a decrease in overall agricultural land[4]. In 1951, the proportion of cultivated land out of total accessible agricultural land was roughly 73%, but fast population growth increased it to 84% by the late 1960s (Figure 3). Though, since the 1970s, this share has remained constant with few variations[5]. It also indicates that land expansion was much higher till late 1960s, as since then green revolution helped to increase the intensification of land over extensification. Growth in the economy made it possible for India's population growth to slow (Keyfitz, 1992; Dyson, 2018). Though the speed of economic development was slow until the 1990s, new liberal economic policies accelerated it, as illustrated in Figure 4 with India's log per capita GDP. Along with economic progress, agricultural development occurred with the green revolution in the late 1960s, which raised output yield (Figure 4), but also reduced the usage of agricultural land in the country. It should be highlighted that agricultural development occurred as a result of the pressures of rapid population expansion, which acted as an impetus for increased production, as well as economic development, particularly after the 1990s.

Figure 2. Trend in population growth rate and cultivated land in India, 1951-2021



[3] Net Sown Area + Current Fallow. Cultivated Land is a type agricultural land which is always in operation. Other agricultural lands have periods of inactivity.

[4] Agricultural Land is combination of 'Cultivated Land with 'Land under Miscellaneous Tree Crops and Groves', 'Culturable Waste Land', and 'Fallows other than current fallow'.

[5] It can be concluded that in until late 1960s, increase in cultivated land occurred in two ways; first within the total agricultural land by using the culturable waste land and other available fallows., secondly by increase in agricultural land itself.

Figure 3. Trend in population growth rate and proportion cultivated land out of total agricultural land in India,1951-2021

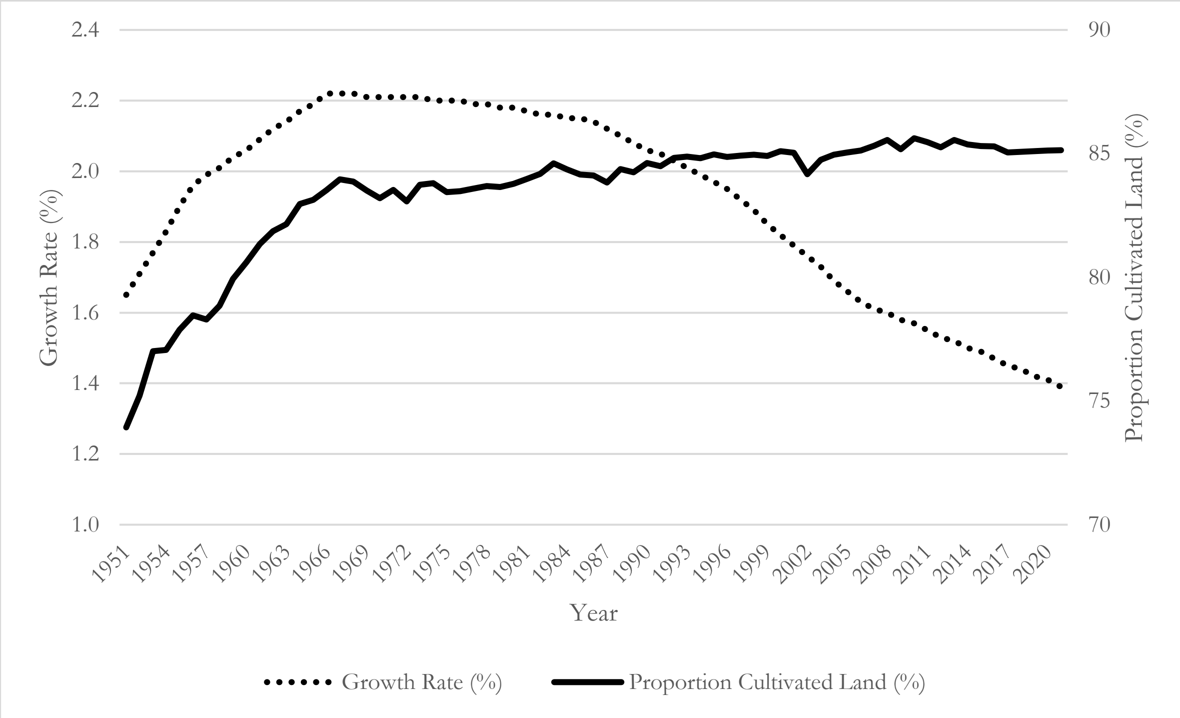
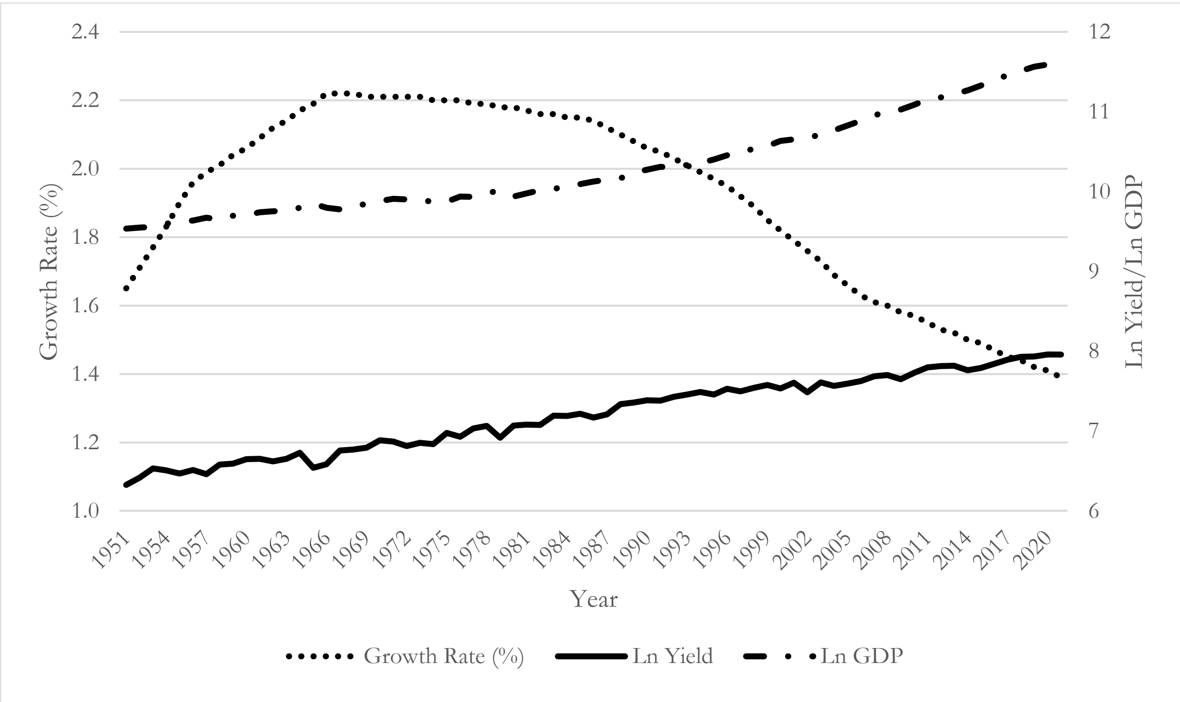


Figure 4. Trend in population growth rate, yield of major crops, and per capita GDP in India, 1951-2021



4 Theoretical Framework

The relationship between man and land, more specifically agricultural land, is evolutionary in nature. The term evolutionary is important since the relationship is not static; it varies throughout time based on population transition conditions. The theoretical framework offered in this study is primarily based on synthesis of two distinct transitional systems: demographic and agricultural system changes described in section 3.

The relationship between land use change and population growth in our theoretical framework forms three stages (Figure 5). In the first stage, starting with the dawn of civilisation, access to unoccupied and unutilised arable lands pushes the population to grow. Assurance of food, necessitate the human acquisition of arable land. This stage would end with a decrease in mortality and consequent population boom with high fertility. This stage of man-land relationship experienced by all the countries before 1800s, some least developed countries are still striving to escape this stage. India had this stage before independence, and India's mortality started steady declining from 1940s (Goli & Arokiasamy, 2013; Dyson, 2018).

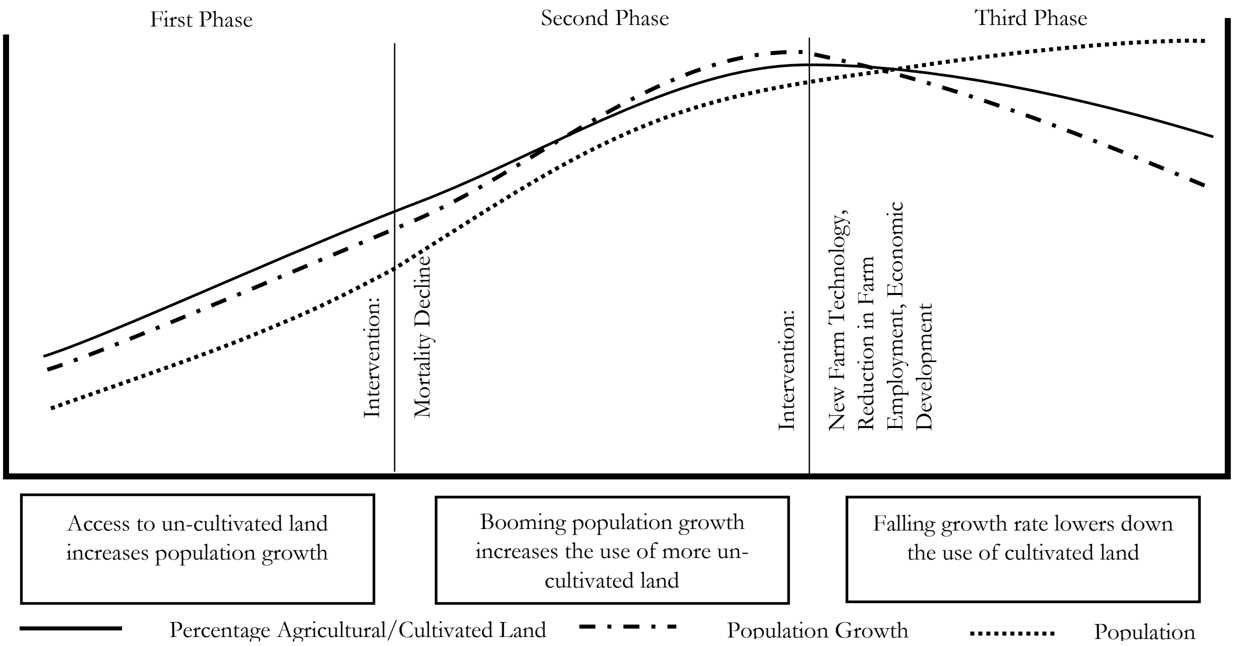
In the second stage, due to a reduction in mortality, the population expands with persistently high fertility, and this population growth increases the utilisation of agricultural land. Early population growth following mortality reduction stimulates economic development by increasing labour force participation (Keyfitz, 1992; Coale & Hoover, 2015). Land scarcity necessitates agricultural intensification. There are two forms of agricultural intensification: labor-intensive and technology-intensive (Boserup, 1965). Only labour intensification was carried out at this stage. Prior to the 1980s, India witnessed high fertility with low mortality (Goli & Arokiasamy, 2013; Dyson, 2018). The advent of new farm technologies marked the end of this stage.

Finally, in the third stage, population growth began to slow down due to socioeconomic improvement and decreased demand for farm labour, attracting agricultural labourers to non-farm industries. Technological innovation (both in agricultural and family planning techniques) helps to balance limited land and overpopulation. Population eventually expands in this stage due to momentum, but the rate of population growth begins to slowdown. To further reduce agricultural land use (while boosting food production in relation to population), the population growth rate shall decline first.

In these three broad stages, agricultural land and population growth relationships alters from one stage to another. In the first stage, land use controls population with a increasing positive growth rate in population, while in the second stage, population growth controls land use with increasing positive growth in both (land and population). Lastly, in the third stage, population growth again controls land use change but with a decline (or negative) in population growth rate. In particular, population growth rate declines faster than agricultural land, as intensification and mechanization happen and demand for agricultural labour declines.

Due to data limitations, this study only examined the second and third stages highlighted in the Theoretical framework (Figure 5). As a result, the second and third stages are referred to as the first and second phases throughout the text for convenience.

Figure 5. Theoretical framework showing co-evolution of agricultural land and population growth transitions and causal-relationship.



5 Empirical Approach

5.1 Hypothesis:

Hypothesis 1: Changes in population growth rate would change the agricultural land.

Hypothesis 2: Effect of population growth rate would be higher in first than in the second phase of 'the transition in agricultural land and population growth relationship'.

5.2 Data:

Data for this study has been collected from multiple secondary data sources of different time points, which is categorised into three broad sub-sections- Socio-economic and Demographic Data, Agricultural Data and Development Data (Table 1).

The sources are Primary Census Abstracts of the Census of India (Census of India, 2001, 2011b), India's district-level socio-economic and demographic database constructed by Vanneman & Barnes (2000), Gridded Population of the World (GPW) version 4.11 for year 2020 (Center for International Earth Science Information Network (CIESIN), 2018), Directorate of Economics and Statistics, Ministry of Agriculture (DES, n.d.), and District Level Database (DLD) by ICRISAT (ICRISAT & TCI, n.d.). Category and time period wise detail data sources is given in table 1.

Table 1. Data sources

Data	Period	Variables	Sources
Demographic and Socio-economic Data	1961-1991	Total Population, Urban Population, Agricultural and Non-Agricultural Workers	India District Database (Based on Census of India)
	2001-2011	Total Population, Urban Population, Agricultural and Non-Agricultural Workers	Census of India: Primary Census Abstracts, Census of India: Education Tables
	2021	Total Population	CIESEN
		Urban Population, Non-Agricultural Workers	Projected by Authors (Linear Extrapolation)
Agricultural Data	1961-2021	Land Use Statistics	Directorate of Economics and Statistics: Ministry of Agriculture
	1961-2021	Crop Area (Hectare), Production (Tonnes), Irrigated Area (Hectare)	Directorate of Economics and Statistics: Ministry of Agriculture, ICRISAT, and Indian District Database, District Census Handbooks of Census of India

5.3 Panel Construction

To enhance and establish a relationship among the variables of interest, we have constructed a district level panel data with 7 time points from 1961 to 2021. The base year for the panel data is 1961 as it happens to be the first census year after state (or provincial) reorganisation. Though there were few changes in district boundaries after 1961 which have been adjusted in the process of creation of panel. There were three types of changes in district boundaries; creation of a new district by merging two or more districts, creation of a new district by bifurcation of an existing district, and creation of a new district by bifurcation of two or more districts. First, we have used the merged district and districts before unification were merged to form the panel. Second, we have simply merged the newly created districts to their parent districts. Third, we have merged the all-parent districts and the newly created districts altogether to secure the unchanged boundary for this broad merged district[6]. To do this exercise we have used the publication by Census of India (Census of India, 2004, 2011a) and earlier literature (Kumar & Somanathan, 2017; Liu et al., 2021). The primary panel consisted of 280 districts with 7 time points. In the major analysis we have considered only major states[7] of India which accounts for 267 consistent districts in the panel.

Census was not conducted in the state of Assam in 1981 and in the state of Jammu & Kashmir in 1991. Values for these two states in particular year are calculated by linear interpolation. For district level panel data, statistics of latest available year is considered for 2021. All the data collected from multiple sources are arranged according to the district panel that has been created.

5.4 Variables:

5.4.1 Main Variables:

The two major variables of this study are Population Growth Rate (%) and Cultivated Land (%). Population growth rate is assumed to follow exponential rate of increase that is why decadal population growth rate is calculated exponentially[8].

Land use statistics in India have 9-fold classification of lands[9]. We have used Cultivated Land as one of major variable. Cultivated Land consists of Net Sown Area and Current Fallow Land. Percentage of cultivated land is calculated by dividing the total cultivated land (hectares) by total reported area (hectares). The reason for taking Cultivated Land as one of explanatory variable is that the area under Cultivated Land is under continuous use throughout the year, rather other cultivable land like 'other fallows' (not used for cultivation for 1-5 years) or 'culturable waste' (not used for last 5 years or more).

Both population growth rate and cultivated land are taken as outcome and explanatory variable alternatively to understand the bi-directional relationship (causality and reverse causality) throughout the time period of interest and how their behaviour changes in different phases of the study period. But cultivated land as a predictor has no significant results and models were also failed, so we have put the results of models with population growth rate as dependent and cultivated land as independent variable in the appendix section.

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[6] For example, Udaipur, Chittorgarh and Banswara in Rajasthan were three separate districts since 1961 to 2001. But creation of Pratapgarh in 2011 from parts of these three districts led to merge all four districts to create unchanged boundary for this panel unit.

[7] Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, Uttarakhand, and West Bengal.

[8] $\{\ln (P_t / P_{t-n})\} *100$, where ln = Natural Logarithm, P = Population, t = time, n=interval

[9] Forests, Area Under Non-agricultural Uses, Barren and Un-culturable l Land, Permanent pastures and other Grazing Land, Land under Miscellaneous Tree Crops and Groves not included in Net Area Sown, Culturable Waste Land, Fallow Lands other than Current Fallows, Current Fallows, Net Sown Area. All these 9 types land aggregated and termed as Reported Area.

5.4.2 Other Explanatory Variables:

Control variables are the combination of agricultural and socio-economic variables (table 1) which are Log Yield, Irrigation Intensity (in %), Cropping Intensity (in %), Urbanisation (in %), Non-farm Workers (in %), Education (in %), and Number of Banks per 1000 population.

The percentage of agricultural land utilised is directly influenced by the yield, irrigation and cropping intensity within a given district. Increase in irrigation facilities would eventually lead to an expansion of cultivated land. On the other hand, increase in cropping intensity will increase the productivity. As productivity can be affected by other factors which are not available at district level, thus we directly take the production yield to control those factors as well.

Urbanisation plays an important role in development of a country. Urbanisation acts as a pull factor for agricultural labourers who would move to urban areas for better job opportunities. The advent of modern agricultural technology leads to job losses among labourers, compelling them to seek better employment opportunities in urban regions (Boserup, 1965; Keyfitz, 1992; Coale & Hoover, 2015). Additionally, as population growth and land use are a relationship of rural population, the variable urbanisation will also account for the ruralness of the district. Similarly, the proportion of non-farm workers also reflects the level of reduction in labour dependency of agriculture in a specific area or district. In absence of Census for last year of panel (2021) we have linearly extrapolated the census variables (Urbanisation, Nonfarm Workers).

All the variables mentioned above have direct or indirect effects on the two primary outcome variables: "population growth rate" and "cultivated land." Consequently, we have included all of these variables as independent variables in our analysis of "population growth rate" and "cultivated land." Summary are given in the Table 2.

Table 2. Summary statistics of the variables

Variables	Calculation	Observations	Mean	SD	Min	Max
Decadal Population Growth Rate (%)	$\{\ln (P_t / P_{t-10})\}$ *100	1,869	19.35	6.89	-17.18	52.52
Cultivated Land (%)	(Cultivated Land/Reported Area) *100	1,869	55.10	20.53	0.00	91.10
Ln Population	Natural Logarithm of Total Population	1,869	14.62	0.93	10.08	16.88
Ln Yield	Natural Logarithm of Yield (kg/hectare)	1,866	7.16	0.99	0.00	9.01
Irrigation Intensity (%)	(Gross Irrigated Area/Net Irrigated Area) *100	1,848	128.72	31.06	100.00	515.79
Cropping Intensity (%)	(Gross Sown Area/Net Sown Area) *100	1,851	133.34	26.43	100.00	277.57
Urbanisation (%)	(Urban Population/Total Population) *100	1,869	22.02	16.47	0.00	100.00
Non-Farm Workers (%)	(Non-Agricultural Workers/Total Main Workers) *100	1,869	31.23	18.56	0.69	83.04

ln = Natural Logarithm, P = Population, t = time

6 Econometric Approach

We employed the following strategies in order to understand and test our key claim about the interaction between man and land. We have taken two major approaches, panel data regression and spatial panel data regression models. They are as follows,

6.1 Dynamic Panel Data Regression Model

OLS estimation is inconsistent if explanatory variable is correlated with unobserved component of dependent variable. Dynamic panel data consider this unobserved component by using lagged dependent variable as a regressor in the model (Cameron & Trivedi, 2005). In this model, we have used Arellano-Bover/Blundell-Bond linear dynamic panel data model with two-step estimator to account for the potential endogeneity issues. In this approach, instead of traditional instruments, lagged variables are used as instruments and then the models are as follows:

$$\Delta cl_{it} = \theta_0 + \alpha\Delta cl_{it-n} + \gamma\Delta gr_{it} + \beta\Delta X_{it} + \Delta\epsilon_{it}$$

Where, cl is cultivated land (%), gr is population growth rate (%), θ_0 is intercept, X is a vector of other explanatory variables, t is the time period, n is the number of lags, $\alpha, \gamma,$ and β are the coefficients.

Further from the time series figures (Figure 2) we have known that there is a structural discontinuity in both population growth rate and percent cultivated land. So, to test the effect of predictor variable on dependent variable for each time period we have applied segmented regression approach within the dynamic panel model. Population growth rate, as an independent variable, has been divided into two periods (before and after breakpoint) and a separate intercept for the later period has also been added.

6.2 Spatial Dynamic Panel Durbin Model

To address the spatial heterogeneity of population growth rate and cultivated land use, that exists in Indian district throughout the time period, we have used the Spatial Dynamic Panel Durbin Model with spatial fixed effects. The model is a spatially weighted regression model which consists of both spatial lag and error model characteristics in a panel dataset. Moreover, along with addressing the spatial lagged values of dependent and independent variables, it also accounts for the lagged dependent variable as a separate independent variable. In given sum, the spatial dynamic panel durbin model incorporates time and space dependency of dependent and independent variable, and both spatial lag and error panel models. This simultaneously controls for spatial dependency, spatial heterogeneity, and time dependency. In this model, both dependent and independent variables are spatially lagged and as a consequence no additional endogeneity problem emerge from estimation point of view (Belotti et al., 2017; Arbia et al., 2021). The model is as follows:

$$cl_{it} = \tau cl_{it-n} + \psi W cl_{it-n} + \rho W cl_{it} + \beta X_{it} + D X_{it}\theta + \alpha_i + \gamma_t + \mu_{it}$$

Where, cl is cultivated land (%), X vector of explanatory variables including population growth rate, W is the spatial matrix for the autoregressive component, D is spatial matrix for the spatially lagged independent variables, α_i is the individual fixed or random effect, γ_t is the time effect, μ_{it} is a normally distributed error term, t is time, n is number of lags, $\tau,\ \psi, \rho, \beta$ and θ are the coefficients.

7 Results

7.1 Trends and Heterogeneity Pattern in Population Growth and Cultivated Land among Districts

Figure 6 depicts the district level decadal population growth rate from 1961 to 2021 using maps. From 1961 to 1971 and 1981, all districts' population growth rates were increased, even though population growth rates varied by region. Eastern states (West Bengal and Assam) and western India have higher population growth rates than other areas, with an elongated cluster from north to south. Population growth rates in all districts were much greater in 1971, 1981, and 1991 as compared to other time periods. This surge in population growth was aided by lower mortality in all regions of India following independence. Southern and coastal eastern states began to slow their population growth rate since 1991, with a major decrease in population growth rate beginning in 2001. The population growth rate of Indian districts began to decline from the southernmost states, which were later joined by the eastern coastline states and other southern states, while higher population growth rate regions were pushed to the north.

Figure 7 depicts maps of percentage cultivated land in India districts that vary greatly in spatial terms. A large proportion (>65%) of agricultural land in India is concentrated in a few areas, namely the Ganga plain regions, central Maharashtra and northern Karnataka, north-eastern Rajasthan, and Gujarat plains. A moderate proportion of cultivated land (45-65%) is found in southern areas bordering Odisha, as well as northern and western Madhya Pradesh. The lowest regions under agriculture are in hilly areas, the central plateau and eastern plateau, and the western desert area. The unequal distribution of cultivated land is closely connected with population density patches in India, and this should have been the primary reason for the early population expansion in highly cultivated areas. The cultivated area in each district has changed by large and small percentages over the seven decades (1961-2021). However, due to the high spatial variation in cultivated land in Indian districts, it is difficult to depict these changes alongside the spatial variation. We need the first differences of variables of panelised districts to capture this variation in both space and time, and the following part will explain the findings of dynamic panel models using the first difference approach. Furthermore, a spatial model would also be beneficial in this context as cultivated land in India are concentrated in several patches with a spatial dependency as suggested by the maps (Figure 6).

Figure 6. District wise decadal population growth rate, 1961-2021

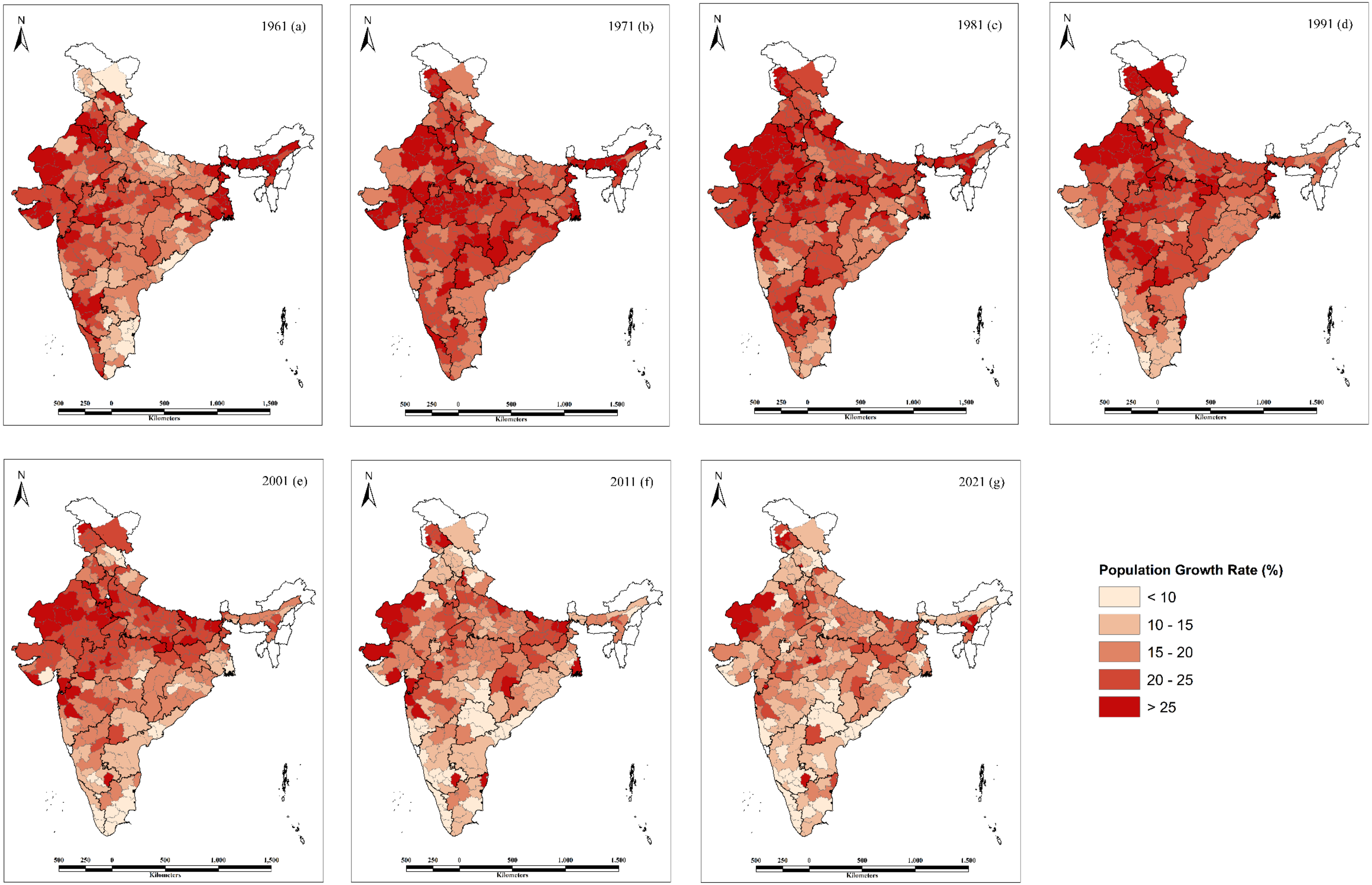
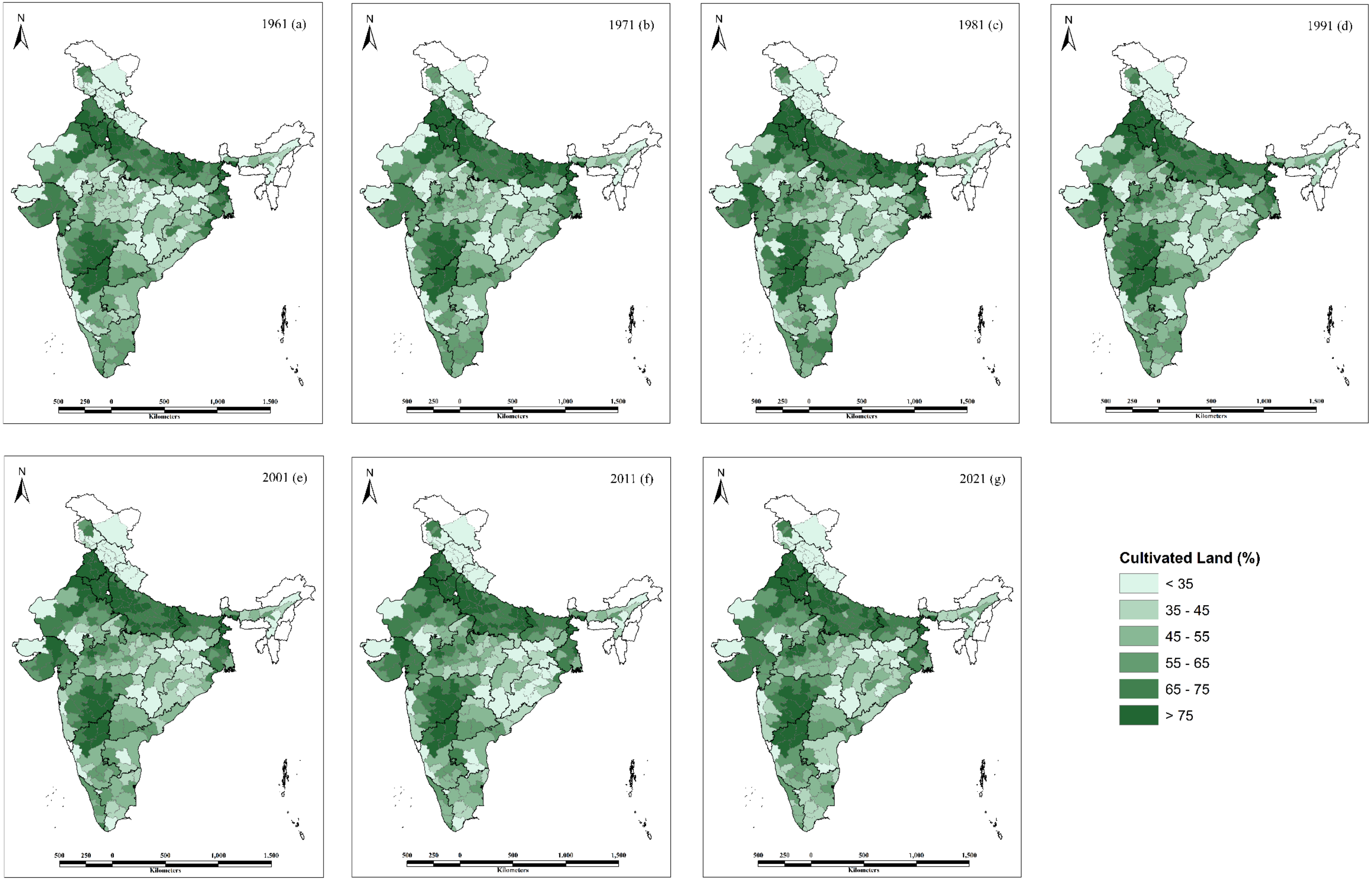


Figure 7. District wise percentage cultivated land, 1961-2021



7.2.1 Dynamic Panel Regression Results

Population growth rate was found as the primary and dominant element in the land-population interaction at the national level. For more robust and rigorous results, we applied the Arellano-Bover/Blundell-Bond linear dynamic model with two-step GMM estimator to our panel data, yielding the results presented in table 3. The dynamic panel model has the benefit of employing the first differences of variables with lagged dependent variables as an instrument. It operates on the assumption that there is no serial autocorrelation, and it also eliminates the possible endogeneity problem by applying lagged variables as instruments. Considering cultivated land as the dependent variable, Table 3 shows that increasing population growth rate is significantly affecting the cultivated land even after controlling all other variables. In each of the model from 1 to 6, the 'a' indicates panel up to 2011 (which has values based on observed data) and 'b' indicates panel up to 2021 (which has two extrapolated variables for 2021). In rest of the tables the full panel (1961-2021) has been considered to get all the time points available and allow the relationship to be established more perfectly. Models are arranged in order of increasing number of explanatory variables to get consistent results.

Two lags of dependent variable have been taken in order to find the possible effects of independent variables after extracting the effects of its own lagged values. In most of the results population growth rate has significantly affects the cultivated land. In Model 2a and 2b after controlling for population size, one unit change in population growth rate would change the percent cultivated land by 7.8% and 6.1% with significant at 0.10% level. Similarly, in model 5a and 5b, after all the variables, one unit change in population growth rate would change cultivated land by 5.5% and 6.5% respectively with 0.05% level of significance. After controlling all the variables in model 6b, with a unit change in population growth rate, cultivated land changes by 9.4% (0.01% level of significance). In the first three models' population growth rates is significant at 10% level, but in those models' population growth rate is the only variable found significant, and those models also satisfy the specification tests. For later models' population growth rate as predictor improves with lower levels of significance (5% and 1%). All the models satisfy the specification tests and both panels 'a' and 'b' are found similar in most the models.

Following the theoretical framework (Figure 2), the first and second phases of the land-population interaction are examined using models 1 to 4 of Table 4. To get the period specific effect of the population growth rate on cultivated land, we have used time-period specific population growth rates and an additional intercept for a time period (1991-2021)[10] following the segmented regression methods. Here the full panel (1961-2021) is used as break of main predictor in two periods reduces the sample for each period in that variable. In table 4, population growth rate comes out to be predominant determinant to alternate cultivated lands in second phase (1991-2021). In all the models from 1 to 4, only population growth rate of the period 1991-2021 is found significant. In model 4, after controlling for all variables, a unit change in population growth rate would change percent cultivated land by 6.2% (significant at 0.05% level) for period 1991-2021. Whereas, in model considering all variables, with full sample and lag of 1 period for cultivated land, found effect of population growth rate on cultivated land significant in both the phases. One unit change in population growth rate would change the cultivated land by 10.4% and 8.7% for the period of 1961-81 and 1991-2021 respectively. All the models have similar results and satisfy the specification tests.

7.2.2 Spatial Dynamic Panel Durbin Model Results

Table 5 depicts the results of spatial dynamic durbin model with fixed effects in order to accommodate both spatially lagged dependency, and geographical heterogeneity along with the possible endogeneity problem in the data. The benefit of employing spatial dynamic panel durbin model is it incorporates both

[10] Constant in the models are the intercepts for period 1961-1981, while intercept for the period 1991-2021 we need to add both model constant and intercept (1991-2021) e.g., in model 1 of table 4, intercept of period 1991-2021 would be (0.755 + 22.978) = 23.733

Table 3. Arellano-Bover/Blundell-Bond linear dynamic panel regression model (dependent variable – cultivated land)

Variables	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b	Model 4a	Model 4b	Model 5a	Model 5b
Cultivated Land$_{t-1}$	0.805*** (0.108)	0.739*** (0.097)	0.900*** (0.144)	0.754*** (0.1)	0.842*** (0.130)	0.723*** (0.087)	0.824*** (0.167)	0.795*** (0.095)	0.751*** (0.153)	0.677*** (0.091)
Cultivated Land$_{t-2}$	-0.074 (0.096)	-0.115 (0.083)	-0.009 (0.177)	-0.162 (0.127)	0.052 (0.143)	-0.061 (0.098)	-0.025 (0.159)	-0.11 (0.101)	-0.032 (0.138)	-0.119 (0.091)
Population Growth Rate	0.057 (0.036)	0.049* (0.027)	0.078* (0.043)	0.061* (0.035)	0.065 (0.040)	0.063* (0.035)	0.074** (0.033)	0.07** (0.031)	0.055* (0.032)	0.065** (0.029)
Log Population			-0.392 (1.162)	0.224 (0.793)	-1.635 (1.274)	-1.103 (0.731)	1.417 (1.772)	1.805 (1.208)	1.066 (1.894)	1.023 (1.326)
Log Yield					0.264 (0.659)	0.489 (0.372)			0.154 (0.45)	0.639* (0.353)
Irrigation Intensity					0.007* (0.004)	-0.004 (0.005)			0.006 (0.005)	-0.007 (0.005)
Cropping Intensity					0.003 (0.017)	0.008 (0.01)			0.002 (0.017)	0.005 (0.009)
Urbanisation							-0.005 (0.051)	0.01 (0.038)	-0.039 (0.049)	-0.012 (0.033)
Nonfarm Workers							-0.065** (0.033)	-0.064*** (0.023)	-0.062* (0.033)	-0.06** (0.025)
Education										
No. of Banks										
Constant	13.770 (10.805)	19.936** (9.255)	10.355 (11.335)	18.183* (9.601)	25.687** (11.401)	30.087*** (9.148)	-8.523 (16.423)	-8.274 (12.508)	0.085 (16.378)	6.606 (12.874)
No. of Groups	267	267	267	267	264	264	267	267	264	264
No. of Observation	1068	1335	1068	1335	1052	1315	1068	1335	1052	1315
No. of Instruments	9	11	10	12	13	15	12	14	15	17
AR (1)	-4.631***	-5.934***	-2.554**	-4.570***	-2.887***	-4.682***	-2.606***	-4.513***	-3.192***	-4.527***
AR (2)	-0.419	-0.137	-0.817	0.181	-0.745	-0.096	-0.677	-0.150	-0.173	0.699
Sargan Test	4.808	6.119	4.974	8.150	4.649	9.258	2.778	4.060	3.622	4.870
Wald Chi^2	154.352***	150.518***	177.978***	220.323***	164.719***	228.833***	65.271***	190.678***	95.252***	205.646***

**** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

spatial and time dependency (lag) in the model. The model will help to understand neighbourhood effects (for both dependent and independent variables), and district specific effects (main effect) after control for lag values of dependent variable. In Model 1, one unit change in population growth rate (in main effect) would change cultivated land by 9.3% and it is statistically significant at 0.01% level of significance, after controlling for the spatial and time lagged values of cultivated land.

Table 4. Time period wise Arellano-Bover/Blundell-Bond linear dynamic panel regression model (dependent variable – cultivated land)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Cultivated Land$_{t-1}$	0.722*** (0.106)	0.706*** (0.097)	0.773*** (0.11)	0.666*** (0.102)	0.649*** (0.068)
Cultivated Land$_{t-2}$	-0.259* (0.142)	-0.107 (0.103)	-0.157 (0.144)	-0.151 (0.124)	
Population Growth Rate (1961-1981)	0.074 (0.098)	0.056 (0.097)	0.140 (0.104)	0.094 (0.100)	0.104* (0.062)
Population Growth Rate (1991-2021)	0.062* (0.034)	0.062* (0.034)	0.068** (0.032)	0.062** (0.029)	0.087** (0.04)
Log Population	0.326 (0.756)	-1.068 (0.693)	1.834 (1.218)	0.958 (1.32)	1.589 (1.418)
Log Yield		0.428 (0.383)		0.660* (0.345)	0.704** (0.319)
Irrigation Intensity		-0.004 (0.005)		-0.007 (0.006)	-0.006 (0.004)
Cropping Intensity		0.01 (0.011)		0.006 (0.01)	-0.014 (0.009)
Urbanisation			0.012 (0.036)	-0.01 (0.033)	0.011 (0.027)
Nonfarm Workers			-0.063*** (0.023)	-0.059** (0.025)	-0.069*** (0.025)
Intercept (1991-2021)	0.755 (1.918)	0.073 (1.956)	1.795 (1.994)	0.878 (1.949)	-0.167 (1.257)
Constant	22.978* (12.464)	33.292*** (12.505)	-6.753 (16.933)	8.88 (16.927)	-5.528 (17.714)
No. of Groups	267	264	267	264	276
No. of Observation	1335	1315	1335	1315	1643
No. of Instruments	14	17	16	19	20
AR (1)	-4.453***	-4.813***	-4.264***	-4.560***	-2.346**
AR (2)	0.763	0.337	0.230	0.838	0.384
Sargan Test	7.199	9.517	3.641	4.536	13.737
Wald Chi^2	233.273***	236.927***	221.283***	224.054***	262.925***

**** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

Table 5. Spatial dynamic panel Durbin model (dependent variable – cultivated land)

Variables	Model 1
Main Effects (x)	
Cultivated Land$_{t-1}$	0.454*** (0.021)
Population Growth Rate	0.093*** (0.026)
Log Population	-2.081 (1.486)
Log Yield	0.123 (0.253)
Irrigation Intensity	0 (0.005)
Cropping Intensity	0.013 (0.009)
Urbanisation	-0.01 (0.023)
Nonfarm Workers	-0.044* (0.024)
Spatially Lagged Effects (W*x)	
Population growth Rate	-0.089** (0.04)
Log Population	1.999 (1.745)

Log Yield	0.357 (0.526)
Irrigation Intensity	-0.018* (0.01)
Cropping Intensity	-0.001 (0.014)
Urbanisation	-0.048 (0.036)
Nonfarm Workers	0.028 (0.034)
ϱ	0.338*** (0.038)
σ^2	14.152*** (0.431)
Number of Observations	1602
Number of Groups	267
R^2 (within)	0.245
R^2 (between)	0.936
R^2 (overall)	0.895
Log-likelihood	-4321.727

*Notes: ϱ is coefficients of spatially lagged dependent variables; W is the weight matrix; *** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

7.3 Robustness Checks

7.3.1 Agricultural land as an alternative measure of cultivated land

As alternative dependent variables for testing robustness, we utilised percentage agricultural land. In models, ‘a’ and ‘b’ are panels up to 2011 and 2021 respectively. Most of the models up to 2011 panel are fine, few of 2021 panel models have some restriction due socio-economic variables as socio-economic variables are not directly influence agricultural land, rather they influence cultivated land which has higher elasticity[11]. Though most of the fitted or unfitted models confirms that population growth rate is significantly contributing in change of percentage agricultural land. In model 5a and 5b, after controlling all the variables one-unit shift in population growth rate changes the agricultural land by 7.3% and 8.1% for two panels respectively (with 0.05% & 0.01% level of significance).

Table 7 shows the results of spatial dynamic panel durbin model with the alternative dependent variable; agricultural land. Model 1 shows a significant impact of population growth rate on percentage agricultural land, with one unit change in population growth rate would change the agricultural land by 6.3% (significant at 0.01% level) after controlling for spatial and time dependency.

7.3.2 Alternative break point

The cultivated land trend reveals that it has been shrinking since 1993 (Figure 3). To test the durability of our result, we used 1991 as the break point rather than 1981. In table 8, Population growth rate has been considered for two separate period (or phases) i.e., 1961 to 1991 and 2001 to 2021. In all the models of table 8, population growth rate of the later phase (2001-2021) is significantly affecting the cultivated land, as our previous results indicates. In model 4, with all the explanatory variables are controlled, one unit change in population growth rate of later phase would change the cultivated land by 6.6% (0.05% level of significance). Test specifications all satisfied the models. Though in no model population growth rate of earlier phase (1961-1991) was found significant.

We have also checked the robustness of the results using full sample with all the districts, which is presented in Appendix C.

[11] Agricultural land, as earlier mentioned is a combination of cultivated land and other lands (Land under Miscellaneous Tree Crops and Groves not included in Net Area Sown, Culturable Waste Land, Fallow Lands other than Current Fallows).

Table 6. Arellano-Bover/Blundell-Bond linear dynamic model (dependent variable: agricultural land)

Variables	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b	Model 4a	Model 4b	Model 5a	Model 5b
Agricultural Land$_{t-1}$	0.608*** (0.135)	0.506*** (0.113)	0.645*** (0.085)	0.65*** (0.074)	0.569*** (0.09)	0.635*** (0.063)	0.655*** (0.091)	0.675*** (0.072)	0.569*** (0.099)	0.624*** (0.063)
Population Growth Rate	0.095*** (0.031)	0.113*** (0.025)	0.085** (0.035)	0.088*** (0.029)	0.068* (0.036)	0.076** (0.03)	0.087*** (0.033)	0.095*** (0.029)	0.073** (0.034)	0.081*** (0.031)
Log Population			-0.092 (0.400)	-0.015 (0.405)	0.573 (1.102)	0.929 (0.705)	-0.420 (0.732)	-0.303 (0.734)	0.194 (1.205)	0.45 (0.991)
Log Yield					-0.119 (0.778)	-0.294 (0.502)			-0.114 (0.682)	-0.494 (0.484)
Irrigation Intensity					0.008 (0.006)	-0.002 (0.005)			0.008 (0.006)	-0.002 (0.005)
Cropping Intensity					-0.039** (0.018)	-0.028** (0.012)			-0.036** (0.018)	-0.03** (0.012)
Urbanisation							-0.011 (0.028)	0.007 (0.015)	-0.002 (0.033)	0.009 (0.024)
Nonfarm Workers							0.019 (0.03)	0.014 (0.027)	0.014 (0.032)	0.027 (0.028)
Constant	22.41*** (8.134)	28.405*** (6.709)	21.612** (8.943)	20.121** (8.496)	22.543* (11.861)	14.098* (8.321)	25.235** (10.877)	21.884** (11.02)	27.132** (13.146)	22.208* (11.619)
No. of Groups	280	280	280	280	276	276	280	280	276	276
No. of Observation	1397	1677	1397	1677	1369	1643	1397	1677	1369	1643
No. of Instruments	10	12	11	13	14	16	13	15	16	18
AR (1)	-3.081***	-2.374***	-3.009***	-2.738***	-2.838***	-2.787***	-2.942***	-2.742***	-2.759***	-2.800***
AR (2)	-0.037	-0.532	-0.013	-0.375	1.026	-0.223	-0.005	-0.352	0.976	-0.239
Sargan Test	4.299	4.700	4.547	7.224	6.035	9.185	4.998	7.921	7.267	12.207
Wald Chi^2	59.612***	126.299***	95.808***	143.516***	93.034***	206.869***	101.103***	166.385***	93.803***	206.908***

**** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

Table 7. Spatial dynamic panel durbin model (dependent variable – agricultural land)

Variables	Model 1
Main Effects (x)	
Agricultural $Land_{t-1}$	0.427*** (0.021)
Population Growth Rate	0.063*** (0.025)
Log Population	-0.867 (1.448)
Log Yield	0.257 (0.248)
Irrigation Intensity	-0.013 (0.005)
Cropping Intensity	0.032 (0.008)
Urbanisation	-0.01 (0.023)
Nonfarm Workers	-0.024* (0.023)
Spatially Lagged Effects (W*x)	
Population Growth Rate	-0.016** (0.039)
Log Population	0.883 (1.697)
Log Yield	-0.063 (0.513)
Irrigation Intensity	0.001* (0.009)
Cropping Intensity	-0.032 (0.013)
Urbanisation	0.003 (0.035)
Nonfarm Workers	0.033 (0.033)
ϱ	0.343*** (0.038)
σ^2	13.385*** (0.408)
Number of Observations	1602
Number of Groups	267
R^2 (within)	0.150
R^2 (between)	0.956
R^2 (overall)	0.911
Log-likelihood	-4276.222

*Notes: ϱ is coefficients of spatially lagged dependent variables; W is the weight matrix; *** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

Table 8. Alternative time period wise Arellano-Bover/Blundell-Bond linear dynamic model (dependent variable – cultivated land)

Variables	Model 1	Model 2	Model 3	Model 4
Cultivated $Land_{t-1}$	0.824*** (0.087)	0.716*** (0.091)	0.782*** (0.111)	0.717*** (0.124)
Cultivated $Land_{t-2}$	-0.067 (0.125)	-0.034 (0.102)	-0.128 (0.121)	-0.054 (0.13)
Population Growth Rate (1961-1991)	0.046 (0.074)	0.027 (0.073)	0.09 (0.079)	0.083 (0.08)
Population Growth Rate (2001-2021)	0.057* (0.031)	0.065** (0.032)	0.068** (0.031)	0.066** (0.029)
Log Population	0.542 (0.834)	-0.295 (0.793)	1.926 (1.178)	0.563 (1.43)
Log Yield	0.824*** (0.087)	0.675* (0.372)		0.727* (0.387)
Irrigation Intensity		-0.005 (0.005)		-0.006 (0.005)
Cropping Intensity		0.006 (0.01)		0.003 (0.01)
Urbanisation			0.01 (0.036)	-0.006 (0.031)
Nonfarm Workers			-0.069* (0.04)	-0.037 (0.047)
Intercept (2001-2021)	-0.666 (1.477)	-1.426 (1.413)	0.529 (1.621)	0.059 (1.586)
Constant	4.937 (10.273)	17.084 (11.834)	-8.592 (13.535)	5.879 (12.689)
No. of Groups	267	264	267	264
No. of Observation	1335	1315	1335	1315
No. of Instruments	14	17	16	19
AR (1)	-4.304***	-4.965***	-4.962***	-4.601***

AR (2)	-0.558	-0.170	0.013	0.049
Sargan Test	7.525	8.181	4.246	4.513
Wald Chi^2	368.775***	283.746***	209.984***	259.632***

****** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

8 Discussion

This study empirically examines the effect of population growth rate on change of cultivated land use by using a long-term panel data. The study is both confirmatory as well as exploratory in nature. This study also explored the different stages of the linkages between land and population with our proposed theoretical framework (Section 4). Decrease in population growth rate is attributed to socio-economic development, while the reduction in cultivated land use is contingent upon a prior decline in population growth rate, even in the presence of agricultural technology. In the initial phase, a rapidly increasing 'population growth rate' contributes to the increase in population size (and density), prompting a corresponding expansion in agricultural land utilisation and agricultural intensification. However, in the subsequent phase, as the 'population growth rate' experiences a gradual decline (while remaining positive), population size and density continue to grow at a slow pace. During this period, the 'rate of growth in agricultural intensification' surpasses the 'rate of population growth' which enables agricultural technology to effectively support food security without expanding agricultural land. Consequently, agricultural land expansion ceases and begins to contract.

Our results also indicate this phenomenon that a decline in population growth rate precedes and is a prerequisite for a reduction in agricultural land utilisation, even in the presence of technological advancements in agriculture. The sustainability and food security of any growing population can be achieved by increasing agricultural productivity by using modern farm technology, rather than expanding land usage. This is owing to the condition that rate of increase in 'agricultural intensification or productivity' must be higher than 'rate of population increase' (Lam, 2011; Bilsborrow, 2022; Lam, 2023). In the case study of India, as the population growth rate declines, it creates an opportunity for a reduction in land utilisation. This causes an 'inverted U-shaped' relationship between population growth rate and agricultural land use in India.

Boserupian perspective is generally concerned with scenarios of expanding population to cause the intensification of agriculture with limited land availability, but in the present study lowering population growth rate alleviates population pressure in the long run which reduces the use of agricultural land. Furthermore, a growth in population density (along with population size) would stimulate more labor-intensive farming practices and the introduction of new farm technologies might help to support the rising population while also easing the shift of agricultural labourers to other sectors. Labour shifts from agriculture to industries would also aid agriculture by increase the manufacturing of modern farm tools (Boserup, 1965, 1981). Only one of our segmented models identifies both the phase significantly and in earlier phase the effect of population growth rate was higher, which supports our second hypothesis. Most of our segmented models identifies only second phase[12] more precisely, although there are vast literatures which would support the fact that increase in population growth rate (during the first phase) increases cultivated land use (Bilsborrow & Okoth Ogendo, 1992; Mishra, 2002). While the phenomenon how declining population growth rate decreases the agricultural land use is need to be checked and our results support this scenario (later phase of the segmented models are associated with the phase of declining growth rate in India). However, the full models have significantly shown that population growth rate determines the cultivated or agricultural land, and the trend of both cultivated land and population growth rate in India

[12] The possible reason for the non-identification of first phase in many of our dynamic models is the spatial heterogeneity, as we have seen, Growth rates (figure 6) for many of states (especially southern states) are declining since 1970s, so to capture those states we need a longer panel (since 1930s or 1940s), which is not possible to due to data constraints.

has 'inverted U-shaped relationship' and cultivated or agricultural land follows the path of population growth rate with a time lag.

In demographic transition, population growth rate eventually increases and decreases with various behavioral and developmental changes in the society. And as population growth is the causal factor for cultivated land use, so the cultivated or agricultural land also increases and decreases with population growth rate, as we have found in the results. The last two stages[13] in the theoretical framework are highly associated with the demographic transition of any region. These two stages are separated in the Indian setting around the 1980s. India's highest recorded population growth rate was in 1971 (2.22% per year), but it remained nearly unchanged until 1981 (2.20% per year), when it began to decline. Following a lag of roughly ten years, the percentage of cultivated land began to decline in the 1990s. Prior to 1981, the Indian population growth not only increased farm land but also worked as a catalyst for a major shift in agricultural technology via the Green Revolution. However, it cannot be concluded that population growth acted as an impetus, as Boserup claimed, even though population growth is the primary cause of the green revolution. In this scenario, both Malthusian and Boserupian perspectives acted independently. In the mid-1960s, India had experienced severe food shortages due to a series of famine years. Despite this fact, the 1971 census results show that the famine had no effect on population growth (Dyson, 2018). However, it raised the risk of starvation. It should be noted that the origins of the 1960s famines were caused by climate variations in the country, such as drought, not by population explosion. Yet this raised concerns about probable future famines that would have a serious impact on the population (Dasgupta, 1977). This terrifying threat to the population functioned as a Boserupian stimulant, introducing high yielding seeds from Mexico, and necessary changes in infrastructure like irrigation, fertiliser, agricultural research etc. Thus, Malthusian vision of disaster through food scarcity served as a push factor in the Indian setting to develop new farm technology for population sustainability (due to high population expansion), but technological intervention as viewed by Boserup did not let the population to be starved. There are several studies which concluded that intensification did happen in India due to population pressure (Mishra, 2002; Lam, 2011; Bilsborrow, 2022). In developed countries where food security is not a major problem, use of agricultural land are reducing due to increase in agricultural productivity, conversion of cropland to forest areas, and urbanisations (Ewers et al., 2009; Sali, 2012). These factors are also true for countries which are rapidly developing, such as India. Though the fact that urbanisation causes a significant loss of croplands but increasing productivity and reducing population growth rate also declines the use of croplands. Forest cover increased, while agricultural land reduced in India due to the increasing agricultural productivity which reserves cropland for forest (Lambin & Meyfroidt, 2011).

In contrast with the land, population growth rate drops in India due to urbanisation and economic development, with increase in non-farm employees, education, adoption of new agriculture technologies which facilitate labour migration and reduces fertility by diminishing demand of labour in fields. Urbanisation, which has been increasing in India since independence, attracts individuals from rural agrarian communities to non-farm high-paying occupations in cities. Urbanisation is both the cause and effect of economic development (Keyfitz, 1992; Coale & Hoover, 2015). In India, declining mortality, since the 1940s, has driven economic progress, which accelerated after independence in 1947. This resulted in significant population growth, which mostly aided economic development by increasing the number of workers in various sectors. Increased rural-urban migration for better jobs has accelerated India's urbanisation process. This rural-urban movement was being pushed by the introduction of sophisticated farm technologies. These factors not only helped to improve the country's economic situation, but also caused socio-demographic changes by increasing education levels and raising awareness about the use of modern contraceptive methods, and lowering the population growth rate (James & Goli, 2016). Thus, originally, expanding population heralded economic development, but later stages of this economic development rescued the population from the 'Malthusian Catastrophe' by sustaining agricultural

[13] As we mentioned earlier that last two stages of theoretical framework are mentioned as the two phases, first and second phase, in the analytical models.

productivity as well as lowering population growth rate in India, which in turn lowers the expansion of agricultural land (Liu et al., 2008; Ewers et al., 2009; Lambin & Meyfroidt, 2011; Sali, 2012).

9 Conclusions

In conclusion we state that, using a long-term panel data and robust econometric tools population growth has been found the dominant driver driving the usage of cultivated land throughout the last 70 years of India's demographic and economic history. The influence of population growth on cultivated land consumption is not static; in India, two distinct phases of this causal relationship exist. The phases separated around 1980s with onset of declining population growth rate in the country. In the first phase, rapidly increasing population growth rate drives the expansion of cultivated land, while declining population growth rate in second phase insisted the use of cultivated land to be declined, with help of introduction of modern farm technology, albeit slowly. It can be argued that, while the Malthusian catastrophe arrived indirectly in the mid-1960s in India as a threat of famine and food shortage, these concerns were resolved by technological advancements in agriculture, as Boserup perceived. Though there are some intermittent influences, such as a drop-in population growth rate due to socioeconomic development, the population growth rate remains the most important factor influencing changes in cultivated land usage in India.

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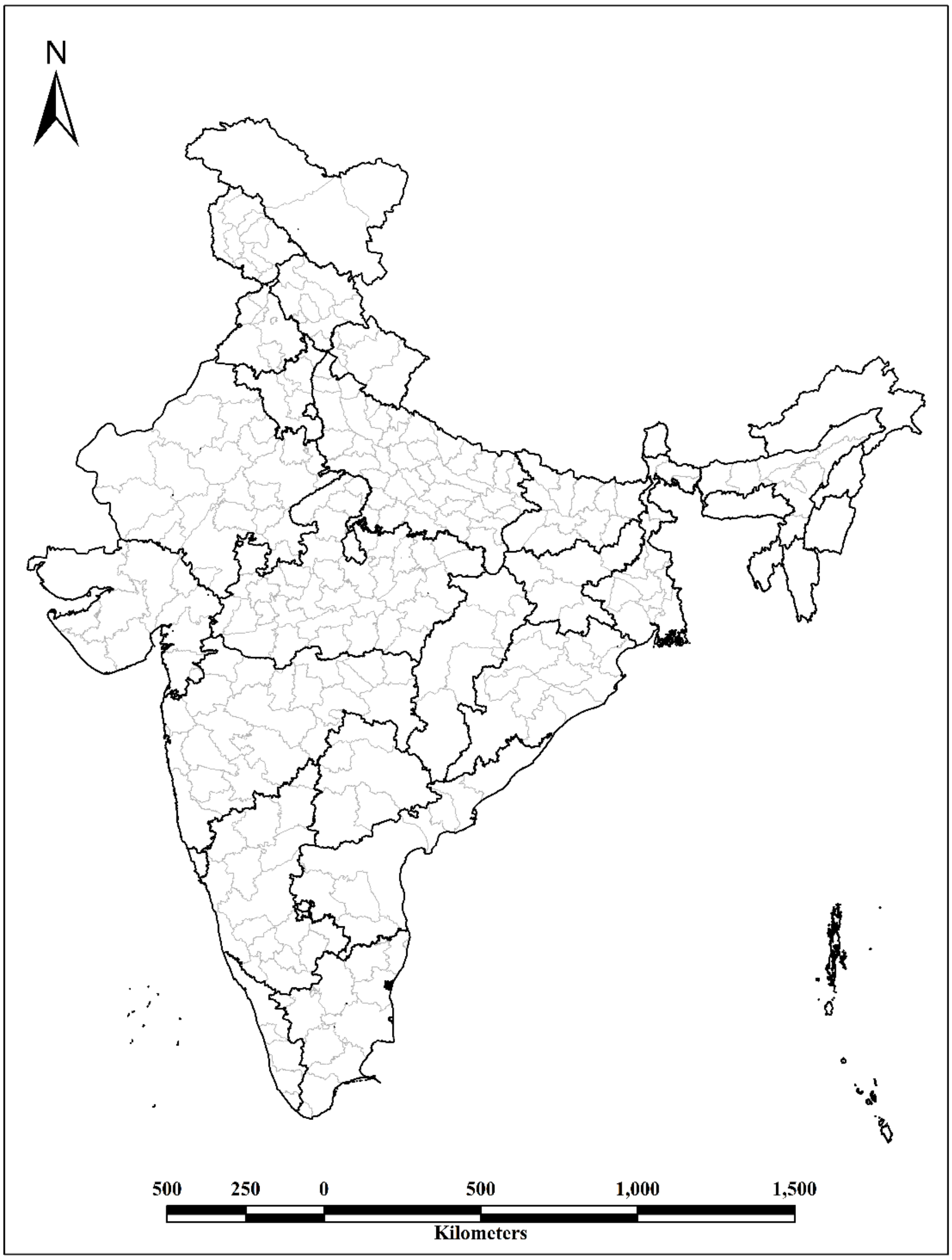
Supplementary (For online Publication only)

Appendix A

Figure A1. Consistent district boundaries, 1961-2021



Note: Figure illustrates 280 consistent district boundaries over 1961-2021. In the analysis only 267 consistent district boundaries have been used as part of major states of India.

Appendix B

Table B1. Year wise summary statistics of district panel

Variables	Mean (Standard Deviation)						
	1961	1971	1981	1991	2001	2011	2021
Decadal Population Growth Rate (%)	20.26 (7.64)	22.47 (5.18)	22.36 (5.05)	21.25 (5.41)	19.11 (6.58)	15.62 (6.85)	14.38 (6.44)
Cultivated Land (%)	53.14 (20.31)	55.05 (20.33)	55.4 (20.93)	55.78 (20.72)	55.68 (20.63)	55.3 (20.72)	55.35 (20.17)
Log Population	14.00 (0.85)	14.22 (0.85)	14.44 (0.84)	14.66 (0.84)	14.85 (0.84)	15.00 (0.85)	15.15 (0.85)
Log Yield	6.56 (0.94)	6.73 (0.81)	6.92 (0.84)	7.13 (0.96)	7.39 (0.91)	7.62 (0.91)	7.78 (0.92)
Irrigation Intensity (%)	112.70 (18.51)	120.51 (21.28)	124.10 (22.76)	129.05 (28.58)	132.94 (37.98)	135.6 (32.22)	146.14 (38.08)
Cropping Intensity (%)	118.58 (16.41)	122.08 (18.52)	127.71 (20.39)	132.46 (24.61)	137.66 (26.53)	141.74 (27.23)	153.19 (31.01)
Urbanisation (%)	15.77 (13.99)	17.20 (14.27)	20.09 (14.65)	22.14 (15.14)	23.57 (15.67)	26.43 (17.41)	28.96 (19.38)
Nonfarm Workers (%)	30.37 (15.17)	27.87 (14.84)	31.02 (15.39)	32.72 (16.03)	42.56 (17.51)	45.45 (18.43)	48.22 (20.12)

Appendix C

For the robustness of the results in table 3 of the main paper we have run the same set of models using the full sample which consist of 280 districts over the panel. The results show in most of the models, population growth rate have significant effect upon cultivated land which re-affirms our earlier models with major states of India.

Table C1. Arellano-Bover/Blundell-Bond linear dynamic model (dependent variable: cultivated land) – Full Sample

Variables	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b	Model 4a	Model 4b	Model 5a	Model 5b
Cultivated Land$_{t-1}$	0.551*** (0.089)	0.529*** (0.079)	0.665*** (0.08)	0.647*** (0.075)	0.635*** (0.082)	0.661*** (0.068)	0.608*** (0.082)	0.622*** (0.08)	0.579*** (0.083)	0.617*** (0.072)
Population Growth Rate	0.105*** (0.027)	0.100*** (0.021)	0.067* (0.037)	0.048 (0.036)	0.068** (0.033)	0.069* (0.038)	0.074** (0.032)	0.054 (0.035)	0.071** (0.029)	0.075** (0.037)
Log Population			-0.79 (0.576)	-0.815 (0.593)	-1.481* (0.854)	-1.356* (0.794)	0.855 (0.824)	0.387 (0.826)	0.659 (1.007)	-0.011 (1.058)
Log Yield					0.659* (0.399)	0.732** (0.325)			0.553* (0.319)	0.78** (0.325)
Irrigation Intensity					0.007 (0.004)	-0.004 (0.004)			0.008 (0.005)	-0.005 (0.004)
Cropping Intensity					-0.007 (0.012)	-0.004 (0.008)			-0.008 (0.012)	-0.006 (0.008)
Urbanisation							-0.016 (0.031)	0.023 (0.017)	-0.025 (0.038)	0.02 (0.026)
Nonfarm Workers							-0.048* (0.028)	-0.051** (0.023)	-0.057** (0.028)	-0.054** (0.025)
Constant	22.682*** (5.145)	23.967*** (4.388)	28.72*** (8.853)	30.544*** (8.904)	36.086*** (10.168)	33.256*** (9.883)	9.745 (10.519)	15.468 (10.566)	11.093 (11.707)	17.387 (12.158)
No. of Groups	280	280	280	280	276	276	280	280	276	276
No. of Observation	1397	1677	1397	1677	1369	1643	1397	1677	1369	1643
No. of Instruments	10	12	11	13	14	16	13	15	16	18
AR (1)	-2.430**	-2.129**	-2.695***	-2.346**	-2.627***	-2.401**	-2.575***	-2.321**	-2.502**	-2.363**
AR (2)	-0.979	-0.052	-1.028	0.046	-0.288	0.389	-1.038	0.026	-0.277	0.369
Sargan Test	5.186	5.752	6.634	8.205	6.227	12.127	8.438	10.668	6.805	11.973
Wald Chi^2	41.155***	67.074***	69.894***	84.429***	65.888***	130.190***	80.037***	101.493***	81.137***	185.110***

**** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

Appendix D

To understand reverse causation, the table D1 places population growth rate as a dependent variable of cultivated and agricultural land alternatively. After attempting for various combinations of independent variables and lags of dependent variables the following two models are passed the specification tests. The models are based on panel up to 2011. None of the models the representative variable of land was found significant.

Table D1. Arellano-Bover/Blundell-Bond linear dynamic model (dependent variable – population growth rate)

Variables	Model 1	Model 2
Population Growth Rate$_{t-1}$	0.735*** (0.139)	0.74*** (0.142)
Population Growth Rate$_{t-2}$	0.202* (0.109)	0.205* (0.112)
Cultivated Land	-0.016 (0.072)	
Agricultural Land		-0.014 (0.076)
Log Population	1.837 (2.956)	1.535 (2.8)
Log Yield	-1.843*** (0.547)	-1.793*** (0.587)
Urbanisation	0.14* (0.084)	0.145* (0.082)
Nonfarm Workers	0.05 (0.077)	0.057 (0.078)
Education	-0.207*** (0.079)	-0.208*** (0.077)
Constant	-11.401 (36.22)	-7.839 (35.135)
No. of Groups	267	267
No. of Observation	1066	1066
No. of Instruments	14	14
AR (1)	-3.904***	-3.844***
AR (2)	1.454	1.413
Sargan Test	3.831	3.809
Wald Chi^2	322.482***	316.545***

**** p<.01, ** p<.05, * p<.1; Standard Errors are in parenthesis*

Appendix E

Granger Causality Model:

The table E1 shows results of granger causality test with considering cultivated land (model 1) and population growth rate (model 2) as the dependent variables. We have used 11 years of lag as population growth rate and cultivated land has a lag of approximately 11 years in India level graphs. And the lags are confirmed by the selection criterions i.e., Likelihood Ratio (LR), Akaike Information Criterion (AIC), Hannan & Quinn Information Criterion (HQIC), and Schwarz's Bayesian Information Criterion (SBIC). The results show that both population growth rate and cultivated land affects each other, though the chi^2 statistics shows that the effect of population growth rate on cultivated land is much higher.

Table E1: Granger causality tests results

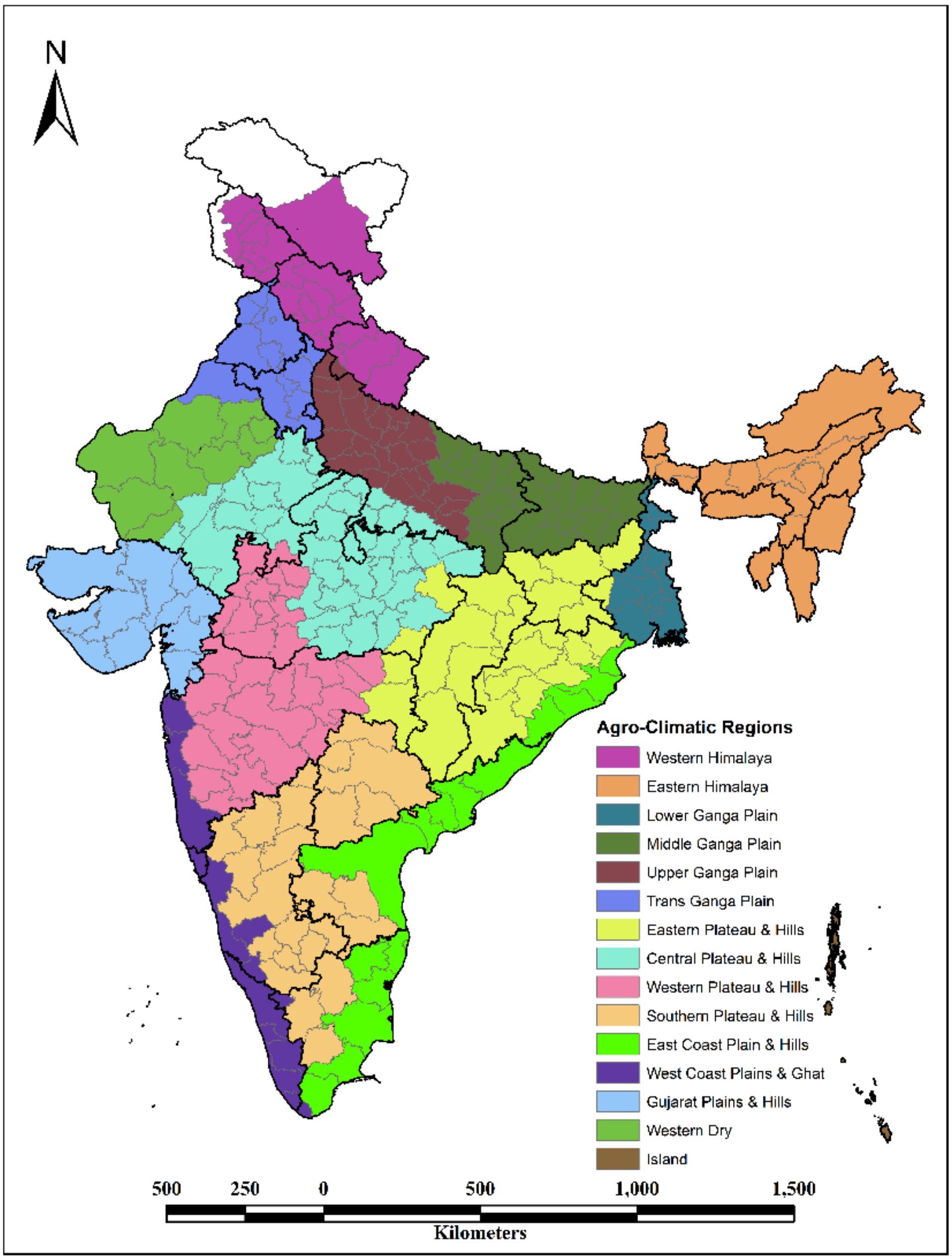
Model 1			**Model 2**		
Equation	Excluded	chi^2	Equation	Excluded	chi^2
Cultivated Land	Population growth Rate	107.27***	Population Growth Rate	Cultivated Land	13.943***
	Log Yield	3.651*		Log Yield	9.245***
	Irrigation Intensity	0.425		Irrigation Intensity	1.739
	Cropping Intensity	0.287		Cropping Intensity	2.455
	Urbanisation	5.001**		Urbanisation	0.986
	Nonfarm Workers	4.569**		Nonfarm Workers	1.475

	Literacy	7.709***		Literacy	9.166***
	Log GDP	3.165*		Log GDP	7.932***
	All	640.91***		All	3364.2***

*** p<.01, ** p<.05, * p<.1*

Appendix F

Figure F1. Districts by agro-climatic regions of India



Note: There are 15 agro-climatic regions in India, classified by Planning Commission of India in 1988. The boundaries may differ negligibly as our districts are clubbed for consistent boundaries.

Figure F2. Agro-Climatic Region wise Co-Evolution of Population growth Rate and Cultivated Land

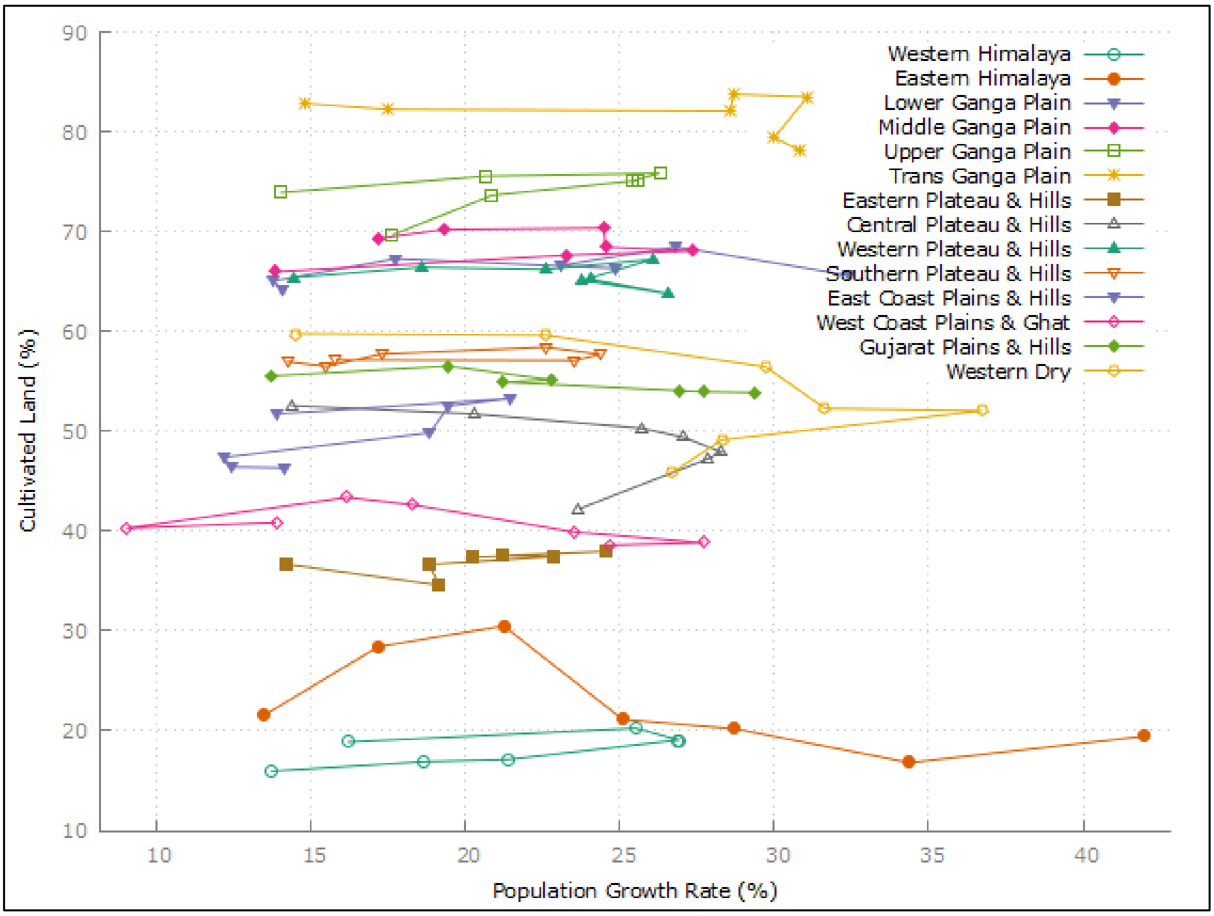


Figure F2 depicts the co-evolution of decadal population growth rates and percentage cultivated land in agro-climatic regions. As population growth rates increase, so does the percentage share of cultivated land. There are sharp bends in almost every co-evolution line, indicating that as population growth rates decreases, cultivated land decreases in most regions. A strong spatial heterogeneity exists in cultivated land among the agro-climatic regions of India, and despite this fact population growth rate has influenced the cultivated land very strongly. In every level of cultivated land percentages, declining population growth rate also declined the cultivated land.